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Proceedings of the 14th International Congress of the International Radiation Protection Association

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Volume 1 of 5

1- Fundamental Science

2- Policy, Standards and Culture

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The Proceedings of the 14th International Congress of the International Radiation Protection Association are divided into 5 volumes, as follows:

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***Area 2*: Policy, Standards and Culture**

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Proceedings of the 14th International Congress of the International Radiation Protection Association

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EDITORIAL

It's Done!

- It always seems impossible until it's done.

Given where IRPA 14 was held, it is apropos that this little bit of wisdom has been attributed to Nobel Laureate and former South African President Nelson Mandela. However, the idea goes back at least as far as Pliny the Elder (AD 23-79) who realised that breaking new ground is never easy, but the first step is always believing that it is possible.

An IRPA International Congress on African soil was a dream a decade ago. Yet, now the 14th International Congress of the International Radiation Protection Association has come and gone, a solid reality. Making it happen was not an easy task. The amount of work over many years was tremendous, and many seemingly unsurmountable obstacles had to be surmounted. None of this would have been possible without the sincere dedication of the International Congress Organising Committee, the International Congress Programme Committee, and the scores of other people who gave of their time, blood, toil, tears, and sweat. The result was a fantastic, highly-memorable, and ground-breaking gathering of professionals from around the world in Cape Town May 9-13, 2016. Of course, the work did not end when the delegates left the venue on the thirteenth of May.

Another undertaking never before accomplished was the production of a full set of published proceedings for an IRPA International Congress. Efforts had been made in the past, and many papers from many previous congresses are available through the IRPA website, but the plans for IRPA 14 were even more ambitious.

These proceedings reflect 244 papers and 660 abstracts, including contributions relating to the Prize lectures (Sievert award; Royal Swedish Academy of Sciences Gold Medal), the twelve topical areas highlighted at the congress (see table), the 50th Anniversary of IRPA celebration session, the 20 Refresher Courses, and the presentations of the Associate Societies. Of these papers, 44 (marked with Ⓡ in the Table of Contents) have been published as a Special IRPA 14 Issue of *Radiation Protection Dosimetry*, thanks to the support of the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). Their abstracts (but, for copyright reasons, not the full papers) of each are included here, as are the abstracts of other papers published elsewhere. The other 200 papers are included here in full.

Contributions to the Topical Sessions	Oral	Poster	Total
1. Fundamental science	32	83	115
2. Policy, standards, and culture	36	102	138
3. Medical	28	139	168
4. General ionising radiation protection	23	60	83
5. Justification, optimisation, and design of new facilities	7	22	29
6. Radiation detection and dosimetry	17	78	95
7. Environment and natural background	23	112	135
8. Transport and sealed sources management	9	14	23
9. Non-ionising radiation	5	2	7
10. Emergency preparedness and management	18	34	52
11. Decommissioning, waste management, and remediation	17	39	56
12. Societies	3	-	3

The numbers in the table should not be over-interpreted. Areas were overlapping; the allocation of papers to areas had to be somewhat arbitrary in some cases; oral contributions range from brief interjections at panel sessions to the full 1 h Sievert lecture. Nevertheless, some comments are warranted. First of all, the number of contributions is not a measure of the importance of a topic. For instance, source and transport safety and security are vitally important; the relatively small number of contributions is a result of a management system which is relatively mature in many countries.

It is not perhaps surprising that radiological protection in medicine attracted the most contributions. Medical applications are ubiquitous, cause a major part of the average dose to the populations, affect both occupational and patient exposures, and are subject to rapid developments. Policy, standards, and culture was the second biggest group, with particular attention to two timely topics: the recent reduction of the dose limit for the lens of the eye, and ethical considerations in radiological protection. We were also very pleased that there were so many contributions concerning fundamental science, again re-confirming the sound scientific basis of radiological protection.

Environment and natural background, also a big group, merges two conceptually quite different topics – effects *on* the environment (i.e., biota in the environment), and exposures *in* (or mediated via) the environment. Intermediate numbers of contributions came to the ‘core groups’ of day-to-day RP: general protection; justification/optimisation and design (including the hot topic of 'new build' nuclear power); detection and dosimetry; emergency preparedness (and response, hopefully not a day-to-day preoccupation!); and decommissioning/waste/remediation.

The seemingly small number of contributions on non-ionising radiation reflects the fact that the International Commission on Non-Ionizing Radiation Protection (ICNIRP), held their 8th International Workshop in conjunction with and at the same venue as IRPA14 (a discounted joint registration was offered). Thus, as part of this very successful collaboration, most non-ionising radiation presentations took place at the ICNIRP workshop; the conclusions of the workshop were presented at IRPA14.

Along another dimension, as usual there were many more posters than oral presentations. This has several reasons, one of which is that the time available restricts the maximal number of oral presentations, while the space for posters is rarely limiting. Thus, all posters fulfilling the (stringent!) quality criteria are usually accepted as such, while only a fraction of requests for oral presentation can be granted. This is sometimes misinterpreted as oral being 'better' than poster presentations. We would like to change the perspective. At IRPA14 all speakers were given sufficient time to make their presentations and take questions; this reduced the number of possible speaker slots – and at the same time, IRPA14 had an unusually high frequency of very good poster presentations.

Talking of high quality, we were really impressed by the contestants for the Young Scientist and Professionals Award. The IRPA Associate Societies had nominated 20 of their best young people, and boy, were they good! The Award winners were Adam Jones of the UK SRP (1st Prize), Teun van Dillen of the Dutch NVS (2nd Prize), and Angelo Infantino of the Italian AIRP (3rd Prize). All entries are marked with Y in the Table of Contents.

So, what were the conclusions of the Congress? We can only touch upon a few selected highlights here. Recurring keywords were trans-disciplinary; epidemiology; optimisation; training; safety; security; harmonisation; communication; and trust. In emergency planning, we must allow for being human, in a non-punitive, self-improving culture. One-eyed risk assessments could lead to expensive and outright dangerous 'over-protection' against radiation, but our assessments must not be hi-jacked by outside forces who wish to downplay, or exaggerate, risks. Dose constraints are a useful tool with a misleading name, often misunderstood and sometimes misused. In medical RP, the justification of examinations and procedures must be improved in real working practice, not just in theory. In the nuclear area, a lot of competence has been lost and must be regained in connection with the 'new build' trend – and the risks associated with rapid phase-out must be observed in countries which are abandoning nuclear power.

Finally, without the sincere dedication of the Editorial Team, these proceedings would not have been possible. However, regardless of how time consuming and challenging it has been to assemble the proceedings, this pales in comparison to the combined effort of the hundreds of authors represented here. It is they who we should thank for their part in IRPA 14, and for their part in producing this important chronicle of the congress.

JACK VALENTIN, IRPA 14 ICPC CHAIR
CHRISTOPHER CLEMENT, IRPA PUBLICATIONS DIRECTOR

PREFACE

In my capacity as IRPA14 Congress President, it has been my great privilege, honour, and pleasure to welcome scientists and radiological protection experts from all over the world to the 14th IRPA International Congress. This was co-hosted by the South African Radiation Protection Societies (SARPA and SARPS) and held at the prestigious and highly efficient Cape Town International Convention Centre, in the beautiful South African “Mother City” of Cape Town.

The Congress marked two milestones, namely the 50th Anniversary of the first IRPA International Congress. IRPA was established in 1964 and the First IRPA International Congress was held in 1966, in Rome. Secondly this was the first time that the prestigious IRPA International Congress was held on the African Continent. This was a key milestone in Africa's engagement in international radiation protection, which has been increasing for several years and will no doubt continue to increase in the future. Further, the Congress being held in South Africa was a great opportunity for Africans to showcase their work in radiological protection, and for people from all countries to learn lessons from one another.

IRPA provides a medium whereby those engaged in radiological protection activities in all countries may communicate and co-operate, thus advancing radiation protection world-wide. The high level representation from all collaborating organisations IAEA, ICRP, WHO, PAHO IOMP, ILO, ICRU, UNSCEAR, ICNIRP, ISRRT, NEA, UNEP and the EC at IRPA14 was clear testament to the high regard the international community has for the work of IRPA.

With the theme of ‘Practising Radiation Protection - Sharing the experience and new challenges’, the IRPA14 Congress was an important milestone in meeting our challenges at the time of rapid change in a globalising environment. Like all previous IRPA International Congresses, IRPA14 provided a broad dialogue platform for consolidating the international voice of radiation safety professionals and other professionals working with nuclear and radiation related technologies.

The vibrant, high quality congress programme addressed both ionising and non-ionising radiation in a series of keynote presentations, parallel scientific sessions (including the exciting and impressive presentations of 20 contestants nominated by their societies competing for the IRPA Young Scientists and Professionals Award), poster sessions, early morning refresher courses, panel discussions, and plenary summaries, as well as presentations from the distinguished winners of the Sievert Award and the Royal Swedish Academy of Sciences Gold Medal for Radiation Protection. All are reflected in the present Congress Proceedings which will remain a permanent record of the scientific advances achieved during IRPA14, as well as the devotion showed by all participants and authors.

The compliments and praise from the more than 900 delegates who attended the IRPA14 International Congress are testament to our successful delivery on the promises of excellent meeting conditions with first-rate organisation, flawless practical support, and top-notch technology in beautiful and safe settings.

I would like to express my heartfelt gratitude to all who contributed to the success of the IRPA14 International Congress, you the delegates, our various sponsors and in particular the Organising and Programme Committees and countless colleagues at home and abroad for their sterling, dedicated and selfless efforts to ensure a highly successful IRPA14 Congress. Looking through the pages of these Proceedings and remembering the days of the IRPA14 Congress, I feel honoured, humbled, and proud to have been involved in this great endeavour.

THIAGAN PATHER
IRPA14 CONGRESS PRESIDENT
IRPA VICE-PRESIDENT FOR CONGRESS AFFAIRS (2012-2016)

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Note:

Submissions marked with (R) represent entries published in a Special IRPA 14 issue of *Radiation Protection Dosimetry*.

Submissions marked with (Y) represent entries by contestants for the Young Scientists and Professionals Award.

ROLF SIEVERT AWARD LECTURE

How to Protect the Public When You Can't Measure the Risk - The Role of Radiation Epidemiology

John D. Boice, Jr.

National Council on Radiation Protection and Measurements, Bethesda, MD, USA

Vanderbilt University School of Medicine, Nashville, TN, USA

Abstract. It is a wonderful honor to be selected as the 12th Sievert Lecturer. I knew each of the previous 11 Lecturers and it is humbling to walk in the shadow of these world leaders in radiation protection! Radiation epidemiology is an observational science but has become so sophisticated that human studies are the basis for radiation protection standards and for compensation schemes throughout the world. Epidemiology forms the basis for managing low doses of radiation even when risks cannot be detected. Here consensus judgment is needed to translate the epidemiology into recommendations and then into standards/regulations. Historically, heritable effects to the next generation were the focus and concern. But when studies of the children of atomic bomb survivors and the children of cancer survivors all showed no evidence of malformations or other serious health issues, the focus turned to somatic effects, mainly cancer. Human studies of cancer have been conducted for over 100 years: radium dial painters, patients given Thorotrast, early radiologists, atomic bomb survivors, medically-exposed populations, nuclear workers, environmental exposures from Chernobyl releases, underground miners and more. Results from these studies have been incorporated into protection standards that have substantially reduced exposures to the general public and workers, and now even medical patients. The wealth of knowledge generated over the past century continues to be synthesized by authoritative committees such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the US National Academy of Sciences (NAS) Committee on the Biological Effects of Ionizing Radiations (BEIR). These scientific reports are then reviewed by protection committees such as the International Commission on Radiological Protection (ICRP) and the US National Council on Radiation Protection and Measurements (NCRP) who make recommendations to regulatory authorities. These authorities then pass regulations and standards that are followed in many countries. There remains controversy over the use of the Linear Non-Threshold (LNT) model for *radiation protection*. All models are wrong but some are useful such as the LNT model in the past. There is misuse and abuse of the LNT model when applied to risk assessment, i.e., LNT does not mean there has been detectable risks at any dose. It is the current model used to manage exposures at low doses. It is for compliance, for regulators, and not for risk assessment. It is inappropriate to multiply a tiny dose to a large population and predict theoretical deaths in the future! The scientific underpinnings of the LNT model (as used in *radiation protection*) can be found in ICRP Publication 99 and NCRP Report 136. But science is a process of constant renewal and new reports from NCRP will be out soon addressing whether the new epidemiology has changed understanding of the use of the LNT model for the practical purposes of *radiation protection*. This paper provides summary overviews of the important epidemiologic studies that have provided exceptional knowledge on radiation risks. The exciting field of genetics and the possible interplay of susceptibility with radiation will also be touched upon. Ongoing research will be briefly mentioned such as the INWORKS studies of French, United Kingdom, and US workers; the Mayak workers; and the study of One Million US Radiation Workers and Veterans. The later has 18 times more adults than the study of atomic bomb survivor, has more high-dose subjects, and exposure was received gradually over time and not in a fraction of a second. The gap in radiation epidemiology that needs to be filled for radiation protection purposes is learning the level of risk from chronic exposures to relatively health populations. Finally, the relevance of research conducted today on populations exposed in years past will be discussed. In particular the research needed for traveling beyond early orbit when considering astronauts going to Mars and the need to integrated radiation biology with the best epidemiology for estimating risk in the low dose domain (biologically-based modelling). In summary, epidemiology forms the basis for protection; committees synthesize the epidemiology and biology and make judgments on protection standards; ICRP and NCRP make recommendation considering the scientific reviews by UNSCEAR and the NAS BEIR Reports; and authorities decide on standards and regulations. There's much to be done as society expands its uses of ionizing radiation! Radiation protection is alive, needed and essential for the future!

GOLD MEDAL FOR RADIATION PROTECTION LECTURE

What Can We Learn from Studies of Nuclear Workers?

Ethel Gilbert

National Cancer Institute, Rockville, MD, USA

Abstract. Epidemiologic studies of workers exposed to radiation allow a direct assessment of risks from low-level radiation exposure, and also provide information on risks from exposure to radionuclides. Dozens of studies of workers exposed primarily to protracted low-level gamma radiation have been conducted in many countries and serve as a check on estimates obtained through extrapolation from the Life Span Study cohort of Japanese atomic bomb survivors. To summarize these data and to obtain more precise estimates of risks, national and international pooled analyses of data from these studies have been carried out and indicate that risks are generally compatible with estimates that form the basis of radiation protection standards. In addition, nuclear workers at the Mayak nuclear facility in the Russian Federation offer the only adequate human data for evaluating cancer risks from exposure to plutonium. These data have demonstrated that risks of lung, liver, and bone cancers increase with increasing plutonium dose with the lung cancer dose-response well-described by a linear function. Strengths and weaknesses of these studies will be discussed.

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Area 1: Fundamental Science

Attenuation Coefficients of Some Species of Wood

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Abstract. Wood is an inevitable building material in any X-ray facility. It is lead-free, very abundant in Africa and friendly to the environment. Attenuation Coefficients of different African species of wood were determined for narrow beam X-ray over the energy range of 40-150keV. Hopewell design X-ray source housed at the Standard Secondary Dosimeter Laboratory of Nigeria Institute of Radiation Protection and Research, University of Ibadan was used for this work. Analysis of the elemental composition of each species of wood was determined using the energy dispersive X-ray fluorescence spectrometer. The elemental composition was used in the theoretical determination of the attenuation coefficient using XCOM software. The experimental mass attenuation coefficients obtained for 40kVp energy X-ray in descending order are 0.458, 0.413, 0.311, 0.308, 0.304, 0.302, 0.269, 0.244, 0.211 for *Milicia excelsa, Nauclea diderrichii, Acacia, Albizia zygia, Cola accuminata, Delonix regia, Albizia falcata, Terminalia catappa, Swartzia fistuloides* respectively. Also the theoretical mass attenuation coefficient obtained at 40kVp energy X-ray ranged from 0.237 to 0.212. The Chi-square test done on the results showed no significant difference in the values of the attenuation coefficients determined experimentally and by theoretical procedures. The two sets of result led to the formation of models for quick estimation of the attenuation coefficient of woods at different thickness and different X-ray energies. At higher energies, the mass attenuation coefficient of *Milicia excelsa, Nauclea diderrichii* and *Acacia* compared well with that of concrete but was less than that of lead. Thus some of the wood could be used in designing shielding facilities for X-ray centres especially in doors, frames and ceiling.

KEYWORDS: X-ray; shielding; wood; attenuation coefficients.

1 INTRODUCTION

In any radiology department, it is required that the X-ray facilities be properly shielded in order to reduce to an acceptable level, exposures to both the public and personnel. Shielding involves placing a suitable material or combination of materials between an X-ray facility and the personnel/public in order to reduce exposure to radiation from the facility. The choice and thickness of the attenuating material (shield) will depend upon the type and energy of the X-ray radiation. Materials that are dense and uniformly spread are more often used for shielding. Examples include lead, iron, concrete and wood. Lead is very efficient in shielding X-ray but it is toxic and it has also been recognized as a source of environmental pollution. This includes lead use for radiation shielding [1]. It is also not possible to use lead to build an X-ray facility from ground to roof. Hence there is need for other shielding materials that will be less toxic and less expensive. In building construction, concrete and wood are the most available materials. Wood is almost inevitable when building because it comes in as doors, frames, roof supports and furniture. Hence it is very necessary to have data of the radiation shielding ability of woods, most especially Nigerian species of wood, for the purpose of x-ray facility design.

The choice of wood in this research is because it is readily available, very abundant and less expensive. Wood is an organic material so will help in reducing global warming. Again most doors, panel and frames of X-ray facilities are made of wood. Long-living wood products contribute to the mitigation of climate change in many ways. They act as a carbon pool during their service life, as they withdraw CO_2 from its natural cycle. Calculations show that an increased use of wood in the building sector is a valid and valuable option for the mitigation of greenhouse gas (GHG) emissions and for reaching GHG emission targets in a mid- to long-term [2].Wood materials also serve as a temporary biogenic carbon stock which can potentially be recycled for energy after its useful life [3].

Plywood has been the common type of wood in diagnostic and therapeutic x-ray facilities. Several researchers have carried out series of research activities on plywood. However, not much work has been carried out on other types of woods, most especially, the Nigerian species of wood. The few available are those of Ero, Imeri and Oni [4-6]. The previous activities on the radiation shielding ability of Nigerian species of wood have been limited to determination of the relative transmission coefficient and broad-beam attenuation characteristics. In this work however, the attenuation coefficient of different species of Nigerian wood, under narrow-beam geometry with respect to the elemental constituents of each variety is considered. The data thus envisaged to be generated under narrow-beam geometry could therefore be a basis for the determination of shielding characteristics of the Nigerian species of wood.

Wood is basically composed of Carbon and little of Nitrogen, Oxygen, Hydrogen, Sulphur, Calcium, Potassium, Chlorine, Tin, Manganese, Iron, Nickel, Copper, Zinc and Argon in different compositions. These elemental compositions determine the attenuation properties of each particular wood. Wood like every other compound is composed of molecules which vibrate when energy (X-ray) is incident on it. Hence we expect that the bigger the size of molecules that are contained in each particular wood, the greater the attenuating properties of that wood [7].

2 METHODOLOGY

2.1 Wood collection and preparation

Nigeria’s forest is rich with different species of wood for different purposes. This research focuses more on those species that are suitable for doors, frames, furniture and other purposes in radiation facility design. The woods used in this research were collected from two locations in Nigeria, namely, Ibadan and Benin City. The wood samples were collected at the point where they were felled and taken to Forestry Research Institute of Nigeria (FRIN) for slicing into different sizes. The thickness of the wood varied from 2cm to 12cm while the length varied from 17cm to 23cm and the breadth from 17cm to 22cm. All the nine wood species were dried at FRIN for 3weeks to ensure that moisture, which would otherwise cause self-absorption of the radiation, was completely eliminated. The mass (in grams) of each sample was then measured and recorded. The volume (in cm^3) was also calculated from the dimension of each wood. The density was calculated from the mass and the volume such that

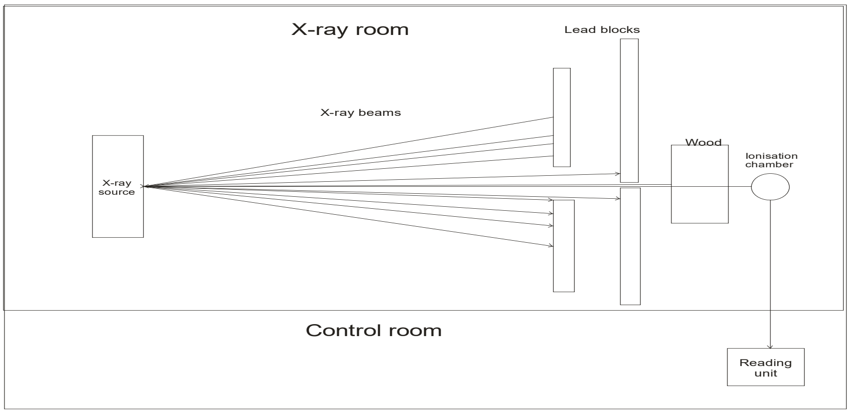
$$\mathbf{Density} = \frac{\mathbf{Mass}}{\mathbf{Volume}} \qquad (1)$$

2.2 Experimental setup

The Secondary Standard Dosimeter Laboratory at the Nigeria Institute of Radiation Protection and Research (NIRPR) was used for this research because an X-ray source which will be operating at a high precision is desired. The temperature of the X-ray room varied from 20.11^0C to 21.49^0C and a relative humidity (RH) of 41.7% to 43.2% throughout the experiment. A source to wood distance of 1.55m and source to ion chamber of 1.75m was used. The current was set at 10mA and FOC 5.5.

The woods were exposed to a narrow beam of X-ray, achieved by using lead block with a small hole at its centre. An arrangement consisting of a lead block with a square opening of 8cm by 8cm was placed in front of the beam then another lead block with a round opening diameter of 1cm was placed behind the 8cm by 8cm lead block. The wood was then placed behind the lead with 1cm diameter opening. The ion chamber was also placed behind the wood. Around the 2 lead blocks (8cm by 8cm and 1cm diameter open block) were placed solid lead blocks to stop both incident and scattered X-ray from getting to the wood and ion chamber. A laser beam was used to align the X-ray beam, lead blocks, the woods and ion chamber in a straight line. A schematic diagram of the experimental set-up is however shown in Fig.1.

Figure 1: Schematic diagram of experimental set-up



After the setup was aligned, the reading of exposure of ion chamber without wood was taken. The different thicknesses of each of the wood samples were exposed, placed between the X-ray source and ionization chamber and the readings recorded. The reading of the ion chamber was given in terms of the charges produced. Since the charge is related to the energy by the equation

$$E = IVt = qV \tag{2}$$

Hence if the voltage is constant then

$$E \propto q \tag{3}$$

Thus the intensity of the x-ray beam was determined and recorded in terms of the charge released. From equation of energy attenuation, we have that

$$E = E_0 e^{-\mu x} \tag{4}$$

$$\rightarrow qV = q_0 V_0 e^{-\mu x} \tag{5}$$

If $V = V_0$ then

$$q = q_0 e^{-\mu x} \tag{6}$$

$$\rightarrow -\ln \frac{q}{q_0} = \mu x \tag{7}$$

Where q_0 is the amount of charge recorded without the wood and q is the amount of charge recorded when the different kinds of wood are placed between the X-ray beam and the ion chamber.

2.3 Determination of Attenuation Coefficient

From equation 2, a plot of $-\ln \frac{q}{q_0}$ against x yields a linear graph, the slope of which gives the linear attenuation coefficients of the wood samples. The mass attenuation coefficient was similarly determined by plotting $-\ln \frac{q}{q_0}$ against ρx such that the slope gives the mass attenuation coefficient.

2.4 Elemental Analysis

At Centre for Energy Research and Development (CERD), Obafemi Awolowo University Ife, Nigeria, the Energy Dispersive X-ray fluorescence (EDXRF) spectrometer which provides one of the simplest, most accurate and the most economic analytical methods for the determination of the chemical composition of many types of materials was used in this work. It is non-destructive and reliable, requires no or very little sample preparation and is suitable for solid, liquid and powdery samples. It can be used for a wide range of element from Chlorine (atomic number=15) to Uranium (atomic number=92) and provides detection limits at sub-ppm (part per million) level. It easily can also measure concentrations of up to 100 %. The EDXRF was used for the analysis of the trace elements from Cl-Zn for each of the wood species. The process involved cutting a small piece of each wood about 1cm by 1cm by 1cm and placing it in the EDXRF analyser. The sample was then exposed to X-ray and a graph of the K_α characteristic X-ray was plotted on the computer connected to the EDXRF analyser. From the characteristic X-ray graph, each of the elements could easily be accounted for. The method of direct comparison of count rates from the table of energy for each element was used. The X-ray tube used had a silver anode and was operated at a voltage of 25.0kV, a current of 50µA and for 1200s (20 minutes).

At International Institute for Tropical Agriculture (IITA), Ibadan, the analysis for Carbon, Phosphorous and Nitrogen was carried out. For carbon content analysis, the organic carbon determination method was employed. At the laboratory, the wood samples were grinded and sieved using a 0.2mm sieve. 250mg each of the prepared sample was weighed out for carbon determination. The weighed samples were put into test tubes. Potassium dichromate ($K_2Cr_2O_7$) and concentrated H_2SO_4 were added to the test tubes containing the samples. The test tube was capped with a rubber stopper and swirled on a vortex mixer until the wood sample was completely dispersed. It was placed in a digestion block, preheated to 150^{o}C. The tube was allowed to cool while still on the digestion block. The samples were read on a spectrophotometer at a wavelength of 600nm using a 1cm cell.

The analysis of the wood samples for nitrogen was carried out in two steps. First the samples were digested in a hot sulphuric acid solution with SeO_2 as a catalyst. The ammonium ions then reacted with phenol to form an indophenols blue dye. The intensity of the blue dye is proportional to the concentration of nitrogen in the solution. The solution was read calorimetrically in an auto-analyser at a wavelength of 630mm. Similar method was used for phosphorus. The samples were first digested with hot sulphuric acid solution with SeO_2 catalyst. Then an acid molybdate solution was added. The molybdate reacted with the sample to form a phosophomolybdate complex. The complex is reduced by ascorbic acid to form a blue dye. The intensity of the colour is proportional to the sulphur in the solution. This is then read at a wavelength of 630nm using an auto-analyser.

2.5 Theoretical calculation

The theoretical calculation of the mass attenuation coefficient was done using the standard XCOM software. The software was specially designed to calculate mass attenuation if the elemental compositions of a particular material are known. Thus, the mass attenuation coefficient was determined using the following element: Carbon, Nitrogen, Phosphorous, Chlorine, Argon, Potassium, Calcium, Manganese, Tin, Nickel, Copper and Zinc. The rest was assumed to be oxygen since hydrogen would contribute very little to the calculation.

3 RESULT AND DISCUSSION

3.1 Wood data analysis

Using the different dimensions of the wood, the volumes and the density of the woods were determined. The average density (shown in table 1) for each species of wood was taken as representing the density of that particular wood species. It was found that *Acacia* had the highest density of 0.86gcm^{-3} while *Albizia* f*alcata* had the lowest density of 0.58gcm^{-3}.

3.2 Experimental result

From the graphs of $-\ln {q}/{q_0}$ plotted against the various thickness of each wood for different energies (40kVp, 80kVp, 100kVp, 120kVp, 150kVp), the linear attenuation coefficients of the wood species were determined. The result is presented in table 1.The results of the linear attenuation coefficient translated to the determination of the mass attenuation coefficient are presented in table 2. It was found that *Milicia* e*xcelsa* had the highest linear attenuation coefficient while *Terminalia catappa* was found to have the lowest for most energy. For the mass attenuation coefficient, *Milicia* e*xcelsa* had the highest while *Swartzia fistuloides* had the lowest for most energy.

Table 1: Linear Attenuation Coefficient in m^{-1} for different energies

Wood Species	Density (gcm^{-3})	40 (kVp)	80 (kVp)	100 (kVp)	120 (kVp)	150 (kVp)
Albiziafalcata	0.58	0.1551	0.0910	0.0809	0.0678	0.0823
Albiziazygia	0.62	0.1898	0.1072	0.0983	0.0831	0.0896
Acacia	0.86	0.2670	0.1437	0.1137	0.1042	0.1197
Cola acuminata	0.64	0.1953	0.1180	0.0951	0.0762	0.0849
Delonixregia	0.71	0.2140	0.1180	0.0924	0.0855	0.0972
Miliciaexcelsa	0.62	0.2841	0.1529	0.1178	0.1080	0.1235
Naucleadiderrichii	0.64	0.2654	0.1376	0.1161	0.1076	0.1078
Swartziafistuloides	0.85	0.1798	0.0995	0.0802	0.0736	0.0834
Terminalia catappa	0.62	0.1520	0.0829	0.0743	0.0626	0.0732

Table 2: Mass Attenuation Coefficient in m^{2}kg^{-1}.

Wood Species	40 (kVp)	80 (kVp)	100 (kVp)	120 (kVp)	150 (kVp)
Albizia falcate	0.2685	0.1575	0.1401	0.1174	0.1425
Albiziazygia	0.3083	0.1741	0.1597	0.1350	0.1455
Acacia	0.3111	0.1674	0.1325	0.1214	0.1395
Cola acuminata	0.3037	0.1835	0.1479	0.1185	0.1320
Delonixregia	0.3015	0.1662	0.1302	0.1205	0.1369
Miliciaexcelsa	0.4584	0.2467	0.1901	0.1743	0.1993
Naucleadiderrichii	0.4126	0.2139	0.1805	0.1673	0.1676
Swartziafistuloides	0.2107	0.1166	0.1090	0.0862	0.0977
Terminalia catappa	0.2438	0.1330	0.1192	0.1004	0.1174

3.3 Theoretical result

The theoretical analysis was done using the software, XCOM and the result given in table 4. As in the experimental part of this work, *Milicia excelsa* was still found to have the highest attenuation coefficient. It was found out that the attenuation coefficient was greatly affected by the atomic mass of the constituent elements. *Milicia excelsa* had the lowest carbon content and hence a high amount of elements with high atomic mass.

Table 3: Elemental compositions of woods.

Wood Species	Atomic mass	*Albizia falcate*	*Albizia*	*Acacia*	*Cola acuminata*	*Delonix regia*	*Milicia excelsa*	*Nauclea diderrichii*	*Swartizia fistuloides*	*Terminalia catappa*
Carbon	12.0107	99.0600	98.9800	97.1100	97.6600	98.1200	95.4000	98.0900	98.3200	98.9000
Nitrogen	14.0067	0.2900	0.2500	0.2900	0.3300	0.5500	0.2800	0.3700	0.2700	0.2600
Oxygen	15.9994	0.3922	0.3383	0.8578	0.9253	1.0707	2.4936	1.2691	0.2176	0.5452
Phosphorous	30.9738	0.0000	0.0000	0.0100	0.0200	0.0100	0.0100	0.0200	0.0100	0.0100
Chlorine	35.453	0.0429	0.0180	0.0301	0.0707	0.0779	0.0768	0.0258	0.0365	0.0704
Argon	39.948	-	-	-	0.6214	-	-	-	-	-
Potassium	39.0983	0.1166	0.2367	0.5436	0.2438	0.1250	0.5301	0.0996	0.3145	0.1178
Calcium	40.078	0.0901	0.1737	1.1550	0.1198	0.0455	1.1980	0.1220	0.8181	0.0927
Manganese	54.938	0.0032	0.0005	-	0.0038	-	-	-	0.0065	-
Iron	55.845	0.0025	0.0011	-	0.0023	-	0.0065	0.0014	0.0034	0.0024
Nickel	58.6934	0.0003	0.0005	0.0018	0.0008	0.0009	0.0022	0.0008	0.0011	0.0006
Copper	63.546	0.0010	0.0006	0.0008	0.0009	-	0.0014	0.0005	0.0010	0.0005
Zinc	65.39	0.0012	0.0006	0.0009	0.0012	-	0.0014	0.0008	0.0013	0.0004
Total		100	100	100	100	100	100	100	100	100

Table 4: Theoretical calculations of mass attenuation coefficient in m^2kg^{-1}.

Wood Species	40(kVp)	80(kVp)	100(kVp)	120(kVp)	150(kVp)
Albizia falcate	0.2116	0.1615	0.1516	0.1440	0.1348
Albizia zygia	0.2141	0.1618	0.1518	0.1440	0.1348
Acacia	0.2346	0.1644	0.1531	0.1448	0.1352
Cola acuminata	0.2208	0.1626	0.1521	0.1442	0.1349
Delonix regia	0.2115	0.1615	0.1516	0.1440	0.1348
Milicia excelsa	0.2367	0.1647	0.1532	0.1449	0.1352
Nauclea diderrichii	0.2122	0.1616	0.1517	0.1440	0.1348
Swartzia fistuloides	0.2261	0.1633	0.1526	0.1445	0.1350
Terminalia catappa	0.2119	0.1615	0.1516	0.1440	0.1348

3.4 Comparison of experimental and theoretical result

The difference between the experimental and theoretical results was subjected to statistical analysis. The chi square (χ^2_{cal}) values and the table chi square (χ^2_{tab}) values for the wood species at different kVp were calculated. At the 5% level of significance, it was observed that there was no significant difference between the values obtained by the two procedures despite the basic assumptions made since the χ^2_{tab} (9.488) was always greater than the χ^2_{cal} (0.294). Some of the pertinent assumptions are: the assumptions made for Oxygen, the elemental analysis that was done by two different methods, the calculation of the density using approximate methods and the difference in the compactness of the wood that is not considered in the theoretical calculation.

3.5 Comparison of mass attenuation coefficient of wood with other shielding materials.

The comparative study of the mass attenuation coefficient of the three wood species with highest attenuation coefficient, with lead and concrete showed that apart from lead with a remarkable attenuation coefficient, Nigerian species of wood compares favourably with concrete. (See table 5)

Table 5: Comparison of Mass Attenuation Coefficient in m^2kg^{-1} of the highest three woods with some radiation shielding materials

MATERIAL	DENSITY (gcm^{-3})	40kVp	80kVp	100kVp	120kVp	150kVp
LEAD	11.36	14.36	2.42	5.55	-	2.01
CONCRETE	2.40	0.51	0.20	0.17	-	0.14
Milicia excelsa	0.62	0.46	0.25	0.19	0.17	0.20
Nauclea diderrichii	0.64	0.41	0.21	0.18	0.17	0.17
Acacia	0.86	0.31	0.17	0.13	0.12	0.14

4 CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The linear and mass attenuation coefficients of some Nigerian species of wood have been determined in this work. Experimental and theoretical procedures have been employed in this determination. The experimental result was found to compare well with the theoretical result. It was found that for both the theoretical and the experimental calculation, *Milicia excelsa* had the highest mass attenuation coefficient. For the experimental analysis, *Swartzia fistuloides* had the lowest while for theoretical calculation, *Delonix regia* had the lowest. It was discovered that though *Acacia* was the heaviest wood, it was not the wood species with highest attenuation coefficient.

4.2 Recommendations

From the elemental analysis done, it is possible that materials with high calcium content can have high attenuating property. Further research can be done to find the exact element in wood that is most important for increasing the attenuating properties of the wood. If the wood is treated with this element it will be good to see how the treated wood will respond to X-ray beam as a shielding material.

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Scoping Study of Possible Chronic Health Effects for Workers at the Rössing Uranium Mine

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Abstract. The Rössing Uranium Mine is a large open pit mine with low-grade uranium located about 70 km inland from the coastal town of Swakopmund in the Erongo Region of Namibia. It is one of the largest and longest running uranium mines in the world. Mining started at Rössing in 1976 and has continued uninterrupted since then. To date, some 12,000 miners have been employed with an average work duration of 6 years. We undertook a scoping study to evaluate and recommend possible health studies that could be undertaken to better understand the occupational health risks, particularly cancer, for those who worked at the Rössing mine. Rössing collected detailed radiation exposure records that date back to when mining operations first began. These exposure records allow for variations in exposure to be described across different occupational groups as well as separately for external and internal radiation exposure pathways. These data demonstrate that the exposures to radiation in the Rössing mine, relative to other uranium mines, are very low. While workers at Rössing are exposed to a variety of occupational exposures, the focus of the current study was on the radiation exposure of workers and the potential for radiation-induced cancers arising from that exposure. In this paper, we discuss possible epidemiological study designs that could be carried out to improve our understanding of the occupational health risks faced by these workers and the strengths and limitations of these different approaches.

KEYWORDS: uranium mining; cancer risks; epidemiology; radiation; feasibility.

1 INTRODUCTION AND BACKGROUND

Rössing is a large open pit uranium mine located about 70 km inland from the coastal town of Swakopmund in the Erongo Region of Namibia. Mining started at Rössing in 1976 and continues today. The mineralogy has been fairly constant throughout the period of mine operations with a relatively low grade of about 300 parts per million (ppm) of natural uranium. Ore from the mine is crushed, ground and acid leached. The leachate is passed through an ion exchange and solvent extraction plant for purification. Uranium is precipitated as ammonium diuranate (commonly referred to as “yellowcake”), and subsequently calcined to uranium oxide to form the final product (calcined uranium concentrate, uranium oxide U_3O_8). The first uranium concentrate at Rössing was produced in May 1976. Since the start of operations in 1976, the number of mine employees has varied between 1,000 and 3,000 in any year. Overall, to date, a total of approximately 12,000 individuals have been employed at the mine. The majority of the employees have been Namibian nationals, and the overwhelming majority were men.

Over the past several years, there has been considerable discussion about the health risks to Rössing workers resulting from exposure to ionizing radiation. Over the past decade, Rössing had initiated a number of studies to investigate whether or not these exposures impacted the health of their miners. However, as of the 2011 Rio Tinto HSE and Product Stewardship Review report [1]. Rössing had been unable demonstrate that workers were not subject to an excess risk of cancer as a result of working at Rössing. In part, the present Scoping Study arose from Rio Tinto’s desire to better understand whether or not there was an association between the workers cancer risk and their workplace exposure to ionizing radiation.

The Scoping Study relied heavily on information provided by Rössing. A site visit by two SENES representatives in June 2014, provided the opportunity to interview stakeholders and discuss available data in detail with: Rössing personnel, the occupational health service provider for the site, the Namibia Uranium Association, and the National Cancer Association of Namibia, albeit, data from the national data-base is currently of limited use since cancer is not a reportable disease and hence the register does not capture all diagnosed cancer cases, or cancer related deaths. Rössing has detailed radiation exposure records that date back to when mining operations first began; however, these data are only available electronically from 1996 onwards. Detailed medical records are available from the start of Mining and recently, in electronic format. The personal work history data from human resources files and pension data are quite detailed. The pension data however, are somewhat limited as they do not track a large portion of the Rössing miners after they have stopped working at the mine.

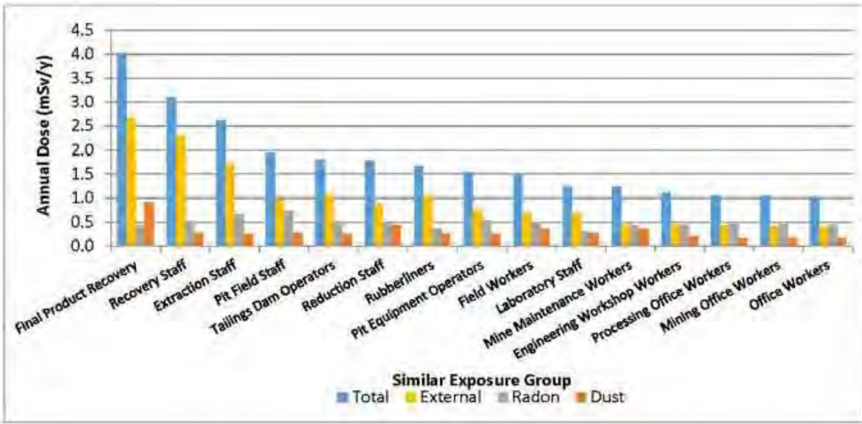
The following paper discusses the information currently available to support an epidemiological study, the alternative possible study designs and provides recommendation should a full epidemiological study of cancer risks in the Rössing cohort be undertaken.

2 MATERIALS AND METHODS

2.1 Worker Exposures

Rössing has organized their dose data for workers into fifteen Similar Exposure Groups (SEG) for all workers. For 'radiation workers' (those with a potential exposure dose from all pathways exceeding 5 mSv per annum) Rössing tracks individual worker exposures.

Figure 1: Mean Radiation Doses over 18 Years at Rössing Mine (1996 – 2013)



Exposure data are available in paper format from the start of mining in 1976 and electronically from 1996. Figure 1 shows the mean total radiation doses from all sources of radiation exposure – external gamma, radon progeny and long lived radioactive dust, for the period from 1996 to 2013 for the 15 SEGs. The doses to workers in all SEGs was well below the annual dose limit of 20 mSv per annum. Note that this graph gives averages over each SEG, then averaged over all years in the range, hence these do not represent population weighted averages of exposure dose.

While there is a range of radon progeny exposures to miners, the annual (effective) doses of most miners to radon-222 and progeny averages about 0.5 mSv/y. Over a working period of 20 years, a typical Rössing worker accumulates an effective dose of 10 mSv from inhalation of radon-222 and progeny.

Although workers in the Final product Recovery (FPR) receive the highest dose from all pathways combined, the mean dose to these workers was less than 20% of the 20 mSv/y dose limit to radiation workers. The maximum yearly dose to any individual was always well below the 20 mSv/y limit. It is understood that workers in the FPR have worn respirators, essentially since start of mining, and the exposures (and doses) to workers in the FPR area assume a protection factor of 10.

In addition to the data on the miners exposure to radiation by SEG or for radiation workers by individual, Rössing also collects data on total dust and silica dust (quartz) levels by SEG as well as performing regular surveys in selected work areas to investigate workplace exposures to other airborne contaminants, namely, volatile organic compounds, manganese, metal fumes, asbestos and acid mists. Job exposure matrices (JEMs) are commonly used at Rössing to organize exposure data, and to classify workers according to their exposure across different types of jobs.

2.2 Medical Surveillance and Human Resources Data

Medical surveillance of Rössing workers has been performed since the start of operations. All data are available in paper records. Since 2005 when the medical surveillance was contracted out, efforts have been made to develop electronic databases. In 2009, the occupational health baseline has been evaluated on a risk informed basis and a separate medical surveillance risk matrix developed for employees and contractors (with more than 2 years on-site). In essence, the medical surveillance matrix assigns specific frequencies of medical tests to workers in each SEG on the basis of a risk assessment of workplace occupational hazards.

Various data are available from human resources and pension files in electronic form. The information contained in these databases includes: occupation, ethnicity, sex, birth date, SEG, job and working area, and start and end dates of employment. These data provide a near complete listing of all individuals who have ever been employed at the mine (both past and present) and can be used to describe many of the key demographic features of the cohort. As of 2014, Rössing Human Resources had information for 12,570 employees grouped into currently working employees and previous employees. At the time of the study, there were 7,726 employees where information on birth date, ethnicity, entry date and duration of employment are available. Gender was available for 12,011 employees, with females accounting for about 10% of the overall workforce (1,060 female employees). Ethnicity was the information most frequently not recorded relative to other variables described (employees provide this information voluntarily).

Records for current workers and recent previous workers had better information than previous workers removed from employment prior to 1996. Some employees had had multiple job duties over their period of employment. Since start of mining, there were more than 1,500 occupations and these could not be uniquely classified into a SEG. This is because the classification into SEG groups is based on the working area and its associated hazards, not on the job title. In principle, however, classification of all past and present workers into the Rössing Uranium Limited (RUL) SEG system is possible. Total exposure and increased risk are related to the duration of exposure. Overall, miners at Rössing had a mean duration of employment of 6 years and a maximum duration of employment of 39 years with the majority of workers employed for less than 5 years. The most active period of hiring and leaving employment occurred up to about 1982 with these early employees tending to have a shorter duration of employment.

Rössing also maintains a comprehensive disease register for current employees, including cancers. These cancers were identified in active employees or those who were receiving pension benefits. As most workers are not tracked post-employment and given that the incidence of cancer increases with age, it is likely that a larger number of cancers occurred among miners who had retired or otherwise left Rössing. At the time of this study, some 24 respiratory cancers (ICD Codes 160-165) had been identified in the workforce.

Smoking cigarettes is the predominant cause of lung cancer. In Namibia, approximately 8% of women and 24% of men use tobacco. In smokers, about 31% of women and 26% of men smoke more than 10 cigarettes [½ pack] per day [2]. During routine medicals, workers are asked about their smoking habits. A recent sample of data for the 225 workers who smoke (about 20% of the miners) shows that about 35% of the miners who smoke, smoke ≥ 1/2 pack per day which can be compared to the 26% of males in the general population who smoke ≥ about ½ pack per day. These rates of smoking are lower than rates observed in most other mining populations [e.g., 3,4.]

At the time of this study, the National Cancer Registry for Namibia was under development and data from the registry were not well suited for scientific studies that rely on comparing cancer incidence rates of the workers to the general population. However, we understand that work is underway to upgrade the coverage of this database and hopefully future studies will be able to use database for making comparisons. At present, an ability to link personal identifiers of workers to the national registry to identify cancers in these workers is likely to be challenging because they are not being captured through mechanisms currently in place.

2.3 Methods

Epidemiological studies are observational in nature. They differ from experimental studies where the investigator is able to exert control over the level of exposure. The quality of observational studies depends on the design used, the types of data available, and the number of participants. High quality epidemiological studies require that the relevant exposure(s) can be adequately characterized, the health outcomes readily identified, and the effects of other risk factors taken into account. While a general survey or cross-sectional study approach was considered, these types of studies only capture a snap-shot of exposure and disease status at a set point in time and are quite limited in terms of providing insights about causality. Both case-control and cohort study designs, while subject to some level of uncertainty, are typically more powerful if they are able to capture data at an individual-level, both for exposure and health outcome.

Historically, underground uranium miners have been exposed to higher levels of ionizing radiation than most other occupations and therefore, the possibility of an increase in the risk of (solid) cancer, in particular, lung cancer, in exposed miners has been a focus of such studies [e.g., 3,4.] To date, the main identified radiation hazard has been an increased risk of lung cancer from exposure in the past to elevated levels of radon and progeny. Studies of uranium miners have also reported a non-statistically significant excess number of other cancers including: leukemia, liver, oral/mouth, bone, and kidney [e.g., 3,4.] In this scoping study, radiation induced solid cancers, notably, cancers of the lung, bone, liver, mouth, and kidney were considered.

Epidemiological analyses use statistical methods to determine whether a different risk is present in an exposed group compared to the risk experienced in an unexposed group. The term power is the probability for a statistically significant, and higher, risk in the exposed group. Typically a target for power is about 80%; that is, there is more than an 80% chance of detecting an excess risk. The statistical power to detect the increased risk depends on the number of individuals in the exposure groups, the magnitude of the increased risk from exposure, and the follow-up period. The baseline probability of a person developing a cancer depends on age, other habits (e.g. smoking), gender, and potentially ethnicity among many factors. These are important considerations in an epidemiological study.

In order to support power calculations, currently available information is used to predict attained age, age distributions and estimated overall cancer mortality and mortality due to selected cancers (e.g., lung cancer) for various follow-up periods. This is illustrated in Table 1 where we show predicted numbers of deaths from cancer overall and from lung cancer. For illustrative calculation, we have used Namibia five year mortality rates as reported by WHO [5] and for a standard European/American population by ICRP 103 [4] for consideration of the range of potential radiation effects. As cancer incidence and mortality rates for Namibia by five year age groups are not currently available, we used cancer rates from IARC 2012 [5,6] to estimate the baseline total and lung cancer mortality of the Rössing cohort male employees as shown in Table 1 for all employees and all exposure categories. and for ethnic groupings of black, NR (not specifically reported) and white. All cancer and lung cancer (ICD Code 162) mortality were predicted for three years (2015, 2025 and 2035. (Similar calculations were also performed for miners classified by exposure category).

Table 1: Estimated Numbers of Baseline Total and Lung Cancer Mortality for the Cohort

Ethnic.	Rates	Num.	All Cancer 2015	Lung 2015	All Cancer 2025	Lung 2025	All Cancer 2035	Lung 2035
All	All	8155	2784	42.6	4352	78.0	6077	112.9
Black	Namibia	3883	1300	6.4	1997	11.2	2775	16.7
NR	Namibia	2642	1139	5.9	1693	9.9	2247	13.8
White	ICRP EA	1630	345	30.3	662	56.9	1055	82.4

For the complete cohort, the illustrative scenario indicates that about 40 lung cancers are expected in 2015, nearly 80 lung cancers by 2025 and about 112 by 2035. As illustrated by data in Table 1, the majority of the lung cancers occur in white employees, for example, in 2035, around 82 of the predicted 112 lung cancers would occur in the white workers who coincidentally, are the heaviest smokers. There will be increases for later follow-up periods and a larger proportion of these will be traceable with improved tracing of employees. The difference in smoking rates and other lifestyle factors suggest that matching should be done on ethnicity and smoking which should be used as either a matching criteria or as a covariate in a statistical analysis.

The statistical power to detect the increased risk depends on the number of individuals in the exposure groups, the magnitude of the increased risk from exposure, and the follow-up period. The baseline probability of a person developing a cancer depends on age, other habits (e.g. smoking), gender, and potentially ethnicity among many factors. These are important considerations in an epidemiological study. The power to detect an increase in risk due to radiological exposures was approximated for several scenarios using the PASS software program (http://www.ncss.com/software/pass/).

For present illustrative purposes, assuming the average cumulative exposure is 10 mSv in a high exposure group, the increase in lifetime risk (of lung cancer) is (very) approximately 1%. It is important to note that this is much smaller than the exposures found in previous (underground) miner studies or recent residential exposure studies.

We allowed the number of cancers in the higher exposure group, which is assumed to be 30% of the employees, to range between 50 and 150 cancers with four controls selected per case. In addition, we estimated study power for a number of different magnitudes of increased risk ranging from odds ratios of 1.25 to 2.25.

Ideally, the study should be designed to provide 80% power to detect a level of increased risk that is thought to be reasonable by the study investigators. Based on the parameters we specified, there will be limited power to detect odds ratios that are less than two, or alternatively, a two fold increase in risk.

3 FINDINGS

Rössing has detailed radiation exposure records that date back to when mining operations first began; however, these data are only available electronically from 1996 onwards. These exposure records allow for differences in exposure to be described across different occupational groups (i.e., similar exposure group or SEG), as well as separately for external and internal radiation exposure pathways. Individual exposure records are available for the miners designated as radiation workers. These data demonstrate that the exposures to radiation in the Rössing mine, relative to other uranium mines, are very low.

Since the exposures are low, it can be reasonably anticipated that the radiation risks (cancer) to miners from workplace exposures at Rössing would be much lower than those encountered at other uranium mines, which suggests that risks of radiation-induced cancers are also likely to be very small, as for example suggested by the power calculation reported in the previous Section.

Detailed data on dust exposures by similar exposure group (SEG) are also available. These data play an important role, as dust exposures have been demonstrated to increase the risk of respiratory cancers (reference), and affect respiratory function for some workers (reference).

Detailed medical records are available from the start of mining, although these data are only recently available in electronic format. These medical records can play an important role in identifying adverse health outcomes, and monitoring changes in the health of these workers over time.

The personal work history data from human resources files and pension data are quite detailed. The pension data however, are somewhat limited as they do not track a large portion of the Rössing miners after they have stopped working at the mine. Therefore, they do not provide the means to identify health outcomes that may occur several years after individuals have stopped working at the mine. This feature is important for studies that aim to detect associations between occupational radiation exposure and cancer given that it is recognized that there is a latency period of at least a decade before increased risks are evident.

At the present time, there are important limitations of using data sources external to Rössing to study health outcomes in their miners. A key limitation is that the national data set lacks coverage to capture mortality and cancer incidence outcomes. In our view, this precludes conducting epidemiological studies whereby patterns of mortality and cancer incidence among Rössing workers are compared to the general population. In addition, at present, the use of the national database is limited as the capacity to conduct record linkage studies has not yet been developed. However, these data hold some promise for identifying cancer outcomes among Rössing workers post-employment and may play a pivotal role in increasing sample sizes needed to better detect lower levels of risk. These sample sizes would be increased as the use of these external data sources may allow us to identify workers who were diagnosed with cancer after employment that were not identified from Rössing medical or pension files.

The occupational exposures to radiation (and other workplace agents) described earlier in this report have potential to the increase the risk of chronic disease as a result of workers being exposed to them over a long period (i.e., several years or even decades). Therefore, epidemiological studies that attempt to better understand their influence on adverse health outcomes must be capable of characterizing workers' exposures to ionizing radiation and cofactors over these long periods of time.

Moreover, given the latency intervals (time from exposure to observation of disease), particularly for occupational exposure to carcinogens and the future development of cancer, epidemiological investigations should ensure that there is sufficient follow-up of individuals. Any increased risk is unlikely to be evident until several decades after first exposure. This necessitates conducting surveillance in the post-employment period to detect these health outcomes. This could be done by implementing processes to track individuals prospectively after they no longer work for Rössing.

Several possible epidemiological study designs were examined; however, it is our view that most of these have serious limitations and that any of the studies are likely to have quite low power to detect an excess risk of cancer. There are only a few viable options that can be pursued at this time. In particular, we recommend that two study designs be considered.

A *nested-case control study* holds the most promise to addressing the question of whether or not workers at Rössing are at risk of increased cancer, including respiratory cancer, arising from workplace exposure to ionizing radiation. This approach would require the identification of current and former workers, who have been diagnosed with potentially radiation-induced cancers. From a review of the scientific literature these include amongst others, cancers of the: lung, kidney, liver, leukemia, bone and oral/mouth. These cancers could be identified from medical surveillance data for these workers, as well as information from pension files. However, as both these data sources do not follow the majority of workers after they have stopped working at the mine, it is necessary that additional means are used to identify cancers that are diagnosed in former workers. In our view, reviewing data from the Namibian Cancer Registry to identify additional Rössing workers who developed any of these types of cancers is a possible way to overcome this limitation. As with most other uranium mining study populations, there will be limited statistical power to detect associations between exposure and these cancers, and therefore, the identification of cancers in Rössing miners should attempt to identify cases in as many workers, and over as long a period as possible. In a nested case-control study a decision needs to be made about the number of controls that would be included. Increasing the number of controls will increase the statistical power of the study to detect increased health risks. The statistical power may also be increased by examining all radiation-induced cancers together, as the sample size may be too small to accurately describe associations for some of the rarer forms of cancer.

Alternatively, a cohort study could be undertaken with current workers to determine whether long term exposure to radiation increases the risk of cancer (including lung cancer). With a cohort study, workers are followed over time and rates of disease are compared among those with different levels of exposure, or in some cases, to a separate population (e.g., general population) that has lower levels of exposure. However, given the current limitations of external data-bases, from a practical perspective this approach may be challenging to implement and the cohort would need to be followed for many years into the future. Specifically, given the long latency period between the first exposure of a worker to a possible carcinogen and subsequent development of cancer, it would be several decades before a new study among current workers would be capable of detecting an increased risk of cancer. Therefore, studies whose goal is to detect increased risks of cancer from occupational exposures need to identify cancer cases among individuals who are of advanced age (i.e., post-employment). As cancer rates increase dramatically with age, a greater number of cancer cases would be expected in former miners, and given the rarity of cancer this would be important to maximize the statistical power of the study to detect increased risks due to occupational exposures.

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Pregnancy Outcomes in Women Exposed Along the Techa River

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Abstract. The aim of this study was to evaluate the impact of chronic low-level radiation exposure on the pregnancy outcomes in women exposed to external and internal irradiation as a result of the Mayak Production Association (Mayak) nuclear plant activity in 1950s in Chelyabinsk Oblast, Russia. In a sample of 864 exposed women, we studied the number of pregnancies and births, and the incidence of adverse pregnancy outcomes (miscarriages, preterm births, stillbirths, congenital malformations, and early neonatal deaths). Mean ovarian dose was 44 mGy; maximum dose was 462 mGy. The average number of births in exposed women was significantly lower compared to the control group (2.7 vs. 3.2 respectively, $P = 0.012$). There was a statistically significant positive correlation between preterm birth frequency and mother's ovarian dose ($Y = 3.17 + 17.18*D$, $R^2 = 0.845$, $P = 0.01$, D – dose). As for the frequency of other adverse pregnancy outcomes we did not observe significant differences between exposed women and the control group nor a significant dose dependence. We also studied population effects as the secondary gender ratio and the frequency of twin births. In 20,502 first generation offspring of the exposed population, the secondary gender ratio was significantly lower compared to 86,478 descendants of unexposed persons (1.03 vs. 1.06 respectively, $P = 0.035$). The gender ratio decreased linearly with the increase total gonadal dose of both parents accumulated to the time of conception ($Y=1.05 - 0.30*D$, $R^2=0.846$, $P=0.009$).In 10,802 offspring of exposed parents, multiple births occurred significantly more frequently than in the control group (1.51% vs. 0.95%, respectively, $P < 0.001$). There was a dose-dependent growth in the incidence of multiple pregnancy in the range of the ovarian dose at the time of conception up to 100 mGy ($Y=1.20 + 39.68*D$, $R^2 = 0.923$, $P = 0.009$).

KEYWORDS: pregnancy outcomes; gender ratio; multiple birth frequency; Techa River; chronic low-level radiation exposure.

1 INTRODUCTION

During the twentieth century, as a result of numerous radiation incidents different groups of people have been exposed to ionizing radiation. Moreover, not only were professionals of the nuclear industry exposed to radiation and exhibited adverse health effects, but also large groups of the population. The effects of ionizing radiation on the reproductive system of human and pregnancy outcomes were investigated by observing the people who were exposed to radiation during the atomic bombings [1,2], emergency incidents [3-5], nuclear tests [6], cancer radiotherapy [7, 8], and occupational exposure [9,10]. At the same time, the impact of chronic low-level radiation on reproductive outcomes in human populations has been less well-studied. In addition, of special interest is the study of reproductive outcomes long after the cessation of radiation exposure and after all exposed persons are past reproductive age. Studies of this kind are rare.

The purpose of this study is to evaluate the impact of chronic low-level radiation exposure on the pregnancy outcomes in women residing in the riverside villages of the Techa River.

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Research objectives:

1. To estimate the effects of chronic low-level exposure in the range of low and intermediate doses to pregnancy outcomes in women environmentally exposed to ionizing radiation by assessing the number of pregnancies and births, the frequency of adverse pregnancy outcomes and their correlation with maternal gonadal dose.

2. To evaluate the secondary gender ratio in the first generation offspring of the residents of the Techa River, and its correlation with the gonadal dose of both parents accumulated to the time of conception.

3. To study the effect of the radiation exposure on the frequency of multiple births among residents of the Techa River and to evaluate the correlation of twin rate with ovarian dose of the mother at the time of conception.

2 MATERIALS AND METHODS

As a result of Mayak nuclear plant activity in the 1950s (Chelyabinsk Oblast, Russia) the population of riverside villages along the Techa River was exposed to internal and external radiation. The main dose-generating radionuclide was ^{90}Sr due to its capacity for accumulating and remaining in the bone tissue for a long time [11].

The object of this study was the population of the riverside villages along the Techa River, and their first generation offspring (F1). In the study of the pregnancy outcomes in 864 women exposed along the Techa River, we used questionnaires filled with survey data on gynecological and reproductive status obtained in the Clinical Department of the URCRM (Table 1).

Table 1: Characteristics of the group for the study of the pregnancy outcomes.

	Slavic ethnicity	Turkic ethnicity	Both ethnicities
Exposed group	505 (65.5 %)	266 (34.5 %)	771
Control group	53 (57.0 %)	40 (43.0 %)	93
Total	558	306	864

The exposed group consisted of women born from 1909 to 1949 and who lived from 1950 to 1956 in various villages along the Techa River. The group consisted of 505 women of Slavic ethnicity (Russian, Ukrainian, and Belarussian), and 266 of Turkic ethnicity (Tatar and Bashkir). The control group consisted of women born from 1918 to 1953, who lived in radioactively unpolluted areas or arrived in the Techa riverside villages after the main exposure, and whose dose to the ovaries did not exceed 1 mGy. The control group included 93 women, 53 of them of Slavic ethnicity and 40 of Turkic ethnicity.

We studied the outcomes of 6,976 pregnancies and 2,379 births carried out by the studied women since 1950 (the start time of exposure).

To estimate the gender ratio and twin frequency we used the following sources of information: 1) the Urals Research Center for Radiation Medicine (URCRM) database containing information on 30,000 offspring of the population exposed along the Techa River; and 2) copies of birth certificate issued by Civil State Registration Department of Chelyabinsk Oblast for more than 106,000 children born during the period from 1950 to 1997.

Table 2: The characteristics of the F1 group to study the gender ratio and twin rate.

Studied characteristics	Exposed group		Control group		Total
	Years of birth	Number of persons	Years of birth	Number of persons	
Gender ratio	1950-1994	20,502	1950-1981	86,478	106,980
Twin rate	1950-1977	10,802	1950-1977	77,589	88,391

Studying gender ratio we analyzed data on 20,502 first-generation offspring of the population exposed to radiation along the Techa River who were born from 1950 to 1994. The control group consisted of residents of the same five administrative districts of the Chelyabinsk oblast where the exposed population lived, but who lived in non-contaminated areas of these districts, and they and their parents were not exposed to radiation. We analyzed 86,478 birth certificates from 1950 to 1981 (Table 2).

To analyze the multiple pregnancy rate we studied a sample of 10,802 birth certificates for F1 offspring of the exposed population (born in 10,638 deliveries). Of these, 161 resulted in the birth of more than one child. The birth took place in the years from 1950 to 1977. The control group consisted of 77,589 children born from 1950 to 1977 to persons residing in the unpolluted territories of the Chelyabinsk Oblast (Table 2).

Gonadal doses were obtained from a database developed for the Techa River Cohort in the biophysical laboratory of the URCRM in 2009 (TRDS-2009) [12]. In the study of the pregnancy outcomes, the overall mean ovarian dose was 44 mGy and the maximum was 462 mGy, the mean ovarian dose for Slavic women was 33 mGy and the maximum dose was 446 mGy, and the mean ovarian dose for women of Turkic ethnicity dose was 64 mGy and the maximum was 462 mGy.

The gender ratio study used doses to the gonads (ovaries and testes) received by each parent for the year preceding the birth of a certain child (dose at the time of conception). The mean dose of exposure to mother's gonads was 32 mGy (maximum - 454 mGy), a father's gonads was 30 mGy (maximum -
531 mGy), and the gonads of both parents was 63 mGy (maximum - 976 mGy). In the study of twin frequency, doses to a mother's gonads for a year preceding the birth of a certain child were used. The
mean dose to a mother's gonads was 36 mGy (maximum dose - 363 mGy).

3 RESULTS

3.1 Pregnancy outcomes in women of Techa riverside villages

As shown in Table 3, the average number of pregnancies and births in women of both Slavic, and Turkish ethnicity was lower in the exposed women than in the comparison group. The average number of births in women of the two ethnicities was significantly different in the exposed and control groups (P = 0.012).

Table 3: The average number of pregnancies and births in the exposed women and in the control group (Mean ± standard error)

Ethnicity	Number of pregnancies		Number of births	
	Exposed group	Control group	Exposed group	Control group
Slavic	7.5 ± 0.3	8.4 ± 0.8	2.1 ± 0.1	2.4 ± 0.2
Turkic	8.9 ± 0.3	9.7 ± 0.9	3.8 ± 0.1	4.1 ± 0.4
Both ethnicities	8.0 ± 0.2	9.0 ± 0.6	**2.7 ± 0.1**[(a)]	3.2 ± 0.2

[(a)]P = 0.012compared to the control group

Figure 1 shows the relationship between the number of pregnancies and ovarian dose. There was no correlation between the number of pregnancies and the doses of ovarian exposure in women of Slavic ethnicity, Turkic ethnicity and in the combined group.

No correlation between the number of births and mother's ovarian dose was found in these groups of women (Fig. 2).

Figure 1: Number of pregnancies depending on ovarian dose.

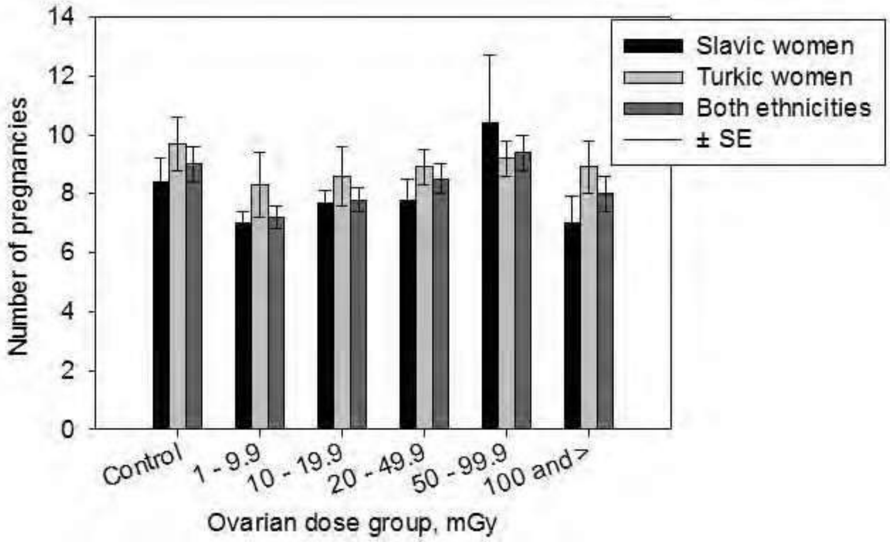
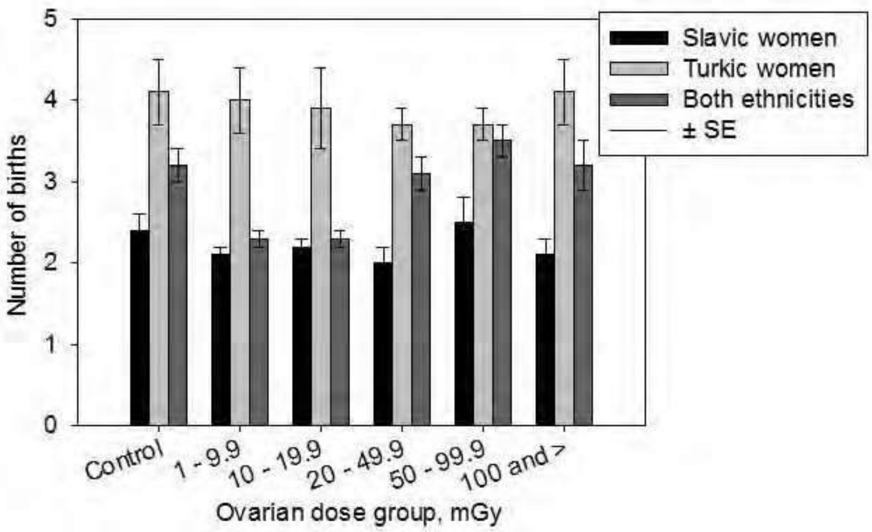


Figure 2: Number of births depending on ovarian dose.



We studied the frequency of adverse pregnancy outcomes such as spontaneous abortion, ectopic pregnancy, preterm birth, pathology of the placenta, stillbirth, congenital malformations, and neonatal death in women exposed along the Techa River. No statistically significant differences in frequencies of these outcomes between the exposed and control groups were found (P > 0.05). A significant positive correlation of preterm birth rate and the ovarian dose has been detected in women of Turkic ethnicity and in the combined group (Table 4). In women of Slavic ethnicity there was a trend to an increase in the number of preterm births with increasing dose. Some other studies have also revealed an increase in the number of preterm births in the exposed women [4, 10].

Table 4: Relationship between various pregnancy outcomes rate and the ovarian dose.

Pregnancy outcome	Ethnicity		
	Slavic	Turkic	Both ethnicities
Spontaneous abortion	$Y = 2.37 + 9.99*D$, $R^2 = 0.565, P = 0.085$	$Y = 2.54 - 0.42*D$, $R^2 = 0.002, P = 0.928$	$Y = 2.71 + 3.13*D$, $R^2 = 0.146, P = 0.454$
Ectopic pregnancy	$Y = 0.86 - 3.60*D$, $R^2 = 0.483, P = 0.125$	$Y = 0.44 - 0.30*D$, $R^2 = 0.003, P = 0.919$	$Y = 0.84 - 3.35*D$, $R^2 = 0.478, P = 0.128$
Preterm birth	$Y = 5.67 - 8.99*D$, $R^2 = 0.042$, $P = 0.696$	**$Y = 1.12 + 47.51*D$, $R^2 = 0.935$, $P = 0.002$**	**$Y = 3.17 + 17.18*D$, $R^2 = 0.845$, $P = 0.010$**
Pathology of the placenta	$Y = 5.37 + 9.37*D, R^2 = 0.053, P = 0.661$	$Y = 1.84 + 0.68*D$, $R^2 = 0.001, P = 0.952$	$Y = 3.64 - 3.24*D$, $R^2 = 0.058, P = 0.647$
Stillbirth	$Y = 1.67 - 1.12*D, R^2 = 0.028, P = 0.750$	$Y = 0.63 + 2.12*D$, $R^2 = 0.035, P = 0.723$	$Y = 1.32 - 1.85*D$, $R^2 = 0.063, P = 0.631$
Congenital malformations	$Y = 1.91 + 6.30*D, R^2 = 0.210$, $P = 0.361$	$Y = 0.29 + 5.20*D, R^2 = 0.473, P = 0.131$	$Y = 1.36 + 1.12*D$, $R^2 = 0.026, P = 0.759$
Neonatal death	$Y = 1.36 + 0.03*D$, $R^2 = 0.000, P = 0.996$	$Y = 1.78 + 11.04*D, R^2 = 0.471, P = 0.132$	$Y = 1.52 + 6.92*D$, $R^2 = 0.568, P = 0.084$
Adverse pregnancy outcomes	$Y = 3.92 + 9.97*D$, $R^2 = 0.222, P = 0.346$	$Y = 2.52 + 19.86*D$, $R^2 = 0.496, P = 0.118$	$Y = 3.46 + 10.86*D$, $R^2 = 0.628, P = 0.060$

Other untoward pregnancy outcomes studied have shown no significant correlation with ovarian dose (Table 4). The correlation of the spontaneous abortion frequency and ovarian dose in women of Slavic ethnicity was not statistically significant (P = 0.085). Also, the dose dependence of the neonatal death frequency in the group of women of the two ethnicities was not statistically significant (P = 0.084). The cumulative incidence of adverse pregnancy outcomes (stillbirth, congenital malformations, and neonatal death) in the combined group of women increases with dose and correlation almost was statistically significant (P = 0.060).

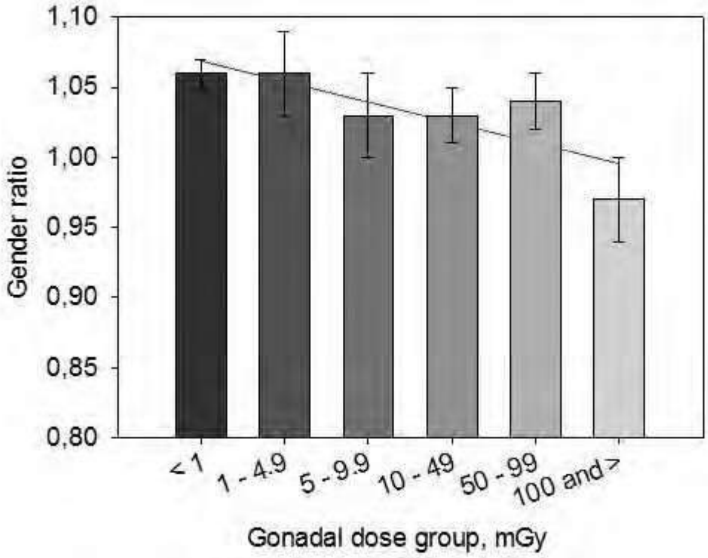
3.2 Secondary gender ratio among the F1 offspring of exposed population

Secondary gender ratio is the ratio of the number of newborn boys to the number of newborn girls. In the study of exposure effect on secondary gender ratio, the authors relied on the hypothesis of Schull and Neel [13] in which the incidence of the radiation-induced recessive lethal mutations in the X- chromosome, due to the hemizygous state, will lead to the elimination of mostly male offspring. The hypothesis states that when only mother was exposed, the gender ratio should decrease, and that it would increase if only the father was exposed. In the case of the exposure of both parents, the decline in gender ratio is expected, but not as prominent as in the case of only mother's exposure [14].

The gender ratio among the first generation offspring of the population exposed along the Techa River was 1.03, which was significantly different from the gender ratio of the control population

1.06 (P = 0.035).
Figure 3 shows an inverse correlation of the secondary gender ratio with the total dose to the gonads of both parents ($Y = 1.05 - 0.30*D$, $R^2 = 0.846$, $P = 0.009$). The observed decrease in the sex ratio with increasing doses is not contrary to Schull and Neel's hypothesis [13]. The separate analyses of the gender ratio correlation with the dose to the gonads of the mother ($Y = 1.05 - 0.19*D$, $R^2 = 0.217$, $P = 0.351$) and gonads of the father ($Y = 1.02 - 0.09*D$, $R^2 = 0.011$, $P = 0.844$) showed trend toward inverse correlation, similar to the results for the combined dose though the results were not statistically significant.

Figure 3: The secondary gender ratio depending on the gonadal dose of both parents.



3.3 Multiple birth frequency in the population of Techa riverside villages

In the offspring of exposed parents multiple births occurred significantly more frequently than in the control group (P < 0.001), as shown in Table 5. The increase in multiple pregnancy rate among the exposed population is consistent with an increase in multiple pregnancy rate in persons who have undergone radiation therapy of tumors [15], as well as exposed to ionizing radiation during nuclear testing [16]. One of the explanations for the increasing frequency of twins can be a hypothesis of stimulating effect of radiation exposure to hyperovulation [17, 18].

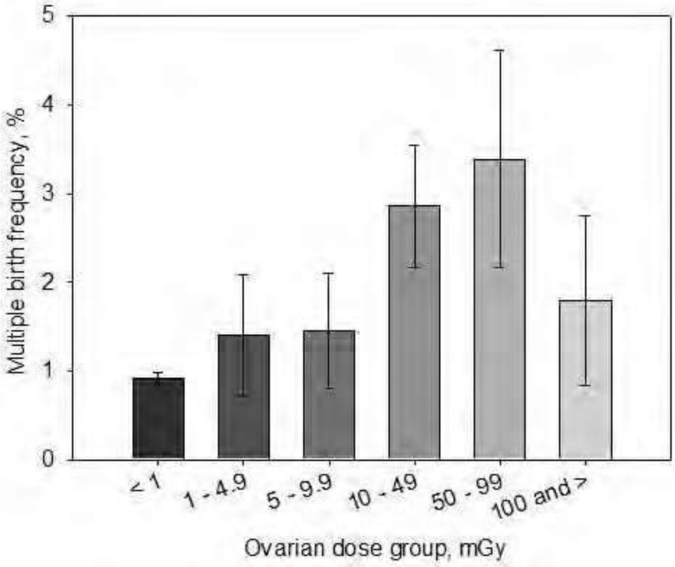
The multiple pregnancy rate in the Techa River population decreases in the series: a family with two exposed parents, a family where only the mother was exposed, families where only the father was exposed. The differences between these groups were statistically significant (Table 5).

Table 5: Multiple birth frequency in relation with the fact of parents' exposure.

Parents	Number of births	Twins (triplets)	Multiple birth frequency, %
Both exposed	6.092	127	2.08 (a)
Only exposed mother	2.388	26	1.09 (b)
Only exposed father	2.158	8	0.37 (b,c)
Exposed group (total)	10.638	161	1.51 (a)
Control group	76.850	727	0.95

(a) P < 0.001 compared to the control group;
(b) P < 0.005 compared to the group with both exposed parents;
(c) P = 0.008 compared to the group with only exposed mother.

Figure 4: Multiple pregnancy frequency depending on the ovarian dose at the time of conception.



The correlation between multiple pregnancy frequency in exposed women and the ovarian dose at the time of the conception of the child was analyzed. In the dose range from 0 to 100 mGy multiple birth rate was gradually increasing (Y = 1.20 + 39.68*D, R^2 = 0.923, P = 0.009). For women with a dose of gonadal exposure of 100 mGy and more multiple pregnancy frequency decreased to a rate of 1.79% (Fig.4).

Thus, the chronic effects of external and internal ionizing radiation leads to a number of consequences, which can be considered indirect evidences of genetic changes in the germ cells of the parents and the occurrence of disorder in the reproductive system of the mother: decrease in the number of births, increased frequency of preterm birth, lower secondary gender ratio, increase in the multiple pregnancy rate.

4 CONCLUSION

1. Women living in the Techa riverside villages, exposed to chronic ionizing radiation in the range of doses to the ovaries reaching 462 mGy, showed a significant decrease in the number of births compared to the control group.

2. A significant positive correlation of preterm birth and ovarian dose was revealed in the group of women of Turkic ethnicity, as well as in the group of women of both Slavic and Turkic ethnicity.

3. The secondary gender ratio among the F1 offspring of the exposed population was 1.03, which was significantly lower than the gender ratio in the offspring of non-exposed population of 1.06. There was a statistically significant inverse correlation of the secondary gender ratio and the combined dose to the gonads of both parents at the time of conception.

4. The multiple birth frequency among the population exposed along the Techa River was 1.51%. This was significantly higher than the multiple pregnancy rate of 0.95% among the non-exposed population. There was a significant positive linear regression dependence of the frequency of multiple pregnancies with an increase in dose to the ovaries of the mother at the time of conception of the child (in the range of up to 100 mGy).

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Amelioration of radiation-induced DNA damage in human and animal cells mediated by natural compounds of plant and animal origin

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Abstract. In the present study we investigated possible radio-protective properties of two natural compounds derived from plant and animal origin against radiation-induced DNA damage *in vitro*. We tested radio-protective effects of whole bee venom (BV, *Apis mellifera* toxin which has a variety of pharmaceutical properties) against 915-MHz microwave radiation-induced DNA damage in the Wistar rat's peripheral blood lymphocytes, and of chlorophyllin (CHL, a semi-synthetic mixture of water-soluble sodium copper salts derived from chlorophyll) against 5 Gy γ-radiation-induced DNA damage in the human peripheral blood lymphocytes. In both cases cells were pre-treated with either BV (1 µg/ml for 4 h) or CHL (100 µg/ml for 2 h) and then irradiated with 915-MHz microwave and 5 Gy γ-radiations, respectively. The possible genotoxic effects of both BV and CHL alone was also assessed on non-irradiated lymphocytes since many of the chemicals that have been demonstrated to have radio-protective effects also have unacceptable toxic side effects. For the evaluation of radiation induced DNA damaging effect and possible protective effect by selected natural compounds comet assay was used as a simple, versatile and sensitive tool for the assessment of DNA strand breaks at the level of single cells. Obtained results showed that both types of radiation induced significant DNA damaging effect in selected cells. Treatment with both BV and CHL prior to radiation exposure protected against DNA damage. Moreover, BV and CHL administered alone in concentrations used did not have any impact on genotoxicity of selected cells based on the comet assay results. Proposed radio-protective mechanisms of BV and CHL are stimulation of the cell repair system and antioxidative effect, respectively. Within this context, both BV and CHL could be considered as effective and non-toxic natural radio-protectors although, further research to determine the exact mechanisms of action and *in vivo* studies on animal models are warranted.

KEYWORDS: bee venom; chlorophyllin; peripheral blood lymphocytes; DNA damage; radio-protection.

1 INTRODUCTION

There is increased use of both ionizing and non-ionizing radiation in industry, commerce, medicine, and at home, especially in mobile telephones which enhances the possibility of adverse effects of radiation to humans. In that manner, there has been a growing concern among the public regarding the potential health hazard of exposure to those types of radiation [1-3]. Large number of different radio-protectors can be found in nature and/or they are being developed every day, but many of them do not reach clinical trials due to their toxicity [4-6]. In that manner, there is a constant need for finding new, efficient and at the same time non-toxic radio-protective candidates.

Bee venom (BV) is a complex mixture of different active components such as peptides, enzymes, and amines, which all have a wide variety of pharmaceutical properties (Fig.1). The major components of whole BV are melittin, phospholipase A_2, apamin, adolapin, histamine, catecholamines, and mast cell degranulating (MCD) peptide. BV is used in the treatment of a variety of conditions, such as arthritis, rheumatism, back pain and skin disease. It also possesses anti-mutagenic, pro-inflammatory, anti-inflammatory, antinociceptive and anti-carcinogenic effects. Besides that, BV also possesses a radio-protective activity that was noted against X-ray and γ-radiation in various test systems [7-9].

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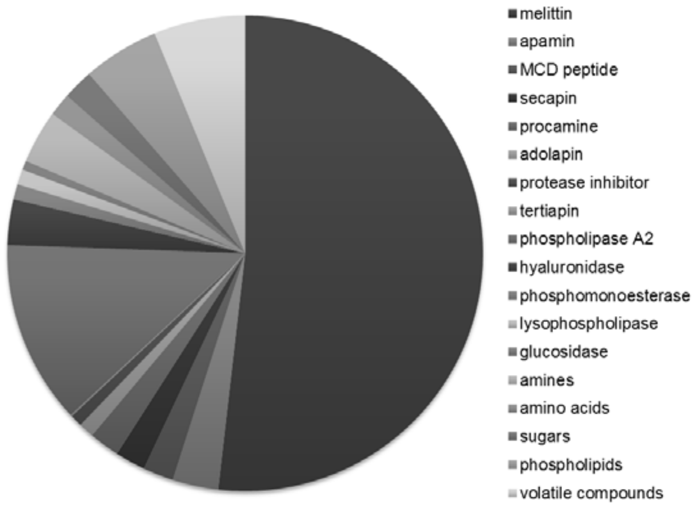
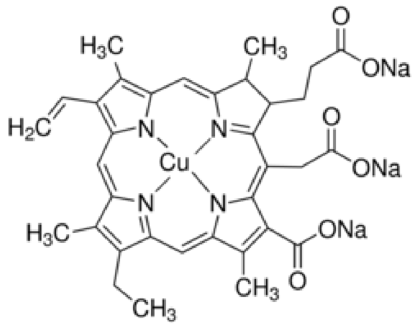
Sodium copper chlorophyllin (CHL) is a semi-synthetic mixture of water-soluble sodium copper salts derived from chlorophyll that is widely used as food colorant (Fig.1). CHL possesses different effects that include anti-mutagenic and anti-carcinogenic effects against large number of dietary and environmental agents [10-12].

Figure 1: The composition of whole bee venom (A) and chemical structure of chlorophyllin sodium copper salt (B).





A B

The aim of the present study was to investigate possible radio-protective effects of two natural compounds derived from plant and animal origin against radiation-induced DNA damage in human and animal cells *in vitro*. We tested radio-protective effects of whole BV against 915-MHz microwave radiation-induced DNA damage in the Wistar rat's peripheral blood lymphocytes, and of CHL against 5 Gy γ-radiation-induced DNA damage in the human peripheral blood lymphocytes.

In both cases cells were pre-treated with either BV (1 µg/ml for 4 h) or CHL (100 µg/ml for 2 h) and then irradiated with 915-MHz microwave and 5 Gy γ-radiations, respectively. The possible genotoxic effects of both BV and CHL alone was also assessed on non-irradiated lymphocytes since many of the chemicals that have been demonstrated to have radio-protective effects also have unacceptable toxic side effects. For the evaluation of radiation induced DNA damaging effect and possible protective effect by selected natural compounds comet assay (single cell gel electrophoresis) was used as a simple, versatile and sensitive tool for detecting DNA damage at the level of individual cells [13-16].

2 MATERIALS AND METHODS

2.1 Blood Sampling and Treatment

For animal cell testing whole blood samples were collected under sterile conditions in heparinized vacutainer tubes from adult male Wistar rats. After collection, blood was divided into aliquots and placed into 24-well culture plates according to the exposure conditions. All experiments were conducted on peripheral blood lymphocytes cultivated at 37 °C in an atmosphere of 5% CO_2 in air. Animal studies were carried out according to the guidelines of the Republic of Croatia and incompliance with the US *Guide for the Care and Use of Laboratory Animals*. Adult male Wistar rats were used in this study. The animals had passed through an accommodation period of 1 week. The animals were kept in steady-state micro-environment conditions and received standard laboratory food and water *ad libitum*, with alternating light and dark cycles.

For human cell testing whole blood samples were collected under sterile conditions in heparinized vacutainer tubes from a healthy male non-smoking donor. The donor had not been exposed to ionizing radiation for diagnostic or therapeutic purposes, or vaccinated and treated with drugs that might have interfered with the results of testing for a year before blood sampling. The subject gave informed consent to participate in this study. The study was part of the project approved by the institutional Ethics Committee and observed the ethical principles of the Declaration of Helsinki.

In both cases cells were pre-treated with either BV (1 µg/ml for 4 h) or CHL (100 µg/ml for 2 h) and then irradiated with 915-MHz microwave and 5 Gy γ-radiations, respectively. After the treatments, individual experiments were conducted according to the standard protocols listed below.

2.2 Exposure Conditions

For animal cell testing an electromagnetic field was generated within the certified gigahertz transversal electromagnetic mode cell (GTEM-cell, USA). Whole blood was exposed to the carrier frequency of 915 MHz with global system mobile (GSM) basic signal modulation for 30 min. Incident electromagnetic field strength of 30 V/m was uniform over the entire object throughout the exposure procedure. The power density of the field was 2.4 W/m^2, corresponding to approximate whole body specific absorption rate (SAR) of 0.6 W/kg.

For human cell testing samples were irradiated using Gammacell 220 (Atomic Energy of Canada Ltd., Canada), containing ^{60}Co as a source of γ-radiation, with the dose rate of 1.163 mGy/s. After irradiation time of 4296 s samples absorbed total dose of 5 Gy.

2.3 DNA Damage Assay

The alkaline comet assay was done according to the standard protocol [17] with minor modifications [18]. After the exposure, 5 ml of whole blood samples were embedded in agarose matrix on fully frosted slides, and lysed (2.5 M NaCl, 100 mM Na_2EDTA, 10 mM Tris, 1% sodium sarcosinate,1% Triton X-100,10% DMSO, pH 10) at 4 °C. After lysis, the slides were placed into alkaline solution (300 mM NaOH, 1 mM Na_2EDTA, pH13) for 20 min at 4 °C to allow DNA unwinding and then electrophoresed for 20 min at 1 V/cm. Afterwards, the slides were neutralized in 0.4M Tris buffer (pH 7.5), stained with EtBr and analysed at 250 × magnification using an epifluorescence microscope (Zeiss) connected through a camera to the image analysis system (Comet Assay II; Perceptive Instruments Ltd., UK). The tail length parameter was used to measure the level of DNA damage, and a total of 100 randomly captured nuclei were examined from each slide.

2.4 Statistics

Statistical analysis was done using the STATISTICA 12 software package (StaSoft, USA). In order to normalize the distribution and to equalize the variances, a logarithmic transformation of comet assay data was applied. Break-down ANOVA was performed to compare variances of each sample with Scheffé *post-hoc* test. The level of statistical significance was set at $P<0.05$.

3 RESULTS

Results indicate that both compounds displayed radio-protective effects against radiation-induced DNA damage according to the alkaline comet assay results. According to the comet assay results microwave radiation induced DNA damaging effect in the Wistar rat's peripheral blood lymphocytes, whereas pre-treatment of cells with whole BV prior to microwave radiation managed to reduce that DNA damaging effect. Moreover, BV alone did not induce any significant ($P<0.05$) DNA damage in the given concentration (Fig.2). According to the comet assay results γ-radiation induced DNA damaging effect in the human peripheral blood lymphocytes, whereas pre-treatment of cells with CHL prior to γ-radiation managed to reduce that DNA damaging effect. Additionally, CHL alone did not induce any significant ($P<0.05$) DNA damage in the given concentration (Fig.3).

Figure 2: Tail length as alkaline comet assay parameter in Wistar rat's peripheral blood lymphocytes of control, after whole bee venom (BV, 1 μg/mL) treatment, after microwave radiation (MW) exposure (915 MHz), and after joint MW/BV treatment. The tail length parameter was used to measure the level of DNA damage, and a total of 100 randomly captured nuclei were examined from each slide. [a] Statistically significant increase compared to control, [b] Statistically significant decrease compared to microwave radiation (P<0.05).

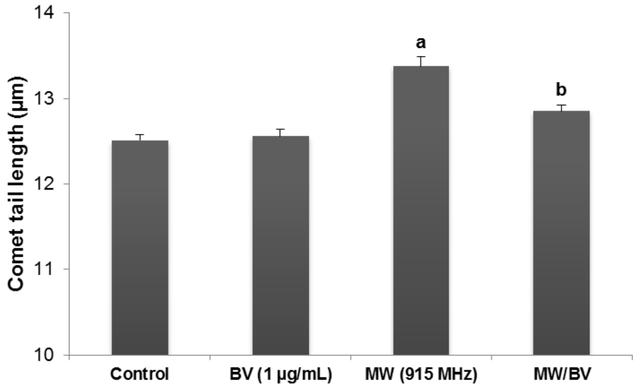
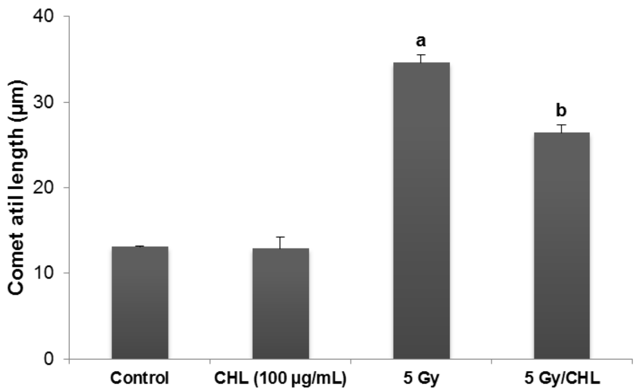


Figure 3: Tail length as alkaline comet assay parameter in human peripheral blood lymphocytes of control, after chlorophyllin (CHL, 100 μg/mL) treatment, after γ-radiation (5 Gy), and after joint 5 Gy/CHL treatment. The tail length parameter was used to measure the level of DNA damage, and a total of 100 randomly captured nuclei were examined from each slide. [a] Statistically significant increase compared to control, [b] Statistically significant decrease compared to γ-radiation (P<0.05).



4 CONCLUSION

Obtained results showed that both microwave radiation and γ-radiation induced significant DNA damaging effect in selected cells. Treatment with both whole BV and CHL prior to radiation exposure protected against DNA damage. Radio-protective effects of both BV and CHL were previously also noted in different cell and animal models both *in vivo* and *in vitro* [19, 20]. Moreover, based on our results, both BV and CHL administered alone in concentrations tested did not have any impact on genotoxicity of selected cells. Radioprotection by BV may be attributed to a stimulation of the cell repair system, whereas proposed radio-protective mechanism of CHL could be its anti-oxidative effect. Within this context, both BV and CHL could be considered as effective and non-toxic natural radio-protectors although, further research to determine the exact mechanisms of action and *in vivo* studies on animal models are warranted.

5 ACKNOWLEDGEMENTS

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Ionizing Radiation and Metastasis: The Dark Side of a Keystone Treatment in Cancer

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Abstract. Radiation therapy is an important therapeutic tool in clinical oncology. Photon radiation has proved its benefits in overall survival, nonetheless some patients present local recurrences or metastases post irradiation (IR). Experimental evidence suggests that this invasive phenotype could be mediated by induction of epithelial mesenchymal transition. In this work we conducted *in vitro* and *in vivo* studies to evaluate the effect of a 2 Gy fraction of gamma radiation in different biological responses related to metastasis formation employing the triple negative breast cancer cell line MDA-MB-231. Irradiation of MDA-MB-231 cells with 2 Gy led to a decrease in the colonies formation and migration capacities in surviving cells at 1-3 days post IR. However, a week after IR, both abilities were regained and doubled non irradiated control value over 15 days. Meanwhile, gelatinolytic activity also duplicated non irradiated values a week post IR. In addition, conditioned media from both irradiated and non-irradiated normal mammary epithelial cells MCF-10A significantly incremented clonogenic proliferation, migration competence and matrix metalloproteinase enzymatic activity on irradiated and non-irradiated MDA-MB-231 cells. We also carried out *in vivo* experiments by implanting 2 Gy irradiated and non-irradiated MDA-MB-231 xenografts in *nude* mice. Irradiated tumors evidenced larger volume than non-irradiated controls after 50 days. *Ex vivo* analysis of xenografts showed a higher mitotic index and PCNA expression in irradiated than in non-irradiated tumors, as well as higher intratumoral vascularity. Lungs of mice bearing irradiated xenografts showed a higher number of metastatic foci than lungs from mice with control tumors.

1 INTRODUCTION

Conventional radiation therapy for breast cancer after surgery is delivered in fractionated doses of 2 Gy to treat post-mastectomy chest wall, or to treat the remaining whole breast post conservative surgery. However in recent years acquisition of radioresistance and a rise of proliferative and invasive capacity of surviving tumor cells have been reported, clinically evidenced by local recurrences and metastasis respectively. Actually the reduction of recurrences is 50% and half of local recurrences are invasive cancers even if initial tumors were in situ carcinoma. Soluble factors secreted by benign mammary epithelial cells could influence these biologic responses, both in irradiated and non-irradiated tumor mammary cells [1,2].

For over two decades, mounting evidence indicates that radiation can damage not only the cells adjacent to the tumor, but also cells out of the radiation track by the generation of gap-junction or cytokine-mediated cellular toxicity. Various cellular and microenvironmental signaling cascades are involved. This phenomenon was termed as radiation-induced bystander effect (RIBE), both *in vitro* and *in vivo*. [1]

Improper activation of epithelial-mesenchymal (EMT) transition in epithelial cancers may contribute to invasion and metastasis. EMT is a physiological process that allows epithelial cells acquire mesenchymal features, migration ability and extracellular matrix degradation by metalloproteases among others. [3,4]

Our laboratory has demonstrated a radio-induced EMT activation in mammary and pancreatic epithelial tumor cells [5]. In this experimental work we studied the *in vitro* influence of 2 Gy dose of gamma irradiation and conditioned medium (CM) from benign mammary cells on clonogenic proliferation and some mesenchymal features as migration and gelatinolytic activity of mammary tumor cells. *In vivo* experiments comprised assessment of tumor growth rate, PCNA expression, angiogenesis and lung metastases.

2 RESULTS

1. Effect of irradiation and conditioned medium of benign mammary cells

MCF-10A cells were used as an experimental model of benign mammary epithelial cells, while MDA-MB-231 as a model of triple negative breast cancer cells.

- MDA-MB-231 cells were 2Gy gamma irradiated or not with an IBL 437C H type irradiator, ^{137}Cs source, dose rate 7.1 Gy/min, and incubated for 1-28 days to perform clonogenic and migration assays at different times after IR.
- MCF-10A cells were 2 Gy irradiated or not, incubated for 24 hours and then the respective conditioned media were collected (2 Gy CM or CM). Those CM could contain soluble factors secreted by benign mammary cells that in turn may affect tumor mammary cells. MDA-MB-231 cells irradiated or not were also incubated for different times with 2 Gy CM or CM (originating six groups of treatments) to evaluate clonogenicity, migration capacity and gelatinolytic activity.

1.1 Clonogenic assay

MDA-MB-231 single-cell suspensions were seeded to perform clonogenic assay. After 5 days incubation, cells were fixed, stained, and colonies of more than 30 cells were counted and expressed as percent of colonies with respect to 0 days post IR.

Clonogenic capacity at 0, 7, 14 and 28 days post IR augmented in a time post IR-dependent way over 162% ($p<0.001$, One way Anova and Bonferroni posttest).

To assess the effect of soluble factors secreted by MCF-10A normal cells, tumor cells were also seeded at 1 and 7 days post IR, treated or not with CM or 2Gy CM. Results were expressed as percent of colonies vs non irradiated control. CM and 2 Gy CM resulted in a significative rise in colony forming ability ($p<0.05$, Two way Anova and Bonferroni posttest).

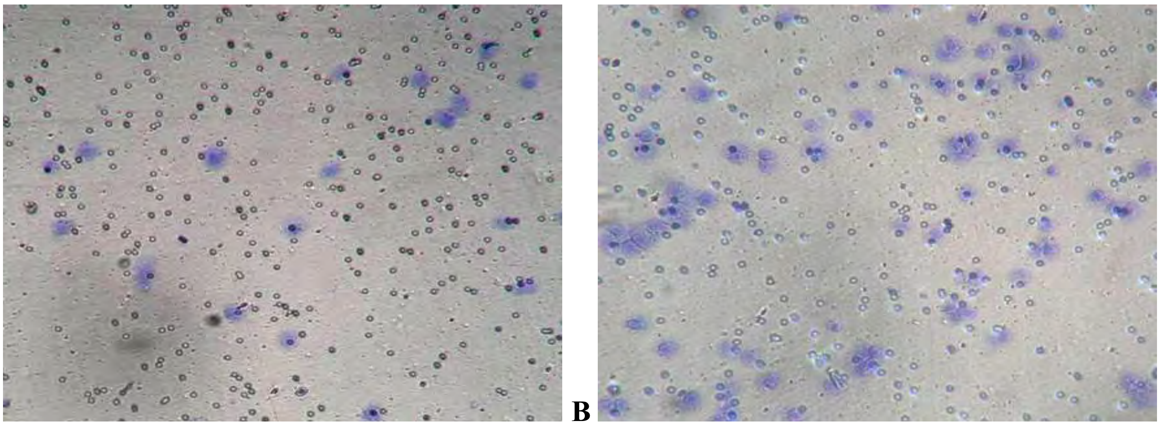
1.2 Cell Migration assay

Migration capacity of MDA-MB-231cells was evaluated by using transwell units with 8 μm pore size PET membranes. After 24 hours incubation, migrated cells were fixed, stained, counted and the results were expressed as percent vs non irradiated control.

Motility assay was done at 3, 7 and 15 days post IR. Three days after IR surviving cells showed a migration capacitiy of 75 % with respect to non-irradiated control. This effect was restored a week later, while two weeks after IR the result was duplicated in relation to control cells (197%, $p<0.05$, One way Anova and Bonferroni posttest), Fig. 1.

Moreover, the result of treatment with CM on irradiated and non-irradiated cells was determined at 7 days post IR. Number of migrated cells was significantly increased by CM and 2 Gy CM in both experimental situations ($p<0.05$, Two way Anova and Bonferroni posttest).

Figure 1: Migration capacity was evaluated by using transwell units. Representative photographs at 3 and 15 days post IR at 200x magnification. A. 3 days post irradiation. B. 15 days post irradiation.



A B

1.3 Gelatinolytic activity assay

MMP-9 metalloproteinase is secreted by MDA-MB-231 cells to 24 hours-serum deprived culture medium. MMP-9 gelatinolytic activity was evaluated by zymography 7 days after IR. Lytic bands were determined by densitometry and normalized to non-irradiated control. IR was able to duplicate enzymatic activity (205%, $p<0.05$, Two may Anova and Bonferroni posttest). In addition, CM and 2 Gy CM augmented this response in non-irradiated and irradiated MDA-MB-231 control cells ($p<0.05$, Two way Anova and Bonferroni posttest).

2. Xenografts, lung metastases and histochemistry in *nude* mice

MDA-MB-231 mammary cancer cells (5×10^6) were inoculated in the flank of two *nude* mice for tumor generation. When tumors reached an average diameter of 3 mm, one of the animals was whole body irradiated with 2 Gy gamma radiation, while the other was kept non irradiated. After irradiation, both irradiated and non-irradiated tumors were excised, cut into pieces and grafted into the flank of 5 non irradiated nude mice. Tumor size was measured with a caliper during 50 days. Mice were then euthanized, tumors and lungs were excised for hematoxylin and eosin staining (HE) and immunodetection of PCNA and CD34.

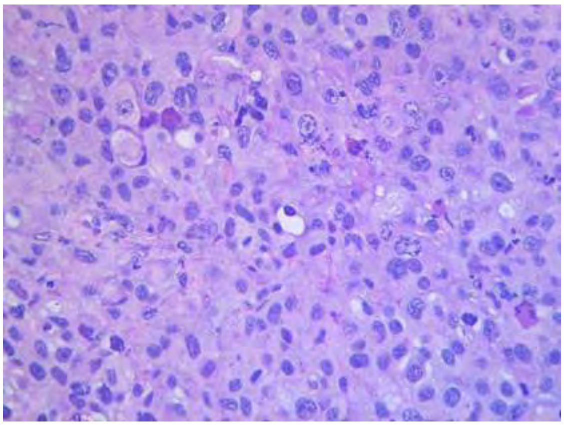
2.1 Tumor growth

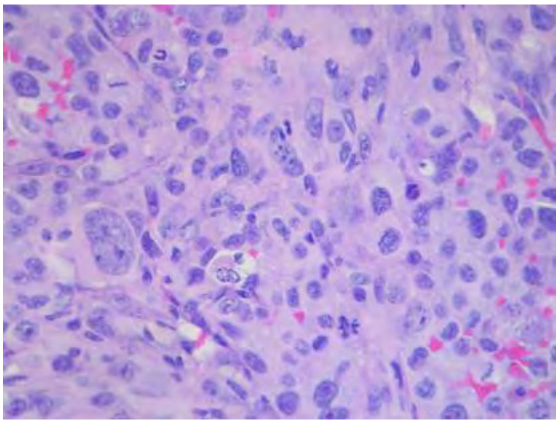
The potential effect of tumor irradiated and transplanted on tumor growth rate and development of lung metastases were studied in *nude* mice bearing non irradiated MDA-MB-231 xenografts and 2 Gy irradiated xenografts (five mice each group). Tumor volumes were determined and referred to the initial volume for each treatment. Relative tumor volumes where plotted as mean ± SEM of two independent experiments and fitted to an exponential growth equation. The group of irradiated mice presented greater relative tumor volume than control group ($p< 0.01$ at 40 days and $p< 0.001$ at 45 and 50 days, two way ANOVA with repeated measures in time and Bonferroni posttest). Doubling times were obtained from fitted tumor growth curve and plotted as mean ± SD (12.5 ± 1.0 and 10.0 ± 0.4 days for control and 2 Gy groups respectively, $p< 0.05$, unpaired t test).

2.2 Histopathology of tumors

Every HE stained tumors were microscopically evaluated. Xenografts of control animals were undifferentiated adenocarcinomas with high grade of mitosis, anisocytosis and anisokaryosis showing a low number of endothelial, stromal or immune cells among non tumoral cells. On the other hand, irradiated tumors xenografted in non-irradiated mice exhibited an even higher grade of atypia and mitosis and a more significant intratumoral vascularity, Fig. 2.

Figure 2: Histopathology of tumors. Representative photographs of HE stained slices at 400x magnification. A. non irradiated. B. 2 Gy irradiated.

A 

B 

In the same HE stained slices, percent of mitotic tumor cells relative to total number of tumor cells was assessed at 400× magnification in ten random fields. Mitotic index was higher in 2 Gy group than control group (1.1% vs 0.4%, $p<0.05$, Unpaired t test).

2.3 PCNA expression in tumors

PCNA (proliferating cell nuclear antigen) is a nuclear nonhistone protein that plays an essential role in nucleic acid metabolism as a component of the replication and repair machinery; hence it is useful as a proliferation marker. PCNA expression was evaluated by immunohistochemistry in tissue sections of tumors at 400× magnification in ten random fields. Tumors of control group showed lesser extent of proliferating cells than 2 Gy group (74% vs 96%, $p<0.05$, Unpaired t test).

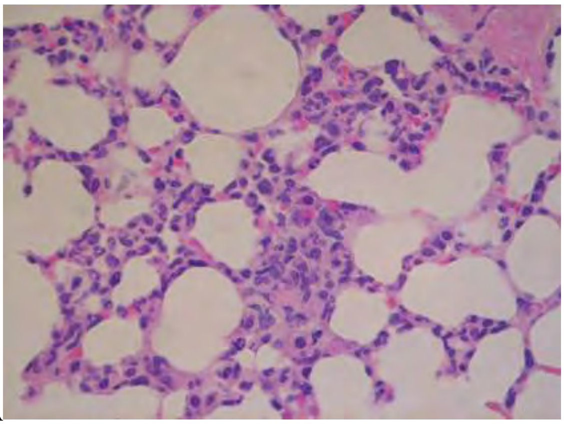
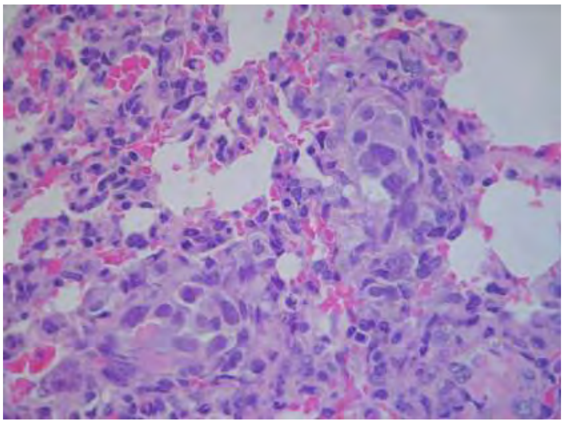
2.4 CD34 expression in tumors

The expression of the endothelial cell marker CD34 was also evaluated by immunohistochemistry. Intratumoral vascularity was assessed in non-necrotic areas of CD34 stained slices. A ratio between CD34 positive area and tumor area was determined by using ImageJ software at 400× magnification in ten random fields. Irradiated group presented a higher vascularity than control group (7.5% vs 2.3%, $p< 0.05$, Unpaired t test).

2.5 Histopathology of lungs

Every HE stained lungs were microscopically evaluated. Lungs of animals bearing non irradiated tumors showed sparce metastatic cells among pneumocytes, the main cellular type of alveoli. Meanwhile, lungs of mice bearing irradiated tumors showed metastatic foci and lung disease with haemorrhagic areas, Fig. 3.

Figure 3: Histopathology of lungs in mice bearing control and irradiated MDA-MB-231 xenografts. Representative photographs of HE stained slices at 400x magnification. A. non irradiated. B. 2 Gy irradiated.

A  B 

2.6 Determination of lung metastases

Development of lung metastases in animals bearing control and irradiated MDA-MB-231xenografts was evaluated. Whole lungs were excised, HE stained and evaluated by counting metastases in whole slices. Mice bearing irradiated tumors showed a major count of lung metastases than control (5.0 vs 0.3, $p<0.05$, Unpaired t test).

2.7 Expression of PCNA in lungs

Proliferation marker PCNA expression was evaluated in the lungs of animals bearing irradiated and non-irradiated tumors. Lungs of control group showed scarce proliferating pneumocytes. Meanwhile, lungs of mice bearing irradiated tumors showed more proliferating pneumocytes and also proliferating metastatic foci.

3 CONCLUSION

It is well documented the interaction between tumor epithelial cells and its cellular and non-cellular microenvironment and also its modulation by photon radiotherapy. Breast cancer, benign mammary epithelium and stromal tissue may be included in irradiation field. This fact led us to investigate the implication of tumor microenvironment and ionizing radiation on local recurrences or metastases as clinical outputs.

EMT has been involved in malignant phenotype of cancer cells, including proliferation and invasion, angiogenesis, stemness of cancer cells and resistance to chemoradiotherapy. Regarding these factors we have *in vitro* studied the effect of irradiated non cancer mammary cells on proliferation and invasion features of irradiated cancer mammary cells, in particular by secreted soluble signaling molecules.

Poczobutt [6] showed augmented clonogenicity on a variant of MDA-MB-231 selected for high tumorigenicity in mice treated with CM derived from MCF-10A cells. Those CM were analyzed using cytokine antibody array resulting in a strong signal of Monocyte chemoattractant protein-1 (MCP-1). Nevertheless, other authors reported an antiproliferative effect of CM derived from benign mammary epithelial cells on breast cancer cell lines.

Regarding invasion, early reports inform an increased motility of breast cancer cells exerted by CM of normal mammary epithelial cells [7]. In particular, Lee [8] demonstrated a rise in number of invading MDA-MB-231 cells when co-cultured with MCF10A cells.

Ohuchida [9] studied the effect of irradiation and soluble factors secreted by stromal cells on pancreatic cancer epithelial cells. Fibroblasts cells intensified invasion of non-irradiated tumor cells and this outcome resulted enhanced when non tumor cells were previously irradiated. Meanwhile, fibroblasts added to irradiated tumor cells also increased invasion and this consequence was improved by gamma irradiation of the former cells. In the absence of reports the combined effect of photon irradiation and normal mammary epithelium secreted molecules on irradiated tumor cells, we conducted our experiments taking into account both factors. Our present *in vitro* findings show that 2 Gy surviving tumor cells acquire increased mesenchymal features related to invasion. This effect is enhanced by CM of normal cells signaling the relevance of tumor-host interaction in tumor response to irradiation.

Our *in vivo* research evidenced not only an enhancement on tumor growth and vascularity but outstanding consequences on lung parenchyma of normal *nude* mice after transplanting 2Gy irradiated MDA-MB-231 tumors. The increase in pneumocyte proliferation, presence of haemorrhagic areas and loss of alveoli structure (which is almost imperceptible in normal *nude* mice grafted with non irradiated tumors) might be a consequence of factors secreted by irradiated cells.
Apart from *in vitro* reports, RIBE was also confirmed by using *in vivo* mouse models although the involved mechanisms are still under study [1,10].

A more thorough understanding of radioinduced biological responses considering the intricate implications in the micro-environment could lead to new therapeutic strategies for enhancing antitumor effectiveness of clinical radiotherapy while minimizing undesirable side effects.

4 ACKNOWLEDGEMENTS

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Concentrations of Radiocesium and ^{90}Sr in Agricultural Plants Collected from Local Markets and Experimental Fields before Resuming Agriculture in Fukushima Prefecture

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Abstract. Agricultural plants were collected from local markets and experimental fields before resuming agriculture in Fukushima Prefecture and concentrations of radiocesium (^{134}Cs + ^{137}Cs) and ^{90}Sr were determined. Mean concentrations of radiocesium in the plants collected from local markets in 2012, 2013 and 2015 were in order of 7.2 ± 9.9 (n=36), 1.6 ± 2.4 (n=46) and 1.9 ± 2.1 Bq kg^{-1} fresh weight (n=14), respectively. The concentration of radiocesium was decreased from 2012 to 2013, but those in 2013 and 2015 were similar. The concentration of ^{90}Sr in the samples collected from local markets in 2013 and 2015 was 0.0086-0.30 (n=8) and 0.0019-0.018 Bq kg^{-1} fresh weight (n=4), respectively. The concentration of radiocesium and ^{90}Sr in the plants collected from the experimental fields, including the difficult-to-return zone in Iitate, Kawamata and Namie, in 2015 were 0.44 ± 0.43 (0.11-1.6) and 0.026 ± 0.030 (0.0036-0.10) Bq kg^{-1} fresh weight (n=11), respectively, which were within the range collected throughout Japan except Fukushima Prefecture. The concentrations of radiocesium in pumpkin and cabbage collected from the experimental field in Okuma (5 km west of the FDNPS) in 2014 were 107 and 67 Bq kg^{-1} fresh weight, respectively. The concentrations of ^{90}Sr in the pumpkin and cabbage were 0.31 and 0.21, respectively, and the concentration ratio of $^{90}Sr/^{137}Cs$ was lower than the estimated values, which was calculated from the ratio of deposition and soil-to-plant transfer factor.

KEYWORDS: agricultural plants; radiocesium; ^{90}Sr; Standard Limits; $^{90}Sr/^{137}Cs$ ratio.

1 INTRODUCTION

A large inventory of radiocesium was deposited across the landscape from TEPCO's Fukushima Daiichi Nuclear Station (FDNPS) accident [1]. Cesium-137 (half-life 30 y) is the major radionuclide released from the accident and an important radionuclide for the assessment of radiation exposure to the public. On April 1, 2012, the Standard Limits of radionuclide concentrations allowed in food were reduced as compared to the Provisional Regulation Values in Japan in 2011 [2]. The Standard Limits are calculated based on 1 mSv y^{-1} annual internal radiation dose through food ingestion of ^{134}Cs, ^{137}Cs, ^{90}Sr, Pu and ^{106}Ru, radionuclides which were detected or possibly released into the environment from the accident at the TEPCO's FDNPS. The concentrations of the radionuclides other than radiocesium used in this assessment were based on the measured values of radiocesium (^{134}Cs + ^{137}Cs); the concentrations of the other radionuclides (^{90}Sr, Pu and ^{106}Ru) were determined from their assumed ratio compared to the ^{137}Cs concentration. These ratios of the concentration in edible plant tissues of a given radionuclide (^{90}Sr, Pu and ^{106}Ru) to that of ^{137}Cs were determined from ratios observed in deposition to soil and from soil-to-plant transfer factors in the literature. The Standard Limit of radiocesium in general food was determined to be 100 Bq kg^{-1} by the Ministry of Health, Labour and Welfare. In the present study, the concentration of radiocesium was measured in agricultural plants collected from local markets in Fukushima, Date, Kawamata and Inawashiro in Fukushima Prefecture, and also collected from experimental fields before resuming agriculture in Okuma, Iitate, Kawamata and Namie within the evacuation-zone. The concentration of ^{90}Sr in a portion of the agricultural plants was also measured, and the concentration ratio of $^{90}Sr/^{137}Cs$ was determined.

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2 MATERIALS AND METHODS

Limited agricultural plants produced within the Fukushima Prefecture were collected from the local markets in Fukushima, Date, Kawamata and Inawashiro in 2012, 2013 and 2015, and also were collected from experimental fields including the difficult-to-return zone (more than 20 mSv y^{-1}) , before resuming agriculture in Okuma, Iitate, Kawamata and Namie in 2014 and 2015 (Fig. 1).

Figure 1: Sampling area of agricultural plants.
Red solid line, agricultural plants collected from experimental fields before resuming agriculture; Blue solid line, agricultural plants collected from local markets. Plants collected from Kawamata include both experimental fields and local markets.

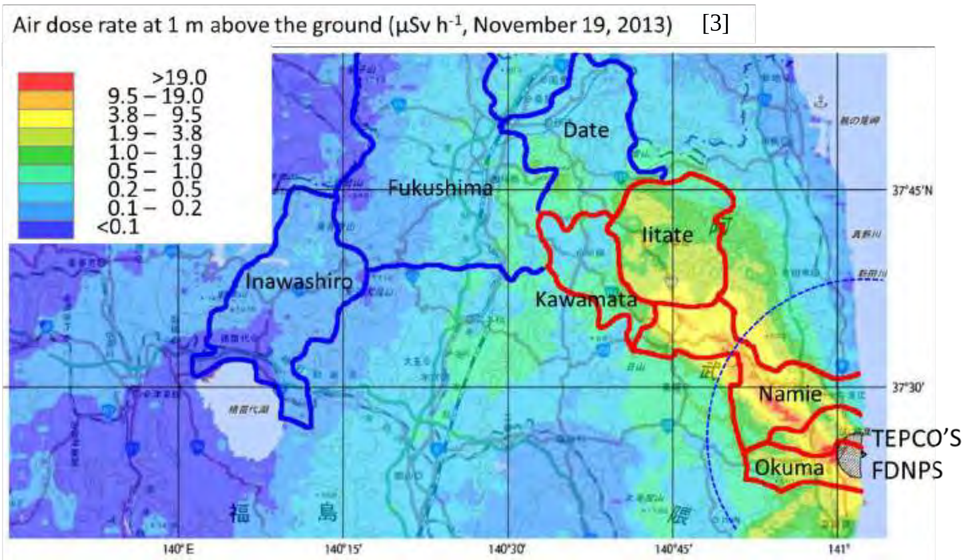


Table 1: Collected agricultural plant

Agricultural plants	Collected sample
Rice	Brown rice
Potatoes	Potato, Sweet potato, Taro
Leaf and stem vegetables	Asparagus, Cabbage, Japanese honeywort, Komatsuna, Leek, Malabar spinach, Mugwort, Onion, Spinach, String bean, Turnip (leaf and stem), Turnip rape, Welsh onion
Root vegetables	Burdock, Carrot, Radish, Turnip
Pulses	Black soybean, Cowpea, Green bean, Green soybean, Soy bean
Fruity vegetables	Broccoli, Cucumber, Eggplant, Green pepper, Okra, Pumpkin, Small green pepper, Snap garden pea, Tomato, Wax gourd, Zucchini
Fruits	Apple, Blue berry, Huckleberry, Japanese plum, Peach, Japanese pear, Persimmon, Plum
Other agricultural plants	Edible chrysanthemum, Hen-of-the-woods, Japanese ginger, Japanese pepper (leaf), Jew's-ear mushroom, Shiitake mushroom

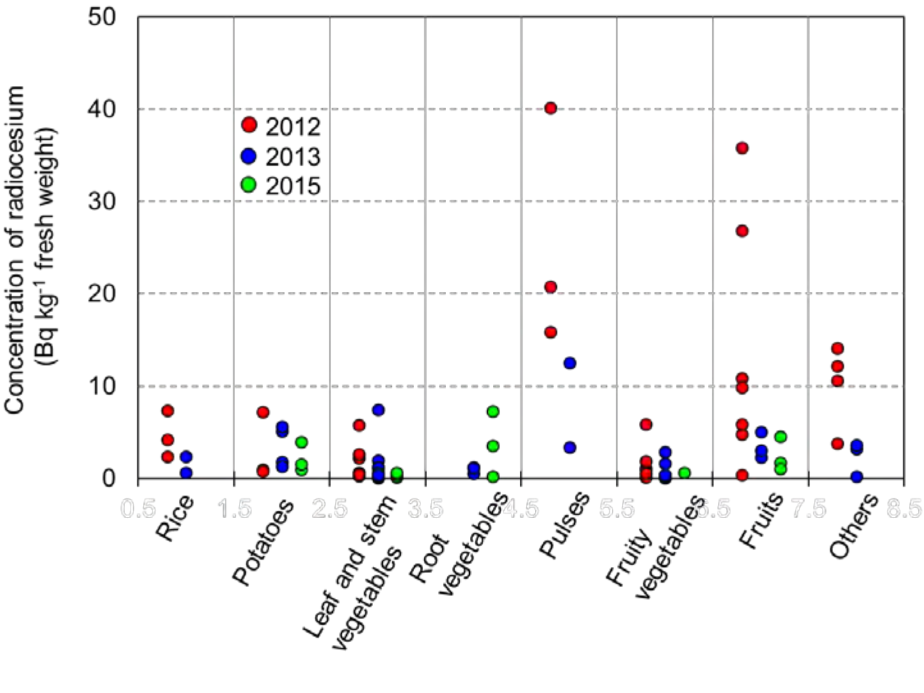
Samples collected from the local markets were separated into eight categories (Table 1) and number of samples collected in 2012, 2013 and 2015 were 36, 46 and 14, respectively (Table 2). Number of samples collected from the experimental fields before resuming agriculture in 2014 and 2015 were 2 and 11, respectively (Table 3). The amounts of samples for radiocesium analysis were collected 100-3000 g and those for both radiocesium and ^{90}Sr were collected 3-15 kg. The plants were washed, peeled, and then the edible parts were cut into small pieces. Each sample was dried at 70 °C for one week and pulverized in a stainless steel cutter blender before being analyzed of radiocesium. The samples were compressed into a plastic container (47 mm in diameter and 50 mm in height) and the concentration of radiocesium and ^{40}K were determined with a Ge detector connected with a multichannel analyzer system by counting for 9400-500000 s. The detection efficiency of Ge detector was dependent on the sample thickness and was obtained by the use of the mixed standard radionuclides material made by Japan Radioisotope Association. Counting statistics for ^{137}Cs concentration in the samples were less than 10%.

The rest of the dried samples were ashed at a temperature below 450 °C for analysis of ^{90}Sr. A radioanalytical method for ^{90}Sr was performed according to the previously reported method [4]. The ash plant samples (15-50 g) were decomposed with HNO_3, H_2O_2 and HCl after the addition of the Sr carrier. The solution was filtered and the residue was discarded. The solution was adjusted to >pH 10 with NaOH and then $SrCO_3$ was precipitated by adding Na_2CO_3. The $SrCO_3$ precipitate was dissolved in HCl and then the oxalates were re-precipitated at pH 4.2 by adding oxalic acid. The supernatant was decanted and the oxalate precipitation was dissolved in HNO_3. Strontium in the solution was separated from Ca by the cation ion exchange method, and then the filtered precipitate was dissolved with water. Any radioactive impurity was eliminated by scavenging on $BaCrO_4$ and $Fe(OH)_3$. An ammonium carbonate solution was added to the solution after scavenging, and the $SrCO_3$ precipitate was filtered using filter paper. The recovery of Sr was estimated by measuring the stable Sr with ICP-AES and then a disk sample was prepared for a low background beta-counting for 6000-60000 s.

3 RESULTS AND DISCUSSION

Fig. 2 shows the concentration of radiocesium in agricultural plants collected from the local markets in Fukushima, Date, Kawamata and Inawashiro in 2012, 2013 (Data in 2012 and 2013 from Tsukada et al. [5]) and 2015. Mean concentration of radiocesium in the agricultural plants collected from the markets in 2012 was 7.2 ± 9.9 (<0.2-40, n=34) Bq kg^{-1} fresh weight, and it decreased in 2013 to 1.6 ± 2.4 (<0.1-13, n=46) Bq kg^{-1} fresh weight, which was approximately one-fourth of the concentration in 2012. The concentration of radiocesium in agricultural plants decrease with time elapsed due to: 1) decay of radiocesium activities, especially ^{134}Cs (half-life, 2.1 y), 2) countermeasure application of K fertilizer for reducing uptake of radiocesium in plants, 3) aging effect in soil, by which radiocesium in exchangeable fraction decreases and that in strongly bound fraction increases with time elapsed [6, 7], etc. The concentration of radiocesium collected from the markets in 2015 was 1.9 ± 2.1 (0.12-7.3, n=14) Bq kg^{-1} fresh weight, which was similar to the values in 2013. The concentration of radiocesium in all the samples was less than the New Standard Limits.

Figure 2: Concentration of radiocesium (^{134}Cs + ^{137}Cs) in agricultural plants collected from local markets in Date, Fukushima, Kawamata and Inawashiro.



The concentration of ^{90}Sr in agricultural plants collected from the markets in Fukushima Prefecture in 2013 and 2015 was 0.060 ± 0.10 (0.0086-0.30, n=8, Data from Tsukada et al. [5]) and 0.0092 ± 0.0066 (0.0019-0.018, n=4) Bq kg^{-1} fresh weight, respectively (Table 2), which was within a similar range (ND-0.91 Bq kg^{-1} fresh weight, data from Environmental Radioactivity and Radiation in Japan [8]) to those collected throughout Japan except Fukushima. It has been previously reported that the concentration of ^{90}Sr in soil collected from Fukushima Prefecture in 2014 was 0.59-1.0 Bq kg^{-1} outside of the difficult-to-return zone [5], and the values were within a range of the ^{90}Sr concentration in soils collected throughout Japan except Fukushima (ND-5.9 Bq kg^{-1}, [8]), which the deposition from the accident was a negligibly small. It is necessary to attribute the ^{90}Sr content in the plants was derived from the global fallout from several decades ago.

Table 2: Concentrations of radiocesium, ^{90}Sr and ^{40}K in agricultural plants collected from local markets

Market circulation product	Agricultural plant	Sampling date	Concentration (Bq kg^{-1} fresh weight)			
Cultivated area			^{134}Cs	^{137}Cs	^{90}Sr	^{40}K
Fukushima	Komatsuna	10/5/2013	0.030 ± 0.0036	0.055 ± 0.0044	0.054 ± 0.0027	100 ± 0.3
Fukushima	Cucumber	10/7/2013	0.063 ± 0.0074	0.11 ± 0.008	0.013 ± 0.0011	66 ± 0.6
Date	Brown rice	10/11/2013	0.74 ± 0.054	1.6 ± 0.08	0.013 ± 0.0018	65 ± 1.9
Fukushima	Potato	10/5/2013	1.7 ± 0.03	3.9 ± 0.04	0.012 ± 0.0009	130 ± 0.9
Fukushima	Carrot	10/13/2013	0.36 ± 0.032	0.78 ± 0.040	0.031 ± 0.0022	130 ± 1.7
Fukushima	Soybean	10/15/2013	3.7 ± 0.32	8.8 ± 0.47	0.30 ± 0.014	540 ± 14
Date	Persimmon	12/25/2013	1.5 ± 0.05	3.6 ± 0.07	0.0086 ± 0.00050	56 ± 1.2
Inawashiro	Edible chrysanthemum	10/10/2013	0.072 ± 0.0040	0.17 ± 0.006	0.044 ± 0.0039	86 ± 0.3
Date	Eggplant	9/1/2015	0.13 ± 0.025	0.49 ± 0.030	0.018 ± 0.0017	72 ± 1.2
Date	Potato	9/1/2015	0.21 ± 0.035	0.75 ± 0.035	0.0075 ± 0.0013	140 ± 1.5
Date	Pear	9/1/2015	0.40 ± 0.038	1.4 ± 0.05	0.0019 ± 0.00024	41 ± 1.1
Date	Onion	9/1/2015	ND	0.12 ± 0.012	0.0095 ± 0.0014	45 ± 0.5

The concentration of radiocesium collected from the experimental fields in Iitate, Kawamata and Namie in 2015 was 0.44 ± 0.43 (0.11-1.6, n=11) Bq kg^{-1} fresh weight (Table 3). It shows that the concentration of radiocesium in the plants has been entirely maintained at less than the Standard Limit under the appropriate agricultural management. The concentrations of radiocesium in pumpkin and cabbage collected from the experimental field in Okuma (5 km west of the FDNPS) in 2014 were 107 and 67 Bq kg^{-1} fresh weight, respectively. The concentration of radiocesium in the plants collected from Okuma was still higher than that in the markets because the concentration of radiocesium in the soil collected from the experimental field in Okuma was 10000 Bq kg^{-1} [5] or higher [9]. The concentration of ^{90}Sr in the plants collected in Okuma was 0.31 (pumpkin) and 0.21 (cabbage), and that in the soil was 1.7 and 4.7 Bq kg^{-1}, respectively. Those values in both the plants and the soils were also within a range of the reported monitoring results throughout Japan excluding Fukushima [8].

The Standard Limits of radiocesium include the contribution of ^{90}Sr concentration in foods. The concentration ratio of $^{90}Sr/^{137}Cs$ in the plants was estimated by using observed $^{90}Sr/^{137}Cs$ concentration ratio in the deposition from the FDNPS accident and the soil-to-plant transfer factor [e.g. 10, 11]. The concentration of ^{90}Sr in plants was determined by multiplying the $^{90}Sr/^{137}Cs$ ratio in plants by the measured ^{137}Cs value in plants. The concentration ratio of $^{90}Sr/^{137}Cs$ in the pumpkin and cabbage collected from Okuma was 0.0039 and 0.0043, respectively and they were lower than the predicted value (0.051 and 0.12, respectively). It indicates that the contribution of ^{90}Sr to ^{137}Cs in the plants collected from Okuma is less than the estimated values in the 5 km west of the FDNPS.

Internal radiation doses from radiocesium through food ingestion in 2012 and 2013 were estimated using the concentration of radiocesium in the agricultural plants collected from local markets and the detection limit of radiocesium concentration in milk in 2012 and 2013 was used 1.0 and 0.89 Bq L^{-1}, respectively [5]. That in drinking water was not included because it was lower than the detection limit. The internal radiation doses for adult males and females (over the age of 19) in 2012 were 0.069 and

0.054 mSv y^{-1}, respectively. And those in 2013 decreased to 0.016 and 0.012 mSv y^{-1} respectively with the time elapsed. It was also reported that the internal radiation dose from radiocesium in Fukushima Prefecture in 2012 was 0.0039-0.0066 mSv y^{-1} by the market basket method [2], which was one order of magnitude lower than that in this study. This is attributed to the fact that the collected foods by the market basket method usually included both products on and off Fukushima Prefecture, and the concentration of radiocesium in the foods decreased by market dilution. The agricultural samples collected in this study were only produced in Fukushima Prefecture and were not influenced by the market dilution effect. The internal radiation doses from radiocesium by the duplicate diet method in Fukushima Prefecture were reported 0.0022 mSv y^{-1} in 2012 [2], which was still lower than that by the market basket method because of reduced by processing and cooking. The internal radiation doses for adult males and females using the radiocesium concentration in the agricultural plants collected from the local markets and the experimental fields in 2015 were 0.013 and 0.0098 mSv y^{-1}, respectively. The values slightly decreased than those in 2013 accompanied by decay of radiocesium activities, especially ^{134}Cs.

Table 3: Concentrations of radiocesium, ^{90}Sr and ^{40}K in agricultural plants collected from experimental field before resuming agriculture

Experimental field	Agricultural plant	Sampling date	Concentration (Bq kg^{-1} fresh weight)							
			^{134}Cs		^{137}Cs		^{90}Sr		^{40}K	
Okuma	Pumpkin	9/3/2014	27	± 0.8	80	± 1.3	0.31	± 0.006	75	± 5.9
Okuma	Cabbage	9/3/2014	17	± 0.4	50	± 0.7	0.21	± 0.006	64	± 3.5
Iitate	Cucumber	8/6/2015	0.065	± 0.0089	0.24	± 0.009	0.014	± 0.0008	56	± 0.4
Iitate	Pumpkin	8/7/2015	0.16	± 0.053	0.39	± 0.034	0.030	± 0.002	155	± 2
Iitate	Egg plant	8/8/2015	ND		0.12	± 0.010	0.012	± 0.0014	62	± 0.5
Iitate	Cherry tomato	8/9/2015	ND		0.12	± 0.014	0.0065	± 0.00050	66	± 0.6
Namie	Green onion	10/8/2015	ND		0.11	± 0.011	0.055	± 0.0026	74	± 0.6
Namie	Carrot	10/25/2015	ND		0.17	± 0.014	0.10	± 0.0026	110	± 0.8
Namie	Brown rice	10/13/2015	ND		1.6	± 0.13	0.0087	± 0.0013	65	± 3.0
Kawamata	Brown rice	10/4/2015	ND		0.56	± 0.050	0.0048	± 0.00093	63	± 1.5
Kawamata	Potato	10/6/2015	ND		0.34	± 0.024	0.0084	± 0.0016	116	± 1
Kawamata	Taro	10/6/2015	ND		0.26	± 0.022	0.034	± 0.0032	199	± 1
Kawamata	Brown rice	10/5/2015	ND		0.65	± 0.063	0.0036	± 0.00079	69	± 1.8

4 CONCLUSION

The concentration of radiocesium in agriculture plants collected from the local markets in Fukushima prefecture was less than the Standard Limits. That collected from the experimental fields before resuming agriculture in Iitate, Kawamata and Namie was also less than the Standards Limits under the appropriate agricultural management. The concentration of ^{90}Sr in agriculture plants collected from the markets and the experimental fields including 5 km west from the FDNPS was within the similar range of the monitoring results throughout Japan.

5 ACKNOWLEDGEMENTS

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The Detriment in Radiation Protection

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Abstract. One issue of ICRP 103 is a refinement of the concept of radiation detriment. In general, radiation detriment contains information on the severity of radiation effects. It is calculated separately for specified organs or tissues, to be summarized to a total detriment for the whole body. In ICRP 103, detriment is defined as a function of several parameters, including incidence of radiation-related cancer or heritable effects, quality of life, relative loss of life expectancy, and lethality. The total detriment can be considered as the additional weighted absolute risk per equivalent dose as a mean value for whole population or working age population, respectively. In the present study, the detriment's resilience against variation of the radiation-independent health parameters, such as lethality or quality of life are analysed. Since those parameters are dependent on improvements in cancer diagnoses and treatments, they may change with time. Hence, the temporal courses of detriment are examined. These considerations are of some relevance, since the detriment, and in turn the radiation "damage", may decrease due to medical progress, although the radiation risk (i.e. the radiation induced cancer incidence rate) remains unaffected.

KEYWORDS: detriment; radiation protection; ICRP 103.

1 INTRODUCTION

The detriment in ICRP 103 [1] is roughly defined as the product of the (organ specific) risk coefficient and the "damage" that may be associated with a (organ specific) cancer or hereditary effect, respectively. This is to indicate a weighted risk according to the radiation sensitivity of the different organs and the severity of damage that may possibly arise.
Whereas the risk coefficients refer to radiation exposure parameters, the scale or degree of damage is independent of these. The radiation independent parameters are the lethality, the loss of quality of life and the reduced life expectancy, which are considered as quantities associated with the severity of a disease or damage, respectively. These parameters may change gradually, on the one hand possibly due to an increase of cancer becoming a common disease within the population. On the other hand, possibly to a decrease of cancer due to the progress in medical diagnostics and treatments that allow patients to survive or at least maintain a higher life quality standard.
The damage and therefore the detriment appears to be mostly affected by the lethality. The lethality is the quotient of mortality to incidence. The investigation of the detriment presented in this paper focuses on the influence of the lethality on the detriment.

2 DETRIMENT

Generally, the detriment can be considered as a risk quantity that is defined by the product of the "probability of occurrence" of a stochastic effect and the its assumed "damage":

$$detriment = probability\ of\ occurence\ x\ damage$$

The damage is represented by the confinements which come with cancer and cancer treatment as well as the possible fatal outcome of the disease. This general approach to the detriment in radiation protection unveils that the detriment is determined by radiation exposure dependent factors (risk coefficients) and the damage, which itself is independent of radiation exposure, but depends on cancer characteristics.

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The proper definition in ICRP 103 is [1]:

$$D = R_T \cdot [k_T + (1 - k_T) \cdot q_T] \cdot L \quad (1)$$

Where R_T represents the (unweighted) incidence risk for cancer in tissue T per equivalent dose. These "nominal risk coefficients" are obtained using the Linear No-Threshold (LNT) hypothesis. To address for an assumed overestimation by the LNT-hypothesis, ICRP defines a so called "dose and dose rate effectiveness factor" (DDREF). Risk coefficients obtained from epidemiological studies by applying the LNT-hypothesis are divided by the DDREF. The ICRP defines a DDREF with a value of 2 for photons and for solid tumours.

The damage in (1) is represented by three cancer related factors:

- The factor L represents the relative loss of life expectancy for a specific cancer type. It is derived from the quotient of the cancer specific absolute loss of life expectancy in years of to the averaged cumulative loss of life expectancy regarding all types of cancer $L = \frac{L_T}{\bar{L}}$
- The lethality relates to the probability of a fatal course of a type of cancer and is expressed through the quotient of the mortality M_T and the incidence I_T of a specific cancer type T. $k_T = \frac{M_T}{I_T}$
- The loss of quality of life q_T is according to ICRP103 defined as a function of k_T. $q_T = q_{min} + k_T \cdot (1 - q_{min})$
  The factor allows to weight the cancer types that tend to be non-fatal with a minimal quality factor q_{min}. This allows a quantitative comparison of different radiation induced types of cancer. The ICRP proposes three organ specific values for q_{min}:
  $q_{min} = 0$ for the skin, $q_{min} = 0.2$ for the thyroid gland and $q_{min} = 0.1$ for the remaining rest of all non fatal types of cancer [1].

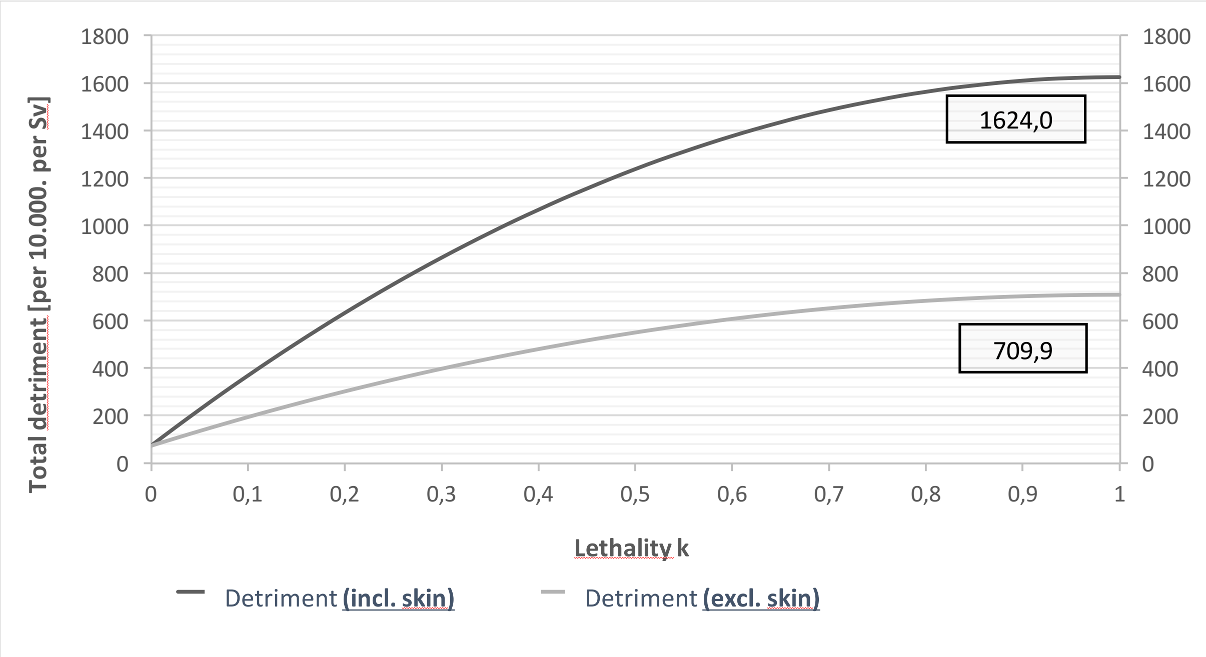
3 METHOD

All calculations were performed according to the definitions provided by the ICRP103 document and the detriment model presented above [1]. The data on cancer development which were exemplary used in this paper origin from Germany. They were obtained from the GENESIS-database of the German Federal Statistical Office [2], the German Information System of Federal Health Monitoring [3], the German Centre for Cancer Registry Data of the Robert-Koch-Institute [4] and the Cancer Register of Saarland, Germany [5]. Calculations represent the time course from 1980 to 2012 for Germany.

4 RESULTS

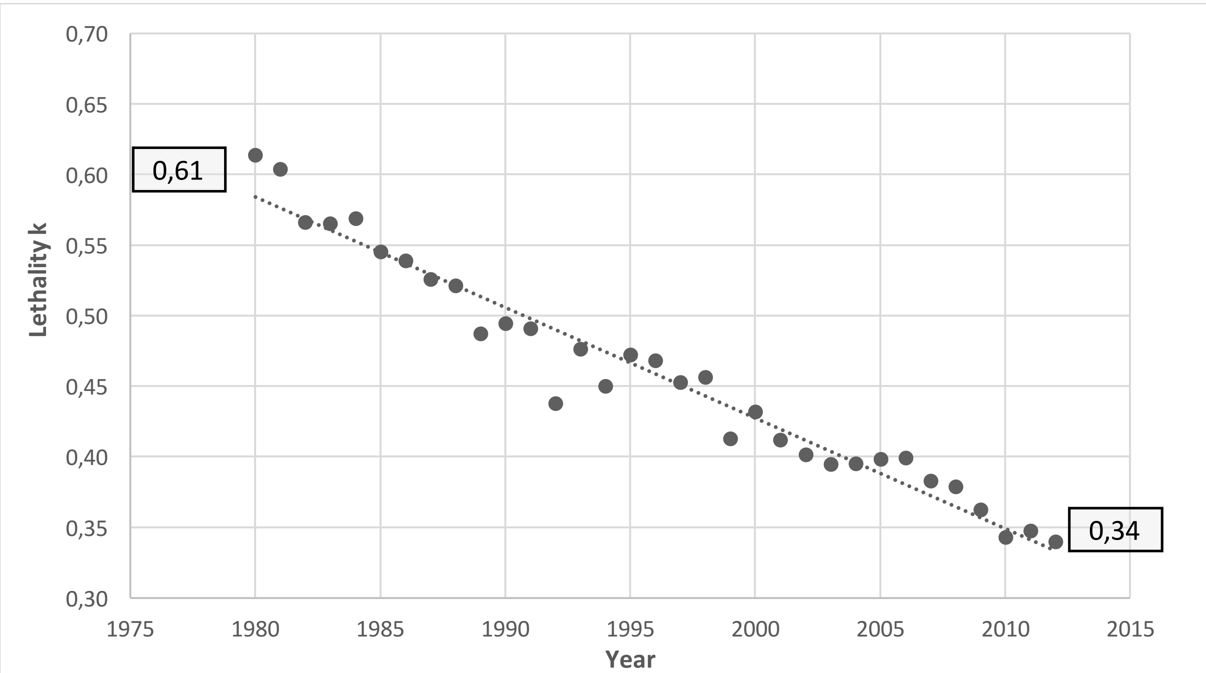
As a first of investigation, the course of the detriment as a function of the lethality was evaluated. The data used for the calculation of a theoretical detriment were taken from the ICRP103 publication, Tab. A.4.1 [1]. The results are presented in Figure 1 and reveal that the detriment as a function of the lethality is expressed as an saturation curve and underlies two major impact factors. On the one hand the calculated detriment depends on the organs included, expecially the skin. As shown in Figure 1, the skin has a massive influence on the detriment since the risk factor for stoachastic effects regarding the skin is defined as $R_T = 1000$. Including the skin as organ in the calculation results in a higher overall detriment and the impact of the lethality on the detriment is bigger, as can be seen comparing the rise of the detriment curves.

Figure 1: The influence of the lethality on the detriment



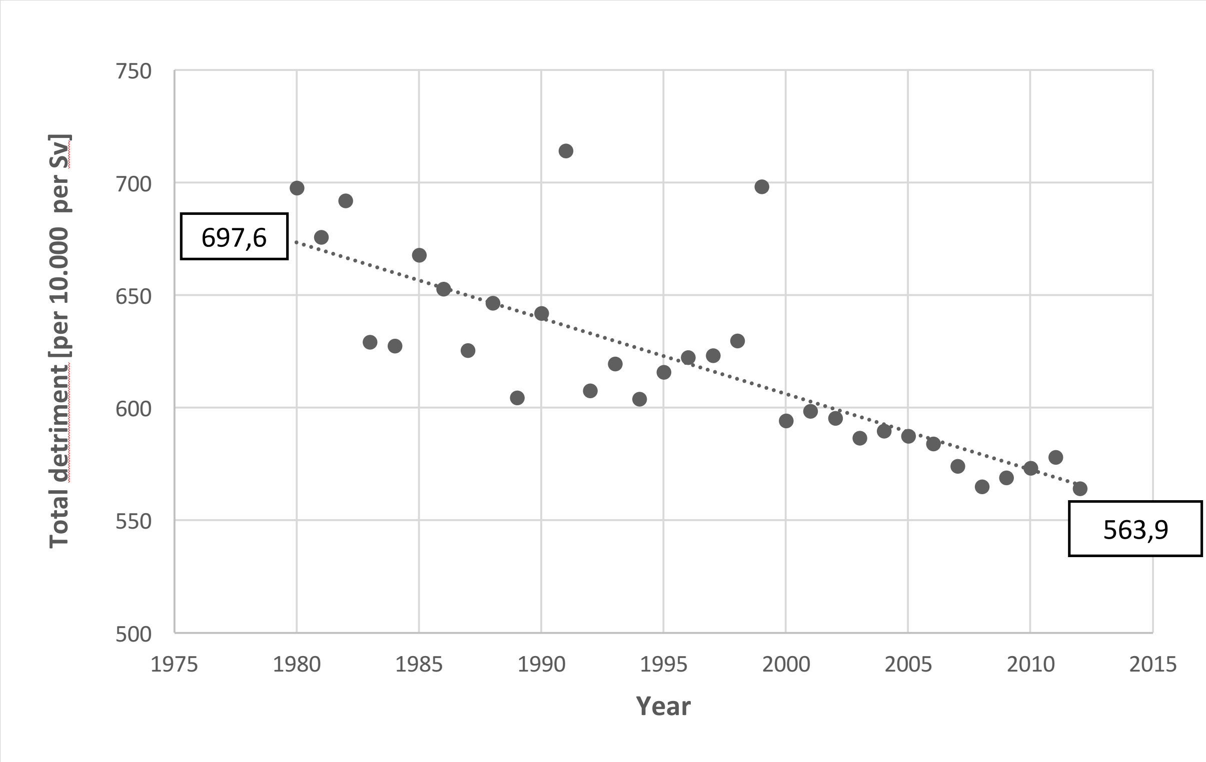
On the other hand, the influence of the lethality can be determined. A change of the letahlity in the lower range (01 to 0.5) of the lethality factor has a stronger influence on the development of the detriment than in the higher range (0.5 to 0.9). To analyse the influence of the lethality the overall lethality for Germany was calculated from 1980 to 2012. The overall lethality constantly decreased over 32 years from 0.61 to 0.34, which is a change of approx. 55%, as presented in Figure 2.

Figure 2: Time course of the lethality factor k_T (Germany)



For comparing purposes the overall detriment was calculated from 1980 to 2012. As well as the lethality, the detriment shows a decreasing development. Whereas the amount is less compared to the change in the lethality. The detriment changed approx. of 20%, as presented in Figure 3.

Figure 3: Time course of the detriment (Germany, including the skin)



5 CONCLUSION

Based on the presented figures following conclusions can be drawn:

- The impact of the lethality is less than may have been expected: a decrease of approx. 50% in the lethality results in a decrease of 20% in the detriment only, for the German data. The decreasing trend of both variables was also identified for data from the USA.
- The decreasing detriment may lead to implications when it comes to assess radiation risks or define dose limits.
- The impact of a possible change of the DDREF, for example DDREF=1, will not be fully compensated by the radiation independent factors (lethality, life quality lost, life expectancy lost). This will result in an overall increase of the detriment of 80%, taking the 20% decrease over time into account, whereas the radiation risk doubles.

6 ACKNOWLEDGEMENTS

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Establishment of Concentration Ratios Riparian and Shrub Steppe Areas of the Eastern Washington Columbia Basin

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Abstract. Concentration ratios are used to determine the transfer of radionuclides from soil to flora to fauna. Some nuclides have limited associated data though this has not prevented predictions from being performed at sites without associated data. These ratios are site specific and are not fully applicable when applied to other locations. A recent literature review for a waste repository performance assessment determined that a significant portion of the environmental data was based on recursively published material. To address this deficiency, neutron activation analysis was used to determine concentration ratios of certain biota. Three sites, two riparian and one shrub steppe, were sampled in the eastern Washington Columbia basin, near the Hanford site. Samples of opportunity were collected for study which included soil and samples of 40 different plant species. These samples were prepared for neutron activation analysis by drying, weighing, and in certain cases ashing to improve detection efficiency. After activation, the samples were placed in a high purity germanium detector to perform spectral analysis. The concentration results of 26 elements of interest are presented, along with newly established concentration ratios for all of the species sampled.

KEYWORDS: concentration ratio; Hanford; Riparian; Shrub Steppe.

1 INTRODUCTION

Radioecology focuses on the mobility and impact of radionuclides throughout the ecosystem. Whicker and Schultz stated that one of the primary subdivisions of radioecology was "radionuclide movement within ecological systems and accumulation within specific ecosystem components such as soil, air, water, and biota." [1] In equilibrium conditions, nuclide movement can be simplified into a ratio of the concentrations between two compartments of an ecosystem, in what is called a concentration ratio (CR). Determination of concentration ratios can be used for site characterization.

Currently, there are three methodologies for site characterization. The first is to sample multiple species at a single site [2], the second is to sample a single species at multiple sites [3], and the third is to compile data from multiple sources [4]. Data collected is used to for model creation and validation.

A problem arises with the quantitative data required to calibrate the models for accuracy. Nuclide transfer data is element specific, though the use of natural analogues has been used in the absence of data for a desired element [5]. This is an important, but sometimes questionable practice, as one source suggested using cesium-137 data for argon-41 and krypton-85 [6].

In an analysis of element specific source terms used in the biosphere sub-model of a performance assessment for Yucca Mountain it was determined that, of 538 parameters, 139 were sourced from a peer reviewed article, 210 were from institutional publications, 140 had no listed reference, and 49 were derived during the creation of the model by the authors [7]. Of the data required to build the model, 35% was either not sourced, or inferred by the authors of the performance assessment. When trying to use data from other locations, it must be considered that CRs from one location are not always appropriate at the other.

Whicker and Shultz described this by saying that a "problem with concentrations ratios is that they are influenced by many factors associated with the properties of the radionuclide, the organism, and the ecosystem. As a result, individual measurements display a great deal of variability" [8]. This brings to question: how solid are predictions for a location in the absence of site specific data?

The focus of this work is to characterize equilibrium conditions for a number of trace elements at three locations surrounding the Hanford Site in Richland, Washington so it can be used in any future site assessments. The area is a geological formation that is unique to the eastern Washington Columbia Basin. During the last ice age, the formation of Glacial Lake Missoula and its periodic release caused floods that were several miles wide at depths of up to 500 feet and at speeds up to fifty miles per hour [9]. There is evidence that this type of flooding occurred up to forty or more times [10]. The current Columbia River channel is the northern and eastern border of the Hanford site.

2 METHODS AND MATERIALS

2.1 Collection

The samples for this study were collected at three locations that surround the Hanford site. The three locations were chosen based on their proximity to the Hanford site. Two riparian locations were selected along with one inland shrub steppe location. The riparian locations were the primary interest for the study and the inland location was chosen due to the prevalence of the local shrub steppe ecosystem. It was also chosen as a comparison against the nearby riparian areas. The riparian sample locations were on the shoreline, the first in the city of Richland (Riparian 1), the second was at Vernita (Riparian 2), just north of the Hanford Site. As the Columbia River flows, the Riparian 2 sampling site is up river of the Riparian 1 sampling site. The third sample site was an arid inland location, just south of the Hanford site (Shrub Steppe).

Samples of opportunity were collected at each site. Five replicates of each sample were collected when it was possible. The samples included soil, sediment, and plants, all of which were collected by hand. They were then labeled, photographed, and bagged. After collection, all samples were stored on ice until being transferred to a freezer at Oregon State University where they were kept at 20 degrees Fahrenheit. In addition to these samples, water, invertebrates, and fish were collected, but the results from these samples are not discussed in this paper.

2.2 Vegetation sample preparation

At the university, the plant samples were washed by hand using deionized water to remove any debris on the roots and other parts of the plants. The first four replicates were always whole plants. If there were only five plants, the fifth replicate remained whole. When more than five plants were collected, all the remaining plants were labeled as a fifth sample with two parts, an above ground portion, and a below ground portion. In certain instances, larger plants were separated into root/stem/branch portions. This was due to their larger size and the inability to fit them into small paper bags for drying. The roots and shoots data is not presented in this paper.

The samples were dried in a drying oven[1] at 55 degrees Celsius for a minimum of 85 hours to a stable weight. After drying, sample masses were recorded and the samples were homogenized. Smaller samples were ground using a blender while larger samples were ground using a Wiley Mill grinder that ground the larger samples until they could pass through a 5 millimeter mesh.

2.3 Soil preparation

The soil samples were dried using a Fisher Isotemp 200 series drying oven. The sample bags were opened and placed in the oven at 65 degrees Celsius for a minimum of 24 hours until the all the water had evaporated. Portions of the dried soil were sent to the Soil Physical Characterization Lab in the OSU Central Analytical Lab in the Department of Crop and Soil Sciences. There, the soil type was determined using a Quick Hydrometer method [11].

2.4 Sample ahsing

To increase detection efficiency, samples over 2 grams were ashed using one of two muffle furnaces[2]. Each furnace was set for 550 degrees Celsius and the samples were left in the ovens at temperature for 23 hours. Sample masses were recorded before and after ashing, along with the empty crucible mass. These three masses were used to determine an ashing ratio. As ashing concentrates the non volatile elements within the sample, an ashing ratio allows for determination of the original concentration within the sample prior to ashing.

2.5 Neutron activation analysis

Neutron activation analysis was performed on the samples for determination of the stable element concentrations. For the plant samples, the amount irradiated was 750 mg of each sample. For the soil samples, 250 mg was used. The samples were double sealed in polypropylene vials. Each batch of samples included reference samples from the National Institute of Standards and Technology (NIST). The reference standards used were different for the soil and plant samples. The samples were compared to 200±5 mg of standard. Three comparison standards were NIST 1633a (Coal Fly Ash), one of NIST 1633b (Coal Fly Ash) and one of NIST 688 (Basalt Rock). The vegetative samples were compared against three NIST 1633a (Coal Fly Ash), one NIST 1570a (Trace elements in Spinach leaves), and one NIST 1547 (Peach Leaves). The vegetative standards were suspended through the sample vials by mixing the standard with cellulose binder[3]. This was chosen because "of the general inertness of organic matter (C, H, O) to neutron activation" [12].

Standards from the National Institute of Standards and Technology are well characterized in their elemental concentrations. NIST standards are certified with 95% confidence intervals to μg/g concentrations. These concentrations were used for calculation of unknown concentrations in samples. After an initial cool down period of one week, the irradiated samples were counted using a well type high purity germanium detector (HPGe) for 5000 seconds of live time each. After another three week cool down period, the samples were counted again using the same HPGe for 15000 seconds of live time. The activities determined were compared against NIST standards to determine the initial stable elemental concentrations.

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[1] VWR Model 1390FM

[2] Cole-Parmer StableTemp® or Thermolyne model CPS-4032P

[3] 3642 SPEX SamplePrep

In certain instances, the activities determined by NAA were below the minimum detectable concentration (MDC). Automatically assuming an amount of zero for non determined activities causes a result bias that is lower than the probable amount. In these instances, a value of half the MDC was used. This practice has been shown to be acceptable when up to 70% of the required activities for a specific element are determined to be below the minimum detectable activity [2].

3 RESULTS AND DISCUSSION

3.1 Plant identification

The plants were identified by a plant ecologist from Pacific Northwest National Laboratory and the author. The plants were visually identified using her expertise and by comparing sample photos against photos on the USDA Natural Resources Conservation Service website [13], the online Burke Museum plant identification tool [14], and *Vascular Plants of the Hanford Site* [15]. A complete list of identified plants can be found in the supplemental information. Forty different plant species were sampled in this study.

3.2 Soil composition and comparison

The soil at the shrub steppe and Riparian 2 sample sites were classified as sand. The Riparian 1 soil was classified as loamy sand. The classification was done using the quick hydrometer method by the OSU Soil Physical Characterization Lab in the Department of Crop and Soil Sciences.

The elemental concentrations determined in the soils were compared against concentration found in the conterminous United States as determined by the USGS [16]. The elements that were not reported by Shacklette and Boerngen were compared to soil concentrations reported by Argonne National Lab [17] and Kabata-Pendias [18]. The percentage variance was calculated for each element at each location. Most concentrations were determined to be within 25% of the reported values. There were certain elements that varied from the reference data. Specifically to the shrub steppe sample site, arsenic (1.84 ppm vs. 7.40 ppm), neodymium (2.61 ppm vs. 4.60 ppm), antimony (0.372 ppm vs. 0.660 ppm), and zirconium (133 ppm vs. 2.30 ppm) were determined to be lower than stated values while cobalt (15.7 ppm vs. 9.10 ppm), scandium (16.3 ppm vs. 8.90 ppm), and strontium (427 ppm vs. 240 ppm) were higher than comparable reference data. At the Riparian 1 sampling location, strontium (494 ppm vs. 240 ppm) and zinc (123 ppm vs. 60 ppm) were found to be higher in concentration than comparable values. At the Riparian 2 sampling location, chromium (145 ppm vs. 54 ppm), iron (4540 ppm vs. 2600 ppm), strontium (600 ppm vs. 240 ppm), uranium (3.05 ppm vs. 2.70 ppm), and zinc (229 ppm vs. 60 ppm), were determined to be higher than comparable values. These values reinforce the concept of variability between sampling locations.

3.3 Comparison of concentration ratios between sample locations

As there were no comparable plant species across the riparian and shrub steppe sampling locations, the average concentration ratios were compared graphically. Figures 1 and 2 show the ranges of calculated concentration ratios for each element determined at the first riparian sample site (Figure 1) and upland sample site (Figure 2). To form these graphs, the concentration ratios for each plant sample were calculated for each element. Four quartiles are represented on each graph. Also, regulatory values are also included in each graph for comparison from Regulatory Guide 1.109 [19], IAEA Technical Document 1616 [20], and Coughtrey and Thorne [21]. The plants of each location were compared against the average soil concentrations of each element from the sampling location. Complete tables of concentration ratio by element in each plant species are listed in the supplemental information.

It is evident from Figure 1 that site specific CRs can vary greatly from standard regulatory values. The inaccuracies could be due to Regulatory Guide 1.109 not being specific enough for the sampled locations or the concentration ratios could not be conservative enough for adequate public protection. At the Riparian 1 sampling site, the listed values for sodium and rubidium were equal to the calculated medians, while for zinc the value was slightly high. For every other value, the number was lower than the 25th percentile of calculated values. In certain instances the listed value was lower than any value calculated in this study. The values determined for the second riparian sample site (Riparian 2) were similar in their differences from Regulatory Guide 1.109 values.

Figure 1: Ranges of calculated concentration ratios from riparian sample site 1 with comparison values from Regulatory Guide 1.109 [19], Technical Document 1616 [20], Coughtrey et al [21] and the TERRA Code [22]

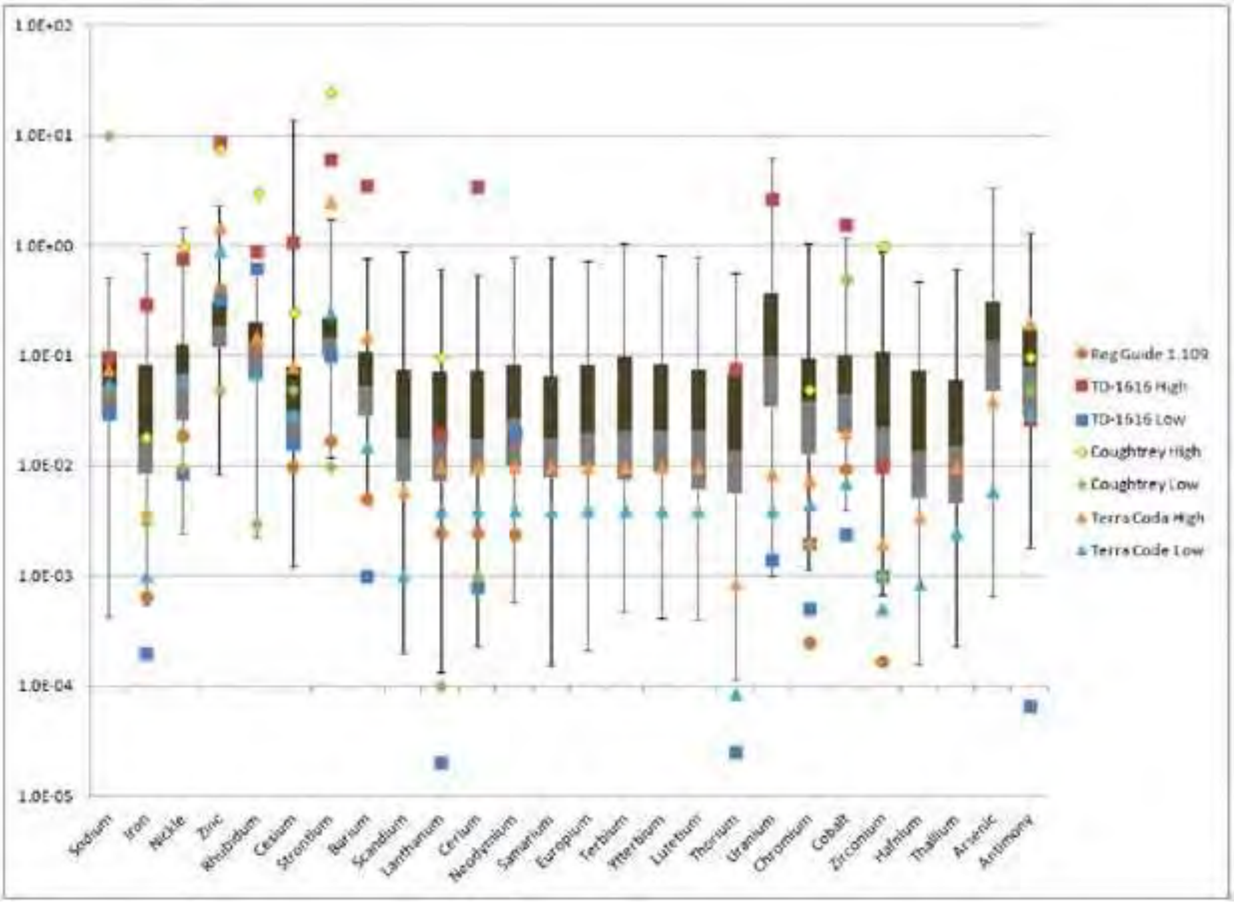
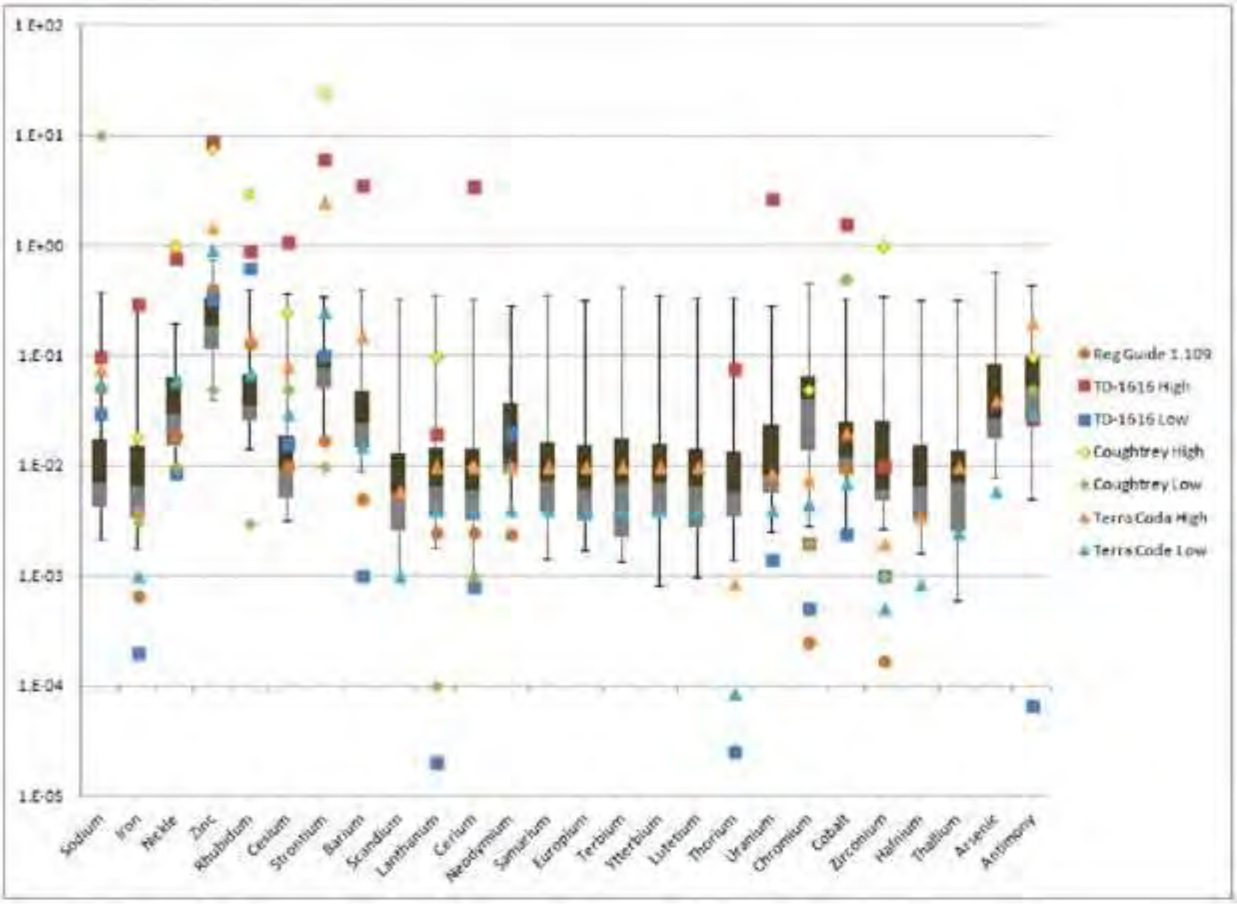


Figure 2: Ranges of calculated concentration ratios from the shrub steppe sampling location with comparison values from Regulatory Guide 1.109 [19], Technical Document 1616 [20], Coughtrey et al [21] and the TERRA Code [22]



The use of ranges, as was done in Technical Document 1616 [20]and Coughtrey and Thorne [21], is a better practice than listing singular values. However, certain CRs did not fall within these ranges. When the Riparian 1 CRs were compared with the most current data in TD-1616, zinc, rubidium, lanthanum, neodymium, chromium, and antimony had 50% of calculated CRs outside of the TD-1616 Ranges. This occurred for values of rubidium, lanthanum, chromium, zirconium, and antimony calculated for the Riparian 2 location. Calculated Shrub Steppe CRs fell outside the ranges of sodium, zinc, rubidium, cesium, neodymium, chromium, and antimony for more than 50% of the samples. In fact, none of the rubidium CRs calculated from upland data was within the ranges listed in TD-1616. It should be noted that neodymium has only a single CR value listed in TD-1616 [20].

Older data from Coughtrey and Thorne [21] was more similar to what was determined in this study. A first point of difference is the CRs for sodium are listed as ranging between 10 and 1000. It is also noted that for sodium "no best estimate can be assigned due to wide variation recorded within and between plant species" [21]. At the Riparian 1 sampling site, iron, cesium, and cerium, had more than 50% of calculated values outside the ranges listed by Coughtrey and Thorne. At the Riparian 2 sampling site, only iron and cerium were outside the ranges more than 50% of the time. The only element to be outside of the Coughtrey and Thorne[21] ranges at the Shrub Steppe sample site was cesium.

The transfer factors listed in the TERRA Code were used as references because transfer factor values were listed for every element in this study and appear as Terra Code Low (NonVegetative) and Terra Code High (Vegetative) on Figure 1 and 2. The transfer factor values from RESRAD [23] were considered for comparison but not every element in this study is available in RESRAD. When considered as ranges, the TERRA Code values are a more viable reference, but even then they do not correlate well with the calculated data. The TERRA Code values were comparable for sodium, rubidium, cesium, barium, and antimony at Riparian Site 1 and 2. The other values were all too low for the riparian sites. At the upland site, the values listed for the actinides and antimony were accurate.

4 CONCLUSIONS

The primary goal of this work was to establish concentration ratios for specific areas surrounding the Hanford site. Forty species of plants were analyzed over three locations. When compared to available standard concentration ratios [19], [20], there was variation from reference standards. This study shows that there are concentration ratios outside of accepted values, so site specific values should be used or determined whenever possible.

Compared against each, the drier shrub steppe environment produced concentration ratios lower than those of the riparian areas. The fewest number of samples were collected at the shrub steppe sampling site, but that would not be a cause for lower concentration ratios. Instead, it is thought that lower water availability for the plants caused this.

The procedures followed by this project can be used for other locations of interest for the creation of site specific data. Results from data that are not site specific can cause calculations to show plant concentrations that are too high or too low. Best practices must include site specific data. Calculation of this data can be done using NAA to characterize element of interest quickly.

5 SUPPLEMENTAL INFORMATION

The supplemental information contains the sampling locations, identification of sampled species, soil type, and average, minimum, and maximum concentration ratio and associated standard deviation for each element for each species. The supplemental information has been uploaded to a google document and can be found at the following link. https://goo.gl/pkdf3v

6 ACKNOWLEDGEMENTS

This work was funded by the Consortium for Risk Evaluation with Stakeholder participation.

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Development of a Standard Procedure For the Irradiation of Biomolecules

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Abstract. In dosimetry the determination of the effectiveness of the damaging processes is standardized and accounted for by the radiation and tissue weighting factor. For the underlying constituents of the tissue, that is the various biomolecules, such a systematic approach doesn't exist. This makes it difficult to compare results obtained under different experimental conditions. In the following work, we will describe a method to obtain comparable values for the radiation-biomolecule interaction, measured under different conditions. This approach can lead to standardization of dose-damage relationship at the molecular level. Such approach is necessary for a better understanding of the relations between the damage of the single constituents of biological tissue and the whole – finally gaining a more complete picture of irradiation damage.

KEYWORDS: dosimetry; irradiation under physiological conditions; microdosimetry; Geant4; Monte Carlo simulation; single strand break; double strand break; plasmid DNA; biomolecules; diffusion.

1 INTRODUCTION

In dosimetry three related quantities describe the damaging effect of radiation on biological tissue. The absorbed dose (D) describes the energy absorbed by a certain amount of mass. To account for the varying effectiveness of different radiation types causing damage the equivalent dose (H) was introduced. H and D are connected by the radiation weighting factor (W_R) which is used to represents the relative biological effectiveness in dependence of the type of radiation.[1] To account accordingly for the varying sensitivity of different types of biological tissue to radiation the effective dose (E) was introduced. E and H are connected by the tissue weighting factor (W_T) which is used to represents the relative biological effectiveness in dependence of the type of irradiated tissue:

$$E=W_T H=W_T W_R D \quad (1)$$

These values are well defined for macroscopic biological tissue. But taking the bottom-up approach of radiation chemistry, starting from the damaging processes on molecular level and looking at DNA or proteins, the situation becomes less well-defined. There, predominately g-values are reported which give the number of a produced damage species per 100 eV of deposited energy. These values naturally depend on the experimental setup, type of radiation, and the concentration of undamaged specie, etc. [2] Hence it is hard to impossible to properly compare results in a quantitative manner. This is mostly owed to the different experimental approaches needed to irradiate different types of samples (*e.g.* single nucleobases, DNA-strands or proteins) with different types or radiation under varying conditions (in vacuum, under humid atmosphere or in liquid). Therefore we are going to propose a generalized experimental and analytical procedure to overcome these limitations thus making results

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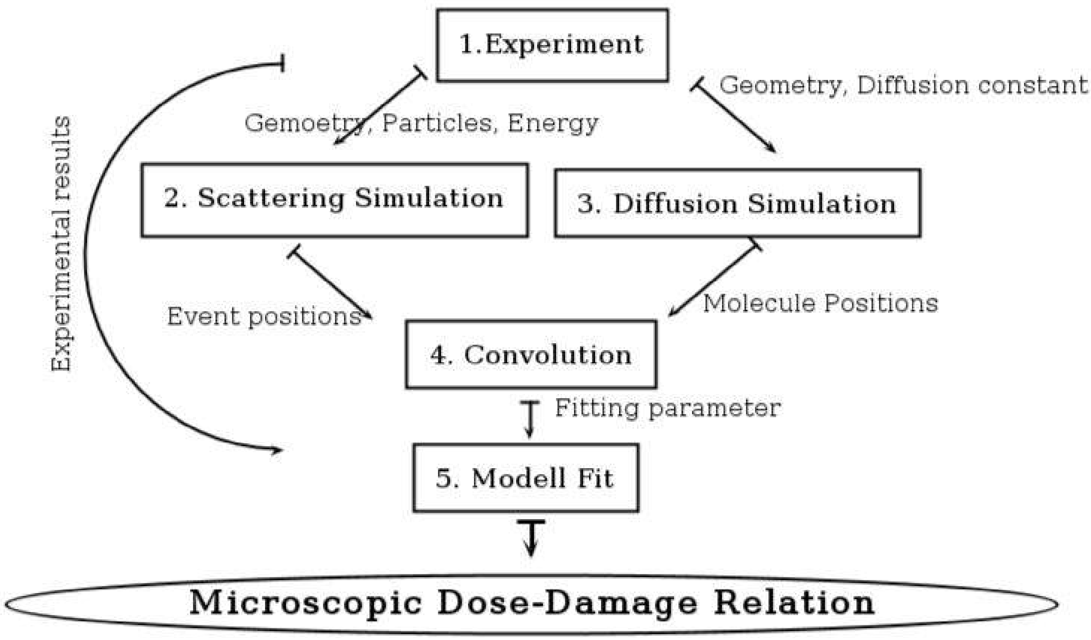
from different setups quantitatively comparable. In the following section we will first give a general, formalized procedure followed by an example application to a given experiment.

2 METHOD

To obtain experiment-independent, comparable results, we define the following properties: The value of interest is a *change of state* (e.g. type of damage, chemical reaction, change in conformation) in dependence of a *generalized event* (e.g. energy deposit, ionization event) occurring within the volume of the *molecule of interest*. After determining such a value, results can be compared for different physical (e.g .types of particles, energy spectra,) and physiological (e.g. salt concentration, pH, cosolutes) conditions. To be able to do so, experimental parameters which are only relevant due to experimental necessities (e.g. number and energy spectra of primary particles before interacting with the molecule of interest, sample holder geometry, etc) have to be eliminated from the experimental results. This can be achieved by the following procedure:

1. Performing the experiment to obtain the *change of state* in dependence of some of the external parameters (e.g. number and energy spectra of primary particles).
2. Performing Monte-Carlo scattering simulations to obtain the spatial and/or time resolved information about the *generalized event* (e.g. energy deposit or ionization events in dependence of the position within the sample holder). Thereby the bin size related to the volume of the *molecule of interest* should be choosen for the resulting histogramm to provide a proper resolution.
3. Due to the fact that most biological relevant processes are occuring in aqueous environment, experiments have to performed in water as well. Therefore the diffusion process of the *molecule of interest* during the experiment has to be taken into account when calculating the positions in space and time. This can be well modelled by means of Monte-Carlo simulations as a random walk process.
4. Convolution of the spatial or time resolved information about the *generalized event* with the positions in space and time of the *molecule of interest*. This results in an average value for *generalized event/molecule of interest.* In case of a non homogeneous distribution of the *generalized events in* space and time, the result would be a histogram of the amounts of molecules undergoing a certain amount of events.
5. To connect the experimental results to simulation an appropriate model has to be chosen to fit the *generalized event/molecule of interest* to the experimental data (the observed *change of state*) to finally obtain the relation of the *change of state* per *generalized event* (e.g. damage probability per energy deposit).

Figure 1: Overview of the procedure as described in the method section. The steps are given in rectangles. The arrows specify the input parameters taken from the former step.



3 RESULTS AND DISCUSSION

To clarify this general procedure an example is given here:

1. A double stranded DNA (*molecule of interest*) is irradiated by monochromatic homogeneous UV-C radiation within a quartz-cuvette. Thereby the duration of the irradiation is varied within the experiment (*external parameter*). After the irradiation, the decrease in the amount of the undamaged DNA-molecules (*change of state)* is determined.
2. The cuvette and irradiation conditions are modelled and simulated by the *Geant4* Monte-Carlo simulation framework.[2] From the scattering simulation the energy deposit can be extracted with a spatial resolution comparable to the molecular size.
3. The diffusion of the DNA gets modelled as a random walk process based on the diffusion coefficient as input parameter.
4. Results from step 2 and 3 have to be convoluted. Due to the low scattering cross section of the radiation with water, the energy deposit (*value of interest*) within the dimensions of the cuvette is nearly constant. So the convolution results in an average amount of energy deposited in the vicinity of a DNA-molecule.
5. As a model, the target theory[4] is applied:

$$S(E)=S(0)\exp(-a\,E(p)) \quad (2)$$

where S is the survival rate in percentage of undamaged species (*change of state*), E(p) the energy deposit in dependence of the *external parameter p* – in case of UV-radiation, for example, the amount of photons per area, which has to be scaled with the simulated photons and the surface of the sample holder.

After fitting equation (2) to the experimental data, the median lethal dose can be calculated from the fitting parameter a as:

$$E1/2 = -\ln(0.5)/a \quad (3)$$

This shows that values of general interest, such as the median lethal dose, can be obtained in a way independent from the specific experiment by combining experimental data with Monte-Carlo simulations.

4 CONCLUSIONS

In conclusion, the presented method opens up a new way to generalize and standardize the determination of radiation induced changes in biomolecules, thereby making these results comparable despite the different underlying experimental setups. When the *value of interest* is identified by the energy deposit in the vicinity of the *molecule of interest* an analogue to equation (1) can be defined by replacing W_T with the molecular weighting factor (W_M) and W_R with the interaction weighting factor (W_I) describing the influence of the *value of interest* on the *change of state:*

$$E=W_M H=W_M W_I D \quad (4)$$

As a molecular standard, plasmidic DNA which is readily avaliable and well-studied, such as pUC19 or pBR322, should be considered. This way standardization for the determination of dose-damage relations on the molecular level can be performed. This method enables a better understanding of the relations between the damage of the molecular constituents and the biological tissue as a whole.[5,6] Such advancements in the fields of radiation protection and radiation chemistry by bridging the gap between both fields should lead to more precise dose-damage predictions.

5 ACKNOWLEDGEMENTS

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Modelling the decrease in ambient dose rate from the Chernobyl fallout using data from the Swedish municipality measurement system

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Abstract. An important part of the Swedish system for emergency preparedness concerning radioactive releases to the environment is the measurements of ambient dose equivalent rate performed by the local authorities in the Swedish municipalities. Soon after the Chernobyl accident periodical measurements of ambient dose equivalent rate were performed at several sites in the communities that were affected by the fallout. In 1990 a comprehensive programme was initiated where measurements are made by gamma survey meters with 7-months interval at pre-defined sites in each Swedish municipally. The data are a continuous record of the existing ambient dose rates that can be used to indicate for any elevations in these levels that need to be investigated. In this study data from municipality measurements at 4 sites have been used to estimate the temporal pattern of the contribution from the Chernobyl fallout to the ambient dose rate about ½ month post fallout. The measuring sites are located in the municipality with the highest average ground deposition of ^{137}Cs in Sweden from the accident in 1986 (c. 80 kBq m^{-2}). It was found that the decrease is relatively well described by a double-exponential decay function that can be quantified by a short- and a long-term ecological half-time (ranging from 0.1-0.2 y and 3-6.4 y, respectively). The short-term component is associated with the rapid decrease of short-lived fission products combined with the initial weathering and run-off of the fresh fallout. The long-term component is related to the depth migration of ^{137}Cs into the soil. However, both the short-term and the long-term half-times differ significantly between the sites and local variations must therefore be taken into account when the external radiation dose to inhabitants at different times after the deposition event is estimated. The results emphasize the usefulness of maintaining a time-series of background measurements.

KEYWORDS: ambient dose rate; Cs-137; migration; Chernobyl fallout.

1 INTRODUCTION

Soon after the Chernobyl fallout in Sweden in May 1986 the affected municipalities in Sweden started to frequently measure ambient dose equivalent rate ($H^*(10)$ h^{-1}) at 1 m above ground. Since 1990, each municipally have measured the dose rate at specific sites every 7th month and reported the data to the authorities. The instruments used have been based on energy-compensated GM tubes. The large number of measurements makes it possible to model the changes in H*(10) rate over time. Exposure forecasts are important since evacuation or other remediation measures after a fall-out will have great economic and social effects. An estimate of the averted dose to the residents during an evacuation period must therefore be reliable and thus requiring some prediction of the continued external dose rate contribution from a fallout in the area.

The external dose rate from deposition of the fission product ^{137}Cs, which is the nuclide of key interest due to its long physical half-life, was studied by Gale et al. [1]. For the study fifteen plots of different soil types were prepared on an air field. An area with the diameter 30 cm in each the plot was contaminated with 37 GBq (=1 mCi) ^{137}Cs. The plots were left without any human interference except from cutting of the grass during seven years. The dose rate 50 cm above the ground was measured periodically using an ionization chamber. Based on the experimental data, Gale presented a bi-exponential equation describing how the dose rate 1 m above ground decreases over time after the initial contamination. The equation has two terms, the first corresponding to a fast decaying component and the second to a slower component:

$$D(t) = a_1 e^{-\frac{\ln 2}{\tau_1}t} + a_2 e^{-\frac{\ln 2}{\tau_2}t} \tag{1}$$

where t is time, τ_1 and τ_2 describes the half-time each component, and a_1 and a_2 describes the relative proportion of the two components, i.e. $a_1 + a_2 = 1$. Gale predicted the following values for the parameters:

$$D(t) = 0.63 e^{-\frac{\ln 2}{0.6}t} + 0.37 e^{-\frac{\ln 2}{22.7}t} \tag{2}$$

where t has the dimension years. The predictions were valid for an infinite surface. The short term component corresponded to a fast washout resulting in a rapid decrease in dose rate during the first years and the long-term component corresponded to the fraction of ^{137}Cs that has been fixated more permanently in the soil.

Eqn (1) can be viewed as a first order approximation of the time pattern in the Cs contribution to the ambient dose rate. However, this expression does not take into account that: i) the initial contribution from the short-lived radionuclides occurring in fresh nuclear power plant (NPP) fallout, such as ^{131}I ($T_{½}$=8.02 d), ^{132}Te ($T_{½}$=3.2 d), and ^{140}Ba ($T_{½}$=12.8 d), and ii) the presence of ^{134}Cs ($T_{½}$=2.06 y) in the fallout from a nuclear reactor accident. ^{134}Cs is not a fission fragment but is found in reactors as a neutron activation product of the fission product ^{133}Cs. In Gale's formula the relative proportion between the short term and long term component was 0.63/0.37=1.7. This ratio is likely to be dependent on the soil type and surface characteristics as well as the fallout composition.

The surface contamination in the experiment by Gale et al. was very high (>40 GBq m^{-2}) compared to the fallout after the Chernobyl disaster, where the most affected areas outside the exhibited ^{137}Cs deposition in the order of a few MBq m^{-2}. This, however, meant that the natural background could be neglected during the whole study.

Karlberg [2] surveyed the time development of surface contamination using a germanium spectrometer positioned 1 metre above ground at some reference points in Sweden during the first year after the Chernobyl accident. After one year, about 40% of the initial surface activity remained. The retention seemed to be the same on several ground materials with the exception of areas covered by paving stones where 80% of the initial contamination remained. Karlberg also used an ionisation chamber to measure the exposure rate at different locations in the city of Gävle, which was the one most contaminated in Sweden (on average 80 kBq m^{-2}). The measurements showed that the exposure rate was the highest over grass and gravel areas. However, the decrease rate in the exposure rate on these types of areas was more rapid than on other materials such as asphalt and concrete. Jacob et al. [3] investigated the reduction of surface contamination on streets and lawns in Munich after the Chernobyl accident using a germanium spectrometer positioned 1 metre above ground. Jacob found that the surface activity decreased with a half-time of about 80 days. Thus, both the measurements by Karlberg and Jacob et al. suggested that the dose rate decreased much faster than what was predicted by Gale. This was, however, predictable since the fallout also consisted of short-lived isotopes and the effect of the physical decay during the first year would be large.

The aim in this study is to determine the time pattern and the corresponding short- and long-term components and their respective half-times in the locations initially also measured by Karlberg et al. [2] using a hitherto unassessed data set, performed by the municipality every 7th month. The aim is also to discern whether there are any notable differences in the half-time of the long-term component between the various sites investigated.

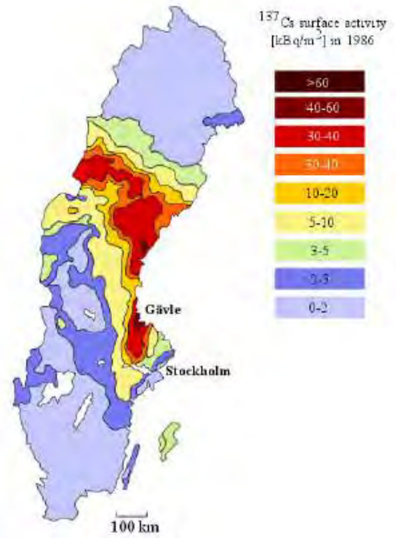
2 MUNICPILATY DOSE RATE MEASUREMENT DATA

Since 1986, ambient dose equivalent rate one meter above ground has been measured every 7th month at several locations in Sweden. In this study, four locations near the town Gävle were chosen. The coordinates of the four sites are listed in Table 1. As mentioned previously the region around Gävle was one of the worst contaminated areas in Europe. This was due to rainfall during the days following the Chernobyl accident. Locally, the surface contamination was as high as >200 kBq m^{-2} after the fallout and hotspots where the activity concentration is even higher can still be found.

Table 1: Measurement sites with coordinates.

Site	Coordinates	Description
Hedesundsgården	60°23'45.03"N, 17° 0'18.40"E	Gravel yard at a nursery school
Ytterharnäs	60°39'10.62"N, 17°21'30.75"E	Gravel path in apple orchard
Espanaden	60°40'35.17"N, 16°8'34.10"E	Park with cleaning twice a year
Bergby	60°55'40.35"N, 17° 2'32.86"E	Nursery school with sandboxes

Figure 1: ^{137}Cs contamination over Sweden in 1986. Redrawn map based on data airborne measurements performed by the Geological Survey of Sweden (SGU) published in 1996 [4].



The measurement were performed using gamma survey meters on a tripod 1 m above ground. The instruments used were initially a Scintrex-BGS 4 gamma survey meter during the period 1986 to 1999, consisting of NaI(Tl) crystal detector (15.6 cm^3 in size). Since then energy compensated GM tubes were used (a Rados SRV-2000 gamma survey meter which was replaced with an instrument of the same model in 2004). The signal from each instrument was converted to ambient dose equivalent rate and the calibration was validated by using a ^{234}Th source at each measuring occasion.

3 MODELING OF DATA

Since the measurements have been continued for such a long time, the dose rate has now dropped to levels where the natural background is the dominant source of radiation at 1 meter above ground. This means that if the equation presented by Gale et al. is to be used to model the data from the measurement series in the locations in Gävle (Table 1), the contribution from the background must be accounted for. This can be done by assuming a relatively constant value, disregarding any seasonal variations due to e.g. snowfall. However, simply adding a constant term, c, in equation 1 would mean that the sum of a_1 and a_2 would not be equal 1 but to $1 - c$. To bypass this a parameter, D_0, was introduced into the equation before the term c was added to the yield the following expression:

$$D(t) = D_0\left(a_1 e^{-\frac{\ln 2}{\tau_1}t} + a_2 e^{-\frac{\ln 2}{\tau_2 \cdot}t}\right) + c \tag{3}$$

The parameter D_0 is the initial elevation of ambient dose rate due to the fresh NPP fallout and c is the constant background dose rate. This means that the criteria $a_1 + a_2 = 1$ is met. Since $a_1 + a_2 = 1$, equation 3 can then be simplified to:

$$D(t) = D_0\left(a_1 e^{-\frac{\ln 2}{\tau_1}t} + (1 - a_1) e^{-\frac{\ln 2}{\tau_2 \cdot}t}\right) + c \tag{4}$$

thus reducing the number of parameters to five. The parameters were optimized to fit the data using the Levenberg-Marquardt algorithm for least square optimization (Scipy library for Python 2.7). Uncertainty of the optimization of each parameter was estimated using the Jackknife method.

4 RESULTS AND DISCUSSIOM

The results of the regressions are presented in Fig. 2. Results with uncertainties are presented in Table 2. It is observed that the half-times of the short-term component (0.1-0.2 y) was much shorter than the time predicted by Gale (0.6 y). The amplitude of the short-term component on the other hand appears to be higher than that predicted by Gale et al. (Table 2). The shorter half-times and higher value of a_1 can be explained by the rapid physical decay of the Chernobyl fallout containing short-lived isotopes. The results presented by Jacob and Karlberg also suggest that the short-term component predicted by Gale is underestimated. It must also be noted that the modelling refers to measurements carried out at least 2 weeks after the initial fallout, and a considerable additional short-term fraction predominated by the short-lived fission products precedes he short-term component presented here. The impact of this first initial phase is subject for ongoing studies.

The uncertainty of τ_1 predicted by the Jackknife method was large. This was probably due to how the Jackknife method works. When one of the earliest values in the data series is excluded from the curve fit, the optimization will not be reliable. However, when all data was used, nearly the same value for τ_1 was calculated at several trials with different start parameters.

Figure 2: Measured dose rate (dots) and curve fit (solid line) for each measurement site. Note that D_0 has been replaced with $\mathrm{H}^*(10)_0$.

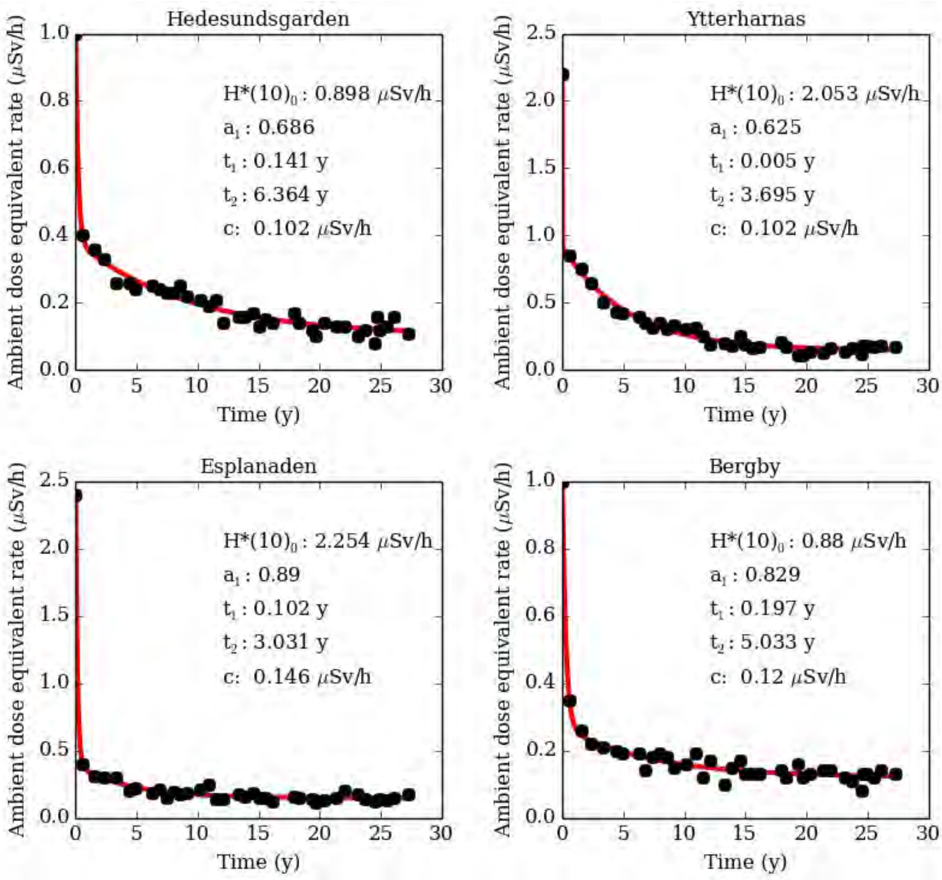


Table 2: Optimized parameters (uncertainty (±1 SD) was estimated using the Jackknife method)

Location	Parameters					
	$H^*(10)_0$ *(µSv h^{-1})	a_1 (1)	τ_1 (y)	a_2 (1)	τ_2(y)	c (µSv h^{-1})
Hedesundsgården	0.90±0.09	0.69±0.07	0.14±0.1	0.31±0.07	6.4±0.3	0.10±0.003
Ytterharnäs	2.1±0.2	0.64±0.06	0.11±0.2	0.36±0.06	3.8±0.2	0.14±0.004
Esplanaden	2.3±1.3	0.89±0.02	0.10±0.01	0.11±0.02	3.0±0.1	0.15±0.001
Bergby	0.88±0.08	0.83±0.03	0.20±0.06	0.17±0.03	5.0±0.4	0.12±0.002
Gale prediction	-	0.63	0.60	0.37	22.7	-

*N.B: that this parameter will be considerably higher when taking the full account of the initial component from short-lived fission products. This is subject for further studies.

The long-term component, a_2, was also several times shorter than the half-time suggested by Gale, (with observed values ranging from 3 to 6.5 y compared with 22.7 y). The difference can be explained by several factors. The data used by Gale came from well controlled surfaces left without any human interference other than from cutting of the grass during the whole study. The data from Sweden came from places with continuous human activity. The content of ^{134}Cs in the Chernobyl fallout would also lead to a more rapid decay in the long-term component compared with the Gale experiment.

There was a large spread (a factor of 2) in the observed long-term half-times, t_2. The highest half-time of t_2 was found at Hedesundsgården where the measurement was performed on a relatively unchanged gravel yard at nursery school. Still, the observed τ_2 was several times shorter than the respective half-time predicted by Gale indicating a higher migration rate of Cs into the ground. The small long-term components observed at Esplanaden and at Bergby meant that very little of the original fallout remained in the top soil layer after the first years. The relatively small value of both a_2 and t_2 for the site Esplananden compared with the corresponding values for Hedesundsgården can be explained by the former site being a park with regular cleaning (higher run-off) and a different soil composition.

As previously mentioned the instrument used during the first years was based on a NaI(Tl) crystal calibrated for exposure rate. Although a conversion can be done from exposure (which is a measure of absorbed dose in the air) to H*(10), the energy dependence of the NaI(Tl) crystal may introduce a great source of uncertainty when detecting gamma radiation that is not mono-energetic. However, the change in type of instrument to GM tubes did not appear to manifest in any noticeable shifts in the times-series plots, indicating that the aforementioned effects is minor with regard to the normalised H*(10) rate data.

5 CONCLUSION

Starting with data about ½ month post fallout, tt was concluded that a bi-exponential expression describes the long-term change in the H*(10) rate above a surface contaminated by Chernobyl fallout relatively well, although the uncertainty in the half-time of the short-term component can be large. A variation of a factor of 2 was observed in the half-times and the relative proportion between the short term and long term component between four investigated sites, which were all located within the highly contaminated municipality of Gävle in Sweden.

This study indicates that the Swedish record of thousands of measurements holds a potential for studying local variation in the Chernobyl associated external exposures to residents. Since data have been collected during such long time, the data set can be used to describe the long term effects of radioactive fallout in different environments. For emergency preparedness the ability to predict the external exposure due to an NPP fallout until the radiation exposure has reached the background level means that more reliable estimates of the averted doses during a long evacuation period can be done. This study can also be useful for making a more comprehensive assessment of the total Chernobyl related dose contributions to the residents, by combining this model with data on internal exposure from Chernobyl related fission products

6 ACKNOWLEDGEMENT

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Reconstruction of the Montenegro territory contamination with ^{238}Pu using ^{238}Pu/$^{239+240}$Pu activity ratio

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Abstract. Cesium-137 and plutonium isotopes were deposited on soils in Montenegro from the global fallout, as well as from the Chernobyl release in 1986. The first systematic survey of ^{137}Cs activity concentration in Montenegro soils was carried out in the end of 1994, while the first plutonium measurements in soil samples – in 2011. Based on the last results (a standard HPGe gamma spectrometry for ^{137}Cs measurements, and alpha spectrometry for plutonium isotopes measurements), an average activity ratio $^{239+240}$Pu/^{137}Cs was found to be 0.02, ^{238}Pu/^{137}Cs – 0.0006, and ^{238}Pu/$^{239+240}$Pu – 0.03, with a standard deviation of 0.007. These ratios confirmed that today present ^{137}Cs in the soils of Montenegro dominantly originates from the Chernobyl reactor accident, while plutonium – from the global fallout (atmospheric weapons testing, high-altitude burn-up of satellite power source SNAP-9A, etc.). Using defined coefficients and previously evaluated $^{239+240}$Pu activity concentrations, a contamination of the territory of Montenegro with ^{238}Pu isotope in 1994 (47 locations) is reconstructed and presented here. The highest estimated concentration is related to the mountain Sinjajevina measuring point, at the altitude of 1702 m, where the highest ^{137}Cs activity was also found (740 Bq/kg). For two soil samples from the capital (Podgorica) direct measurements of ^{238}Pu showed activity concentrations of (0.094±0.020) and (0.049±0.014) Bq/kg, while reconstructed level of ^{238}Pu in 1994 in town and its periphery (four locations – Crne zemlje, Podhum, Pikalja, Sadine) showed values of (0.0096±0.0012), (0.0354±0.0024), (0.0624±0.0066) and (0.018±0.0024) Bq/kg, respectively.

KEYWORDS*: *plutonium; soil; Montenegro.

1 INTRODUCTION

As it is known, plutonium isotopes should be monitored in the environment, in particular because some of them (highly radiotoxic) have very long half-lives (to tens million of years, such as ^{244}Pu, with a half-life of approximately $8.1 \cdot 10^7$ yr, ^{239}Pu – 24 110 yr, ^{240}Pu – 6563 yr, ^{238}Pu – 87.7 yr [1]). A mixture of ^{239}Pu and ^{240}Pu, i.e., $^{239+240}$Pu, usually reported in environmental measurements, generally means ~60 % of ^{239}Pu in terms of activity.

Plutonium-238 and $^{239+240}$Pu present at the territory of Montenegro could originate from different fallout, such as the SNAP-9A burn-up, weapons testing global fallout, the Chernobyl release in 1986. Cs-137 (fission product with a half-life of 30.1 yr) could also be deposited on the Montenegro soils from nuclear weapons testing, as well as from the Chernobyl accident. It is important to point out that there are no pre-Chernobyl data available on plutonium and cesium concentrations in Montenegro, and there are no data available about plutonium isotopes in soils of any other ex-Yugoslav republic before the reactor accident at Chernobyl. On the other hand, a level of contamination with ^{137}Cs in the Montenegro's neighboring (and ex-Yugoslav republic) Bosnia and Herzegovina before 1986 (maximum of 30 Bq/kg, and a mean of 13 Bq/kg [2]), can be used for a comparison, since its level in Montenegro at that time may be taken as practically the same.

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Cesium-137 activity concentrations in Montenegro soils have been for the first time systematically measured eight years after the Chernobyl accident, in 1994 [3], while $^{239+240}Pu$ and ^{238}Pu activity in soil samples – in 2011 (in the Radiation and Nuclear Safety Authority STUK – Helsinki, Finland, under the contract between the STUK and Montenegrin Academy of Sciences and Arts, 2010).

A survey of relevant literature shows that the $^{238}Pu/^{239+240}Pu$ activity ratio in soils contaminated by the Chernobyl release ranges from 0.3 to 0.7, whilst typical ratio for environmental plutonium in undisturbed soils originating from the global fallout ranges from 0.015 to 0.05 (e.g. [4,5]).

Although plutonium and cesium are chemically different isotopes, their activity ratio, if consistent in various soil samples, could be used to evaluate a level of contamination with plutonium, by using known ^{137}Cs activity (the correlations between plutonium activity and activities of the other radionuclides – ^{137}Cs, $^{103,106}Ru$, etc., were previously used to estimate plutonium content in the radioactive fallout [6,7]).

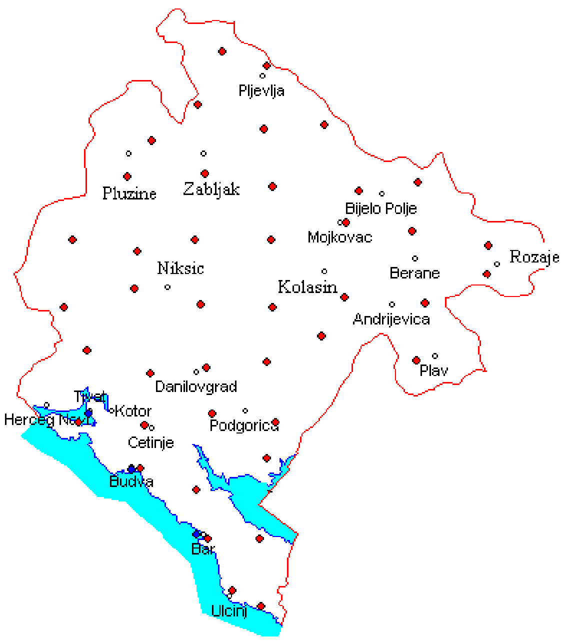
Therefore, in order to locate Montenegro points for further research, an approximate level of contamination with ^{238}Pu in 1994 is given in the present study, based on previously evaluated $^{239+240}Pu$ activity concentrations and the average $^{238}Pu/^{239+240}Pu$ activity ratio for Montenegro soils.

2 MATERIALS AND METHODS

A level of the ^{137}Cs activity in soils all over Montenegro – one of the Western Balkan countries, has been determined in 1994 (a map of measuring sites is shown in Fig. 1).

In situ measurements were performed using portable gamma spectrometer (HPGe n-type detector, beryllium window, 100 cm^3 active volume, 1.95 keV FWHM at 1332 keV), 4k-multichannel analyzer and lap-top computer. Measuring points were chosen in regard to geological and pedological characteristics, in the frame of a regular 15 km x 20 km sampling grid covering the whole Montenegro territory. Measured ^{137}Cs activity at one location in each rectangle of the grid was considered as representative for that area, and ^{137}Cs was found to be almost present only in the surface soil layer 0-6 cm [3].

Figure 1: A map of Montenegro for *in situ* measurements: ° town, ♦ measuring site



Forty-seven locations of the total considered in 1994 were selected for the present analysis (Table 1).

As abovementioned, soil samples from Montenegro were analyzed for ^{238}Pu and $^{239+240}$Pu activity in a standard alpha spectrometric procedure in the STUK a few years ago, and determined ratio of ^{238}Pu/$^{239+240}$Pu gave an opportunity to derive some conclusions about their origin. Namely, an average the ^{238}Pu/$^{239+240}$Pu activity ratio was found to be 0.03, with a standard deviation of 0.007, indicating that Pu contamination originated essentially from the global fallout [8].

The same soil samples in which Pu isotopes activity was determined, as well the others collected at 24 locations in Montenegro (taken from different depth – 0-5, 5-10 and 10-15 cm; in the frame of 25 cm x 25 cm), were measured in a standard procedure by the coaxial ORTEC HPGe spectrometer. Cesium-137 activity concentrations were in a good accordance with those measured in 1994, taking into account decay and some downward migration in the mean time [8]. It is still mostly in a surface soil layer, as well as plutonium isotopes, though the Pu isotopes mobility was previously found to be higher than that of ^{137}Cs [9].

The $^{239+240}$Pu/^{137}Cs activity ratio for Montenegro soils showed an average of 0.02 and standard deviation of 0.007, and then was applied to estimate a level of $^{239+240}$Pu activity concentration in the other soil samples from 24 locations, in which ^{137}Cs activity had been measured [8]. Since consistent, this ratio could be used in estimating the $^{239+240}$Pu level in 1994 [10]. Based on all determined ratios, ^{137}Cs present in Montenegro soils came predominantly from the Chernobyl release.

The ^{238}Pu/^{137}Cs activity ratio for Montenegro soils was also determined from alpha and gamma spectrometric measurements and found to be with an average of 0.0006 and standard deviation of 0.0003, but was not consistent over soil samples [11]. It was concluded that since these isotopes behave differently in the environment and were not deposited together, additional plutonium measurements in soils are needed to apply the ratio for an estimation of ^{238}Pu from known ^{137}Cs activity [11].

3 RESULTS AND DISCUSSION

The ^{137}Cs activity concentrations at 47 locations in 1994 are given in Table 1. The highest contamination of 740 Bq/kg was found on the north, at the mountain Sinjajevina measuring site (altitude of 1702 m). The measurements generally revealed that the ^{137}Cs contamination followed topographical map of Montenegro, increasing with altitude [3].

Later the ^{137}Cs measurements confirmed its dominant presence in surface soil layers, and activity which corresponds to the one which is expected taking into account decay in the mean time and just slight downward migration. Comparing these results with ones from Bosnia and Herzegovina before the Chernobyl accident [2], it is clear that the Montenegro soil contamination with ^{137}Cs increased significantly due to the Chernobyl release.

At the same time, determined the $^{239+240}$Pu/^{137}Cs activity ratio (0.02) enable a reconstructing territory contamination with $^{239+240}$Pu at any moment in the post-Chernobyl period. It should be noted that previous research showed that, for example, in the middle of the nineties these two chemically different isotopes from nuclear weapons tests were fixed together in the soils in the same ratio as seen over many years ago [12]. Then, $^{239+240}$Pu activity concentration for majority of here considered measuring sites (43) was evaluated [10]. Those results, as well as ones for additional 4 locations (Bratica – Ulcinj, Crne Zemlje – Podgorica, Sadine – Tolosi, Kodre – Tolosi) are given in Table 1.

Since the ^{238}Pu/^{137}Cs activity ratio previously defined on the basis of six soil samples measurements cannot be used for this purpose, the ^{238}Pu/$^{239+240}$Pu activity ratio was applied to estimate a level of

^{238}Pu in 1994 (although different mobility of these isotopes, as well as of radiocesium in various soil types was reported [13,14]). These data are also presented in Table 1, and summarized through – statistics of the measurements and estimations (Table 2), ^{137}Cs activity concentration at each measuring site (Fig. 2a), estimated $^{239+240}$Pu and ^{238}Pu activity concentrations (Figs. 2b and 2c, respectively), as well as an estimated cumulative $^{239+240}$Pu and ^{238}Pu activity concentration on the sites (Fig. 2d).

Table 1: Results of ^{137}Cs measurements and plutonium isotope activity estimations (1994).

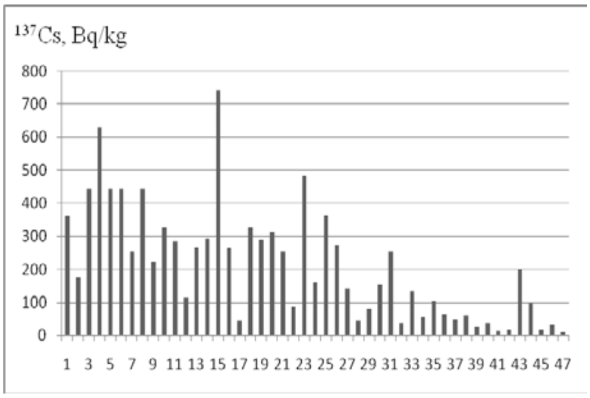
	Measuring site	^{137}Cs activity concentration, Bq/kg	Estimation of $^{239+240}$Pu activity concentration (based on ^{137}Cs), Bq/kg [10]	Estimation of a ^{238}Pu level (based on $^{239+240}$Pu), Bq/kg
1	Jakupov Grob (Boljanici)	359±37	7.18±0.74	0.2154
2	Gornja Rudica (Pljevlja)	174±19	3.48±0.38	0.1044
3	Trsa (Piva)	444±37	8.88±0.74	0.2664
4	Podkokot (Bobovo)	629±74	12.6±1.5	0.3774
5	Drljino Brdo (Kosanica)	444±37	8.88±0.74	0.2664
6	Kozicka Rijeka	444±37	8.88±0.74	0.2664
7	Seljani (Piva)	252±26	5.04±0.52	0.1512
8	Pašina Voda (Durmitor)	444±37	8.88±0.74	0.2664
9	Donja Dobrilovina (Tara river)	222±22	4.44±0.44	0.1332
10	Glibavac (Tomasevo)	326±33	6.52±0.66	0.1956
11	Mokri Lug (Bistrica)	285±30	5.70±0.60	0.1710
12	Dubocke (Banjani)	115±11	2.30±0.22	0.0690
13	Duga (Niksic)	266±26	5.32±0.52	0.1596
14	Krusevice (Savnik)	292±22	5.84±0.44	0.1752
15	Bunar Smrdan (Sinjajevina)	740±74	14.8±1.5	0.4440
16	Marica Luka (Mojkovac)	263±26	5.26±0.52	0.1578
17	Bioca (Berane)	45±4	0.90±0.08	0.0270
18	Basca (Rozaje)	326±33	6.52±0.66	0.1956
19	Vilusi	289±22	5.78±0.44	0.1734
20	Kuside (Niksic)	314±30	6.28±0.60	0.1884
21	Kuta (Niksic)	252±26	5.04±0.52	0.1512
22	Kodza (Medjurecje)	85±7	1.70±0.14	0.0510
23	Matesevo (Bare Kraljske)	481±37	9.62±0.74	0.2886
24	Sekular	159±15	3.18±0.30	0.0954
25	Kozare (Rozaje)	363±33	7.26±0.66	0.2178
26	Dragalj	270±26	5.40±0.52	0.1620
27	Cevo	141±14	2.82±0.28	0.0846
28	Zdrebaonik (Danilovgrad)	44±4	0.88±0.08	0.0264
29	Piperska Rijeka (Radunovici)	81±7	1.62±0.14	0.0486
30	Verusa	155±15	3.10±0.30	0.0930
31	Martinovici (Gusinje)	252±26	5.04±0.52	0.1512
32	Krasici (Tivat)	37±4	0.74±0.08	0.0222
33	Bajice (Cetinje)	133±11	2.66±0.22	0.0798
34	Drazevina (Kruse)	56±4	1.12±0.08	0.0336
35	Pikalja (Cijevna)	104±11	2.08±0.22	0.0624
36	Becici (Budva)	63±7	1.26±0.14	0.0378
37	Boljevici (Crmnica)	48±4	0.96±0.08	0.0288

38	Podhum (Tuzi)	59±4	1.18±0.08	0.0354
39	Celuga (Bar)	26±4	0.52±0.08	0.0156
40	Curovici (Ostros)	37±4	0.74±0.08	0.0222
41	Bratica (Ulcinj)	14±2	0.28±0.04	0.0084
42	Gornji Stoj (Ulcinj)	15±2	0.30±0.04	0.0090
43	Ilino Brdo (Pljevlja)	200±19	4.00±0.38	0.1200
44	Budimlja (Berane)	100±11	2.00±0.22	0.0600
45	Crne Zemlje (Podgorica)	16±2	0.32±0.04	0.0096
46	Sadine (Tolosi)	30±4	0.60±0.08	0.0180
47	Kodre (Tolosi)	10±1	0.20±0.02	0.0060

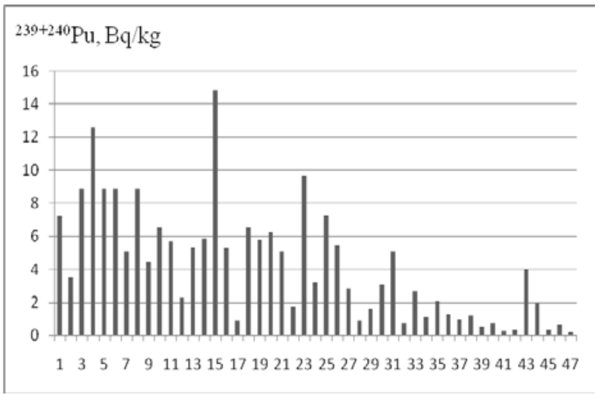
Table 2: Statistics of measurements and estimations (1994).

	Minimum	Maximum	Mean	Standard deviation	Median
^{137}Cs, Bq/kg	10	740	211	173	174
$^{239+240}$Pu, Bq/kg	0.2	14.8	4.21	3.46	3.48
^{238}Pu, Bq/kg	0.006	0.444	0.126	0.104	0.104

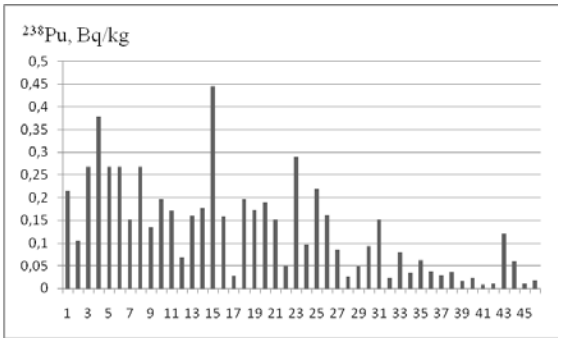
Figure 2: Radionuclide level in 1994 (47 locations in Montenegro, Table 1) – measured and estimated: ^{137}Cs (a), $^{239+240}$Pu (b), ^{238}Pu (c), a cumulative plutonium activity (d)



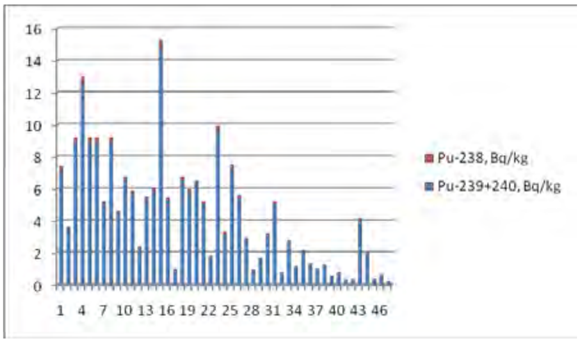
a)



b)



c)



d)

For a comparison, in soil samples from the Prague area mean ^{238}Pu activity was found to be around 0.01 Bq/kg [15]. Additionally, the cumulative deposition of ^{238}Pu at 50 sites in former Czechoslovakia in the end of 1990, ranged from 0.5 to 6.2 Bq/m^2, whilst mean value was 1.7 Bq/m^2, and no significant contribution to the cumulative deposition of ^{238}Pu originating from the Chernobyl release was found

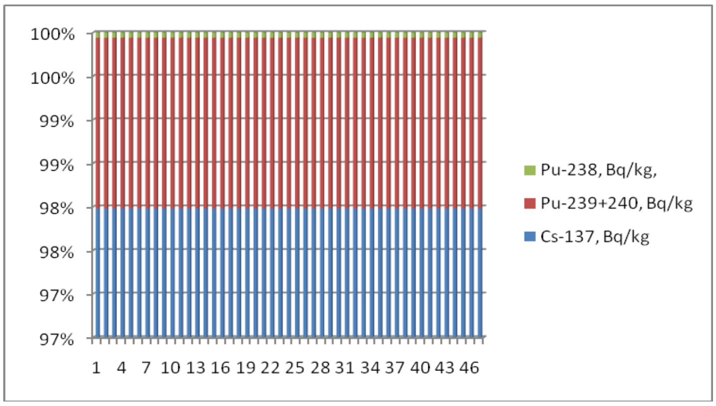
[16]. Moreover, ^{238}Pu activity in soils from Bulgaria ranged to 0.0514 Bq kg^{-1} [17], in Jordanian soils – to 0.062 Bq/kg [18], as in Italy an average in uncultivated soils was found to be 0.023 Bq/kg [9].

Since ^{137}Cs activity at the same locations was lower at the time of the Pu direct measurements (giving the abovementioned $^{238}Pu/^{239+240}Pu$ ratio), an expected activity of ^{137}Cs in 2011 was evaluated as an illustration, taking into account decay in the mean time only. A statistics of these estimations is given in Table 3, while corresponding cumulative activity is shown in Fig. 3. It is important to note that the highest ^{238}Pu activity directly measured in soil samples from Montenegro in that year was 0.094 Bq/kg, in the sample with ^{137}Cs activity of 100 Bq/kg [11], as well as $^{239+240}Pu$ of 2.61 Bq/kg in the same sample [8].

Table 3: Statistics of estimations (2011).

	Minimum	Maximum	Mean	Standard deviation	Median
^{137}Cs, Bq/kg	6.89	510	141	120	110
$^{239+240}Pu$, Bq/kg	0.14	10.2	2.82	2.41	2.19
^{238}Pu, Bq/kg	0.004	0.306	0.08	0.07	0.06

Figure 3: A cumulative activity estimated for 2011



It is important to point out that this study was conducted to estimate approximate level of ^{238}Pu in 1994, based on none direct measurement. Although the objective was to locate points for further study, some comparison with the results of later measurements of ^{238}Pu in soil samples from Montenegro [11] might be given.

For two soil samples from the capital (Podgorica), for example, direct measurements of ^{238}Pu showed activity concentrations of (0.094±0.020) and (0.049±0.014) Bq/kg [11], while an estimated 1994-level of ^{238}Pu in the town and its periphery (four locations – Crne zemlje, Podhum, Pikalja, Sadine; Table 1) showed values of (0.0096±0.0012), (0.0354±0.0024), (0.0624±0.0066) and (0.018±0.0024) Bq/kg, respectively.

Looking at Table 1, further research should be focused on several northern locations but also on central Montenegro (Niksic, Podgorica).

4 CONCLUSION

All the analysis showed that plutonium isotopes on the territory of Montenegro originate from the global fallout, while ^{137}Cs – predominantly from the Chernobyl accident.

The highest ^{238}Pu and $^{239+240}$Pu activity directly measured in soil samples from Montenegro in 2011 was – 0.094 and 2.61 Bq/kg, respectively, in the sample with ^{137}Cs activity of 100 Bq/kg. The highest ^{238}Pu and $^{239+240}$Pu activity estimated for Montenegro soils in 1994 was 0.4 and 14.8 Bq/kg, respectively, at the location with ^{137}Cs activity of 740 Bq/kg.

The results confirmed that further research is needed, including direct measurements of ^{238}Pu in soils from particular Montenegro locations.

5 ACKNOWLEDGEMENTS

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A probabilistic/stochastic model for contamination levels of Cs-137 in wild boars

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Abstract. Thirty years after the Chernobyl accident, radiocaesium contamination of wild boars (*Sus scrofa*) still exceeds 10,000 Bq/kg fw in some parts of Europe and shows an extraordinary variability. Whereas radiocaesium levels in roe deer and red deer meat are decreasing, those of wild boar remain constant on average. Recent studies identified the irregular uptake of highly contaminated deer truffles (*Elaphomyces granulatus*), a minor food item, in conjunction with the short biological half-life of Cs-137 in wild boar as the key mechanism for both the high peak values and the large variability. For Monte Carlo simulations a one-compartment model and mass-dependent biological half-lives were chosen to predict the activity levels of wild boars. The highly variable intake of Cs-137 is described by two random variables, representing the daily intake of deer truffles and their contamination levels, respectively. In addition, the varying body mass of the animals is a probabilistic model parameter. The numerical results of Monte Carlo simulations demonstrate a fairly good agreement of predicted and measured statistical parameters. The predicted expected value of the contamination levels (7,800 Bq/kg fw) agrees well with the measured value (6,200 Bq/kg fw). The estimated 95th percentile (16,300 Bq/kg fw) underestimates the measured value (21,900 Bq/kg fw) by only 25 %. The results support the validity of this rather simple model. It is essential to note that the predicted activity levels are exclusively based on parameter values taken from literature. No parameter fitting or model calibration procedure whatsoever has been executed. According to our findings, Cs-137 contamination of wild boars should always be seen in the context of the contamination levels of deer truffles and the body mass distribution of the hunted animals, the latter being primarily a result of the local hunting strategy.

KEYWORDS: Chernobyl, wild boars, radioecology, stochastic modelling

1 INTRODUCTION

Even thirty years after the Chernobyl accident, the contamination of specific fungal species and game with Cs-137 is significantly elevated in some parts of Europe. While agricultural products show very low contaminations due to the strong binding of Cs in mineral soils, the forest ecosystem provides a high availability of Cs to plants, fungi and forest animals. Extensive measurement programs [1, 2] show that radiocaesium levels of roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*) are continuously decreasing, whereas those of wild boar (*Sus scrofa*) are either remaining fairly constant or even increase [3]. Radiocaesium contamination of wild boar with Cs-137 still achieves more than 10,000 Bq/kg fresh weight (fw), while showing an extraordinary variability.

The reasons for the peculiar contamination pattern of wild boar have been investigated intensively [1, 2]. The authors conclude that the irregular uptake of highly contaminated deer truffles (*Elaphomyces granulatus*) as a 'treat' for these animals in conjunction with the short biological half-life of Cs-137 in wild boar is the dominant mechanism for the observed contamination pattern. Fielitz [1] developed a radioecological model for the prediction of the time-dependent distribution of the Cs-137 contamination in wild boar. He extended his model in order to predict the time-dependent Cs-137 contamination levels of wild boars in Germany, taking into account the spatial variation of sensitive parameters, e.g. the occurrence of deer truffles, the size and structure of forests [4]. His model reproduces the contamination levels of wild boars after 'calibrating' the transfer factor from food to meat against the measured data [1].

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The sporadic uptake of Cs-137 with deer truffles is an intrinsically stochastic process: The animals irregularly consume highly variable amounts of Cs-137 with these fungi. Fielitz [1] takes this variability in uptake into account by a probabilistic variation of the model parameters. As Barthel and Thierfeldt [5] stress, the application of such an approach to a process with intrinsic stochastic nature can be misleading.

In this article, we present a rather simple one-compartment model, including radiocaesium uptake and excretion, to predict the contamination pattern of wild boars. We model deer truffle uptake as a time-discrete stochastic process: Each daily meal of an animal is treated as an independent random event. Additionally, the variability of the body mass of the wild boars is considered as a probabilistic parameter. Data refers to a study area in the German Bavarian Forest [1].

2 METHODS

2.1 Model framework

In our model, the wild boar is represented by a homogeneously contaminated compartment with two characteristic parameters: body mass m of the animal and biological half-life T_{bio} for Cs-137. Given this, the activity *A(t)* of Cs-137 in a wild boar can be expressed as

$$\dot{A}(t) = fI(t) - (\lambda_{bio} + \lambda_{phys}) \cdot A(t), \quad (1)$$

where *A(t)* is the activity of Cs-137 in wild boar (Bq), *I(t)* is the intake rate of Cs-137 (Bq d^{-1}), f is the fraction of Cs-137 absorbed in the gastro-intestinal tract, $\lambda_{bio} = ln2/T_{bio}$ is the rate constant for the excretion of Cs-137 (d^{-1}) and $\lambda_{phys} = ln2/T_{phys}$ is the rate constant for the physical decay of Cs-137 (d^{-1}). Hence, the concentration $C(t)$ of Cs-137 in wild boars can be expressed by:

$$\dot{C}(t) = \frac{1}{m} fI(t) - \lambda \cdot C(t), \quad (2)$$

with $\lambda = \lambda_{bio} + \lambda_{phys}$ and $C(t)$ given in Bq kg^{-1} fw. The solution of this equation is:

$$C(t) = \exp(-\lambda t) \cdot \left(C(t_0) + \frac{1}{m} f \int_0^t I(s) \cdot \exp(\lambda s) ds \right) \quad (3)$$

Deer truffles are taken up irregularly. In our model, the total intake rate of Cs-137 is approximated by a stochastic term I_{tr} (tr = truffles) representing the intake of Cs-137 via deer truffles and a smooth function $I_{of}(t)$ (of = other food) representing the contribution of all other food items:

$$I(t) = I_{tr}(t) + I_{of}(t) \quad (4)$$

For simplicity we assume a time-discrete process, where wild boars take up their food once per day at points in time $t_k = k \cdot \Delta t$:

$$I = \sum_k (I_{tr,k} + I_{of,k}) \cdot \delta(t - t_k), \quad (5)$$

with $\Delta t = 1$ d. Within this approach, food uptake is modelled as discrete events leading to an intake of Cs-137 according to a specific distribution. The stochastic contribution to the daily intake can be written as:

$$I_{tr,k} = Z_{mass,tr,k} \cdot Z_{act,tr,k} \quad (6)$$

$Z_{mass,tr}$ is a random variable describing the frequency distribution of the mass of deer truffles (kg) taken up per day and $Z_{act,tr}$ is a random variable describing the frequency distribution of the activity concentration of deer truffles (Bq kg^{-1} fw). The product of these random variables defines the daily intake of Cs-137 via deer truffles. Using Eq. (3), the activity concentration $C(t_j)$ at time $t_j = j\Delta t$ can be expressed as:

$$C(t_j) = C(t_0)\, e^{-\lambda t_j} + \frac{f}{m} \sum_{k=1}^{j} \left(Z_{mass,tr,k} \cdot Z_{act,tr,k} + I_{of} \right) \cdot e^{-\lambda (t_j - t_k)} \quad (7)$$

2.2 Biological half-life

According to [6], the biological half-life of wild boars has been calculated using the following allometric relation:

$$T_{biol} = 3.5 \cdot m^{0.24}, \quad (8)$$

with T_{biol} and m given in d and g, respectively. It should be highlighted that, in our model, the mass m is a random variable and therefore the biological half-life T_{biol} differs for each animal.

2.3 Animal weight and dressing weight

Directly after shooting the animals, the hunter dresses them. In this process, organs are removed in order to prevent biological contamination of the meat and to guarantee a quick cooling process. The weight of the animal afterwards is called dressing weight and is about 30 % lower than the total weight of the animal. Usually, hunters measure exclusively dressing weight, because the dressing process is done directly in the field and the animals are weighed only afterwards. For the determination of the body mass we use the linear relationship as determined by Mattioli and Pedone [7]:

$$m_{animal} = 1.42 + 1.17 \cdot m_{dressed} \quad (9)$$

2.4 Numerical computation

To estimate the frequency distribution of the Cs-137 contamination of wild boars, the contamination of a sufficient number n of individual animals has to be calculated. After a sufficient number of days, the addend $C_0 \cdot \exp(-\lambda t_j)$ becomes negligible. The contamination of the lth animal results from a finite sum according to Eq. (7), which considers the k past daily meals of the wild boar:

$$C_l(t_j) \approx \frac{f}{m_l} \sum_{k=1}^{j} \left(Z_{mass,tr,k} \cdot Z_{act,tr,k} + I_{of} \right) \cdot e^{-\lambda(m_l)\Delta t \cdot (j-k)} \quad (10)$$

Each addend represents the contribution of one meal multiplied by a term that essentially describes the excretion of Cs-137. According to the model, the mass m_l is constant for a single animal but a random variable for the whole population. For *each animal*, m_l is sampled once from the respective discrete mass distribution (see Fig. 1). The concentration of Cs-137 in deer truffles, $Z_{act,tr,k}$, and the mass of deer truffles taken up per meal $Z_{mass,tr,k}$ are both sampled separately for *each addend* (representing *j* meals in the past for each animal). While both elements of the model, radiocaesium uptake with food and body mass, are represented by random variables, they are different in nature and should not be confused. Radiocaesium uptake is a stochastic process leading to significant variability in the contamination level of *a single animal*. Body mass m_l is a probabilistic parameter in the model and leads to dispersion of the contamination levels *within the population*. Computation has been carried out using Python 3.3.5 running on a Windows 7 PC (64 bit).

2.5 Model parameters (constant parameters and random variables)

2.5.1 Constant parameters

The presented model uses two constant parameters: f and I_{of}. The fraction of Cs-137 absorbed in the gastro-intestinal tract f is assumed to be 1. The average total quantity of food taken up per day is considered to be constant (1.8 kg d^{-1}) [1]. The daily uptake of Cs-137 due to food items other than deer truffles was estimated from their typical contaminated levels in the study area in the Bavarian Forest [1].

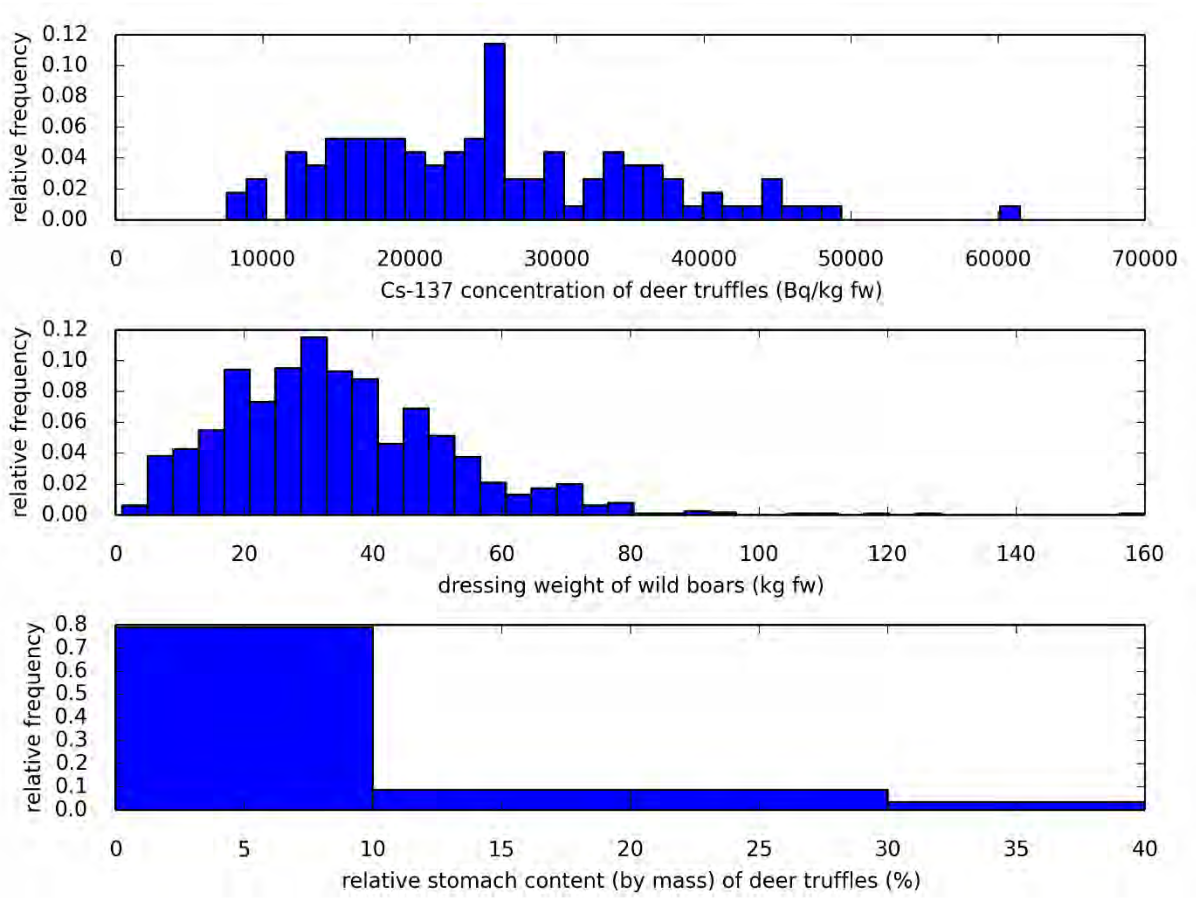
2.5.2 Random variables

In the presented model, three random variables are used: $Z_{act,tr,k}$, $Z_{mass,tr,k}$ and m_l. Values for $Z_{mass,tr,i}$ were generated according to the distribution published in [1]. Deer truffles were found in

81 % of the stomachs. The distribution of deer truffles by mass in these stomachs is given in Fig. 1 [1]. Within the bins of the histogram, equal distribution was assumed.

For m_l and $Z_{act,tr,k}$, samples were created by simple random sampling with replacement from the original sample of measurement data. For m_l the original sample size is 1,148, for $Z_{act,tr,k}$ it is 114. Fig. 1 presents the distributions of these random variables in form of histograms. Simple random sampling with replacement has been chosen as a method, because there is no sufficient a priori knowledge about the empirical distribution in order to justify a specific parametric distribution. The distribution of the contamination of wild boars was calculated for equilibrium conditions, i.e. for high values of j. For the simulations we have chosen $j = 10^5$ and $l \in \{1,2, \dots 10^4\}$. This means, that the model is simulated for 10^5 days and the size of the simulated animal population is 10^4.

Figure 1: Distributions of the three random variables used in the model. The lower plot refers to the stomachs, in which deer truffles were found (81 % of all stomachs).



3 RESULTS

In Fig. 2, the results from the simulations of the contamination pattern of wild boars according to the presented model are shown. The upper plot shows the radiocaesium levels of the wild boars against the total body mass. A strong negative (non-linear) correlation of the contamination level with the body mass, including a steep decrease at low masses, can be observed. Motivated by this observation, the distribution of the predicted contamination levels is presented separately for the group of animals with $m > 15$ kg and the group of animals with $m \leq 15$ kg (middle plot). It is clearly visible, that the contamination levels of the lighter animals are higher and more widely dispersed than the contamination levels of the heavier animals. The lower histogram plot shows the distribution of the complete sample of wild boars.

Figure 2: Simulated distribution of Cs-137 contamination levels of wild boars based on the mass distribution of the animals representative of the Bavarian Forest

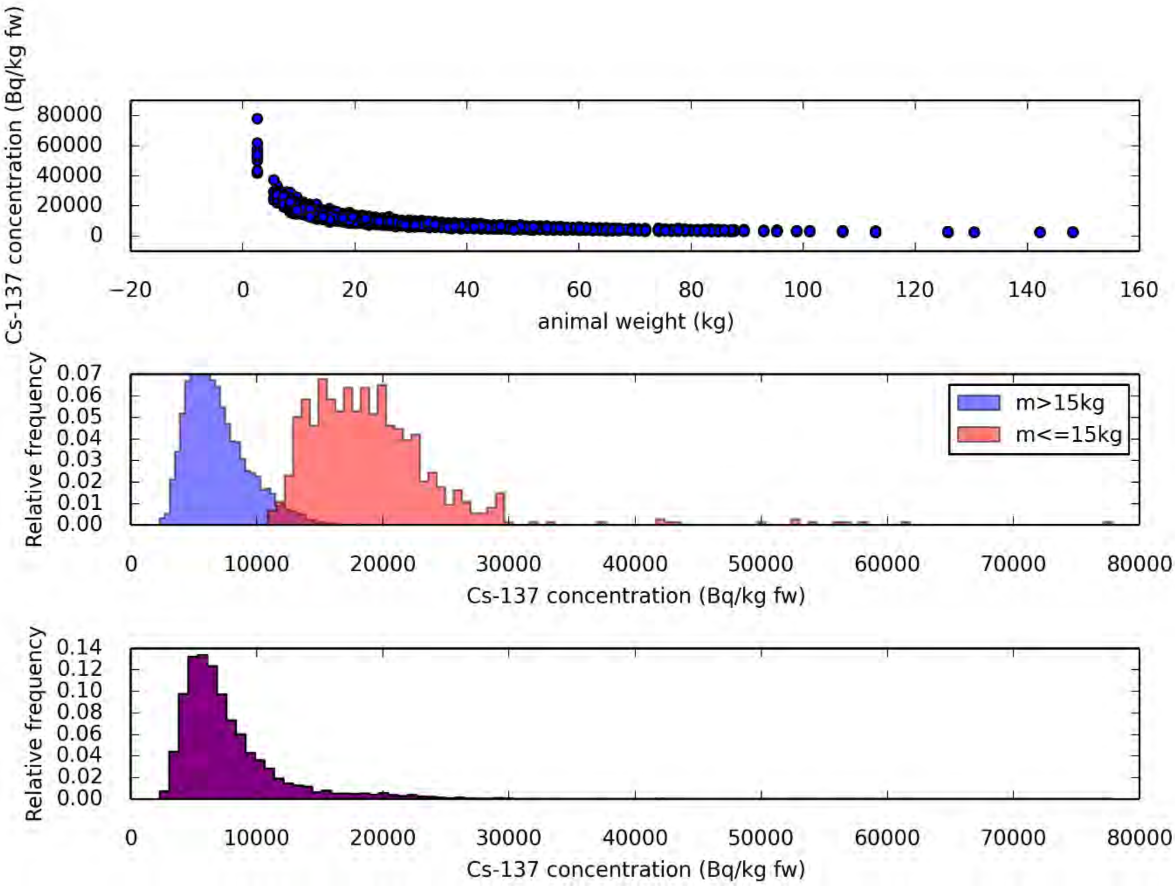


Table 1 shows the statistical properties of the same three groups and the measured contamination levels in [1]. The expected value of the simulation (all animals) is 23 % higher than the expected value of the measurements. The simulations overestimate the median by a factor of 2 and the 5th percentile by a factor of 7, respectively. The model underestimates the 95th percentile by only 25 %.

Table 1: Results of model simulations and measurements (Bq/kg fw).

	Model simulations			Measurements (a)
	All animals	$m > 15$ kg	$m \leq 15$ kg	
sample size	-	-	-	169
expected value	7,757	6,843	19,247	6,217
median	6,597	6,126	18,376	3,424
variance	18,774,346	5,808,279	39,203,623	53,821,645
coefficient of variation	0.56	0.35	0.33	1.18
5th percentile	3,801	3,747	13,039	582
95th percentile	16,294	11,545	27,702	21,886

(a) Measured values from January 2002 until beginning of October 2004

Remarkably, both the expected value as well as the median of the contamination of the animals with low body mass are about three times higher than for heavier animals. The coefficient of variation, a measure for the degree of dispersion of the simulated distributions, is approximately the same for light and heavy animals. When considering all animals, expected value and median are only slightly increased compared to the group of heavy animals. However, the degree of dispersion, as reflected by the coefficient of variation, is significantly increased compared to both sub-groups.

4 DISCUSSION

The distribution resulting from the numerical simulation coincides well with the distribution of the measured values regarding the expected value and the 95^{th} percentile. It is important to highlight that this result could be achieved *without any fitting of parameters*. All input parameters of the model were derived from measurements or from literature without using the measured data on the contamination levels of wild boars. Therefore, the results show the validity of the model.

The overestimation of median and 5^{th} percentile can be explained by a mast period that has not been taken into account. Fielitz [1] reports a food composition averaged over the period from May 2002 until August 2004. From September 2003 until February 2004, beechnuts dominated the food spectrum (beech mast event), leading to a significantly smaller intake of Cs-137. This additional spatial and temporal variability in Cs-137 intake could also explain the increased dispersion of the measured contamination values compared to modelling results. Furthermore, the investigated wild boars could have migrated from neighbouring areas, where the food spectrum and the activity levels in specific food items are different.

The results of the numerical simulations show clearly that the body mass of the animals has a major impact on the radiocaesium contamination levels. The resulting distributions of contamination levels for animals with $m > 15$ kg and $m \leq 15$ kg differ significantly. Expected values and median are by a factor of two higher for the light animals, while the relative degree of dispersion is approximately the same. The lighter individuals have negligible influence on median and expected value of the contamination levels of all animals due to their small number (only 7.4 % of the animals investigated weigh less than 15 kg) but increase the relative dispersion significantly. Since the peak contamination levels in this group exceed by far the contamination levels of the heavy animals, the 95^{th} percentile of the total population is heavily affected by the light animals.

According to the modelling results, it is expected that the highest contamination values are primarily shown by animals with very low body masses. Hohmann and Huckschlag [2], who analysed 2,385 measurements of wild boars in Rhineland-Palatinate, support this finding. They found that the average Cs-137 concentration in animals with less than 10 kg dressed weight is more than two times higher than in animals with more than 10 kg dressed weight.

5 CONCLUSION

The probabilistic/stochastic modelling approach presented here allows robust predictions of the expected value of the activity levels in wild boars from first principles, i.e. without calibrating empirical parameter against measured values. We were able to demonstrate that a rather simple model structure can be sufficient for robust predictions, provided that the key processes are properly taken into account.

From the results in this article two major conclusions can be drawn:

- The variability of the Cs-137 contamination levels of wild boars can be explained by a one-compartment model considering the stochastic consumption of deer truffles.
- The influence of body mass on contamination levels is of major importance as can be observed in the model results and field data.

The latter result can be seen as an argument in order to adapt hunting strategies in areas with high contamination levels towards heavier animals.

6 ACKNOWLEDGEMENTS

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Results of proficiency test using radioactive brown rice sample contaminated by the accident at Fukushima Daiichi Nuclear Power Plant

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Abstract. After the accident at Fukushima Daiichi Nuclear Power Plant, huge amounts of radioactive materials in atmosphere were released. Measurement of Cs-134 and Cs-137 is conducted by a lot of laboratories. Reliability of the measurement results reported from these laboratories is required. We held a proficiency test as a pilot laboratory at January 2015 to March 2015. The proficiency test was planned for laboratories which had high purity germanium detector in Japan. A protocol which prescribed procedure of the proficiency test in both pilot and participant laboratory was distributed from the pilot laboratory. Brown rice which had sufficient stability and uniformity in terms of radioactivity concentration was chosen as sample of the proficiency test. Reference values at the proficiency test were given by the pilot laboratory. The reference values were 17.8 ± 0.8 Bq kg^{-1} and 57.8 ± 2.8 Bq kg^{-1} (k=2) for Cs-134 and Cs-137, respectively. The values were blinded before disclosure of final report. The median of the report level was 58.5 Bq kg^{-1} and 17.4 Bq kg^{-1} for Cs-137 and Cs-134. The number of reports whose absolute value of the En value was bigger than 1 was 25 for Cs-134 or Cs-137. 14 for Cs-134 only, 6 for Cs-137 only, and 5 for both nuclides. We found that several laboratories made a mistake about their measurement.

KEYWORDS: Proficiency testing; Quality control; Radioactivity measurement; Uncertainty; Gamma ray spectrometry; HPGe detector; Cs-134, Cs-137.

1 INTRODUCTION

Radioactive materials were released to environment after the Fukushima daiichi Nuclear Power Plant accident which was occurred in March 2011 [1]. It has been concerned that farm products and foods may be contaminated. A limit on radioactive materials in general foods was determined as 100 Bq kg^{-1} of summation of Cs-134 (Half-life 2.064 y) and Cs-137 (Half-life 30.05 y) [2].

Many laboratories belonging with municipalities started inspection of the radioactivity of farm product immediately after the accident in 2011 [3] and the number of laboratory which receives certificate of ISO/IEC 17025:2005 is increasing in Japan. Foods whose radioactivity concentration exceeds the limit are prohibited from shipment. Gamma-ray spectrometry is applied to the inspection. For accomplishment of the inspection, sufficiently low detection limit and accurate value are required. Additionally, high throughput capacity of the measurement is desired because the number of measurement is enormous.

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The measurement which meets the requirement above is effective to get rid of uneasiness in consumers to the radioactivity and to prevent the damage of farmer by rumors. To attain this effect, it is important for measurers to carry out the measurement accurately and show the reliability objectively. The accuracy of the measurement should be checked strictly from the viewpoint of social concern. However, natural nuclide in neighboring backgrounds and samples may influence measurement accuracy. Radioactivity of Cs-134 may be underestimated by insufficient correction for the coincidence summing effect.

For self-measurement quality management, it is effective to utilize the objective results of the proficiency testing. Measurer can evaluate their skill regard to the measurement through comparison of the result of the proficiency testing. But the number of the proficiency testing seems not to be enough to make clear entire tendency now in Japan, it was important to determine SI treceable reference value of samples based on the national standard.

Before the present proficiency testing, we carried out proficiency testing for several times, and the number of participant was increasing smoothly every time. In this study, we report the latest result of which the number of participant is the maximum in the past.

2 METHOD OF THE PROFICIENCY TESTING

2.1 Preparation of the samples

Homogeneity and stability of samples used in proficiency testing are important to minimize the difference of the sample between participants. In this proficiency testing, we selected unpolished brown rice which was harvested in Fukushima in 2011 for the sample. Rice is a staple kind of food for Japanese and has a maximum amount of consumption. Domestic amount of production and domestic self- sufficiency ratio are the most in the other grains including wheat and the soybean in Japan. There are many knowledges and results to save it stable for a long term. The brown rice grain has relatively small size, so a cavity in a container for measurement becomes small. Because of the granular sample, fear of scattering and deviation of the filling density is small, so the handling by the participant is easy.

The brown rice we used for sample had been filled in 30 kg bag and saved in 15 degree Celsius environment after harvest. We collected samples from the upper and the lower part side of the bag, filled 2L Marinelli beaker with them. We measured the Marinelli samples as representative value of each bag. We chose a bag whose representative values were close to the limit on radioactive materials in general foods, 100 Bq kg^{-1}.

We homogenized the brown rice in the bag. Specifically, we placed 2 sheets on the floor and spread the brown rice on one sheet. We collected grains for one cup of scoop from the pile of brown rice and put the grains on the other sheet. We mixed the grains on the sheet. We repeated this work for all brown rice grains. We fractionated and packed it in the aluminum pouch of 100 g. We send the pouch to the participant of the proficiency testing.

As for brown rice, nevertheless mass ratio of albumen and bran layer are 9:1, it was revealed that a lot of radioactive cesium distribute in the rice bran layer and the ratio is 4:6 for albumen and bran layer [4]. The damage of the rice bran layer of the brown rice grain leads to a loss of the homogeneity of the sample. So we carried out the homogenization work calmly.

It was revealed that moisture content of brown rice grain is kept stably in 15% if they are stored in 70% of relative humidity [5]. We recommend a method [6] to keep the samples with aqueous sodium chloride solution to the participant of the proficiency testing to prevent for damage of the rice bran layer and keep the ratio of the sample weight and radioactivity fixed.

2.2 Determination of the reference values

We selected 22 aluminum pouch which was filled by brown rice at random and filled 81 g of the brown rice. The samples were 48 mm in height, 0.94 g of density cm^{-3} in U-8 containers which were made by polypropylene and 100 cm^3 in nominal volume. We measured them 2 times by an HPGe detector (ORTEC, GEM130108) and pulse height analyzer (MCA-7, SEIKO EG&G) for signal processing. From pulse height distribution, we obtained counting rates of Cs-134 and Cs-137 full energy peak at 796 keV and 662 keV by the Covell method. We calculated radioactivities from the counting rates by devision by counting efficiencies and emission rates of gamma ray and multiplication of coefficient to correct the difference between self-absorption and geometry condition. Radioactivity concentration was obtained by and deviding it by weight.

When we determined the reference values, we referred for ISO Guide 35:2006 to evaluate the uncertainty that include the difference between the sample and an evaluation of the stability. The measurement devices were calibrated by SI traceable standard radiation source [7]. We calculated the self-absorption [8] which varied with density and material of the sample by the Monte Carlo simulation method using the EGS5 code [9].

At the former preliminary prificiency testing we determined the reference value by the same way. At that time, we requested 2 calibration institutions to measure the samples, and compare the results. The results agreed each other within the uncertainty.

2.3 Preparation of the protocol

We specified a measuring procedure and required participants to follow the protocol. All participants used HPGe detectors. The reference values were blinded to the participants until the report published. The proficiency testing was held from January to March in 2015. We totalled the reports of participants and calculated the *E*n values. In a final report from us, the participants were labelled anonymously.

2.3.1 Measurement procedure and report of the radioactivity

Participants filled containers with the brown rice after they received the aluminum pouch bag from us and measured radioactivity concentration of the sample with their own measured height and weight of the sample. The samples should be kept in a wet state by the method mentioned above. Participants obtained counting rates by an HPGe detector and a pulse height analyzer using commercially available softwares to calculate radioactivity. Most of these softwares follow the domestic official method how to estimate counting efficiencies, collection factors, and counts of the peak [10]. The maesurement time was same with their usual measurement. Participants reported radioactivity concentration (Bq kg^{-1}) of the sample.

2.3.2 The method to calculate the uncertainty

We required the participants to follow the GUM (Guide to the Expression of Uncertainty in Measurement) [11] to evaluate the uncertainty. In fact, most of participants were unfamiliar with evaluation of uncertainty. However, causes of uncertainty are common among participants as for gamma ray spectrometry. We showed participants how to estimate dominant 5 cases of uncertainties before the proficiency testing.

We required the participants to calculate uncertainties about statistics using counts at calibration and at the sample measurement. The uncertainty about calibration should correspond to the values written on the calibration certification. Uncertainty about correction factors should be evaluated from difference of the correction factor related to height and density of the sample. We showed participants how to calcurate uncertainties about these causes mentioned above with assumption to rectangular distribution and gaussian distribtion. Some participants considered the uncertainties about another cause originally and reported it as a part of combined uncertainty.

2.3.3 Supplemental measurement information from participants

We required participants to report their measurement condition such as the sample density and correction factors. We verified 1) whether participants use accurate correction factors and counting efficiencies from the information of the device which was used, and 2) whether deviations from the reference value were reasonable in consideration with measurement times and supplied sample quantities.

3 RESULTS

3.1 Evaluation of the reference value

The reference values were obtained as 17.8 ± 0.8 Bq kg^{-1} and 57.8 ± 2.8 Bq kg^{-1} (k=2) for Cs-134 and Cs-137, respectively. Figure 1 shows concentration of the samples which were selected random. Table 1 shows causes of uncertainty. Causes of uncertainty were uncertainty about calibration, statistics, height of samples. These uncertainties were reasonably achievable minimum values at present..

Figure 1: Radioactivity concentration of the samples for determination of the reference value

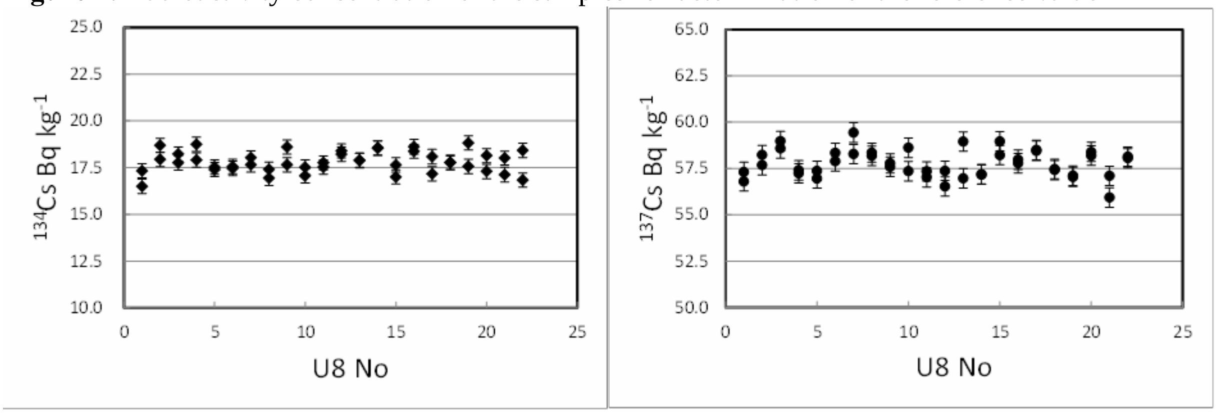


Table 1: Causes of uncertainty budget for the reference value

Items of uncertainty		^{134}Cs Relative standard uncertainty	^{137}Cs Relative standard uncertainty
measurement (u_{char})	Net counts	0.33 %	0.14 %
	Count per second of back ground	0.12 %	0.03 %
	Count per second of peek	1.56 %	1.81 %
	Stability of device	0.76 %	0.37 %
	Collection of radioactive decay	0.0014 %	0.00036 %
	Measurement time	0.10 %	0.10 %
	Height of the samples	1.29 %	1.50 %
	Density of the samples	0.52 %	0.14 %
homogeneity of samples(u_{hom})		0.53 %	0.24 %
Combined standard uncertainty		2.32 %	2.40 %
expanded uncertainty (k=2)		4.6 %	4.8 %

3.2 Analyzation of reports from participants

145 laboratories reported 176 measurement results with their uncertainties, but some of them reported no itemized uncertainties. The medians of the report values were 17.4 Bq kg^{-1} and 58.5 Bq kg^{-1} for Cs-134 and Cs-137, and Normalized Inter Quartile Range (NIQR) were 3.9% and 6.3%, respectively. The medians of the reported values agreed with the reference values in the range of uncertainties, and it was confirmed that there was no bias between the reference and the reported values. Figure 2 shows reported values of concentration of Cs-134, and fig. 3 shows reported values of concentration of Cs-137. The institutes whose reported values were different from the reference level more than 10% were 20.45% for Cs-134, 5.11% for Cs-137 in the whole participant laboratories. The reason why the rate about Cs-134 was bigger than Cs-137 seemed that the uncertainty about counting statistics in Cs-134 was larger than Cs-137. Figure 4 shows histogram of uncertainty of activity measurement of Cs-134, fig.5 shows that of Cs-137. The number of reports, whose absolute value of the *E*n value was bigger than 1 was 25 for Cs-134 or Cs-137, 14 for Cs-134 only, 6 for Cs-137 only, and 5 for both nuclides (Fig. 6, Fig. 7). 7 laboratories mistook evaluation of uncertainties and 3 laboratories evaluation mistook uncertainties evaluation of the mass quantity.

Figure 2: Reported values of radioactivity concentration of Cs-134. A horizontal axis shows the participation numbers.

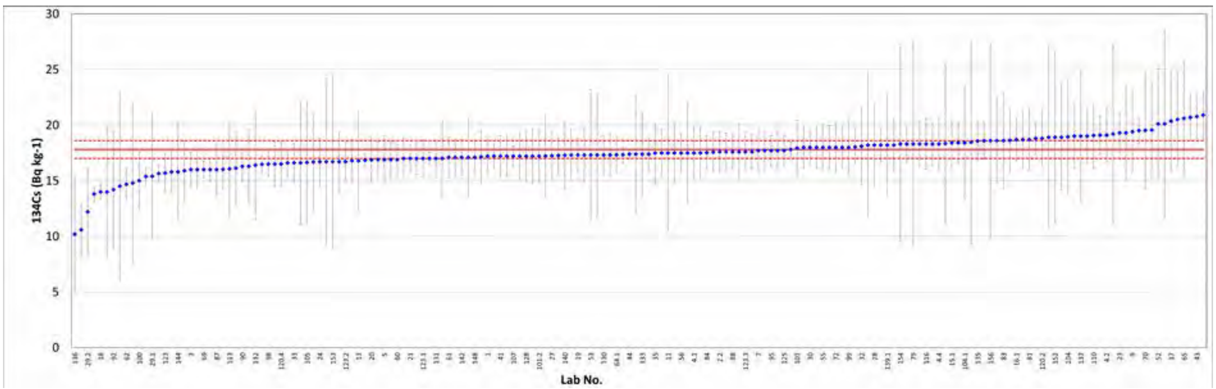


Figure 3: Reported values of radioactivity concentration of Cs-137. A horizontal axis shows the participation numbers.

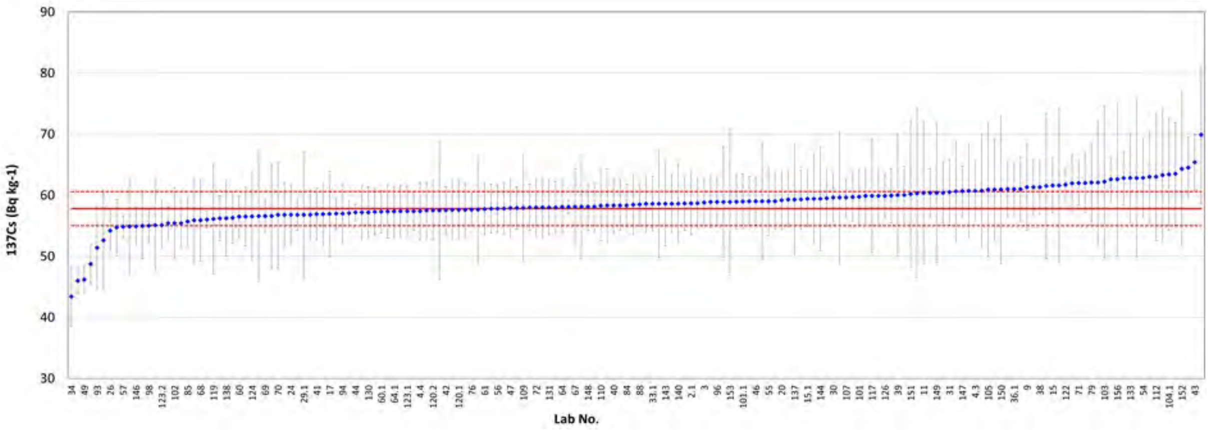


Figure 4: Histogram of uncertainty of Cs-134

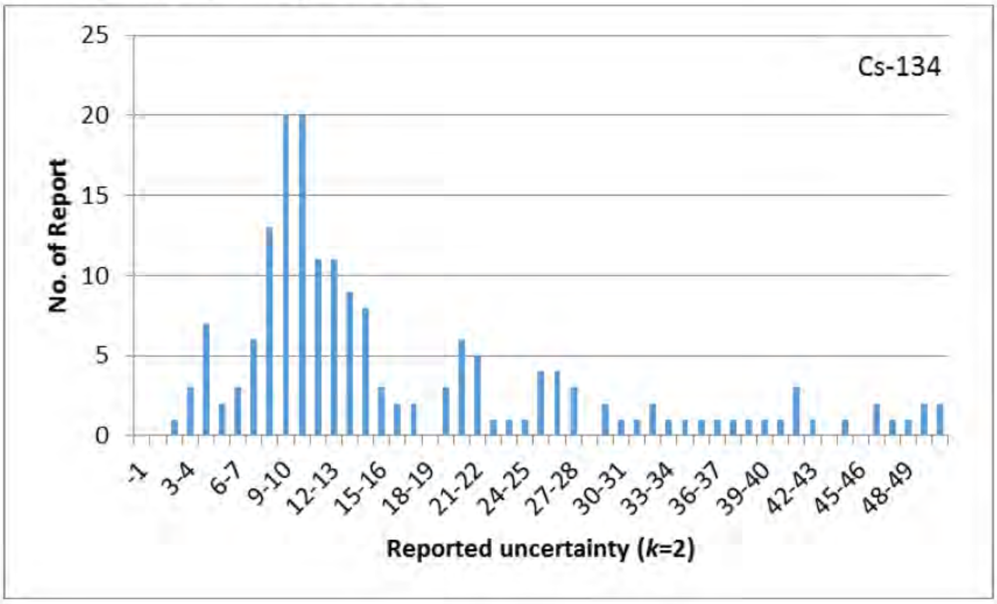


Figure 5: Histogram of uncertainty of Cs-137

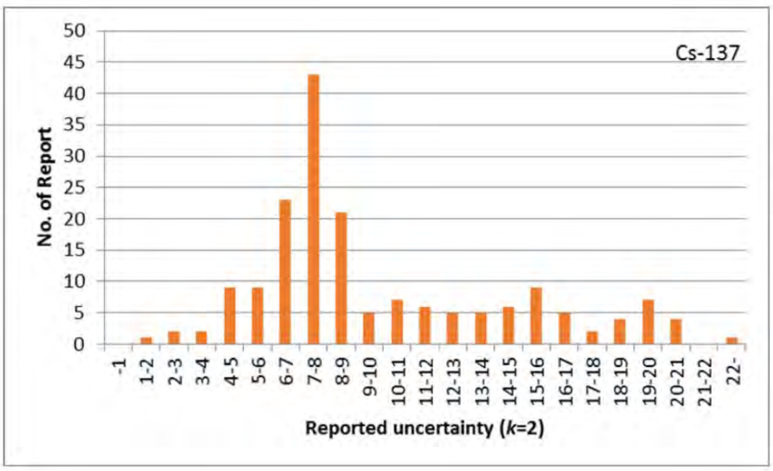


Figure 6: Calculated *E*n value distribution of Cs-134. A horizontal axis shows the participation numbers.

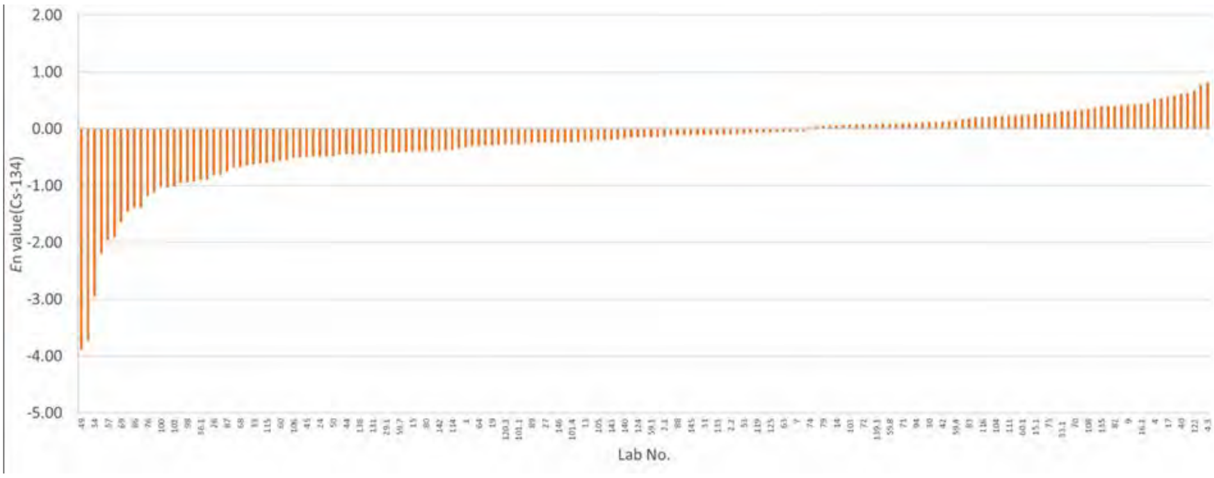
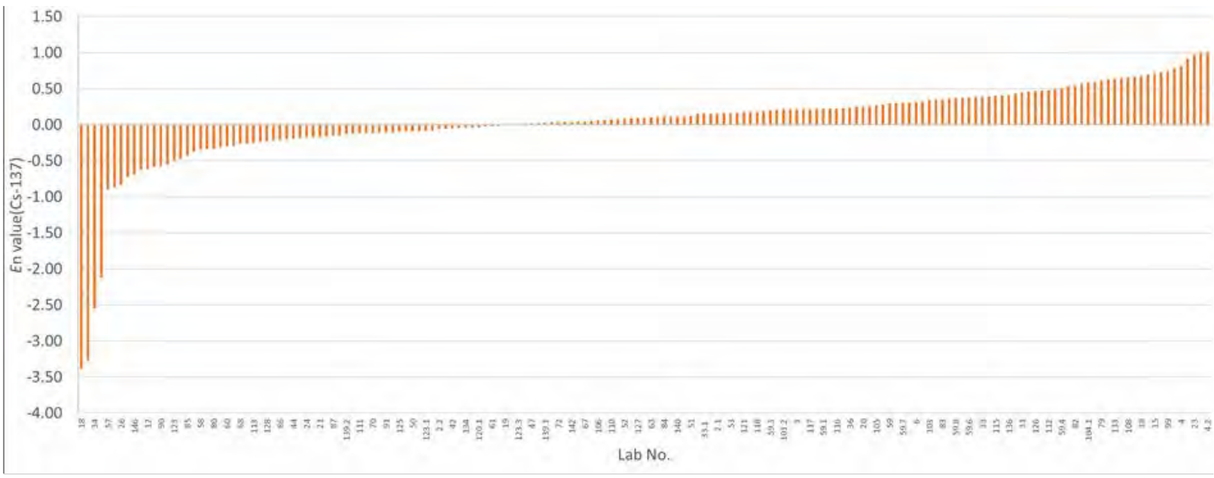


Figure 7: Calculated *E*n value distribution of Cs-137. A horizontal axis shows the participation numbers.



4 CONCLUSION

We carried out a proficiency testing of activity measurement of radioactive caesium. We prepared homogeneous and stable samples whose level of concentrations were about 100 Bq kg^{-1}. We required participants to report their measurement values and uncertainties according to the prepared protocol. We obtained 176 measurement results. The totals of the reported results were exhibited with the reference values. The *E*n values were calculated for all the participant laboratories.

5 ACKNOWLEDGEMENTS

We would like to express appreciation to the participant and co-operators of the proficiency testing.

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The non-linear effects of low dose ionizing radiation on the eye lens and the tools needed to determine.

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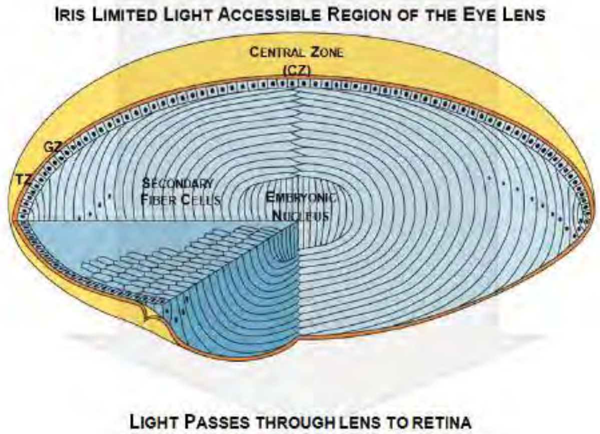
Abstract. The ICRP have recommended an occupational exposure limit of 20 mSv/year (averaged over 5 years, with no single year > 50 mSv/year) to prevent ionizing radiation (IR) induced cataracts. These new low dose limits represent a significant reduction in previously recommended occupational exposure limits of 0.5 Gy/year for IR. We have established previously that the eye lens is not only a radiosensitive tissue, but also a tissue whose IR response is cell location specific. For example, the lens epithelial cells covering the anterior pole are equivalent if not faster than circulating blood lymphocytes in repairing double strand breaks (DSBs) in their chromatin. The epithelial cells at the lens periphery were, however, much slower than both the polar epithelial cells and blood lymphocytes in their repair of DSBs. Here we describe the emergent cell behavior of peripheral lens epithelial cells that affects the "roundness of the lens". This is an example of a nonlinear biological response induced by low dose IR exposure. It is a consequence of a non-uniform increase in cell proliferation in the lens epithelium. These data support a low dose hormesis model for the murine lens epithelium. An issue for the radiobiology community is the measurement of epithelial cell density and cell proliferation rates in the lenses of IR exposed animals (eg mouse, rat, zebrafish). Here we present a rapid imaging method to measure these parameters in the mouse and zebrafish lens, which we believe will assist the community to compile the datasets required to evidence significant effects of low dose ionizing radiation on the lens epithelium. This tool will answer important questions regarding the proposed emergent cell properties caused by exposure to low dose IR.

KEYWORD: Eye Lens, Low dose Ionizing Radiation, Cell density, Cell Proliferation, LNT.

1 INTRODUCTION

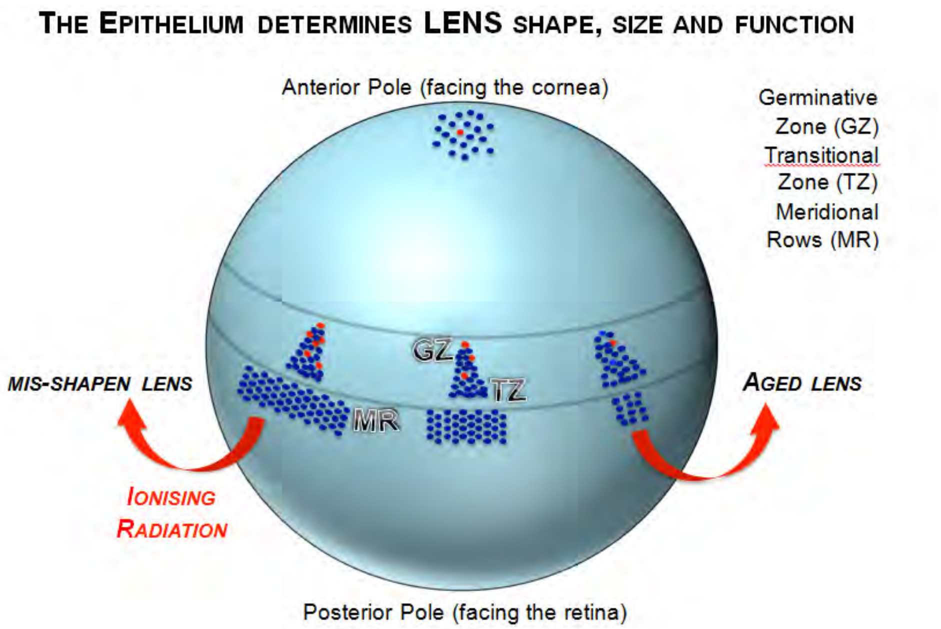
The ICRP have recommended an occupational exposure limit of 1 Gy or 20 mSv/year (averaged over 5 years with no single year exceeding 50 mSv), to prevent radiation-induced cataracts [1]. The lens epithelium is described as a simple columnar epithelium, but there is an intrinsic organisation to the lens that is established in this cell layer that not only ensures lens growth throughout life, but also that this growth is coordinated and properly organised to ensure that the lens grows symmetrically (Fig. 1).

Figure 1: The eye lens and its cellular domains.



The lens is contained within the lens capsule, a collagenous-based basement membrane, which is one of the thickest in the human body. This is continuously sculptured throughout life to allow for the linear growth of the lens as it ages. The anterior pole of the lens is covered by a single layer of epithelial cells. Although these cells produce the bulk of the lens from their progeny, cell proliferation and the differentiation of the epithelial cells into lens fibre cells is restricted to a region at the lens equator. Lens cell differentiation into lens fibre cells involves the displacement of these differentiating cells from the epithelial layer and their elongation. The direct correlation between cell proliferation. The next step is the selective destruction of all organelles including nuclei, mitochondria and endoplasmic reticulum, in other words all the biosynthetic machinery to make new proteins and to replicate DNA. The lens fibre cells are many thousands of microns in length, but hexagonal in cross section. Their eventual length depends on the size of the animal. With this underlying biology, the oldest cells and the oldest proteins in our body are to be found in the lens nucleus, which was formed in week4/5 after fertilisation. The careful orchestration, registration and integration of all lens fibre cells is essential to the function of the lens. One manifestation of the complexity of this cellular organisation are the lens sutures, formed from the inter-digitation of the opposing ends of fibre cells when they meet at the anterior and posterior poles. The lens epithelium can be subdivided into three distinct regions on the basis of cell metrics and proliferative capacity. The central zone (CZ) is the largest and it is where cell proliferation occurs at a very low basal rate. The cells in this region are in the visual axis. Cell proliferation is largely restricted to the germinative zone (GZ) and progeny from these cells are destined to become lens fibre cells by pass through the transitional zone (TZ) before exiting the lens epithelium into the body of the lens via the meridional rows. Cells in this region are post-mitotic. The GZ, TZ and meridional rows are collectively called the peripheral region of the lens.

Figure 2: Consequences of changes in the cell proliferation rate for the lens.



The number of dividing cells (red) within the germinative zone (GZ) can vary. Normally the progeny from these cell divisions proceed toward the meridional rows (MR) via the transitional zone (TZ) and as indicated the cells become aligned in columns,that are offset by one half cell width to the adjacent column. This is because at the stage the cells have adopted their hexagonal cell shape and this ensures the most efficient packing, but also the collective coordination of the growth of the lens preserving its geometry. As the lens age so the number of proliferating cells reduces and the organisation deteriorates as seen in both human and mouse [2]. This also disrupts the organisation of the MR too. In contrast, low dose ionising radiation (IR) stimulates cell proliferation [3] and now the coordinated growth of the lens becomes disrupted resulting a misshapen lens.

To study the effects of low dose IR (20-1000mGy) upon the lens and particularly the lens epithelium, we measured the number and timing of γH2AX foci in lenses. We found a dose dependency for foci formation, including 20 mGy [3]. We also established that the lens epithelial cells in the periphery were less efficient in their DNA repair as γH2AX foci persisted longer in this region than the CZ. In the CZ, γH2AX foci had all but disappeared 3h after IR exposure. Nevertheless after 24h, all γH2AX foci had disappeared. Compared to circulating blood lymphocytes from the same animal, the epithelial cells in the peripheral region are more susceptible to DNA damage by low dose (20-2000mGy) IR. Interestingly, and as an internal control, the cells in the CZ are equivalent in their DNA repair potential to circulating blood lymphocytes. Exposure of epithelial cells in the peripheral zone to 100 and 250 mGy IR produces significant changes in their proliferation and cell cycle regulation as evidenced by the increased cell density, EdU incorporation and cyclin D1 levels respectively [3]. As a consequence of the increased cell proliferation, the control of the lens geometry was disturbed manifested as changes to the aspect ratio of lenses exposed to low dose radiation [3]. There are therefore significant non-linear effects resulting from the exposure of lens epithelial cells in the peripheral region to low dose IR [3].

A consequence of the increased cell proliferation is effects upon the control of the lens geometry manifested as changes to the aspect ratio of lenses exposed to low dose radiation. It would appear that there are non-linear effects resulting from the exposure of lens epithelial cells in the peripheral region to low dose IR.

The human lens is sensitive to low dose IR as implied from a raft of epidemiological studies from A- bomb survival, medical health care workers, and reactor accidents [4-10]. At this point it is important to consider the purpose and sequence of events involved in the DNA repair process and the protein complexes involved [11-14]. Clearly the goal of these complexes is to prevent DNA damage from causing DNA rearrangements that could initiate disease or start the process of cell transformation. When double strand breaks (DSBs) occur in cells that are not actively replicating their DNA, the process of repairing these breaks is efficient and results in very few chromosomal abnormalities. This is the process of non-homologous end joining (NHEJ). A competing pathway for DSB repair is by Homologous Recombination (HR), the defining step for this pathway being strand invasion by Rad51 recombinase. Both HR and NHEJ proceed simultaneously in IR damaged cells. A key role for H2AX was discovered when IR was used to induce DSBs, which induced the specific phosphorylation of H2AX, on serine 139, to give rise to γH2AX, phosphorylated by the kinases ATM, ATR, DNA-PKcs. Chromatin compaction then occurs and the recruitment of a scaffolding protein, MDC1 assists in the building of specific protein complexes (eg Rad51) needed for the repair of these DSBs. MDC1 binding brings in the MRN (Mre11/Rad50/Nbs1) complex, which is critical for the early (<1 h response) to DSBs. Once this complex is built, then other repair proteins bind [14] and these include BRCA1 and its partner BARD1, 53BP1 (marker for NHEJ mediated repair) and Rad51 (marker for HR mediated repair). The binding of 53BP1 to DSBs is actually dependent upon other histone modifications as well as being influenced by the phosphorylation of H2AX [15]. These are demethylated histone H4, H4K20Me2, and an ubiquitinylated form of H2A: H2AK15Ub [16]. E demonstrated a linear relationship for both MRE11 and 53BP1 over the 20-1000 mGy dose range.

Previous studies required the flat mounting of mouse lenses [3, 17], which is a time consuming process requiring both in terms of the dissection and the imaging/computational processing of the data. Nevertheless, in order to be able to gather sufficient data to evidence significant changes in the proliferation rates, cell density and organization of the lens epithelium in animal models, both laboratory and in the field [18, 19], then a robust methodology and analytical standard needs to be established. Here we describe a method to preserve, fix and analyse cell proliferation and cell density in the whole lens from two important animal models, mouse and zebrafish, obviating the need for either sectioning or flat mounting.

2 MATERIALS AND METHODS

2.1 Sample Preparation

Six week old Balb C mice received a single intra-peritoneal injection of EdU (Jena Bioscience GmbH, Germany) at a dose of 90 mg kg^{-1} body weight. Animals were euthanized 3 hours post injection. All procedures strictly followed the UK Animals (Scientific Procedures) Act 1986 and had ethical approval of the UK Home Office. Whole eyes were extracted and fixed in 4% (w/v) paraformaldehyde (Sigma, Germany) overnight, then washed in PBS overnight. The lenses were isolated and separated into two cohorts. Wild-type (Golden) zebrafish were kept in the Durham zebrafish facility on a 14-h light/10-h dark cycle at 28.5°C. All the experiments were carried out in accordance with the animal ethics guidelines of the UK Animals Act 1986 and had ethical approval of the UK Home Office. Two male, 1 year 2 month old animals were exposed to single doses of ionizing radiation in an X-ray chamber irradiator (AGO Ltd, model no.: CD160/1 Serial no.: 1032–1109; copper- and aluminium-filtered). Animals were irradiated with dose of 10 or 0.25 Gy. A mock control was included. Fish were euthanized 24 h post-irradiation using ms-222 (Sigma, Germany). Eyes were collected and post-mortem lens dissections were performed. Isolated lenses were processed as described above. After washing three times with PBS 1X, samples were stored in PBS until they could be imaged.

2.2 EdU proliferation assay

Lenses were permeabilised with 0.5% (v/v) Triton X-100 for 20 minutes at room temperature and washed three times with phosphate buffer saline (PBS) 1X. The reaction cocktail was prepared as specified in the EdU-Click 594 kit (Baseclick, Jena Bioscience GmbH, Germany) with the substitution of FITC in place of the provided azide. Lenses were incubated for 30 minutes in light-safe containers at room temperature, washed three times with PBS 1X, and then counterstained with Hoechst 33342 (Sigma, Germany) 10µM for 30 minutes in light-safe containers. Lenses were stored in PBS 1X at 4ºC.

2.3 Imaging

Images were recorded using a Leica SP5 II confocal microscope equipped with HXC APO x10/0.40 NA oil (n=1.518) immersion and HXC APO x20/0.7 NA oil (n=1.518) immersion objectives. Data were collected using 100Hz/line scan speed with a 2 line average and bidirectional scanning at 355 nm (3rd harmonic NdYAG laser) with 2mW laser power. The microscope was equipped with a triple channel imaging detector comprising of two conventional PMT systems and a HyD hybrid avalanche photodiode detector. When operated in BrightRed mode, the latter is capable of improving imaging sensitivity by 25% and reduces signal to noise by a factor of 5. Frame size was determined at 1024 x 1024 pixel, with 0.6 airy disc unit determining the applied pinhole diameter rendering one voxel to be corresponding to 76 x 76 nm with a section thickness of 6µm for the data collected with the x10 objective, and 1.58µm for the data collected with the x20 objective. This LSCM is equipped with a novel structural illumination module called PhMoNa, with achievable resolution of 62 x 62 x 280 nm (Pal, R. ref). Nuclear Hoechst staining in blue: λ_{ex} = 355 nm (2mW), λ_{em} = 390-500 nm; EdU- positive staining in green: λ_{ex} = 488 nm (4mW), λ_{em} = 500-575 nm; TUNEL-positive staining in red: λ_{ex} = 543 nm(2mW), λ_{em} = 560-600 nm. These values are the same for all experiments completed using the LSCM[20].

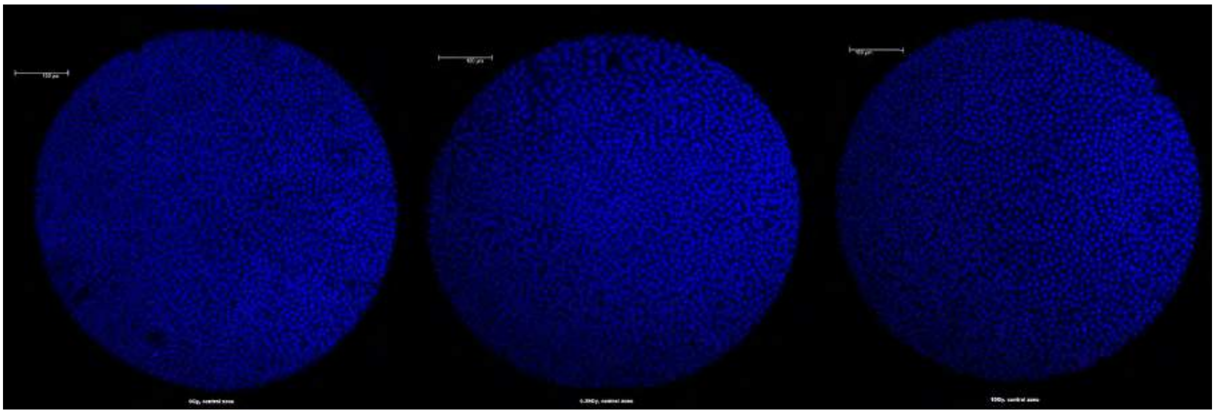
2.4 Image Reconstruction

3D reconstruction and projection has been executed using ImageJ 1.49r software with a 10% overstitching saturation elimination algorithm.

3 RESULTS AND DISCUSSION

Whole lens nuclear staining permits accurate reconstruction of the lens epithelium. Nuclear staining in isolated murine and zebrafish lenses allow for the clear imaging of the epithelium using confocal immunofluorescence microscopy; by preserving lens geometry with the use of whole samples we are able to accurately reconstruct the lens epithelium in maximum projections (Fig. 3, 4). This methodology allows the whole eye to removed from the animal either in the laboratory or in the field [18, 19] and these to be collected then for analysis in the laboratory.

Figure 3: Maximum projection of the central epithelium zone in zebrafish.



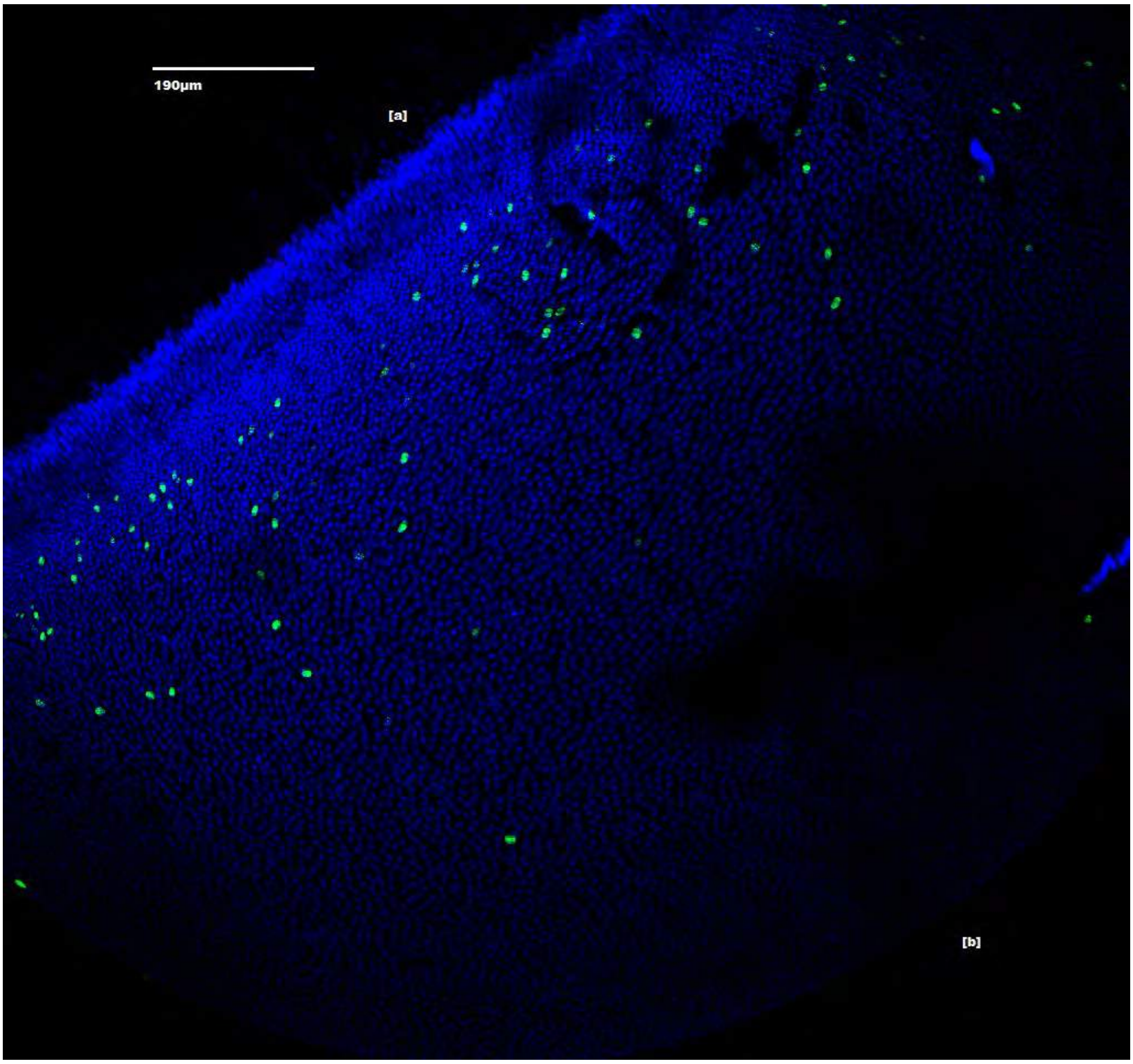
Nuclear staining of the central epithelial zone of zebrafish exposed to 0 Gy, 0.25 Gy, and 10 Gy respectively; captured at x20 magnification, these images allow both the mapping of cell populations across the epithelium and the analysis of nuclear physiology.

In the example shown (Fig. 3), Zebrafish were exposed to 0.25 and 10 Gy IR and the lenses isolated 24h later. In a previous murine study [3], cell density changes were seen after 24h. The 10Gy treated lens shows nuclear shape abnormalities and nuclear fragmentation, and the data set evidences its suitability for computer-based segmentation and data collection in order to generate a suitably powered data set for statistical significance, using for example the “Delineator” python-based algorithm to count nuclear number [2].

Proliferating cells can be visualised across the germinative zone: Murine lenses isolated from animals injected with EdU, 2 h before sacrifice were processed to detect the incorporated label by CLICK chemistry. The assay reveals clear evidence of proliferating cells in the GZ of the mouse lens (Fig.4), in accordance to previously recorded experimental data [3]. Due to the objective working distance, images including both the anterior pole and the meridional rows in the murine lens can only be produced by use of the HXC APO x10/0.4 NA objective, so one data set allows most of the lens epithelium to be captured. Notice that the position and number of the proliferating cells (Fig. 4; green channel) is variable, so that a sectioning method would likely underestimate or overestimate the ratio of proliferating cells depending on the section orientation. In this specific example the MR at the very perimeter of the lens epithelium is very clearly seen as well as the increase in nuclear density in the GZ in line with previously published lens flat mount data [3].

The peripheral region of the zebrafish lens extends more posteriorly than seen for the murine lens [21], but this method can image both the CZ and MR simultaneously (Fig. 4). The MR are clearly visible, as too is changing profile in cell density across the lens epithelium. This method therefore has application to a wide range of small vertebrate lenses where either experimental or environmental [18] exposure to IR is to be studied.

Figure 4: Maximum projection of the murine lens epithelium; lateral plane. Whole lens nuclear staining, in addition to EdU detection performed on a Balb C mouse. **[a]** The MR can be clearly identified, with distinct cellular organisation. Instances of proliferating cells, represented in green, have been recorded across the GZ. **[b]** The anterior pole, included in a portion of the CZ.



A model is based upon linear differential equations and requiring only three dimensionless parameters has been developed for mammalian lenses [2]. Due to the dimensionless parameters that are measured, the model can be applied to lenses independent of their size. The model was used to successfully predict age-related changes in the cell density of both mouse and human lenses. We suggest that it will also be appropriate to analyse the effects of low dose IR upon the lens epithelium.

4 ACKNOWLEDGEMENTS

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Shielding design for reducing secondary neutron doses to paediatric patients during intracranial proton therapy: Monte Carlo simulation of the neutron energy spectrum and its organ doses

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Abstract. Proton therapy has the physical advantage of a Bragg peak, which provides a better dose distribution than conventional X-ray therapy. The radiation exposure to normal tissues cannot be ignored because it likely increases the risk of secondary cancer. The interaction of a proton beam with the structure of the treatment beamline generates secondary neutrons. This study aimed to reduce secondary neutron doses by improving the shielding materials used in proton therapy devices. In this study, the organ dose and energy spectrum were calculated for secondary neutrons using Monte Carlo simulations. The Monte Carlo code known as the particle and heavy ion transport code system (PHITS) was used to simulate proton transport and its interaction with the structure of the treatment beamline and to model the double-scattering system of the treatment nozzle. The doses were calculated for organs in a hybrid computational phantom and simulated for a 5-year-old boy. The neutron equivalent dose was also calculated for each organ by multiplying the neutron-absorbed dose by the radiation weighting factor (WR), thereby quantifying the optimisation of the shielding structure. The secondary neutron WR was calculated from the incident neutron energy spectrum entering the phantom. The WRs with and without a polyethylene shielding structure were 11.3 and 6.68, respectively. The secondary neutron equivalent dose was reduced by as much as 89.7% in the breast region. In general, materials with a high-atomic number efficiently reduce the fluence of neutrons with energies of approximately 100 MeV but are less effective for neutrons with energies of approximately 1 MeV; polyethylene efficiently reduces the fluence of both these neutron energies. This study suggests that a polyethylene-based shielding structure is most effective in reducing the neutron equivalent dose.

KEYWORDS; proton-therapy; neutron doses; Monte-Carlo simulation.

1 INTRODUCTION

Children are more sensitive than adults to radiation-induced cancer incidence and have smaller bodies in which the radiation scattered from a treatment volume is more significant [1]. A proton beam is physically characterised as a Bragg peak and exhibits small lateral dispersion in biological tissues [2, 3, 4]. Therefore, proton therapy achieves a better dose distribution than conventional X-ray therapy [5.6.7]. Since the Bragg peak for protons of a mono energy is very sharp, beams of multiple energies have to be superimposed to generate a spread-out Bragg peak (SOBP) that covers the whole tumour. A SOBP can be generated in two ways namely passive modulation and active modulation.

In proton therapy, a patient receives secondary neutron radiation generated by the nuclear reaction of the primary proton beam with structures in the beamline [8.9.10]. The effects of neutron exposure on normal tissues cannot be ignored because neutrons contribute to the development of secondary cancer [1]. The optimisation of radiation protection requires that the magnitude of an individual dose is kept as low as reasonably achievable. Recent studies have indicated that the risk of secondary cancer incidences owing to neutrons is the highest for the lungs, thyroid and breasts, and the risk of secondary cancer mortality is highest for cancers in the lungs and breasts [10].

Previous study reveal the influence of shield structure on neutron effective dose reduction for prostate cancer patients [11]. A few study reveal the influence of shield structure on neutron dose reduction for pediatric intracranial cancer patients. The form and material of the shield require optimisation to reduce secondary neutron exposure and the related risk of secondary cancer. These improvements are particularly important for expanding paediatric radiation therapy because the cancer risk is higher for children than adults [12].

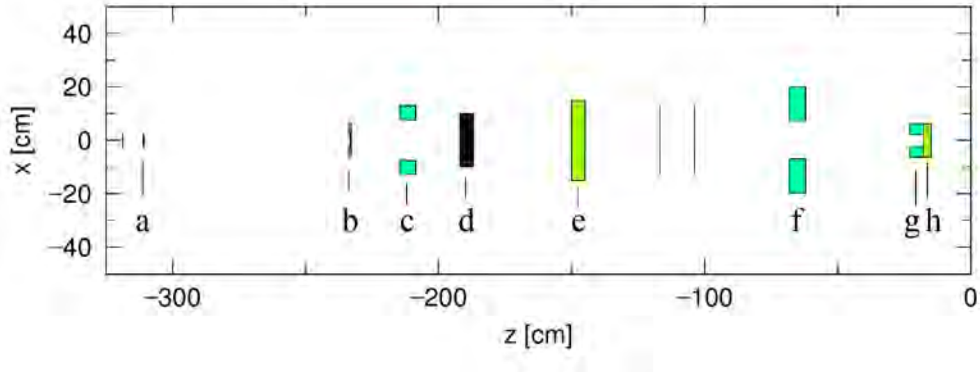
The purpose of this study was to model a shielding design that reduced the secondary neutron dose to paediatric patients treated using a proton therapy device. Shielding was modelled using a Monte Carlo simulation code, namely the particle and heavy ion transport code system (PHITS) Version 2.7.6 [13]. This study used hybrid computational phantoms that were developed through a collaboration between the University of Florida (UF) and the US National Cancer Institute (US-NCI) [14.15]. The energy spectrum was calculated for the secondary neutrons received by the patient. For each organ, the absorbed and equivalent doses from secondary neutrons were calculated in non-targeted regions located outside the clinical target volume. In a previous study, we characterised the secondary neutron energy spectra for incident neutrons with three energy peaks: 1×10^{-7}, 1 and 100 MeV. Block (BC) and patient-specific collimators (PC) significantly contributed to organ doses (Matsumoto *et al.* 2015). This study examined a more effective way to improve secondary neutron shielding in paediatric proton therapy.

2 METHODS AND MATERIALS

2.1 Beamline at NCCHE

The configuration of the beamline in port 2 of the National Cancer Center Hospital East (NCCHE) in Japan is shown in Fig. 1. Three beam-limiting devices exist upstream of the patient: a preparing collimator (RC), BC and PC. The RC, comprising 50-mm-thick brass with a 150-mm diameter, was located just before the ridge filter (RF) to prevent the leakage of primary and secondary particles and consequently the activation of the RF. The BC comprised two pairs of one-dimensional, 50-mm-thick brass collimators. The PC comprised 5-cm-thick brass and was also used as a final collimator. These three collimators were moved together along the beam axis to make the lateral penumbra smaller by approaching the patient. To obtain a uniform depth-dose distribution within the spread-out Bragg peak (SOBP), a RF comprising aluminium was used. A range shifter, comprising ten Polymethyl methacrylate plates of various thicknesses and a bolus made of polyethylene, was used to compare the dosage delivered to the distal end of the SOBP to that delivered at the target volume. The beamline was equipped with three identical parallel-plate ionization chambers that acted as both primary and secondary beam monitors.

Figure 1: The simplified nozzle is modelled in PHITS. The components are as follows: (a) first scatter, (b) second scatter, (c) RC, (d) RF, (e) fine degrader, (f) BC, (g) patient bolus and (h) PC. The other features are dose monitors.



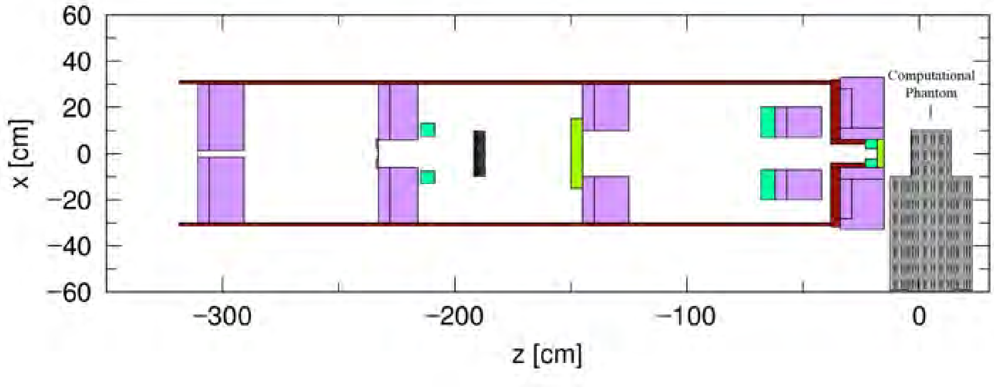
2.2 Treatment parameters

This study focussed on the proton therapy treatment of a child patient suffering from an ependymoma of the cerebellum. The standard ependymoma treatment plan delivers a total Relative Biological Effectiveness (RBE)-weighted dose of 49 Gy, where the RBE of a proton to the tumour is 1.1. The dose calculation was performed under the conditions of a 189-MeV proton beam, a 9-cm SOBP and opposing portal irradiation. All these elements were modelled based on manufacturers' and engineering drawings.

2.3 Shielding construction

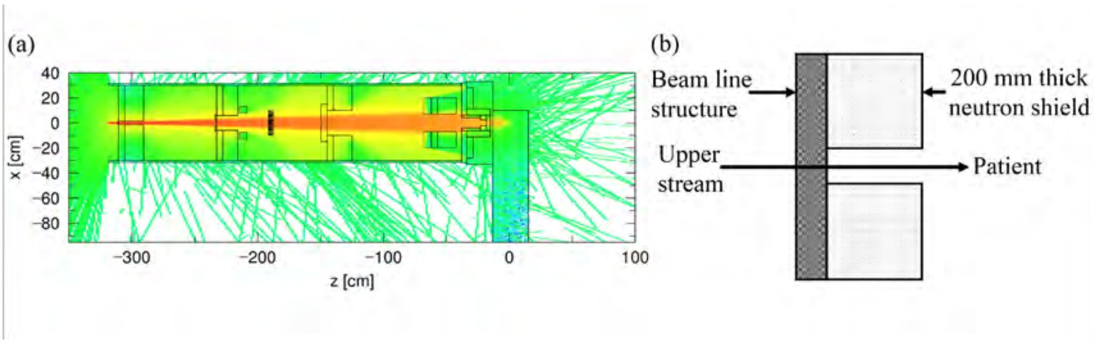
The shielding structure was placed downstream of the beamline because secondary neutrons are generated by the nuclear reaction of the primary proton beam with structures in the beamline. The shielding structures were located internally because all components of the beamline are sources of secondary neutrons and require shielding. Moreover, the installation location has space restrictions. The modelled shielding structures were 20-cm-thick and did not make contact with the other beamline components (Fig. 2).

Figure 2: Regions indicated in purple show secondary neutron shielding structures.



The shielding structures were perforated so as not to affect the characteristics of the primary proton beam (Fig. 3a,b).

Figure 3: (a) the whole image of the primary proton beamline modelled in PHITS and (b) the perforated shielding structures modelled for each beam modulators.



The diameter of the proton beam varied with the location of the shielding structure. The aperture diameter was selected on the basis of the beam diameter at a given installation position. The diameters at the first and second scattering and fine beam degrader were 5, 15 and 26 cm, respectively. The BC and PC had rectangular apertures (20 cm × 20 cm and 5 cm × 5 cm, respectively). The energy spectra were calculated for various materials (e.g. iron, lead, tungsten and polyethylene) to determine the optimal materials for shielding.

The Monte Carlo code known as the PHITS was used to simulate the proton transport and calculate secondary neutron doses and spectra.

Secondary neutron energy spectra and organ doses were calculated to assess the effectiveness of each shielding structure.

Monte Carlo calculations of the secondary neutron dose to organs used realistic computational phantoms that represented treated patients, namely 5–10-year-old children, who comprise the age peak in the incidence of intracranial tumours. Therefore, a 5-year-old phantom (UFH5M) was selected from the series of 12 hybrid phantoms that were developed at the UF and US-NCI. These phantoms had the same anatomical and chemical composition of the body as reference individuals reported by International Commission on Radiological Protection (ICRP) Publication 89 [16]. The UFH5M was converted to PHITS through voxel format fitting.

The neutron equivalent dose (H_T) was also calculated for each organ by multiplying the neutron-absorbed dose by the W_R. This W_R was determined according to the incident neutron spectra for the phantom using a continuous function in neutron energy [17]. The dose deposition derived from neutron was weighted by neutron radiation weighting factor, which was calculated from the energy of the neutron.

The radiation weighting factor values are energy dependent (ICRP 2007), therefore a mean radiation weighting factor value was determined for whole body using the calculated neutron energy spectra incident upon phantom (from the simulated neutron fluence) and the energy-dependent function $W_R(E)$ defined in ICRP Publication 103.

3 RESULTS

3.1 Secondary neutron energy spectra for different materials

Polyethylene reduces the fluence of neutrons in approximately 1 MeV and is an appropriate candidate for neutron shielding. The polyethylene shield was able to effectively reduce neutrons with energies of approximately 1 MeV, which have a larger impact on human health. Therefore, polyethylene is the preferred material for protecting patients from secondary neutrons.

3.2 Secondary neutron doses

3.2.1 Secondary neutron-absorbed dose

The absorbed organ doses from secondary neutrons were calculated with and without the shielding structures. A neutron absorbed organ dose decrease approximately 20% in all shielding materials.

3.2.2 Secondary neutron equivalent dose

The secondary neutron equivalent dose was calculated as the neutron-absorbed dose multiplied by the W_R for the incident neutron energy spectrum entering the phantom. The polyethylene shield more effectively reduced the neutron equivalent dose compared with other shielding materials, owing to its lower W_R.

Polyethylene-based shielding structures decreased the neutron equivalent doses can be reduced by approximately 50%. The results of this calculation suggest that polyethylene-based shielding structures may be the most effective in reducing the neutron equivalent dose during intracranial proton therapy.

4 DISCUSSION

In this study, we sought a more effective way to design a shielding from secondary neutrons in paediatric proton therapy. The thickness was restricted for shielding structures that were built in proton therapy units, thereby reducing the efficiency of neutron absorption. Calculations indicated that effective radiation protection was achieved by reducing the fluence of neutrons with energies of approximately 1 MeV. Therefore, neutron equivalent doses can be reduced by decreasing the W_R. This study showed that the W_R for polyethylene shielding was the lowest of all materials examined; the equivalent dose decreased by 89%.

The neutron W_R have a large uncertainties owing to the insufficient neutron RBE data (Dennis 1987, Kellerer 2000, Brenner and Hall 2008). However the neutron W_R is kind of associated with the risk of developing secondary cancer. Therefore neutron equivalent doses were calculated in this study. Gamma doses from neutron shield in therapeutic Gy was estimated about the negative effect of neutron shield. Results of calculation the gamma doses are low level compared to neutron doses. These observations suggest that improved shielding materials can decrease the risk of developing radiation-related secondary cancer in pediatric proton therapy.

5 CONCLUSIONS

This study proposes a new shielding design for reducing secondary neutron doses to pediatric patients during intracranial proton therapy. Secondary neutrons can cause radiation-related cancer. Few previous studies have been conducted to develop methods of reducing the number of secondary neutrons. The present study describes the use of improved shielding materials in the beamline to reduce the fluence of secondary neutrons.

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A Study on UF_6 Transportation Accident Scenarios and Diffusion Model

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Abstract. This paper discussed UF_6 leak scenarios in transportation accidents, it's different from UF_6 release accident occur in nuclear fuel cycle facilities. On transport condition, physical changes and direct chemical reaction with vapor will happen after UF_6 release, and then diffusion. Combined with physical properties, chemical properties and straight-line Gaussian plume models, this paper established a new diffusion model for UF_6. Based on the data of three UF_6 release experiments carried by the French Bordeaux National Experimental Base and calculation data of HGSYSTEM/UF_6 model, the new model was tested preliminary. The result shows that, this model can describe the diffusion of UF_6 in environment accurately, and apply to UF_6 transport accident assessment.

***KEYWORDS:** UF_6; scenarios; diffusion model; tests; appliance.*

1 INTRODUCTION

UF_6 is an important product during the process of nuclear fuel cycle, and also has acute chemical effects. In the UF_6 release accidents occur in Uranium transform or enrich facilities from 1944 to 1987, the main reason is valve damage, cylinder rupture and operating mistake. But in transportation, UF_6 releases also associated chemical, radiological and environmental impacts directly without any protection. That's why the UF_6 release accident in transportation is more serious than in facilities. This paper analyzed the UF_6 transportation accident scenarios and created a diffusion model, and a help for UF_6 accident assessment and environment protection is expected.

1.1 Accident Scenarios

In the process of UF_6 transportation, some accident scenarios maybe result in leakage of UF_6, which include cylinder rupture or valve failure caused by acute crash, fire or terrorist attack. According to release source term, accident scenarios and severity level, the release accidents could be divided into solid phase spatter and gas or liquid phase release, and gas or liquid phase release is obviously more serious and more complex.

Solid phase spatter is simple. After crash accident occur, then solid UF_6 spatter accompanied by the weak weld failing. The velocity of sublimation is about 23.6g/(s·m^2), so as long as manage in time, this kind of accident could not bring about serious consequence. Ordinarily, gas or liquid phase release will occurred after crash and a long time fire. Heat was transported into the container and the gas or liquid was formed, which caused the pressure higher, and then caused valve failed, cylinder rupture or even explosion. Liquid UF_6 will flash to gas, and the gas reacts with vapor.

The physical and chemical changes of liquid UF_6 was showed in Figure 1.

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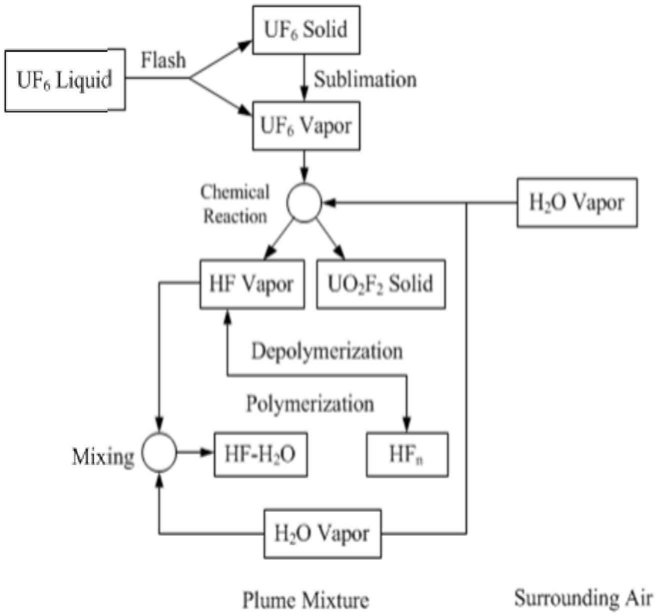
Figure 1: The physical and chemical changes of liquid UF_6



2 CREATE DIFFUSION MODEL

Since several decades ago, researchers have studied the consequence of UF_6 release accidents. Before 1977, Gaussian model was used generally, and then PLM89A, HGSYSTEM, RTM-96, SAIC, etc. Now, HGSYSTEM/UF_6 model and RASCAL4 model are more advanced. This paper established a model based on UF_6 control volume from RASCAL4, physical and chemical properties of UF_6 and Gaussian diffusion model, especially used a Box model to describe early dense gas characters and contact the hydrolysis reaction with Gaussian diffusion.

2.1 UF_6 Control Volume Model

The UF6 release rate and density define an initial UF6 control volume. The initial cross-section of the UF6 control volume is square with the cross-sectional are given by:

$$A_{UF6} = \frac{Q'_{UF6}}{\rho_{UF6} u^2}$$

Defined the control volume at the first second is the initial volume, and the BOX Model was pulled into this model, which is often used to describe the dense gas diffusion, so the thickness at any time is:

$$H_{UF6} = 4 \times \sqrt{\frac{Q_{UF6}}{\rho_{UF6v}}} \frac{u \cdot t}{\pi \cdot w_{UF6}^2}$$

and the width:

$$w_{UF6} = 2 \times \left[w_{UF6c}^2 + 2 \cdot t \cdot \sqrt{g \cdot \frac{\rho_{UF6v} - \rho_{air}}{\rho_{air} \cdot \pi} \cdot Q_{UF6} \rho_{UF6v}} \right]^{1/2}$$

2.2 Chemical and Thermodynamic Model

Dewitt (1960) cites work by D.W. Magnuson in presenting the following relationship for a UF_6 compressibility factor:

$$Z = \frac{(1.9T + 572.69)^3}{(1.9T + 572.69)^3 + 4.892 + 10^5 P / 6.896}$$

where: T--the temperature(℃); P-- the pressure (kPa).

The density of UF_6 vapor is:

$$\rho_{UF6} = \frac{MW \cdot P \cdot Z}{R \cdot (1.9T + 572.69)}$$

where: *R*-- the universal gas constant, 8.314J/(mol·K); *MW* = the molecular weight of UF_6.

We assumed that air was entrained into the UF_6 control volume only through the top while the sides is negligible. So the water available for reaction is:

$$m_{H2O} = \rho_{H2Ov} V_{air} + p_r w_{UF6} u \Delta t \rho_{H2Ol}$$

where: Δt -- the duration of the time step ; p_r -- precipitation rate. The value of m_{H2O} is the judgment of reaction completed.

2.3 Passive Diffusion of HF/UO_2F_2

As the control volume moves downwind, the plume rise, and we used the following formula to calculate the plume rise:

$$\Delta h_t = 1.6 F_b^{1/3} x^{2/3} uz^{-1}$$

where: F_b-- buoyancy flux (m^4/s^3), as the reaction is exothermic, the plume rise is caused by heat. After all UF_6 is converted to HF and UO_2F_2, the diffusion of UF_6 was simulated by Gaussian model.

3 PRELIMINARY TESTS ON THE NEW MODEL

The new model was tested by two sides, one was based on the data of three UF_6 release experiments carried by the French Bordeaux National Experimental Base between 1986 and 1989. the results were showed in Table 1.

The other test was error comparison with HGSYSTEM/UF_6. We used Fractional Bias, Geometric Mean Bias, Geometric Mean Variance, and Normalized Square Error to test the model. Table 2 showed the results of comparison.

Table 1: Predicted concentration of total uranium from HGSYSTEM/UF_6 and our model (mg/m^3)

Downwind distance (m)	First experiment			Second experiment			Third experiment		
	Observation	Prediction of HGSYSTEM/UF_6	Prediction of our model	Observation	Prediction of HGSYSTEM/UF_6	Prediction of our model	Observation	Prediction of HGSYSTEM/UF_6	Prediction of our model
10	434	490	557.1	543	507	533	231	248	362.9
20	262	232	244.6	281	356	241.3	154	185	152.7
40	93	168	102.6	112	236	99.7	61.2	95.6	57.8
70	-	-	-	43	115	45.1	26.5	39.6	23.6
100	10	67.6	18.1	24	63.7	26.2	16.1	21	12.7
200	-	-	-	7.4	18.1	8.4	4.9	5.7	3.6
500	1.5	4	2	1.2	3.2	1.66	-	-	-

Table 2: Error comparison result

Number	Prediction	FB	MG	VG	NMSE
	Ideal	0	1	1	0
First experiment	HGSYSTEM/UF_6	-0.09137	0.498427	2.711553	1.265878
	Our model	0.012874	0.949708	1.166177	0.160457
Second experiment	HGSYSTEM/UF_6	-0.24877	1.970619	1.848016	0.062857
	Our model	0.009128	0.973092	1.008994	0.008965
Third experiment	HGSYSTEM/UF_6	-0.18593	1.28811	1.085535	0.03487
	Our model	0.027364	1.341068	1.146408	0.138798

The tests showed that our model has smaller errors and same variation trend of soluble uranium concentration.

4 APPLIANCE OF THE NEW MODEL

The new model has been used in the work about a nuclear fuel cycle facility's emergency assessment. The circuits of assessment were showed in figure 2. We choose 1000kg as the source of UF_6 release accident, and the results were showed in figure 3.

Figure 2: The circuit of assessment

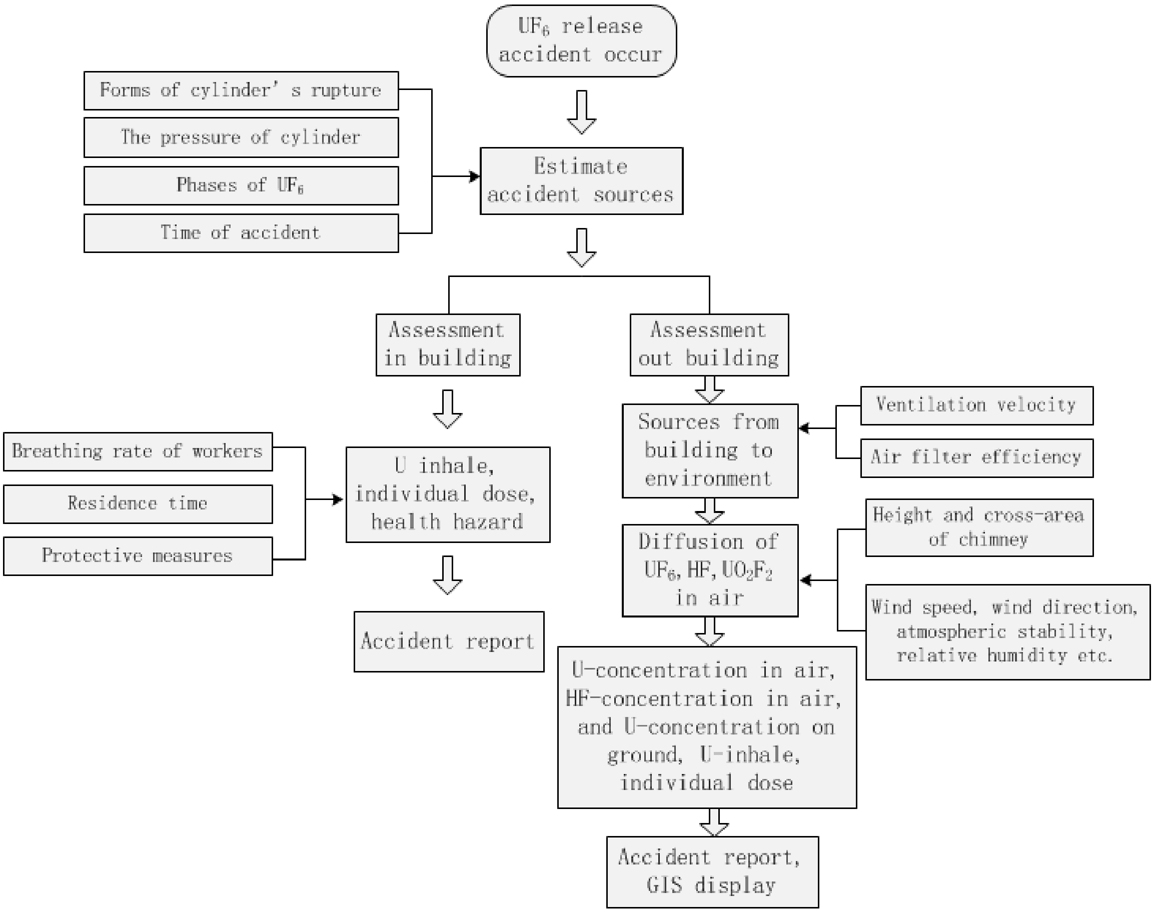
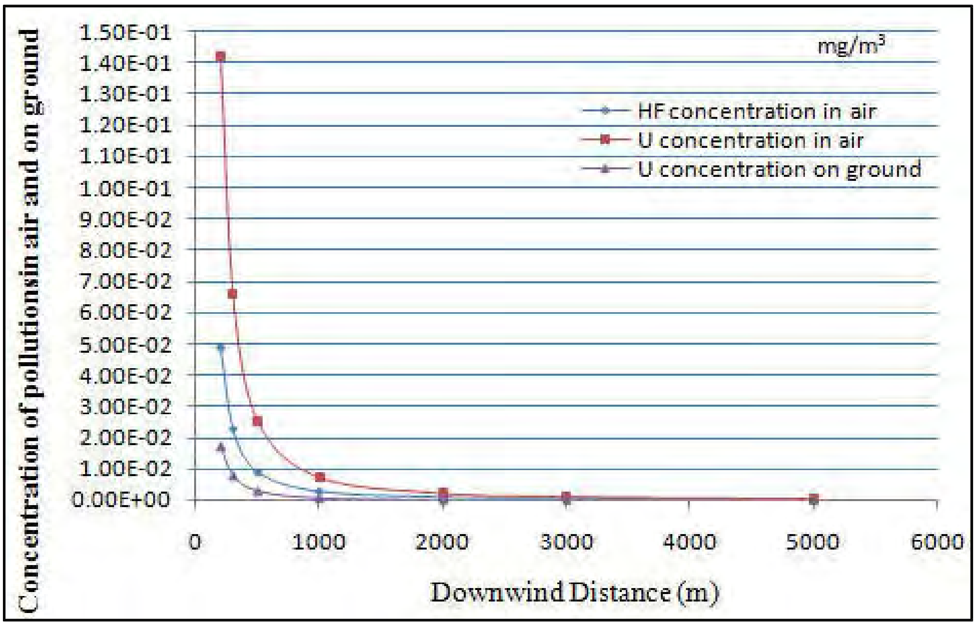


Figure 3: The result of a nuclear fuel cycle facility's emergency assessment



5 DISCUSSION

In both UF_6 transport and the nuclear fuel cycle process, UF_6 release is a kind of topic accident scenario. In order to simulate the consequence, we tried to use different models, and different hypothesizes, and formed a new model SAFUIT/UF_6. Tests and appliance proved that the new model was suit in modeling UF_6 diffusion initially. More work and changes should be done in the future.

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Optimization of Sr/Y-90 measurement instrument for contaminated mixture sample without chemical separation

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Abstract. We developed a Sr/Y-90 radioactivity measurement instrument which had advantages of high sensitivity and compact size. This study aimed to correspond to requirement that Sr/Y-90 radioactivity could be measured rapidly without chemical separation. We had already proposed a subtracting method of β ray emission rate. In this report, we confirmed that a measurement result obtained by the present instrument agreed with a known value. An uncertainty of the measurement result and minimum detectable activity were also estimated. In consideration with monitoring reports about released radioactivity by the accident at Fukushima Daiichi nuclear power plant, we assumed that mixed radionuclides in a sample were Cs-134, Cs-137, and Sr-Y-90.

KEYWORDS: Radioactivity; Cs-134; Cs-137; Sr/Y-90; Mixture sample; NaI(Tl) scintillation detector; Plastic scintillation detector; Uncertainty; Minimum detectable activity.

1 INTRODUCTION

Sr-90 (Half life 28.80 y) emits only β rays, and reaches radioactive equilibrium with Y-90 (2.6684 d) [1]. Usually, a measurement instrument for Sr/Y-90 radioactivity counts β rays. A radioactivity of Sr/Y-90 is obtained by division of the count rate by a counting efficiency as described in the official method in Japan [2]. A higher counting efficiency is advantageous to accuracy of measurment results for lower radioactive concentration.

Sr-90 is one of the primary fission product. Accurate measurement results for radioacitivity of Sr/Y-90 were important to understand the situation in the site of Fukushima Daiichi Nuclear Power Plant. It was eagerly required that measurement instruments achived a adequate sensitivity for low radioactive concentration in rapid measurement procedure. Sr/Y-90 was mixed with Cs-134 (Half life 2.0644 y [3]) and Cs-137 (Half life 30.05 y [1]) according to measurement result from the accident site [4].

In conventional analysis method of Sr/Y-90 [2], chemical separation procedure is conducted before the β ray counting to discriminate β ray counts between Sr/Y-90 and the other nuclides. Additionally, a waiting time of the radioactive equilibrium consumes 2 weeks. We proposed a method in which Sr/Y-90 radioactivity was obtained by substracting β ray emission rates of the other nuclides from the entire one without chemical separation [5].

The method employed β ray and γ ray detectors which had high sensitivities, respectively. Compact size and light weight were desired in consideration with practical uses on-site. Therefore, we developed a new measurement instrument which was composed by combination of plastic and NaI(Tl) scintillation detector for β and γ rays, respectively. In this study, experimental results for validation and evaluation of the measurement result were exhibited. It was presumed that Sr/Y-90 was mixed with Cs-134 and Cs-137 in samples.

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2 INSTRUMENTS

2.1 Sample preparation and detector setup

A developed measurement instrument was composed of finely placed β and γ ray detectors. As shown in Fig. 1, the β ray detector was a pair of concave-convex shaped plastic scintillator. 30 mg at most of sample solution was directly dropped on the concave plastic, and the convex plastic was put on the concave with bonding at the edge of the plastic after complete drying the sample solution. The whole plastic scintillator was 8 mm in diameter, and 2 mm thick. The plastic scintillator was used as disposable. The method of sample preparation enabled us to form 4π solid angle for β ray counting with minimum absorption of β rays. The plastic scintillator was optically coupled with a diagonal pair of photomultiplier (Hamamatsu, R9880U-210). Direct coupling with optical grease let sensitivity high for even small scintillation light.

The photomultipliers had benefits of thimble-size, ultra bialkali photo-cathode, and high gain. We chose this type of photomultiplier because of the highest sensitivity for scintillation in the same size of photomultiplier. The β rays from sample were counted as coincident events of the diagonal photomultiplier. That was effective to reject self-noise events in each photomultiplier and adjust a threshold level down. In preliminary experiment, it was confirmed that a counting efficiency for radioactivity of Cs-134 which have a low energy β ray decay branch was 91 % at most.

Figure 2 show a detector setup of γ ray detector with the β ray detector. The γ ray detector was made of cylindrical shape NaI(Tl) scintillator which had a through hole. The hole (20 mm in diameter) was dug to insert the β ray detector fitly. The sample was placed at the centre of the NaI(Tl) scintillator. This setup arrangement realised a high γ ray counting efficiency with a compact size.

In preliminary experiment, it was confirmed that pulse height resolution of the through hole type NaI(Tl) scintillation detector was poorer than the usual cylindrical one. A full width at half maximum (FWHM) at 662 keV full enerygy peak of Cs-137 was 17 % in case of the centered sample. It was revealed that collection efficiencies of scintillation light in the NaI(Tl) scintillator crystal were different between the front and back side of the hole with a view from photomultiplier. This caused the poorer resolution, but there is not so much relation with measurement capability of Sr/Y-90 radioactivity.

Figure 1: Preparing samples on a plastic scintillator and coupling with a diagonal pair of photomultiplier.

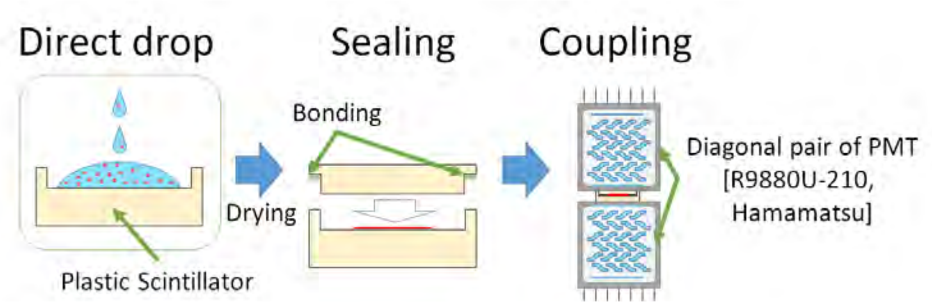
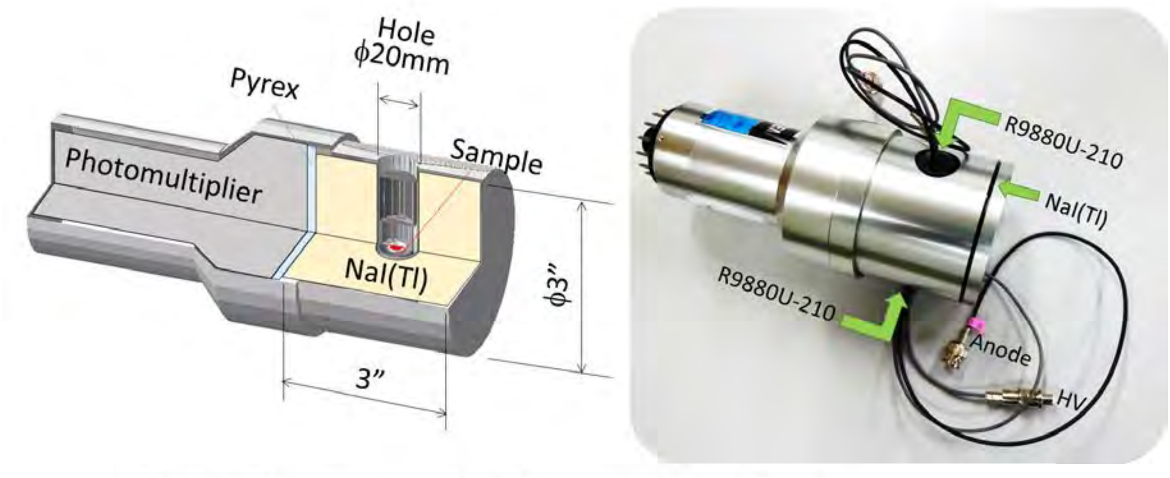


Figure 2: (Left) Cross-section view of the radioactivity measurement instrument and (Right) its picture.



2.2 Data acquirement

Figure 3 shows a brock diagram of electrical circuit for data acquirement. This system worked to obtained pulse heights of β and γ ray events in list mode. Each labelled modules was listed with functions, implementers and model numbers in Table 1. Gates of data acquire system were opened by signals generated by logic sum of β ray events, and γ ray events. Obtained list data was analysed off-line. Count rates of γ rays in region of interest, β rays at higher pulse height than the threshold level were gathered. Events which satisfied the both condition were counted as β-γ coincidence.

Figure 3: Brock diagram of electrical circuit for data acquirement.

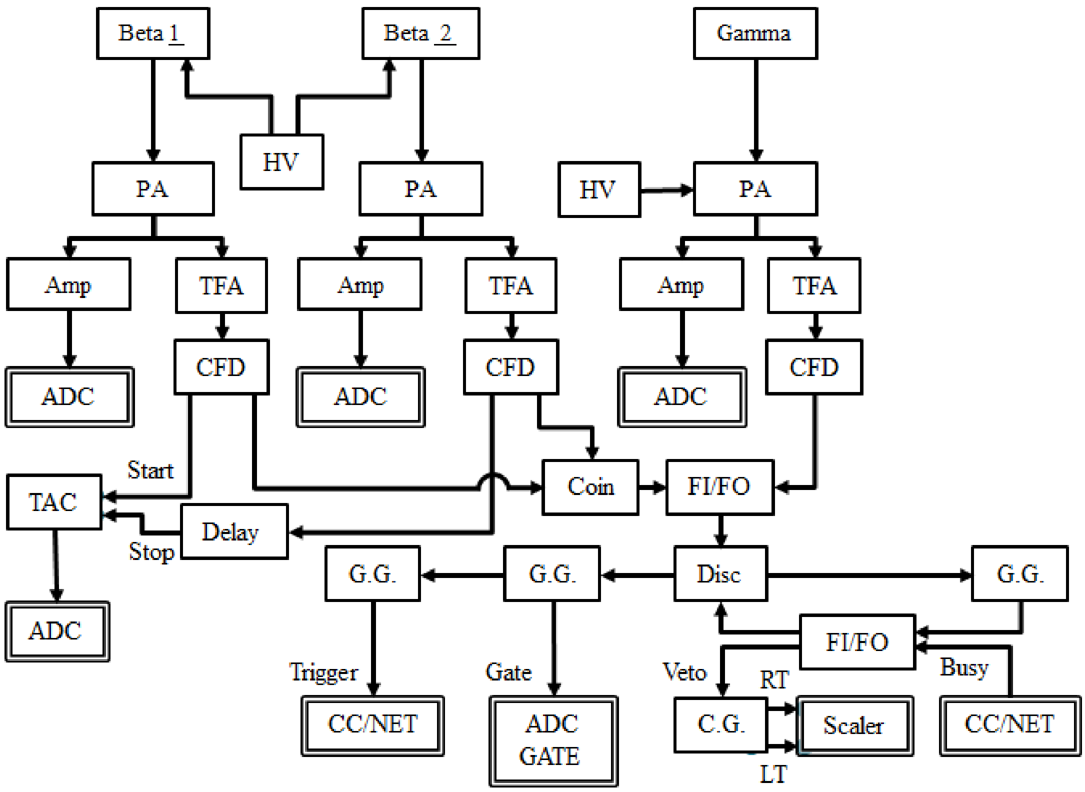


Table 1: List of principal modules in the data acquire system

Label	Function	Implementer	Model No.
PA	Pre amplifier	Canberra (β) / Clear Pulse (γ)	2005 (β) / 5626 (γ)
HV	High voltage supply	ORTEC	556
Amp	Shaping amplifier	ORTEC	572A
TFA	Timing filter amp	ORTEC	474
CFD	Constant fraction discriminator	ORTEC	935
TAC	Time to amplitude converter	Canberra	2043
ADC	Analog to digital converter	Technoland	C-TM405
G.G.	Gate generator	Kaizu Works	KN1500
Coin	Coincidence (Logical AND)	Technoland	N-TM103
FI/FO	Fun in and fun out (Logical OR)	Technoland	N-TM102
C.G.	Clock generator	Technoland	N-TM203
CC/NET	Network crate controller	Toyo	CC/NET

3 RESULT

Results of comparison between known and obtained values were shown with deviation in Table 2. Here, we presumed that the ratio of the nuclides was roughly 1: 2: 3 corresponding to Cs-134: Cs-137: Sr/Y-90, respectively. The obtained values agreed with the known values of all nuclides. This results indicated that measurement employing the present instrument and method had adequate accuracy.

We evaluated a measurement uncertainty of Sr/Y-90 radioactivity as 10 % (k=1). A primary component of the uncertainty was about counting statistics. Data acquirement time was 3000 s^{-1} in the present measurement. Additionally, uncertainties about determination of counting efficiency for β and γ rays were dominant in the present evaluation. The relative uncertainty varies significantly according to existence ration between Sr/Y-90 and the other, and amount of Sr/Y-90 radioactivity.

Table 2: Comparison between known and obtained radioactivities of Cs-134, Cs-137 and Sr/Y-90.

Nuclide	Known value [Bq]	Obtained value [Bq]	Deviation [%]
Cs-134	76.3	77.0	+ 1.0
Cs-137	108.7	109.8	+ 1.0
Sr/Y-90	42.4	42.5	+ 0.1

4 DISCUSSION

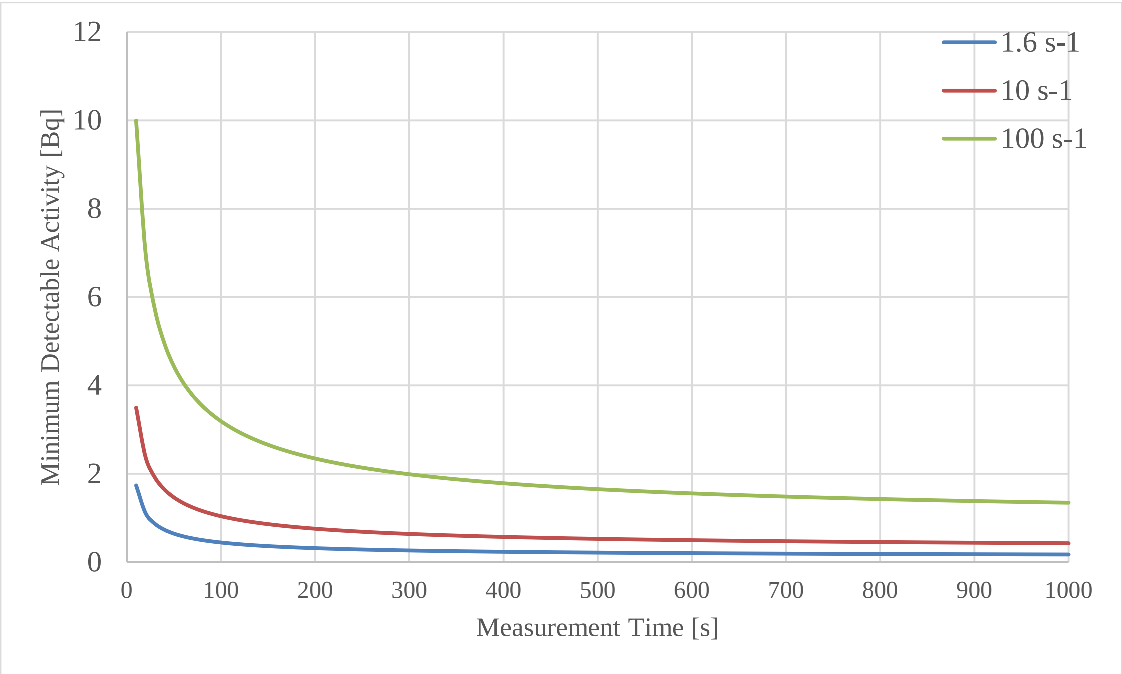
In the present result, existence ratio of Sr/Y-90 was minority in the whole. An uncertainty of Sr/Y-90 radioactivity by our method is dominated by uncertainty about determination of the entire and the other nuclide electron emission rate. Therefore, small ratio of Sr/Y-90 leads to large measurement relative uncertainty. The relation is similar to the case that normally occurring radioactive materials (NORM) are included in sample. Small amount of Sr/Y-90 radioactivity also let the uncertainty up because the β ray count ray is affected by background.

Figure 4 shows functions of minimum detectable activity (MDA) to measurement time estimated by the following equation,

$$MDA = (k/2)\left(k/t + \sqrt{(k/t)^2 + 4n_b(1/t + 1/t_b)}\right),$$

Where, k is confidence level, t is measurement time, n_b is background count rate, t_b is background measurement time. A background count rate in the present was 1.6 s^{-1}. The other case was shown in the cases of 10 s^{-1} and 100 s^{-1} on the assumption of the existence of the other nuclides.

Figure 4: Minimum detectable activity in three cases of background count rate in β ray detector. ((a) 1.6 s^{-1} was at present, (b) 10 s^{-1} and (c) 100 s^{-1} were assumed in consideration with existence of Cs-134, Cs-137 and naturally occurring radioactive material.



5 CONCLUSION

This study developed the compact detector setup with the high counting efficiency for measurement of Sr/Y-90 radioactivity. This was realised by the combination of the thimble size β ray detector and the through hole type γ ray detector. It was used with the simple sample preparation. The accuracy of the measurement was exhibited in comparison between the known and obtained values. The uncertainty and the minimum detectable activity were evaluated as a capability of the instrument. It was noticed that the capability varies with ratio and amount of Sr/Y-90 radioactivity in samples.

6 ACKNOWLEDGEMENTS

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Development of Integrated Nuclear Emergency Command and Decision Support System for Nuclear Power Plant

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Abstract. The nuclear power plant (NPP) accident, with massive radioactive nuclides released to the atmosphere, will bring radiation damage to people, even seriously psychology and society influence. The nuclear emergency command and decision support system(NECDSS) play an import role during the accident, is the platform for data exchange and sharing, information acquire and release, command receive and execute during the period of accident response. This paper introduce an integrated NECDSS development. The NECDSS based on the flow of emergency response business, adopt modularization function design, standardization data manage and interface protocol, multi-phase decision-making model, to improve the ability of emergency response. The NECDSS real- time acquire the data of reactor operation, meteorology, environment radiation from relative databases, monitoring the reactor operation by picture configuration, execute the emergency status degree assisted judgment, reactor core damage assessment, source term calculation, post-accident consequence prediction analysis, operation intervention level(OIL) calculation.

KEYWORDS: nuclear emergency; nuclear accident; decision support; emergency command.

1 INTRODUCTION

There had been three typical serious nuclear accident[1][2][3] during the history of nuclear power plants: (1) the Three Mile Island accident in the United States in 1979, although a lot of radioactive material was finally safe blocked by containment, only a small amount released into the environment, but still caused serious psychological impact on the surrounding public and society; (2) the Chernobyl accident in 1986, a great amount of radioactive materials released directly into the environment, resulting in the evacuation of all personnel around 30Km range, and causing death of 28 people exposed to radiation; (3) the Fukushima nuclear accident in Japan in 2011, a direct hydrogen explosion destroyed the roof of the plant, resulting in a large number of airborne release of radioactive material into the environment, the amount of fission product released was about one-tenth of the Chernobyl accident. The nuclear accident has far exceeded the radiation hazard areas, also caused severe psychological and social impact on the public, even leaded social instability event.

The nuclear accident emergency decision support system is an important means to improve the ability to respond to nuclear accidents, also an important platform for the exchange of information and command during the emergency response period. The system can provide practical action suggestions for the development of emergency response programs.

In order to enhance the overall nuclear emergency response and decision support capabilities under the NPP accident, the achieve of phased emergency command and decision support must base on emergency's work flow and data flow, and standard data interface protocol, and follow the emergency response procedures and accident sequence, and consider the various functional modules, and adopt phased decision-making models.

This paper presents an integrated solutions, give a detailed description of the business process, functional module design, as well as major emergency assessment models.

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2 OVERALL SYSTEM DESIGN

2.1 Business Process Analysis

Based on the system's operation, the System's architecture can be divided into basic data collection and pre-process, emergency assessment, emergency command, emergency data management, etc.

(1) Basic data collection and pre-process: basic data include NPP online real-time operation data and emergency related data. The online real-time means data be acquired by a fixed frequency from the facility, such as, unit and simulator operation parameters, environmental radiation monitoring data and meteorological monitoring data, etc. The emergency related data includes: Geographic Information System(GIS), physical protection, personal dose, documents, etc.

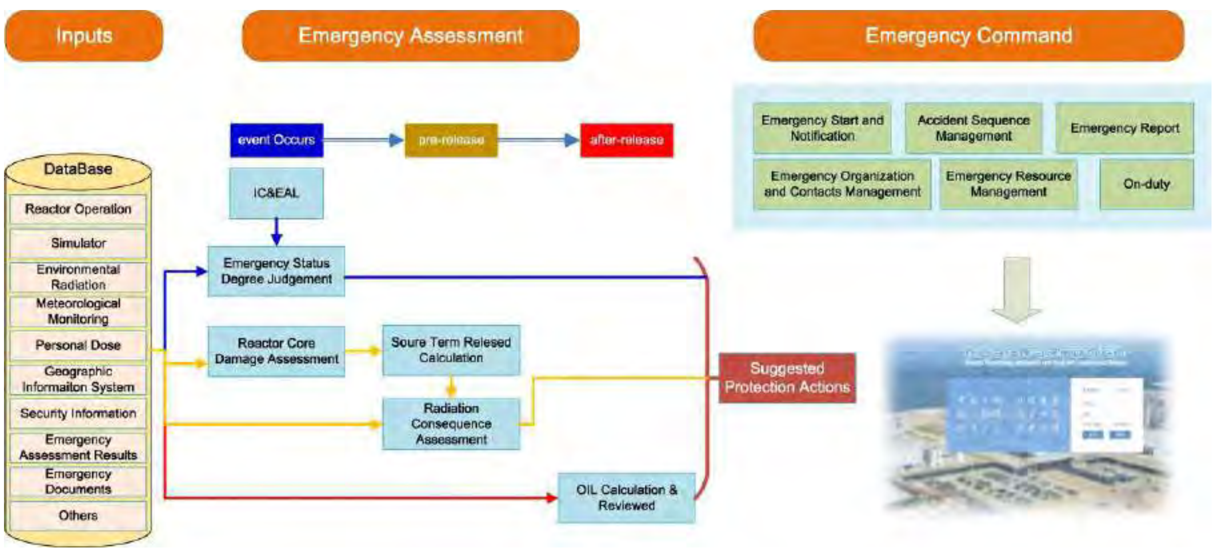
(2) Emergency assessment: include the major emergency decision support computing module, such as, emergency status level assist judgment, core damage evaluation, source term calculation, environmental impact prediction and analysis, operator intervention level(OIL), protective action recommendations, etc.

(3) Emergency command: to carry out an emergency command and emergency response operations, management and comprehensive dispatching emergency response facilities/resources, also include emergency document management, emergency response personnel dose management, emergency start and inform, emergency notification and reporting, emergency memorabilia, emergency duty, public opinion monitoring and information dissemination, and other functions.

(4) Emergency Data management: the basic platform of management, maintenance and use of nuclear emergency data and resource information, the data will be classified and managed, and can be inquired. The data can be show neither by tabulated or by graph.

The simplified business process of nuclear emergency command and decision support system is show in fig.1.

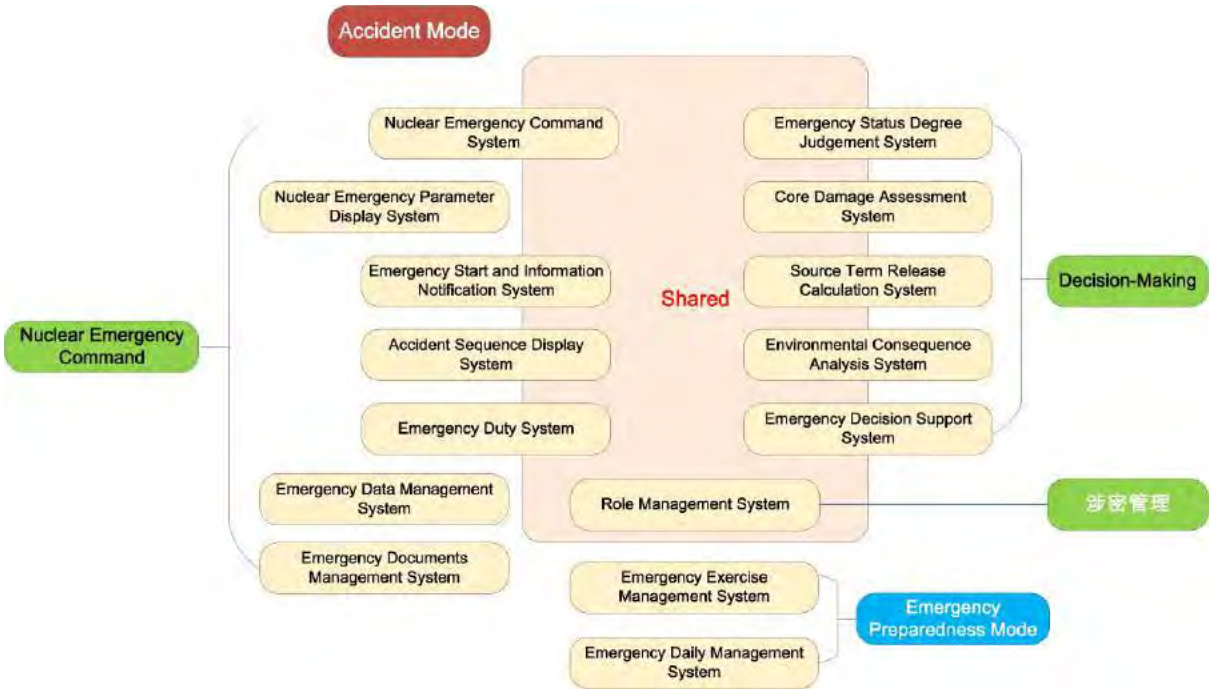
Figure1: Simplified business process of nuclear emergency command and decision support system



2.3 System functional modules design

The system have two operation modes, emergency preparedness mode and accident response mode, the former emphasize on the emergency daily management and emergency training and drill/exercise management, the latter emphasize on the really response actions be taken once an accident occurring. Through the system's operation, there are is two major business lines: nuclear emergency command and decision-making support. Both the modes have some mutual and independent modules, which be detailed in fig.2

Figure 2: Main systems included in the Integrated Nuclear Emergency Command and Decision Support System for Nuclear Power Plant



2.3.1 Nuclear Emergency Parameter Display System

The nuclear safety related operational parameters of nuclear power plant can be displayed in the form of picture configuration, with real-time and historical trends and alarm thresholds, etc. Once an exception occurs, we report immediately.

The main control room in NPP is equipped with a special Safety Parameter Display System (SPDS)[7], variable display information of the unit, to help the operator find fault indication, detection and diagnosis unit operating state deviating from normal condition. According to hierarchical display, SPDS system parameters are divided into three layers based on the degree of importance:

1) Top Level parameters: with the highest priority parameter displayed on the screen in main control room;
2) Second Level parameters: query for details of the parameters;
3) Third Level System Flow: Displays the operating status and parameters of a few important components of the system and the system flow chart of major equipment.

This system is deployed in the emergency command post, using only the third level system flow chart to display nuclear safety related parameters.

2.3.2 Nuclear Emergency Command system

The system establishes business workflow model of emergency response action based on the roles and responsibilities of emergency organizations in the plant, monitor the each instruction's sequence and its implementation using timeline.

Three-dimensional simulation technology for major emergency response facilities and nuclear power plant emergency management processes show that observe personnel involved in emergency response personnel and emergency drills, emergency response system to be intuitive to understand.

2.3.3 Emergency Notification and Reporting

After the nuclear accident, the corresponding notice and reporting documents will be sent to the relevant emergency response organizations through a network fax systems, and stored in the database, according to the nuclear emergency plan. Emergency announcement generally includes: company name, reactor name, time of the accident, accident conditions, expected trends, current status level and access to emergency time, emergency response measures have been or will be taken and so on. Emergency reports include: initial report, follow-up report and final report. Emergency initial report on the basis of a detailed description of the accident and off-site emergency protective action recommendations. Emergency follow-up report to be sent reactor conditions, critical process parameters, radioactive releases, the level of radioactivity, etc.

2.3.4 Core Damage Assessment System

(1) Evaluation of core damage
Evaluation of core damage is mainly based WCAP-14696-A (CDAG) guidelines[4] recommended a comprehensive analysis methods were evaluated, also made reference to the IAEA-TECDOC-955[5] based on the core exposed time determination core damage the degree of approach. The main core damage evaluation parameters used are: Containment Radiation Monitor(CRM), Core Exit Thermocouple(CET), Containment Hydrogen Concentration(CH), Reactor Vessel Water Level(RVL), Hot-leg RTD Temperature(RTD), Source Range Monitor(SRM), Reactor Coolant System Pressure(RCP). CRM and CET are the key parameters to determine core damage status and fraction, CH, RVL, RTD, SRM used to assessment the rationality of the evaluation results, RCP used to divide different circumstances CH limits.

(2) Source term calculation
Source term calculation method[6] is divided into two categories: 1) based on the reactor source term conditions, such as: time core is uncovered, specified core damage endpoint, containment radiation monitor, coolant sample, and containment air sample, etc. 2) based on effluent monitoring results, such as: effluent release rate, effluent concentration, the release of a mixture and other monitoring based effluent.

Source term calculation process can be divided into: shutdown time inventory estimates, the fraction of the core is released, the source term release pathway and removal mechanisms, the fraction of containment leakage, mainly calculated as follows:

$$S_i = FPI_i \times CRF_i \times \prod_{j=1}^{N} RDF(i,j) \times EF_i$$

Where,

S_i: activity of radionuclide *i* released to the environment
FPI_i: inventory of radionuclide *i*
CRF_i: fraction for radionuclide *i* available for release
$RDF(i,j)$: reduction factor for radionuclide *i* and reduction mechanisms *j*
EF_i: leakage fraction to the environment

The release pathway considered in the source term calculation includes: containment failure, steam generator tube rupture (SGTR), containment bypass, direct release into the environment. The release pathway of different calculation methods corresponding to Table 1.

Table 1: Main release pathway considered in source term calculation

Source term calculation methods		Release Path			
		containment failure	bypass	SGTR	direct release into the environment
time core is uncovered		√	√	√	
specified core damage endpoint	normal coolant release		√	√	
	Spiking release		√	√	
	Cladding failure	√	√	√	
containment radiation monitor		√			
coolant sample			√	√	
containment air sample		√			
effluent release rate					√
effluent release concentration					√
effluent release mixture					√

2.3.5 *Nuclear Emergency Decision Support [7-8]*

(1) Based on IC & EAL
At the emergency start time, the emergency decision support is mainly based on IC & EAL. Determining the emergency degree is mainly based on IC&EAL matrix, combined with a nuclear power plant operating data. Analysing model is based on the identification of different classes for different operating modes (such as Class A, S, F and H, etc.).

(2) Based on OIL
After the release of radioactivity into the environment, emergency decision model requires a gradual transition from the impact assessment to predict based on the results of the field monitoring. According to the typical source term meteorological conditions and the establishment of a library OIL, OIL values can be corrected by monitoring the data, get the final protective action recommendations.

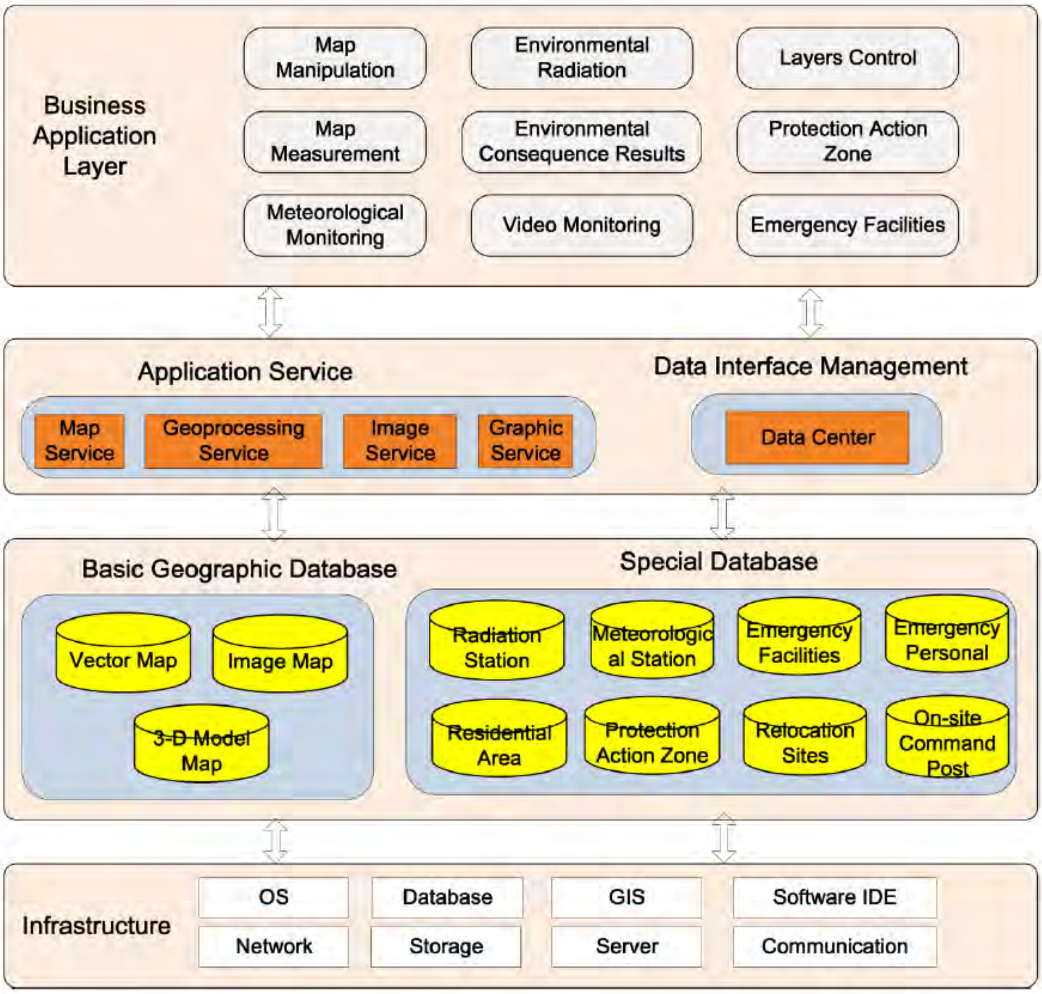
2.3.6 Geographic Information System

The system display the emergency resources and facilities, emergency assessment results (wind field, equivalent dose curve, protection action region, etc.) using Web based Geographic Information System.

By GIS system, user can check off-site emergency facilities, meteorological stations, environmental radiation monitoring stations, draw a map of the wind field diffusion, concentration, dose rate, dose distribution, the protective action in the region, the impact area of the region, the population, the number of villages and so on.

The main framework used in the system for emergency assessment results graphic display is detailed in Fig.3.

Figure 3: Main framework used in the system for emergency assessment results graphic display



3 CONCLUSION

The design and development of the NECDSS system taking into account the experience feedback from the Fukushima nuclear accident [13], operating experience requirements of the new demand for new nuclear safety regulators and nuclear power plants operating units, as well as domestic and foreign related systems . The main technical features of the system are:

(1) High degree of integration, data interface specification;
(2) Evaluation model uses well-proven and absorb the latest research results;
(3) Both peacetime and wartime, include the simulation exercises and accident conditions of emergency response modes;
(4) Comply with the nuclear emergency response management systems and processes;
(5) Follow the relevant laws and regulations, standards and guidelines;
(6) Based on the results of the evaluation of nuclear emergency command and show WebGIS.

The system is modular development, using standard interface protocols to achieve a high degree of functional modules integrated. The system realizes the emergency status degree judgment, nuclear emergency command, emergency evaluation, decision support, emergency data management and other functions, can be used as a tool for nuclear accident emergency preparedness and response in for nuclear power plant, enhance the ability to respond to emergencies.

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Cognitive and Cerebrovascular Effects Induced by Low Dose Ionizing Radiation 'CEREBRAD' (Grant agreement: 295552)

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Abstract. Epidemiological evidences about the occurrence of late cognitive and cerebrovascular diseases due to exposure to radiation early in life (in utero or during childhood) are scarce. Nevertheless, A-bomb survivor data indicate a linear dose-response curve with a threshold around 200 mGy. Thus, raising the concern regarding the uncertainty of low-dose radiation, which is in part due to the lack of sufficiently large cohorts, combined with a lack of understanding the underlying mechanisms. Moreover, the increasing use of radiation in medical diagnostics urges the need for appropriate research to define precisely the effect of low dose radiation on the brain. The FP7 CEREBRAD project for cognitive and cerebrovascular effects induced by low dose ionizing radiation (grant agreement n°295552), aimed to gather sufficient scientific evidence to increase the statistical power of epidemiological data. Thus, epidemiological evaluations of the risk of cerebrovascular disease following low dose exposures(Excess of Odds Ratio (EOR) of stroke per Gy of average radiation dose to the cerebral arteries, was equal to EOR/Gy = 0.49 (95% CI: 0.22 to 1.17)) based upon a cohort of survivors of childhood cancer receiving radiation therapy before the age of 5 year. While cognitive impairments have been evaluated in a medical and in in utero exposed cohorts from Chernobyl. The project aimed in addition to explain the related cellular and molecular events modulated early after exposure and most probably responsible for late cognitive and cerebrovascular diseases. The shape of the dose-response curve for cognitive impairments in animal models shows a linear dose-response curve with age-dependent sensitivity. Interestingly the cellular and molecular investigations revealed obvious effects of low-dose ionizing radiation 'LD-IR' on the brain at multiple levels. In general, we could observe a clear dose-dependent effect and could unveil different anomalies induced by the lowest X-ray dose studied (0.1 Gy) in terms of cognition, cell death and neurogenesis. Finally, mechanisms acting at low doses are different from those at high doses, while, processing of the late response could in part be mastered through epigenetic events, requiring thus additional future investigations.

Evaluation of the Effect of Low and Intermediate Frequency Electromagnetic Waves on Radiosensitivity

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Abstract. Kaposi's sarcoma (KS) is a skin cancer caused by human herpes virus 8 that develops from the cells that line lymph or blood vessels. Currently, the incidence of KS co-morbidity in HIV/AIDS patients is high due to their compromised immune system. HIV-positive individuals presenting with cancer are treated in much the same way as those who do not have HIV through surgery, chemotherapy, radiation therapy and biological therapy, putting HIV-positive persons at a higher risk of developing severe side effects that they may not recover from. Therefore, there is the need to find non-invasive methods to sensitise cancer cells to therapeutic doses of ionising radiation. To achieve this goal, the effect of low-medium frequency electromagnetic fields (EMF) on the radiosensitivity of apparently normal Chinese hamster lung fibroblasts (V79) and human malignant melanoma cells (MeWo) was evaluated using the colony forming assay. Radiation modifying factors were determined for 100 and 1000 Hz fields. Pre-exposure of the fibroblasts to both fields had no effect on their radiosensitivity, if X- ray irradiation followed within 2 h or at 6 h. Radiosensitisation with modifying factors (MF) of up to 1.30 was observed when X-rays are administered 4 h after EMF exposure. For the MeWo cells, pre-exposure to 100 Hz resulted in a significant radioprotection (MF: 0.68-0.79) when irradiation followed within 6 h. On the other hand, treatment of these cells with a 1000 Hz field significantly potentiated the effect of X-rays (MF: 1.51-1.52). When cells were irradiated prior to EMF exposure, the V79 cells were marginally protected by the 100 Hz field (MF: 0.87-0.96) and sensitised by the 1000 Hz field (MF: 1.06-1.13). In contrast, the melanoma cells were slightly protected by the 1000 Hz field (MF: 0.90-0.94) and sensitised by the 100 Hz field (MF: 1.34-1.76). These data suggest that informed combination of low-medium frequency electromagnetic fields and radiotherapy might be beneficial in the management of cancers, especially those presented by HIV-positive patients.

KEYWORDS: electromagnetic fields; radiomodulatory effects; melanoma; Kaposi's sarcoma.

Educational and Occupational Outcomes of Childhood Cancer Survivors 30 Years after Irradiation

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Abstract. Background: Childhood cancer may delay or prevent educational and occupational attainment. While survival from childhood cancer has increased, little is known about the long- term impact of childhood cancer related-treatments on these outcomes. Methods: Eligible patients were treated before the age of 19 for solid or haematological tumours in ten French cancer centres between 1948 and 2000. Educational level, occupation and employment status of survivors were compared to sex-age rates recorded in the French population at the same calendar period, using indirect method of standardization. Educational level of survivors adjusted on their father's occupational class was also considered to control for the role of survivors' socioeconomic background on their achievement. Results: Overall, 2,006 survivors were included in the study. Among respondents, mean follow-up time was 30 years. Survivors were more likely to graduate from college than the French population of the same age and gender (38.9% vs. 33.5% expected; $P < .0001$). They were also more likely to belong to the upper occupational class (23.1% were managers/professionals vs. 15.4% expected; $P < .0001$). The educational level of survivors adjusted on their father's social class was also higher than expected. However, this higher social achievement was not observed either for leukaemia or brain tumour survivors. Health- related unemployment was significantly higher for brain tumour survivors (28.1% vs. 4.3% expected; $P < .0001$). Conclusion: Most of survivors had a higher socioeconomic position than expected from the French population statistics.

Radiation Survival Curve for Paediatrics Rhabdomyosarcoma Cells

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Abstract. We report on the survival curve of cultured paediatric rhabdomyosarcoma (RD) cells derived from children. X-ray radiation of variable doses (i.e. 4 Gy up to 20 Gy) was used for this purpose. Radio sensitivity was determined by clonogenic assay. Both single-hit multi-target model and linear-quadratic model which base on the target theory allowed for the description of the survival curve, and for the calculations of characteristic parameters such as mean lethal dose (D_0), extrapolation number (n), dose at which the contribution of linear and quadratic components of cell killing are equal (α/β) and the radio sensitivity of the cells (SF_4 value). From the results obtained the survival curve was constructed, and it was found that $D_0 = 3.2$ Gy, $n = 11$, $\alpha/\beta = 9$ Gy and $SF_4 = 0.79$. Low radio sensitivity of cells under study was concluded.

How Nuclear Issues are Imagined: Social Perception in Relation to Radiation Protection

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Abstract. This paper will show some imaginary forms, pasts and presents, about nuclear issues. That is, what were the visions that have been deployed involving imaginary fantasies about nuclear energy? Through literary works, films, and essays the paper will depict some meaningful ideas about the "nuclear world". Many documents, including some produced by nuclear institutions recognize the communication problems that a democratic management of this activity faces. We argue here that these problems do not come merely from misapplication of communication techniques, but the way in which subjects in nuclear safety systems are integrated. Workers, public and patients, constitute a key element in any system of radiation protection -and not just as biological entities. What may seem obvious, it must be made clear: men and women are social subjects who live embedded in a set of relationships. They adopt forms of perception about their own lives and their living conditions. But the question of truth is not applicable directly to these forms. This value only can be applied on scientific knowledge and not to all forms of perception. Not weighting these perceptual frames, particularly about nuclear activity -even when they could be false, and even contrary to their benefit- leads to a reductionist perspective that could have consequences in any nuclear program. It would be unrealistic –or "unscientific"- to ignore what ideas are projected onto the nuclear activity and this constitutes an intellectual mistake. Here it will be showed that the ideological and perceptual frameworks not always are incorporated adequately as an input to be considered in an important way in radiation safety systems.

Chromosomal Aberrations and Telomere Dysfunction Induced by Low Dose- irradiation Measured by Telomere and Centromere Staining

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Abstract. Background: Exposure to low doses of ionizing radiation is an inevitable byproduct of modern life. Dose response curves obtained after exposure to medium or high doses of ionizing radiation are well established. The dose effect relation for low dose radiation (<100mGy) remains unclear. In this study, we revaluated the sensitivity of the gold standard method using telomere and centromere staining and provide the possible link between the dose response curve and telomere status after low exposure. Materials and methods: Human peripheral blood lymphocytes from 15 heathy donors were exposed to cobalt 60 g-rays at 4 doses from 10mGy to 200 mGy at a dose rate of 10mGy/min. Blood lymphocytes were cultured for 48h and chromosomal aberrations in the first mitosis were scored after telomere and centromere staining. Telomere length and telomere aberrations were assessed in the same analysed metaphases. Results: Telomere and centromere staining permits the scoring of all unstable chromosomal aberrations leading to a precise calculation of the number of DNA double stand breaks (DSB). Mean results of this study showed a significant difference observed between the frequency of calculated DSB after exposure to all tested low doses and controls ($P<10^{-2}$ for 10mGy). However, nonlinearity in the low dose region was observed. A significant difference was observed between telomere aberrations (telomere loss and telomere doublet) after exposure to all doses and the control. Also, the change in telomere length after low exposure was dependent on the baseline telomere length. Increased telomere length of donors with short telomeres was observed after exposure to low doses. Conclusion: The resulting improvement of unstable chromosomal aberration detection using telomere and centromere staining has led to an increase in the sensitivity of chromosomal aberration detection following low dose exposure, making it possible to apply this technique to the field of low dose research, as low dose exposure due to radiodiagnostic procedures (CT scan) is an ongoing health concern. The nonlinearity of the dose response curve observed at low doses could be related to hypersensitivity phenomenon. The role of telomere maintenance in this hypersensitivity needs further investigation.

Transmission of Induced Chromosomal Aberrations and Telomere Dysfunction through Successive Mitotic Divisions in Human Lymphocytes after In Vitro Exposure Measured by Telomere and Centromere Staining

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Abstract. Background: The introduction of telomere and centromere staining in radiation biology studies offers the potential to render not only dicentric chromosome and centric ring scoring more efficient and robust but also permits the detection of different types of acentric chromosomes and terminal deletions leading to the precise calculation of the number of DNA double strand breaks (DSB). In this study, we first reevaluated the induction and the transmission of unstable chromosomal aberrations to second and third division cells. Second, we studied the variation of telomere length and the transmission of telomere aberrations during the cell cycle. Material and Methods: Blood samples from 3 heathy donors (1 female and 2 males, mean age 43 years (36-52 years)) were exposed to 137Cs at 4 Gy and harvested at 48, 72 and 96 h. Bromodeoxyuridine (BrdU) was incorporated to evaluate the cell cycle status. Chromosomal aberrations were evaluated after telomere and centromere staining using PNA probes. Telomere length was assessed before and after irradiation in each cell using the Q- FISH technique. Results: The yield of dicentric chromosomes decreased by 51.8% between M1 and M2. However the decrease of the yield of centric rings and calculated DSB were greater (22% and 20% respectively) as well as the decrease of complete acentric chromosomes (36%) Also, only the yield of interstitial acentric chromosomes (without telomeres) increased during cell cycle progression phase (29%). The induction and transmission of chromosomal aberrations were related to proliferation index and telomere length. Of note, the frequency of aberrations in first division metaphases increased with culture time and was associated with significant telomere shortening of these cells. Conclusion: the reevaluation of the transmission of induced chromosomal aberrations demonstrate the importance of the scoring of all chromosomal aberrations in retrospective biological dosimetry and the establishment of dose response curves using calculated DSB. It will be important to score the first mitosis not only after 48h but also 72h of culture. This study is the first to associate telomere dysfunction, proliferative index and the transmission of induced chromosomal aberrations. Also, the transmission of complete acentric chromosome as well as interstitial chromosome was 1.23 and 0.8 between respectively. Interestingly, the yield of total calculated DSB decreased slowly between M1 and M2.

EPI-CT - European Cohort Study of Paediatric CT Risks: Challenges, Achievements and Perspectives

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Abstract. The European collaborative epidemiological study to quantify risks for paediatric computerised tomography and to optimise doses (EPI-CT) was designed as a multinational cohort study of children and young adults who have received substantial doses of ionising radiation from CT scanning. It comprises three main parts: the epidemiological cohort study is assessing the cancer effects of radiation exposure from CT; the dosimetry package is developing sophisticated methodology for individual CT dosimetry and related uncertainty and furthering dose reduction and optimisation strategies; the biological part is exploring potential biomarkers of exposure and sensitivity to study biological mechanisms underlying hypersensitivity observed in paediatric patients exposed to CT radiation. EPI-CT is based on a common protocol. The study includes 1,163,571 patients from nine European countries (Belgium, Denmark, France, Germany, the Netherlands, Norway, Spain, Sweden and the UK). Data on 2,166,479 CT examinations (53.33% of those being head CT scans) have been retrieved from participating radiology departments. Passive follow-up is being conducted by linkage to population-based cancer and mortality registries. A flexible approach for dose reconstruction was developed that can accommodate collection of data from historical sources (prior to 2000) and automatically extracted data from the Digital Imaging and Communications in Medicine (DICOM) headers of recorded images available in the Picture Archiving Communication System (PACS). The issues which may affect the precision of study results include missing doses from other radiological procedures, missing CTs conducted in non-participating radiology departments, reverse causation, confounding by socio-economic status and cancer predisposing conditions. Although it is impossible to evaluate impact of these potential confounders in the entire study, several participating countries are conducting sub-studies addressing these issues and their results are taken into account. EPI-CT, the first large-scale international collaborative study, will contribute not only to estimating effects of low level radiation in children and providing bases for the optimisation of paediatric CT protocols and patient protection but also has a potential to consolidate a European paediatric cohort for long-term follow-up.

DNA Double Strand Break Formation and Repair in Human Fibroblasts Continuously Exposed to X-ray Radiation

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Abstract. While molecular and cellular responses to acute ionizing radiation (IR) exposure are well-studied, fewer studies have examined responses to continuous (protracted) exposures. The challenges for such continuous irradiation studies include both technical ones related to irradiation facilities and difficulties in interpreting results. The goal of this study was to study of formation and repair of the most deleterious DNA damage induced by IR - double-strand breaks (DSBs) in primary human dermal fibroblasts under continuous (up to 6 hours) exposure to X-ray radiation at a dose-rate of 4.5 mGy/min. We used two markers to measure the effects: phosphorylated histone H2AX (γH2AX) foci indicates a change in the total number of DSBs, and RAD51 foci, a marker of the slow, but error free homologous recombination (HR) repair process. The apoptotic cell frequency and production of reactive oxygen species (ROS) were also evaluated. It was shown that under continuous X-ray radiation exposure the γH2AX foci number increases linearly up to a dose of 540 mGy (2 hour exposure time), reaches "plateau" at doses ranged from 540 to 1080 mGy and after it slightly decreases at doses of 1350 and 1620 mGy (irradiation time - 5 and 6 hours, accordingly). The dose-response curve obtained shows the result of two simultaneously occurring processes in continuously exposed cells: formation and repair of DSBs. There were no changes in the apoptotic cell frequency during 6 hour exposure at this dose-rate; however, the results of the ROS production measurements showed that changes in the ROS production rate are associated with the γH2AX foci number in these cells. In contrast to the γH2AX, the number and intensity of foci formed by HR protein RAD51 demonstrated a continuous increase during 6 h of irradiation, indicating that continuous irradiation of normal human cells triggers DNA repair responses that are different from those elicited after acute irradiation. Our results provide an insight into the mechanisms of DNA DSB formation and repair upon continuous exposure to X-ray radiation in normal human cells. The demonstrated activation of DNA DSB repair and the found predominant role of the HR pathway in this repair may be utilized in various medical practices and help improve management of health risks associated with continuous exposure to IR.

DNA Double-strand Break Repair in Mammalian Cells Exposed to Low-LET Radiation at Low Doses: The Controversy Continues

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Abstract. Current uncertainty with respect to early and delayed biological effects of low dose ionizing radiation represents a major challenge for the linear no-threshold model currently used for radiological risk estimates. Indeed, multiple studies have demonstrated that DNA damage induced by low doses and low dose rates of ionizing radiation is treated by cellular defence mechanisms in ways different to those induced by high doses and high dose rates. Among the various types of primary DNA lesions produced by ionizing radiation, DNA double-strand breaks (DSBs) are considered the most important due to their potential to cause cell death, mutagenesis and carcinogenesis. Advances in understanding molecular mechanisms of DNA repair provide powerful experimental tools. In particular, these include identification of individual proteins or protein post-translational modifications that form complex dynamic structures in the vicinity of individual DSBs. Immunofluorescent labeling of such proteins makes possible microscopic visualization of the DNA repair structures as distinct spots, commonly termed DNA repair foci, that typically correspond to individual DNA DSBs. This allows for very accurate and sensitive indirect quantification of DNA DSBs and their repair, thus facilitating examination of molecular mechanisms of the repair process. In spite of the large number of studies examining various aspects of DNA repair foci in mammalian cells following exposure to low dose ionizing radiation, substantial controversies still exist making the topic one of the most discussed topics in modern radiation biology. The most debatable issues can be identified as: 1) correspondence between the number of DNA repair foci and the number of DNA DSBs; 3) the threshold dose, and the slope of the dose-response curve; 4) efficiency of DNA DSB repair; 5) biological significance of persistent or delayed DNA repair foci and of spontaneous foci. The present report provides a critical overview of the recent literature and of our own results concerning these unresolved issues.

The ANDANTE Project: A Multidisciplinary Evaluation of the Risk from Neutrons Relative to Photons

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Abstract. New experimental and theoretical efforts have recently been undertaken in the framework of the European project ANDANTE, with the overarching objective of determining values of Relative Biological Effectiveness for neutrons for chosen tissues and as a function of neutron energies. The context of the project was specifically the possible role of secondary neutrons in the induction of second primary neoplasms following particle therapy, especially for paediatric patients. The success of proton therapy demands a renewed effort to unravel the mechanisms behind neutron biological effectiveness and its energy dependence. The ANDANTE project addressed this issue with a multidisciplinary approach, combining: (1) Physics: neutron interactions in tissue were Monte Carlo simulated at the cellular and sub- cellular level, and an ab-initio energy dependent RBE model for the induction of DNA lesions was developed; an analytical method was developed for reconstructing the scattered neutron doses outside the treatment volume during proton therapy; (2) Stem Cell Radiobiology: Stem cells from thyroid, salivary gland, and breast tissue were exposed to well characterized neutron beams and a reference 200 kV X-ray field, and the relative risk of damage from neutrons compared to photons was estimated using a number of endpoints. In vivo investigations were also carried out, by transplantation of exposed cells into mice with a subsequent search for signs of malignancy; Epidemiology: The project has developed the dose reconstruction and data analysis tools required for a multi-centre prospective epidemiological study using data from paediatric proton therapy treatments, which will test the relative risk models proposed by the project. The results from ANDANTE have largely endorsed the RBE-based radiation weighting factors for neutrons published by the ICRP. In the longer term, the prospective study will provide greater certainty on how well these factors apply to humans receiving proton therapy. This work was supported by the FP7-Euratom projects ANDANTE (Project No. 295970).

Morphological and Molecular Analysis of Radiation-Induced Posterior Capsule Opacification (PCO) of the Lens

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Abstract. It is well established that exposure to ionizing radiation leads to Posterior Capsular Opacifications (PCO) and, in extreme cases, to the formation of cataracts. After radiation exposure, changes in lens tissue take many years to manifest as visible lesions, and the latency of such changes is inversely related to dose. The International Comission on Radiological Protection (ICRP) has classified cataracts as a deterministic effect with a threshold in absorbed dose of 0.5 Gy. However in recent years, an increasing number of studies have been published containing evidence that conflicts with the current assumption of the deterministic nature of PCO and the associated threshold dose. The etiology and the molecular basis of cataractogenesis is not fully understood although it is assumed as a multifactorial process, in which changes generally first appear in the posterior region of the lens as small dots and vacuoles and/or as the result of migration of aberrant cells originated in the germinal epithelium. It is considered that the accumulation of differentiated epithelial cells at the level of the posterior subcapsular region is the consequence of a process known as epithelial-mesenchymal transition (EMT). EMT is a well-documented phenomenon characterized by the expression of specific markers and conferring the cells a distinctive morphology. In order to characterize specific molecular markers that could be associated with PCO as the result of exposures at low doses of ionizing radiation, EMT markers and morphological alterations were studied in human lenses obtained from eye bank donors at the Santa Lucia Ophthalmology Hospital. Analyses of morphological changes and characterization of markers after exposure to sub-threshold doses of ionizing radiation may contribute to a better understanding of cataract etiology and the optimization of the radiation protection measures.

Muscular Pathology due to High Dose Irradiation in Human Muscle

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Abstract. Understanding the pathological features and delayed effects of muscle damage after high dose irradiation is important for developing effective therapy. In this study, we conducted a complete histological, structural and biochemical analysis of muscle tissues from victims of 2 radiological accidents. Biopsy from case #1 (~70 Gy to the skin), harvested 191 days post-accident, displayed two distinct areas with gradual increase of fiber atrophy and fibrosis, and reduced endothelial cell numbers along the muscle-to-skin axis. Inflammatory cell infiltration was evident in the whole muscle biopsy. In addition, TUNEL assay and phospho (P)-γH2AX staining revealed massive apoptosis. Remarkably, we detected the presence of embryonic MHC-positive fibers, demonstrating that despite these serious pathological features, irradiated muscle could still undergo regeneration. Muscle from case #2, harvested 23 days after exposure, benefited from dosimetric reconstruction to isolate samples according to isodoses 20-50 Gy, 50-100 Gy, >100 Gy and >500 Gy. Fibrosis and fiber atrophy were evident in all samples, with more pronounced fiber retraction >50 Gy. Myofiber nuclei were strongly decreased in >100 Gy sample, and completely disappeared >500 Gy. Of note, vascular and immunological abnormalities similar to case #1 were observed in 20-50 Gy sample. Western- blot analysis revealed increased expression of total and activated p53 in all samples, with highest levels >50 Gy. In contrast, p21 was strongly downregulated >50 Gy. Expression of soluble AIF, Bax, caspases 3 and 8, p62 and P-p38 was elevated in all irradiated tissues compared to control. Total AKT level remained similar to control in 20-50 Gy sample, then declined >50 Gy, while P-AKT was virtually undetectable in all irradiated tissues. Last, autophagy-associated Beclin1 and Lc3-II were detected in 20-50 Gy sample. We provide here, for the first time, a detailed analysis of the muscular pathology induced by accidental exposure to high dose irradiation. Our results indicate a dose-dependent effect on structural and functional properties of muscle tissue, involving concomitant activation of stress response, apoptotic and autophagic processes. Importantly, the presence of regenerating fibers in irradiated muscle opens new avenues for the medical management of these lesions, including stem cell therapy, currently under study using animal models of radio-induced muscle injury.

Alveolar Macrophages as a Key Target for Decorporating Agents Following Pulmonary Contamination with Moderately Soluble Actinides

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Abstract. Plutonium (Pu) intake by inhalation is a potential consequence following a nuclear industry accident. After inhalation alveolar macrophages represent a major reservoir for Pu. Macrophages participate in lung clearance by dissolution of internalized compounds depending on their solubility. The only approved countermeasure for Pu is the chelator Ca- DTPA that reportedly has only a limited efficacy on macrophage-internalized Pu. The objectives of this work were i) to evaluate the capacity of macrophages to internalize the moderately soluble Pu nitrate in vivo in rats and in vitro in rat or human macrophage cultures ii) to estimate the release of Pu by cultured macrophages and iii) to assess DTPA efficacy in vivo and in vitro to reduce macrophage-associated Pu. Both in vivo after lung administration and in vitro, Pu accumulation by macrophages was time dependent. In vitro normal rat alveolar macrophages or human macrophage-like cells (THP-1 cells) were incubated for 2h with Pu nitrate to assess Pu uptake and dissolution. DTPA efficacy was evaluated both in vivo and in vitro. In rats, two weeks post exposure whole lung retention was decreased by 3.4 fold in animals treated with local DTPA as compared to untreated ones and retention in alveolar macrophages by 9.4 fold. IV DTPA was ineffective on both parameters. Addition of DTPA (500 µM) enhanced Pu 7 day-release by alveolar macrophages and THP-1 cells. Our data indicate that macrophages represent an important target for chelating treatments following pulmonary exposure with moderately soluble forms of Pu. Such in vitro method could be, as a first assessment, a good alternative to in vivo experiments for determining Pu retention in lung macrophages and chelating agent efficacy. Authors thank AREVA NC for financial support.

Refinement of *In Vitro* Approaches for Radiotoxicological Studies to Predict Actinide Bioavailability *In Vivo*

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Abstract. After accidental or experimental exposure to alpha-emitting actinides, measurement of urinary excretion is used to estimate the transfer from the contamination site to the systemic compartment. New simple and rapid experimental approaches have been developed *in vitro* to address the question of actinide behavior and transfer from contamination site. The first model, the human cell line THP-1 (macrophage-like cells), represents macrophages that play a major role in actinide retention in lungs, solubilization as well as transfer from the lungs. The second model, actinide retention in an agarose gel, has been developed to simulate contamination and retention sites along with different biological media responsible for actinide transfer. These two models have been compared to urinary excretion data obtained *in vivo* from past studies in the rat. For the experimental models several forms of plutonium of different chemical solubilities were used. For macrophages the uptake and subsequent release of Pu into culture media was measured in the absence and presence of the chelator Diethylene Triamine Penta Acetic Acid (DTPA). Similarly the different forms of Pu were included in agarose gels and the transfer of Pu from static to fluid phase was determined. In both the cellular and acellular model Pu transfer from static to fluid phase was greater for the more soluble citrate form of Pu as compared with the Pu colloid preparation. Furthermore DTPA enhanced Pu transfer from either THP-1 cells or from agarose gels. These data are in good agreement with results obtained *in vivo*. In conclusion both the cellular and acellular models demonstrate that actinide retention and transfer depends on the physicochemical properties of the material. In addition the physicochemical and physiological properties of the biological site of contamination and retention are also determinant factors. These two models are in good agreement with data obtained in animals and in man. In particular the acellular model is a simple, rapid technique with which to obtain information on contaminant properties after accidental contamination. Furthermore these approaches are alternative methods that fulfil current societal demands to limit animal experimentation. Financial support from Areva NC is gratefully acknowledged.

Effect of Natural Chronic Low Dose Radiation on Human Population Residing in High Background Radiation Areas of Kerala Coast, in Southwest India

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Abstract. Human Population living in high level natural radiation areas (HLNRA) of Kerala coast provides an ideal situation to delineate the effect of low dose/low dose rate ionizing radiation directly in humans. The narrow coastal strip (55 Km long and 0.5 Km wide) of Kerala extending from Neendakara in the south to Purakkad in the north contains monazite in its beach which has 8-10% thorium. The external gamma radiation level in this area ranges from <1 mGy/year to 45 mGy/year. Several investigations are carried out by BARC to study the effect of natural chronic low dose radiation in human population living in this area since generations. So far, over 1,50,000 newborns have been screened in hospital based study and the incidence of congenital malformations, sex ratio at birth, still births and down syndrome did not show any significant difference between normal level natural radiation areas (NLNRA) and HLNRA. A Case control study on cleft lip/palate and mental retardation did not reveal any association with background radiation dose. Cytogenetic investigation of over 27,000 newborns did not reveal any increased frequency of constitutional anomalies, and chromosomal aberrations. DNA damage parameters such as micronuclei, telomere length and DNA strand breaks did not show any significant difference between HLNRA and NLNRA population. Study on DNA damage and repair revealed efficient repair of DNA strand breaks in HLNRA individuals. Further, molecular studies are in progress to understand mechanistic effect of low dose radiation in this area. In conclusion, so far, our study did not reveal significant difference in any of the biological end points between NLNRA and HLNRA population of Kerala coast.

Radiomodifying Effects of Medicinal Plants *Centella asiatica* and *Withania somnifera*

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Abstract. There is a continuous rise in cancer burden in Africa due to changes in lifestyle, ageing and population growth. Since 50% of cancer patients undergo radiotherapy with varying responses based on tumour radiosensitivity, modification of radiotherapy treatment could be one approach that may assist in maximising tumour control and minimising adverse effects. Thus it would be ideal to use "natural constituents" that act as radiomodulators to assist in the sensitisation of tumour cells without causing significant damage in normal cells. Medicinal plants like *Centella asiatica* (*C. asiatica*) and *Withania somnifera* (*W. somnifera*) have been shown to have anticancer properties, and these anticancer properties may assist in radiosensitising cancer cells without causing significant damage to normal cells. To test the hypothesis, aqueous extracts of *C. asiatica* and *W. somnifera* were evaluated for their radiomodifying effects in apparently normal Chinese hamster lung fibroblasts (V79) and human breast epithelial cells (MCF-12A). For this, the V79 and MCF-12A cells were pre-treated with aqueous extracts of *C. asiatica* and *W. somnifera* and immediately irradiated to 2 Gy of X-rays. Radiomodifying effects of the extracts in each cell line were evaluated, using the colony forming assay. Pre-exposure to aqueous extracts of *C. asiatica* and *W. somnifera* resulted in a significant and moderate radiosensitisation in V79 cells, with radiation modifying factors of 2.17±0.43 (P=0.0051) and 1.71±0.23 (P=0.0463), respectively. For the MCF12-A cell line, the modifying factors emerged as 1.13±0.17 (P=0.3751) and 2.45±0.55 (P=0.0026), respectively, indicating no radiomodulatory effect from *C. asiatica*. These findings show that pre-treatment with aqueous extracts of *C. asiatica* and *W. somnifera* may significantly sensitise normal cells to ionising radiation, and potentially enhance tumour response to radiotherapy. Further studies on a larger panel of tumour and normal cell lines might assist in fully determining the degree of radiosensitisation and potential benefits of these extracts.

KEYWORDS: Centella asiatica; Withania somnifera; radiomodulatory effects; normal tissue response.

Highlights of the Russian Health Studies Program and Updated Research Findings

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Abstract. Recognized for conducting cutting-edge science in the field of radiation health effects research, the Department of Energy's (DOE) Russian Health Studies Program has continued to generate excitement and enthusiasm throughout its 23-year mission to assess worker and public health risks from radiation exposure resulting from nuclear weapons production activities in the former Soviet Union. The three goals of the Program are to: (1) clarify the relationship between health effects and chronic, low-to-medium dose radiation exposure; (2) estimate the cancer risks from exposure to gamma, neutron, and alpha radiation; and (3) provide information to the national and international organizations that determine radiation protection standards and practices. Research sponsored by DOE's Russian Health Studies Program is conducted under the authority of the Joint Coordinating Committee for Radiation Effects Research (JCCRER), a bi-national committee representing Federal agencies in the United States and the Russian Federation. Signed in 1994, the JCCRER Agreement established the legal basis for the collaborative research between USA and Russian scientists to determine the risks associated with working at or living near Russian former nuclear weapons production sites. The products of the Program are peer-reviewed publications on cancer risk estimates from worker and community exposure to ionizing radiation following the production of nuclear weapons in Russia. The scientific return on investment has been substantial. Through 31 December 2015, JCCRER researchers have published 299 peer-reviewed publications. To date, the research has focused on the Mayak Production Association (Mayak) in Ozersk, Russia, which is the site of the first Soviet nuclear weapons production facility, and people in surrounding communities along the Techa River. There are five current projects in the Russian Health Studies Program: two radiation epidemiology studies; two historical dose reconstruction studies and a worker biorepository. National and international standard-setting organizations use cancer risk estimates computed from epidemiological and historical dose reconstruction studies to validate or revise radiation protection standards. An overview of the most important research results will be presented.

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Modifying the Cytokinesis-Block Micronucleus Assay for Triage Biodosimetry

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Abstract. Purpose: Reduction of efforts for applying the cytokinesis-block-micronucleus assay (CBMN) for biodosimetry by adapting scoring procedures to triage demands (dose range, speed, simplicity, field deployability) and avoiding expensive and susceptible automation. Material and Method: Peripheral blood of 20 donors was irradiated in vitro (0-6 Gy X-ray) and processed for CBMN. Two manual scoring strategies were applied and their precision assessed. 1. Conventional scoring: Micronucleus frequency in up to 1,000 binucleated cells (MN/1,000 BN; CBMN_convent). 2. Modified scoring: Evaluation of only 1,000/2,000/3,000 cells in total and differentiation of cellular subsets referring to MN formation and proliferation (e.g. BN with or without MN, mononucleated cells). The association of cellular subsets with dose and the discrimination ability among different doses/dose-categories were examined using linear and logistic regression models. Based on observed dose-response relationships and the discrimination ability of different dose categories, most promising subsets and their combinations were identified and validated with 16 blind samples covering a dose range of 0-8.3 Gy. Results and Conclusion: Linear dose-response relationships with a strength comparable to CBMN_convent (r^2=0.86) were found for BN without MN (r^2=0.84) and BN with MN (r^2=0.84). Models of combined cell counts (CCC) of BN without or with MN (BN^{-MN} or BN^{+MN}) with mononucleated cells (Mono) even improved this association (r^2=0.92). CBMN_convent at 1,000 total cell counts performs as efficient as based on counting 1,000 BN. Discriminating and counting only BN with/without MN after 1,000 BN at < 4 Gy reveal performances comparable to the CBMN_convent. CCC(Mono + BN^{+MN}) after scoring at least 3,000 total cells appeared even superior to the CBMN-convent at > 4 up to about 8 Gy. Thus, a modification of CBMN evaluation aimed to save time as well as to extend the dose range at least up to 6 Gy for triage biodosimetry could be developed.

Ionising Radiation Biological Markers for Health Risk Prediction

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Abstract. Ionizing radiation is a known human carcinogen that can induce a variety of biological effects depending on the physical nature, duration, doses and dose-rates of exposure. However, the magnitude of health risks at low doses and dose-rates (<100 mSv) remains controversial due to a lack of direct human evidence. Biological markers of ionizing radiation present some quantitative changes that occur in biological systems as a result of their action. There are a number of biological markers that indicate the dose-dependent effect: Cytogenetic biomarkers, Biomarkers related to nucleotide pool damage and DNA damage, Biomarkers related to germline inherited mutations/variants, Biomarkers related to induced mutations, Biomarkers related to transcriptional/ translational changes, Biomarkers related to epigenomic modifications, etc. Cytogenetic changes in peripheral blood lymphocytes and-electronic paramagnetic resonance (EPR) of the enamel are currently the most used methods validated for biological dosimeter by the International Atomic Energy Agency. Biodosimetry is part of radiological protection and is normally used in cases of overexposure. Biodosimetry in case of accident include biophysical methods, that provide information about the distribution of dose and dose neutron component, and classical methods (assessing of the amount of lymphocytes, dicentric and acentric fragments, electroencephalography, biochemical markers), by which we can evaluate the average of biological dose. Biodosimetry rating remains a difficult task, because of the particularly heterogeneity of exposure. The only way of solving the problem is to determine the dose using several technologies. Unlike physical dosimetry methods, biodosimetry usually are not used for evaluation of doses <0.1Gy, and in addition the radio-individual variability acts upon them. Usually immediately after the accident is used biodosimetry method based on evaluating of the frequency of unstable chromosome aberrations (dicentric and centric rings). By comparing the frequency of dicentric/ centric rings with standard curve "dose-effect" obtained under in vitro it is possible to determine the exposure dose. EPR dosimetry was used successfully after Chernobyl disaster. The essence of the method consists in the quantitative determination of lesions of the tooth enamel. Tooth enamel is fairly accurate individual natural dosimeters that exist in humans since the formation of teeth. Based on analysis of RPE signal level, amount of free radicals in enamel edging is determined. EPR dosimetry have essential threshold of sensitivity (50mGy) and highest accuracy for retrospective methods (30-50%).

Sustainable Development and Nuclear Law in Argentina

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Abstract. Considering the serious problems posed by natural disasters and taking into account the role of man as maker of his environment, a new concept of development, which incorporated the environmental variable, has been outlined. The Report of the United Nations Conference on the Human Environment (1972) and the Report of the World Commission on Environment and Development of the same organization (Our common future, 1987), have noticed this new paradigm, being the latter which established the concept of sustainable development. The idea of "sustainable development" sets out the need for a development capable of satisfying the needs of the present without compromising the ability of future generations to meet their own needs. Thus, limitations to all human activities from the perspective of not affecting the environment within previously established parameters are certain to arise. In legal terms, these limits are projected both in the international and national environmental legal framework. The constitutional reform of Argentine Republic (1994) incorporates this concept. It establishes in its Article 41: "All inhabitants are entitled to the right to a healthy and balanced environment fit for human development in order that productive activities shall meet present needs without endangering those of future generations... ". In accordance with this new tendency, the environment is considered as a "good of collective impact", that should be legally protected, when positioning the environmental issue as a specific subject of regulation. Nuclear energy and the various applications of nuclear technology contribute with big benefits to humanity. Moreover as any activity, it has the capability of changing the environment and people's health and also can result in property damages. For this reason, there exists a legal framework that legislates and regulates the nuclear activity at a national and international level. Notwithstanding, the environmentalist approach permeates this framework based on the environmental principles set up by the international community. In this work, we will summarize the national and international legal framework of nuclear activity, in order to detect the influence of the environmental law principles in the legal and regulatory framework of nuclear energy in Argentina. It shall be taken into account the position of environmental issues as specific subject of legislation, and the distribution of competencies performed by the National Constitution on this issue.

Design, Development and Application of a Desk-Top Laser Produced Plasma X- Ray Source for Radiobiology Studies

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Abstract. A compact laser plasma source has been developed and applied for determination of DNA damage by soft X-rays. The source is based on a commercially available laser, synchronized to irradiate Ar/He gas puff target and optimised to give higher emission in the X-ray “water window” spectral wavelength range. The source allows irradiation of samples under vacuum and helium conditions. Single- and double-strand breaks induced in DNA plasmids pBR322 and pUC19 induced by nanosecond X-ray pulses have been determined. The different conformations of the plasmid DNA were separated by agarose gel electrophoresis. An exponential decrease in the supercoiled form with an increase in linear and relaxed forms of the plasmids has been observed as a function of photon fluence. The ratios of the yields of single-strand break (SSB) to double-strand break (DSB) for both dry plasmid DNA samples were approximately 11, whiles the SSB/DSB ratios for pUC19 and pBR322 DNA samples irradiated in water solution were 3 and 7, respectively. The formation of DSBs in the case of wet samples was more significant as compared to the dry irradiated samples. This may be explained that the soft X-rays from the source is capable of inducing free radicals in the wet sample and subsequently inducing indirect effect to the plasmid DNA. The source is, therefore, a potential device for prospective radiobiology experiments.

Low Dose Effect Research at the Electric Power Research Institute

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Abstract. Research on low dose and low dose rate effects is being conducted in many places throughout the world. In the United States, the Electric Power Research Institute (EPRI) has been supporting a set of activities for several years, with the objective to help better define the dose-response relationship in the low dose region. The original "roadmap" of work was developed several years ago, and included topics in low dose rate effectiveness, evaluation of non-cancer effects, and critical analysis of population study proposals. EPRI is now updating its roadmap, and considering broader engagements to reduce uncertainty in risk estimates, and develop a framework for international collaboration. While there are a number of regional organizations, such as within the European Union, and the international organizations such as the International Commission on Radiological Protection and the United Nations Scientific Committee on the Effects of Atomic Radiation, there is no international framework to coordinate research around a common goal between researchers in Europe, Asia, and the Americas. Coordination would lead to better leveraging of resources, communication of information, and integration of results which will enhance the effectiveness of all R&D programs. This paper will describe the current EPRI program of work, the EPRI roadmap for work over the next several years, and the proposals to initiate a framework for coordination among the research organizations throughout the world.

Role of Radiation Dose in Cardiac and Cerebrovascular Disease Risk following Childhood Cancer: Results from CEREBRAD and PROCARDIO FP7-European Projects

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Abstract. Childhood cancer survivors having been treated by radiation therapy are the population the most at risk of cardiac and cerebrovascular radiation-induced diseases. To predict cardiovascular risk in yet treated patients and to anticipate the risk induced by new radiation therapy techniques, needs to establish reliable dose-response for radiation dose. In the Frame of CEREBRAD FP7 project, we set up a European case-control study, including 233 cases of strokes having occurred 5 years or more following a childhood cancer and 233 controls matched on cohort, gender, age and date of childhood cancer, and length of follow- up. We performed very detailed radiation dose estimation in all brain structures and in cerebral arteries (CA), based on medical records and human voxelized phantoms. When all types of strokes were considered together, the excess odds ratio (EOR) of stroke per Gy of average radiation dose to the cerebral arteries, was equal to EOR/Gy = 0.5 (95% CI: 0.2 to 1.2) in a linear model. Adding an exponential or a quadratic term to the model did not improve the fit of the data. The radiation dose received to brain structures other than brain arteries did not play any role. In the Frame of PROCARDIO FP7 project, we set up a similar European case-control study including 222 cardiac diseases and 222 individually matched controls. The EOR at 1Gy of average heart radiation dose was equal to 0.08 (95%CI: 0.05-0.1), no interaction being observed with anthracycline administration, which is a strong risk factor, but did not significantly interact with the radiation dose response.
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Dose-related Effects of Long-term Radiation Exposure on Aquatic Biota within the Chernobyl Exclusion Zone: 30 years after accident

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Abstract. The established during 1998-2015 effects of long-term radiation exposure on hydrobionts of water bodies within the Chernobyl exclusion zone indicates a damage of biological systems at subcellular, cellular, tissue, organ, organism and population levels as a result of low doses of ionizing radiation. The rate of chromosomal aberrations in cells of aquatic species in many times exceeds the level of spontaneous mutagenesis level to aquatic biota. Increased levels of chromosome damages may be a manifestation of radiation-induced genetic instability. It is determined that the rate of chromosomal aberrations in the roots of the helophyte plants of the most contaminated lakes on average in 2-3 times and in cells of the pond snail embryos in 4-6 times exceeding the spontaneous mutagenesis level, inherent to aquatic organisms. Leukogram analysis of peripheral blood of fish showed the decrease of part of lymphocytes, responsible for the implementation of immunological reactions. At that it is registered increase in the number of granulocytic elements (neutrophils and pseudoeosinophils), responsible for phagocytic function and involved in allergic and autoimmune reactions. Along with changes in leukograms an increased level of morphological damages of erythrocytes (deformation of nucleus and cell membrane, nucleus and cytoplasm vacuolization, pyknosis and lysis of cells, forming of microcytes, schistocytes, double nucleus cells and micronuclei) was determined, which is generally for pray fish in 4-12 times and for predatory fish in 7-15 times higher than in fish from reservoirs with background levels of radioactive contamination. Analysis of the viability of the seed progeny of the common reed at germination in the laboratory showed that in gradient of absorbed dose rate from 0.03 to 11.95 cGy year^{-1} for parental plants in lakes, there is a reduction in technical germination (from 93 to 60%), germination energy (from 91 to 30%) and seed viability (from 54 to 38%). At the same time significantly increased the number of abnormalities of seed seedlings: necrosis of roots (from 1.3 to 14.7%); disturbance of gravitropism (from 2.6 to 17.0%); damages of organogenesis (from 4 to 24%) and disturbance of chlorophyll synthesis (from 0 to 2%).

The International Nuclear Workers Study (INWORKS): a collaborative epidemiological study to improve knowledge about health effects of protracted low dose exposure

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Abstract. INWORKS is a multinational cohort study, gathering 308,297 workers in the nuclear industry in France, the United Kingdom, and the United States of America, with detailed individual monitoring data for external exposure to ionizing radiation. Over a mean duration of follow-up of 27 years, the number of observed deaths was 66,632, including 17,957 deaths due to solid cancers, 1791 deaths due to haematological cancers and 27,848 deaths due to cardiovascular diseases. Mean individual cumulative external dose over the period 1945 to 2005 was 25 mSv. Analyses demonstrated a significant association between red bone marrow dose and the risk of leukaemia (excluding chronic lymphocytic leukaemia) and between colon dose and the risk of solid cancers. INWORKS assembled some of the strongest evidence to strengthen the scientific basis for the protection of adults from low dose, low dose rate, exposures to ionizing radiation.

KEYWORDS: cancer; leukaemia; mortality study; ionizing radiation; nuclear workers; epidemiology.

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Estimates Of Radiation Effects On Cancer Risks In The Mayak Worker, Techa River and Atomic Bomb Survivor Studies

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Abstract. For almost 50y, the Life Span Study cohort of atomic bomb survivor studies has been the primary source of the quantitative estimates of cancer and non-cancer risks that form the basis of international radiation protection standards. However, the long-term follow-up and extensive individual dose reconstruction for the Russian Mayak worker cohort (MWC) and Techa River cohort (TRC) are providing quantitative information about radiation effects on cancer risks that complement the atomic bomb survivor-based risk estimates. The MWC, which includes ~26000 men and women who began working at Mayak between 1948 and 1982, is the primary source for estimates of the effects of plutonium on cancer risks and also provides information on the effects of low-dose rate external gamma exposures. The TRC consists of ~30000 men and women of all ages who received low-dose-rate, low-dose exposures as a consequence of Mayak's release of radioactive material into the Techa River. The TRC data are of interest because the exposures are broadly similar to those experienced by populations exposed as a consequence of nuclear accidents such as Chernobyl. In this presentation, it is described the strengths and limitations of these three cohorts, outline and compare recent solid cancer and leukemia risk estimates and discussed why information from the Mayak and Techa River studies might play a role in the development and refinement of the radiation risk estimates that form the basis for radiation protection standards.

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Study on Cytotoxic Effects of the Auger Electron Emitter Technetium-99m in Functional Rat Thyroid Cells

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Abstract. Because of its favorable half-life (6.02 hours) and distinct characteristic gamma-line, Technetium-99m (^{99m}Tc) is the most widespread radionuclide in nuclear medicine. Additionally, ^{99m}Tc emits low energetic, short-range Auger electrons. When located in close proximity to the DNA, the biological effects caused by Auger electron emitters (AEE) are severe and comparable with those induced by high-LET particles. This poses the question towards an enhanced relative biological effectiveness (RBE) of AEE. To assess the potential impact of ^{99m}Tc-Pertechnetate on the cellular level, the cytotoxicity of ^{99m}Tc was investigated after extracellular and intracellular localization in the functional rat thyroid cell line, FRTL-5. Moreover, the AEE Iodine-125 (^{125}I) as well as external γ-radiation were used to compare effects. FRTL-5 cells were exposed to ^{99m}Tc-pertechnetate (25, 50 and 75 MBq) respectively ^{125}I-chloride (0.075 – 1.2 MBq), either intra- or extracellular located, and to external ^{137}Cs γ-irradiation (0.7 Gy/min; Gammacell-40). Clonogenic assay (colony-forming assay, CFA) was performed to determine cell killing, i.e. loss of reproductive capacity. To achieve extracellular localization of ^{99m}Tc respectively ^{125}I, the Sodium-Iodide Symporter was inhibited with sodium perchlorate. Point kernel calculations based on Monte Carlo simulated Auger electron spectra (Pomplun, 2012) allowed to convert the nuclides' activities into dose values. Rapid uptake of ^{99m}Tc and ^{125}I by the FRTL-5 cells was observed within the first few minutes after application. Both AEE were more cytotoxic per decay when located intracellular compared to extracellular localization. On a dose related scale, however, the differences in case of ^{99m}Tc disappeared. Compared to high-dose rate external ^{137}Cs γ-irradiation, cell killing was much weaker after ^{99m}Tc-exposure supporting previous experimental findings on MN induction in SCL-II cells (Kriehuber et al. 2004). The SP treatment itself had no influence on cytotoxic damage. Since no significant effect on cell killing due to the position (intra- vs extracellular) of ^{99m}Tc could be detected per unit dose, the establishment of an enhanced RBE for ^{99m}Tc-pertechnetate due to the emitted Auger electrons seems to be unnecessary. Furthermore, the extremely weak cytotoxic effect of ^{99m}Tc compared to external high-dose rate exposure (^{137}Cs) is most likely to be explained by the low dose rate of the ^{99m}Tc exposure.

The Growth of Biostatistics and Estimation of Cancer Risk Estimates: Past, Current, and Future Challenges

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Abstract. There has been a long process of growth and development of statistical approaches to the analysis of cancer incidence and mortality data obtained from the follow-up of radiation exposed populations. The challenges of obtaining the most useful descriptions of cancer risk in relation to dose for the purpose of radiation protection provided impetus for the development of many innovative statistical methods, including, perhaps most notably, the inception and continued improvement of hazard rate regression methods. Other key statistical contributions that improved cancer risk estimation include many statistical advances pertaining to the measurement error problem, which, if not addressed, affects risk estimation in multiple ways, e.g., attenuation due to random dose error, loss of control of type I error, and distortion of covariance structures for multiple radiogenic outcomes. Current statistical problems involve extensions of the measurement error methods to account for shared non-independent uncertainties in dose estimation, “transportability” of risk coefficients from unique studies to the world at large (for radioprotection and risk estimation), and extrapolation from high dose rate to low dose rate exposures or from low LET to high LET. Future problems include quantification of individual sensitivity to radiation-related diseases due to individual genetic differences (or other factors), and in understanding the synergy (additive, multiplicative, etc.) between underlying individual risk and radiation exposure. A historical view of these statistical challenges and the past and continued contribution of biostatistics to cancer risk estimation will be provided.

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External Irradiation of the Thyroid Results in Non-targeted Transcriptional Response in the Kidneys and Liver

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Abstract. Introduction: The thyroid gland may be exposed by ^{131}I after release at a nuclear accident or when used in nuclear medicine. The thyroid takes part in metabolic regulation in the body in a systemic manner that needs to be considered when analyzing normal tissue response for biomarker discovery and risk assessment. The aim of the study was to examine out-of-field or long-range non-targeted response in the kidneys, liver, lungs or spleen after external irradiation of the thyroid. Methods: Female BALB/C nude mice were irradiated by 4 MV (nominal) photons to 2 Gy. In group A the collum, in group B thorax and abdomen were irradiated, and in group C collum, thorax, and abdomen were irradiated. The control group was mock-treated. Animals were killed after 24 h and the kidneys, liver, lungs, spleen, and thyroid were collected, flash-frozen, and stored at -80°C until extraction of total RNA. Genome-wide transcriptional regulation was analyzed by microarray technique. Significantly regulated transcripts were identified with Nexus Expression 3.0. The Gene Ontology database was used to identify enriched biological processes and categorize them after cellular function. A specific analysis of ionizing radiation-associated signature genes and thyroid hormone-responding signature genes was made. Pathway analysis was performed using IPA. Results: Irradiation of the thyroid resulted in transcriptional regulation in kidney medulla and liver that was similar to that after irradiation of thorax and abdomen, both considering expression intensity and regulated genes. Kidney cortex showed a lower degree of similarity between the groups, while lungs and spleen exhibited only marginal out-of-field response. Conclusion: Out-of-field response resembled in-field response on the transcriptomic level to varying degree in different tissues. Further studies are needed to identify the molecular mechanisms underlying these non-targeted effects and to assess the relative contribution from physiological systemic factors and ionizing radiation-associated pathways. The results may be important for better risk assessment.

Genome-wide Transcriptional Response in Normal Tissues are Influenced by Time of Day of I.V. Injection of ^{131}I in Mice

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Abstract. Aim: The aim of this work was to study the influence of circadian rhythm on genome-wide transcriptional response to ionizing radiation exposure. Methods: Female BALB/c nude mice were i.v. injected with 90 kBq ^{131}I at 9:00 am, 12:00 am, or 3:00 pm. For each time-point a control mice were mock-treated with saline. At 24 h after respective treatment mice were killed. The kidneys, liver, lungs, spleen, and thyroid were excised, flash-frozen, and stored at -80°C. Cortical and medullary kidney tissues were prepared separately. Total RNA was extracted from tissue samples and analyzed using the Illumina microarray platform. Data processing was performed with Nexus Expression 3.0 and transcripts were regarded statistically significant regulated when fold change>1.5 and adjusted P<0.01. Response of ionizing radiation or thyroid hormone signature genes was specifically analyzed. MIRD formalism was used to estimate absorbed dose to each tissue. Results: Absorbed dose to the thyroid was 5.9 Gy and to non-thyroid tissues 0.75-2.2 mGy during 24 h. The biological response was strongest in the thyroid at 9:00 am with 1015 significantly regulated transcripts, compared with only 50 (12:00 am) and 57 (3:00 pm) transcripts at later time-points. In the thyroid, 29 of the 30 transcripts that responded at all time points showed a distinct pattern with pronounced down-regulation at 9:00 am and weak up-regulation at 12:00 am and 3:00 pm. Most of these genes belong to the kallikrein family, and their transcription may be related to hormone levels. In non-thyroid tissues, the strongest biological response was seen in kidney medulla followed by liver and kidney cortex, with a distinct maximum at 12:00 am with 444, 184, and 105 regulated transcripts, respectively. In lungs and spleen, <6 transcripts responded at any time point. Thyroid hormone-associated signature genes were regulated more frequently than ionizing radiation-associated signature genes. The circadian rhythm core genes showed a negligible response. Conclusion: Transcriptional response 24 h after ^{131}I injection differed significantly due to time-point of injection, both regarding intensity but also regarding associated biological function. The dominantly exposed thyroid seems to influence transcriptional response in kidneys and liver via systemic factors. These findings are important to consider for biomarker discovery and might be of interest in risk estimations.

The potential impact of circadian rhythms on paediatric medical imaging and radiotherapy

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Abstract. Circadian (24-hour) rhythms and cell division are fundamental biological systems in most organisms. There is substantial evidence that, in mammals, circadian rhythms affect the timing of cell divisions in vivo. Day-night variations in both the mitotic index and DNA synthesis occur in many tissues (e.g. oral mucosa, tongue keratinocytes, intestinal epithelium, skin, and bone marrow) [1-12]. How the circadian clock controls the timing of cell divisions, however, is not known. Determining how this clock organizes important processes such as cell division, apoptosis, and DNA damage repair is key to understanding the links between circadian dysfunction and malignant cell proliferation, but it is also key to understanding how best to organize radiotherapy and medical imaging for children.

KEYWORDS: circadian rhythm; cell proliferation; radiosensitivity; medical imaging; eye lens.

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DS02R1: Improvements to Atomic Bomb Survivors' Input Data and Implementation of Dosimetry System 2002 (DS02) and Resulting Changes in Estimated Doses

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Abstract. Individual dose estimates calculated by Dosimetry System 2002 (DS02) for the Life Span Study (LSS) of atomic bomb survivors are based on input data that specify location and shielding at the time of the bombing (ATB). A multi-year effort to improve information on survivors' locations ATB has recently been completed, along with comprehensive improvements in their terrain shielding input data and several improvements to computational algorithms used in combination with DS02 at RERF. We explain how the improved doses were achieved. To understand the impact of the updated doses, analyses from RERF's latest report estimating the radiation risk for solid cancer mortality were repeated using the new doses and the results were compared. Generally, sex- averaged dose response estimates were nearly identical over both the full range as well as a restricted range (0-2 gray weighted absorbed colon dose). Sex-specific results were also very similar while there were slight differences in the restricted range less than 2 Gy. The revised doses will become the primary doses for future RERF analyses.

Solid cancer incidence among the Life Span Study of atomic bomb survivors: 1958-2009

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Abstract. This is the third comprehensive analysis of solid cancer incidence among the Life Span Study (LSS) cohort of atomic-bomb survivors in Hiroshima and Nagasaki, adding eleven years of follow-up data through 2009. The eligible cohort included 105,444 subjects who were alive and had no known history of cancer at the start of follow-up, which included 80,205 subjects with individual dose estimates and 25,235 who were not in either city at the time of the bombings. 22,538 incident first primary solid cancer cases were observed, 5,918 cases (26%) occurred in the 11 years (1999-2009) since the previous report. As of the end of follow-up, 36% of the cohort was alive. New doses based on better estimates of the survivor's locations at the time of the bombing were included as well as adjustment for smoking based on survey data. Poisson regression methods were used to describe the nature of the radiation risks using both excess relative risk (ERR) and absolute risk (EAR) models. Modifications of risk estimates by sex, age at exposure, and attained age were explored. Results using a linear model were consistent with the previous report, with little impact due to the new doses or adjustment for smoking. However, unlike the previous report, a linear-quadratic fit the data better for men while a linear model fit the data better for women. Smoking adjustment had little or no impact on the shape of the dose response. As observed in previous reports, the ERR decreased with increasing age at exposure for both males and females; the ERR decreased significantly with increasing attained age but tended to do so more rapidly for males than females. Despite the long follow-up of this cohort, the recent results have produced some unresolved issues. As these issues are evolving and under investigation, we urge caution with the interpretation of the curvature findings and drawing conclusions from the present data.

Protein Status in Atomic Workers in Distant Period after Long-term Occupational Combined Low-dose Exposure

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Abstract. Search of informative biomarkers of late effects of long-term exposure to external γ-radiation and α-radiation due to incorporated ^{239}Pu in low doses is considered to be an extremely important and complicated task. Biological mechanisms of low dose radiation exposure and its quantitative assessment are still a matter of argument and the problem of their personal hazard is not solved yet. The objective of the work – assessment of the protein status of 34 atomic workers exposed to long-term external and internal radiation in low doses. Material and methods. Concentration of regulatory proteins (stem cell factor – SCF, transforming growth factor – TGF-β1, receptor of the epidermal growth factor EGF – HER-2/neu, interleukins IL-15, IL-17, IL-18) participating in immune protection and regulating anti- tumor immunity was measured in the blood by ELISA method. The samples of blood serum stored under the temperature -80ºC were obtained in Radiobiological Human Tissue Repository of the Southern Urals Biophysics Institute of the FMBA of Russia that was established and maintained by the Joint Coordination Committee for Radiation Effects Research (JCCRER). Calculated cumulative doses accumulated for 3-35 years of external occupational exposure were 49±4 mSv to red bone marrow, 61±4 mSv to lungs, 73±5 mSv to bone surface, 60±4 mSv to liver; plutonium doses were correspondingly 8±1 mSv, 25±4 mSv, 145±28 mSv and 39±7 mSv. The age of the studied individuals was 61.8±1.4 years. Concentration of growth factor SCF in blood was above the upper normal limit in 20.6% of the exposed workers, TGF-β1 – in 6% of the individuals, HER-2/neu – in 11.7%; concentration of IL-15, 17 and 18 was above the upper normal limit in 26%, 16% and 25% of the individuals respectively. It should be noted that in the course of investigation in 41% of the individuals IL-15 was not detected as it was below the lower limit of sensitivity of the test-system. The results give evidence of the activation of expression of growth factors and multifunctional interleukins responsible for proliferation, differentiation and apoptosis of immunocompetent cells among the old stagers of atomic industry exposed to long-term low dose radiation.

Cancer Incidence among Mayak Workers

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Abstract. Introduction: The Mayak Workers Cohort is a unique data set, which provides direct evidence that internal plutonium exposure increases cancer risk in humans. Materials: Last study was conducted on the cohort of 22,377 workers hired at reactor, radiochemical and plutonium plants of Mayak Production Association in 1948-1982 followed up to end of 2008. Annual individual occupational gamma rays doses and doses due to inhaled Pu-239 exposure, calculated according to Mayak Worker Dosimetry System – 2008 methodology, were used for estimation of excess relative risks per unit of accumulated doses. Cancer incidence with more detailed analysis (if compared to earlier works) of radiation risk for separate cancer localizations and histological types was the objective of the study. Results: The results obtained for lung cancer with regard to histological types indicated that all cell types (excl. small-cell cancer) were associated with plutonium exposure, but the excess relative risk among males for adenocarcinoma was greater than that for squamous- cell cancer, small-cell cancer and other epithelial cancers. For liver cancers, the hepatocellular histological type of carcinoma was associated with internal plutonium exposure, although hemangiosarcomas were mainly observed at high internal plutonium doses. A statistically significant risk of external gamma-radiation was observed for lung, lip, oesophagus, stomach and thyroid. In terms of plutonium exposure, the incidence data did reveal suggestive evidence for solid cancers as a group, but became statistically insignificant once an adjustment for external dose was made. As for hematopoietic cancers, the estimates obtained in the course of current study confirmed the lack of evidence of the effect of incorporated plutonium for incidence of any form of hemoblastosis.

Comparison of Total Antioxidant Capacity level between radiation workers in diagnostic radiology and other staffs of hospital in Zahedan

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Abstract. Introduction: Antioxidant system is essential for life and metabolism of body cells. The balance among free radicals and reactive oxygen species and antioxidants is optimal, as both extremes, oxidative and antioxidative stress, are damaging. Consistently cause of violation this balance is oxidative stress–induced Radiations mainly produced by interaction of ionizing radiation with water exists in tissues. Radiation workers in diagnostic departments are exposed to low dose rate ionizing radiations. So it was necessary to assay the total antioxidant capacity (TAC) of radiation workers serum in diagnostic radiology centers of Zahedan city in I.R.Iran. Method and Materials: This case-control study contained by 41 case radiation workers and 81 controls from January 2013 to October 2014, in biochemistry Laboratory of Zahedan university of medical science. Case persons were taken from radiation workers who didn't go vacation in the past month and control from staffs of other parts of centers with the least probability of man-made radiation exposure. Case-control arms matched in age, gender and economic situation. Then 5 ml whole blood was taken from each of them. For measurement TAC of serum we used FRAP assay (Ferric Reducing Ability of Plasma). P values <0.05 were considered as statistically significant. Results: Mean capacities of antioxidant were 801.3 and 879.89 µmol/L for control and case groups respectively. It was not statistically significant ($P=0.062$). There was statistically significant relation with gender. ($P=0.021$, $F=0.96$). Average level was measured 941.20 ± 149.09 and 826.95 ± 93.95 µmol/L for men and women respectively. Conclusion: It seems that antioxidant systems are effective in deactivating produced free radicals. It can be concluded exposure to radiation was not amount to have significant effect on TAC of persons in this study. It matched data extracted from film badge dosimeters. Antioxidant level was higher in men than women, because of higher uric acid of serum.

Effects of Radon Inhalation on Biophysical Properties of Blood in Rats

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Abstract. The present study performed on rats was designed to investigate the effect of radon exposure on blood properties particularly osmolality and fragility, the absorption spectra of haemoglobin, the rheological properties of blood such as the consistency index, yield stress, apparent viscosity and flow index. Measurements have been performed in a radon chamber where rats were exposed to radon gas for four hours a day, for three days per week simulating in this case the circumstances in which miners are exposed to radon. Different groups of rats were exposed to radon for one, five or seven weeks. The conclusion of the results indicates that the biological membranes are very sensitive to alpha particles emitted from radon gas. This conclusion was born out from the results obtained from the RBCs membrane (blood film, osometry and viscosity). The blood viscosity, consistency index, yield stress, and aggregation index of RBCs increase with increasing radon doses. Exposure to radon alters the mechanical properties of RBCs membrane (permeability and elasticity) reflecting a change in its physiological properties.

Assessment of Respiratory Toxicity of ITER-like Tungsten Metal Nanoparticles using an in vitro 3D Human Airway Epithelium Model

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Abstract. During ITER operation, tritiated tungsten nanoparticles (W-NPs) will be generated. They could be possibly released in the tokamak vicinity during a “Loss of Vacuum Accident” (LOVA). Accidental inhalation of such radioactive NPs could be harmful for ITER workers. Given the deficit of knowledge concerning their potential radiotoxicity, we evaluated W-NP toxicity on an innovative 3D in vitro cell model of the human airway epithelium grown on air-liquid-interface, MucilAir®. This model is characterized by similar morphology and functions of the normal human airway epithelium and by mucus secretion and cilia beating. Epithelia were exposed to either W-NPs produced by planetary milling (50-100nm), soluble tungsten (WO4), or tungsten carbide cobalt alloy (WC-Co) positive control, for 24 h at 10; 20; 50 µg/cm^2. Due to the long shelf life of this model, NP cytotoxicity was studied immediately after treatment and in a kinetic mode up to 1 month after cell exposure to assess the reversibility of toxic effects. Acute and long-term toxicities were monitored by several endpoints: 1) epithelial tightness, 2) cellular metabolic activity, 3) pro-inflammatory response, 4) mucus secretion, and 5) morphological modifications. Transmission Electronic Microscopy (TEM) observations and ICP-MS measurements were performed to determine NP entry, behaviour and passage across the MucilAir® model. After 24h of W-treatment, Trans-pithelial Electric Resistance and metabolic activity decreased and IL-8 apical secretion increased (coupled with mucus hyper- secretion). These results were more or less pronounced depending on the tungsten form. One week later, the effects were no longer observed for W-NP treatment but still observed for WO4 and WC-Co. Different tungsten cellular distributions were found in function of the restoration period and tungsten form. More than 90% of W04 cross the epithelial barrier in 24h whereas W-NPs continue to cross 1 week after treatment. In conclusion, our first results have shown that tungsten has limited and transient impacts on human pulmonary epithelium. The MucilAir® model is a valuable tool for monitoring the W- translocation and the reversibility of its toxic effects. Tritiated W-NPs are currently being studied to evaluate the combined effects of chemical and radioactive stress.

Beyond Paternalism and Strategy: Understanding Radiological Risks as a Mutual Learning Experience

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Abstract. The presentation elaborates on the issue of risk communication by situating it in a governance perspective that starts from the question of what it would imply to 'fairly' deal with the complexity of nuclear risk governance as such. The motivation for this approach is that the idea of 'effective risk communication', although valuable in itself, remains problematic if not taken up as a necessary element of concern of a fair approach to risk governance. As nuclear energy risk assessment in general has to take into account knowledge-related uncertainties and value judgements, one can understand that all nuclear energy risk perception is 'relative', not only with citizens, but also with activists, scientists, engineers and policy makers. How good the intentions may be, one has to acknowledge that the approach to effective risk communication remains paternalistic if seen only as a one-directional transfer of information from 'experts' to 'lay people' instead of as a dialogue set up as a mutual learning experience. Therefore, from a social justice perspective, involving the (potentially) affected in making sense of the risks and in consequent decision making should be the prime concern. The arguments developed in the presentation will be underpinned with reflections on the post- accident situation in Fukushima and with findings from research on risk perception and risk communication done in a European Context.

Survey of the Effect of Ionizing Radiation Energy on the Blood Indices of Occupationally Exposed Staff (radiologic technologists and radiologists)

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Abstract. Introduction: During the last decades using of ionizing radiation expanded in the context of medical diagnosis and treatment extensively. Prolonged low ionizing radiation dose affects occupationally exposed staff health. Radiation energy is an efficient factor that affects ionizing radiation biological deleterious effects. The current study aimed to evaluate blood indices of occupationally exposed individuals in conventional radiology, nuclear medicine and radiotherapy departments. Methods: In general 72 apparently healthy and non-smoker ionizing radiation exposed staff of four tertiary teaching hospitals were recruited. Complete blood count was done for every subject according to protocol. Results: The results of this study showed that there was no significant differences between groups of subjects on hematological factors including platelet, leukocytes, neutrophils and lymphocytes. Also no significant differences was found between group of the subjects on hematocrit and hemoglobin ($P>0.05$, CI=95%). Since abnormal leukocytes were detected in the blood of the groups of staff who worked in nuclear medicine and radiotherapy departments, white blood cells count of those were reported as mixed leukocytes. But was not reported for conventional radiology staff. No significant difference was found between groups of staff who worked in nuclear medicine and radiotherapy department on mixed leukocytes($P>0.05$, CI=95%). The results of Pearson correlation tests showed that there was not a correlation between years of working and the number of platelet, between years of working and the number of leukocytes, between years of working and the number of neutrophils, between years of working and the number of lymphocytes, between years of working and hematocrit, between years of working and hemoglobin ($P>0.05$). But a correlation was observed between gender and hematocrit and between gender and hemoglobin ($P<0.0001$). Conclusion: The results of this study showed that energy of ionizing radiation affects bone marrow to release abnormal white blood cells. More studies are needed to ascertain the types of abnormal cells.

Development of Radiological Protection Powder

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Abstract. In radiation medical examination, reduction of doses of radioactivity, such as a doctor, is an important subject. Although the dose of radioactivity of the fingers especially in IVR becomes a high value, there is little use of a lead content glove etc. Although a disposable thin glove is used with such a radiation medical examination, there is no shielding effect and there is displeasure by sweat. It devised giving the radiation shield effect to the powder which stops sweat from this situation. By applying this to the skin and using a disposable glove, the effect of the radiation shield was given simultaneously with the effect which stops sweat. This radiological protection powder makes it possible to use it for the whole body, and also when radiological protection clothes are worn, it can use it. It is useful from this also to environmental radiation. The purpose of this research is to develop radiological protection powder with the effect which stops sweat, and to evaluate the effect. The developed radiological protection powder does not have an effect of high shield. Therefore, use of barium sulfate with the high shield effect was lessened. Calcination scallop powder was used as shield material mixed with the powder which stops sweat. The advantage of this calcination scallop powder is excelling in the effect which stops sweat, and the deodorization effect. The ratio of the calcination scallop powder mixed to the powder which stops sweat, and barium sulfate was changed, and radiological protection powder was manufactured. This was put into the container at a 10cm rectangular parallelepiped. Powder was spread by shaking. The rate of a radiation shield was measured in this state. As a result, several percent - 10% of shielding effect was acquired with calcination scallop powder, and the rate of a radiation shield changed with content of barium sulfate. Moreover, an increase of barium sulfate would increase the shield ratio. Although it is in the state which protection powder spread to the space of 10cm thickness, it seems that a shield ratio decreases when it applies to the skin of a human body. However, it is thought that some shield rate is obtained. Although it is possible to raise a shield ratio with increasing the quantity of barium sulfate according to the use situation of radiological protection powder, the effect which stops sweat is lost. It can respond by increasing the quantity of scallop powder to this. In this research, radiological protection powder was developed by adding calcination scallop powder and barium sulfate to the powder which stops sweat. While the radiation shield ratio appeared, the effect of stopping sweat was shown. It can contribute to dose reduction of exposure by using this radiological protection powder to radiation medical examination and environmental radiation.

Risk of Thyroid Cancer Incidence due to Living Close to Atomic Facility in Childhood

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Abstract. Background: Risk assessment of carcinogenic effects among population due to their living close to atomic facilities is urgent problem. Over the years, we have carried out studies of cancer incidence among the population of Ozersk - the closest town to the "Mayak" Production Association. It is known that uncontrolled gas-aerosol emissions into the atmosphere took place in the early years of "Mayak" operation. The main dose-related radionuclide in the releases was ^{131}I. The subject of the present research is a continuation of thyroid cancer risk assessment studies in a cohort of individuals who lived in Ozersk in childhood. Material and methods: Epidemiological study was carried out among Ozersk residents who were born here in 1934-1962 or came to the town before age 15. Thyroid cancer incidence rates were estimated by standardized incidence ratio (SIR) with 95% confidence interval. National and regional statistics data were used for comparison. Excess relative risk per dose unit was estimated by AMFIT module of EPICURE software on the basis of data on collective doses of thyroid exposure. Results: 86 cases of thyroid cancer were diagnosed among 30,000 cohort members. SIR among men was 3,16 (CI 95%: 1,68 - 5,06) and 2,04 (CI 95%: 1,08 - 3,26) compared to national and regional incidence rates respectively. SIR among women was 2,07 (CI 95%: 1,52 - 2,65) compared to national statistics and 1,59 (CI 95%: 1,17 - 2,04) compared to regional statistics data. There was no significant dose-response effect for ^{131}I exposure. Conclusions: Statistically significant increase of thyroid cancer incidence among Ozersk residents, who lived in the town during the period of unmonitored gas-aerosol emissions from "Mayak" PA (1948-1962), was found in comparison with national and regional incidence rates. The lack of significant dose-response effect for ^{131}I exposure may be due to uncertainty of collective doses estimation.

Retrospective Estimation of Organ Doses for an Epidemiology Study of CT Scanning in Paediatric Patients (EPI-CT)

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Abstract. The increasing use of paediatric computed tomography (CT) worldwide lead to concerns of inducing cancers due to ionizing radiation. Results from the first retrospective cohort studies have been published recently. These epidemiology studies have relied, so far, on group- average approaches to estimate organ doses delivered to patients, rather than estimating doses based on individual data. In the international collaborative study EPI-CT, we developed a flexible approach to reconstruct individual organ doses based both of information from the Radiology Information System (RIS) and the data recorded in the Picture Archiving Communication System (PACS) of participating hospitals. Individual organ doses are estimated for each child using Monte Carlo radiation transport on hybrid spline phantoms of different sex and ages (NCICT). The derived doses are based on data collected for a variety of scanners used in nine countries over several different time periods. Accounting for missing examination parameter data is one of the main challenges, especially for earlier years (in the pre-PACS period), when only incomplete information on CT protocols in different hospitals are available. Our approach quantifies uncertainties in doses due to missing data following a newly developed Two-Dimensional Monte-Carlo (2DMC) simulation approach. The 2DMC approach produces possibly true sets of doses for the cohort, each set suitable for use in a dose-response as a surrogate of the true doses. Emphasis is put on generating the dose sets for the entire cohort in order to maintain proper correlations among persons with similar (shared) attributes. Each missing parameter is represented by a probability density function (PDF) representative of the state of knowledge for the time period. For each calculation of the cohort dose set, values of parameters are selected from the appropriate PDFs while maintaining proper correlations between parameters. Our approach of acquiring information suitable for individual dose estimation in a very large cohort, combined with a strategy for assessing uncertainty due to missing data, makes EPI-CT a unique contribution to the science of retrospective dose estimation as well as to the worldwide effort to understand health risk from CT exams.

Biological Dosimetry after Total Body Irradiation (TBI) for Hematologic Malignancy Patients using Premature Chromosomal Condensation in Combination with Fluorescence in Situ Hybridization

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Abstract. Background: The PCC fusion technique induces the premature condensation of chromosomes, allowing rapid scoring of radiation-induced chromosomal aberrations. It has also been recognized as a powerful biodosimetric tool in a technical report on international standards. Recently, the introduction of fluorescence in situ hybridization permits not only efficiency of the scoring of chromosomal aberrations but also widespread use of the PCC fusion technique and the exploitation of its full potential. In this study, we applied biological dosimetry using PCC fusion to patients receiving a homogeneous beam in total body irradiation (TBI) before bone marrow transplantation. In addition, the in vitro sensitivity of the PCC technique was assessed. Patients and methods: Blood samples from 10 patients with hematological malignancies were taken before and after the first fraction (1.8 Gy) of TBI. PCC fusions were carried and metaphases from PHA-stimulated lymphocytes were prepared. Chromosomal aberrations were assessed by chromosome 1, 3, and 4 painting. A standard dose-effect curve was established by in vitro irradiation of lymphocytes from 7 healthy volunteers using the same irradiator as that used for TBI (0-2 Gy). Results: The lowest in vitro dose detected via the PCC fusion technique was 0.05 Gy versus 0.2Gy for PHA-stimulated lymphocytes. A linear dose response curve was obtained using PCC fusion, and a linear quadratic dose response curve was obtained for PHA-stimulated lymphocytes. Immediately after the first fraction of TBI (1.80 Gy), the estimated mean absorbed dose was 1.78 Gy (1.48-2.11 Gy) using PCC fusions, and 1.68 Gy (1.48-2.11 Gy) using PHA-stimulated lymphocytes. A close relationship was found between the estimated dose using cytogenetic biological dosimetry, in this case of homogeneous distribution radiation of TBI and the delivered dose calculated by physical dosimetry. Conclusion: Our data validate PCC-FISH as a reliable cytogenetic biological dosimetry method. The high sensitivity of the PCC technique to detect chromosomal aberrations demonstrates the importance of this technique, especially in determining cytogenetic effects immediately after low dose exposure. It can be a valuable method for programmed dosimetry studies.

KEYWORDS: PCC; FISH; biological dosimetry; TBI; low dose.

Doses and risks from radon and other internal emitters and their control

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Abstract. Central to the control of radiation exposures, including dose limitation and optimisation below constraints and reference levels, is the use of effective dose. Effective dose enables the summation of all internal and external radiation exposures, making simplified risk adjustment to absorbed dose to allow for radiation quality and contributions of individual organs / tissues to overall stochastic detriment (cancer + hereditary effects). This treatment of internal and external exposures depends on the reliability of biokinetic and dosimetric models for internal emitters in providing reliable estimates of dose that correlate with risk estimates derived for exposures to external radiation. Epidemiological studies of workers exposed by inhalation to radon-222 and progeny in underground mines and to plutonium-239 in nuclear facilities have provided risk estimates for lung cancer induced by alpha particle radiation that depend on application of the biokinetic and dosimetric model of the human respiratory tract developed by the International Commission on Radiological Protection (ICRP). The two radionuclides result in very different temporal and spatial delivery of doses within lung tissues but similar risk estimates were obtained. Comparing these results with values derived from follow-up of the survivors of the Japanese atomic bombings, who were exposed to external gamma rays, show differences in central estimates of factors of around 10 – 20, consistent with expected values of the Relative Biological Effectiveness (RBE) of alpha particles compared with gamma rays. These and other data provide support for the use of ICRP models in the calculation of doses from internal emitters that will provide a meaningful measure of possible risk and validate the use of effective dose as the central protection quantity for control of all radiation exposures.

Synthesis of Novel Psammaplin A-based Radiosensitizers

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Abstract. Psammaplin A (PsA), a known DNA methyltransferase inhibitor, shows radiosensitizing effect in human cancer cells. Eight novel PsA derivatives (MA2, MA3, MA5, MA6, MA7, MA8, MA9, and MA5M) were synthesized and screened for radiosensitizing effect. For the screening, 2 different cancer cell lines were chosen: A549, a human lung cancer cell line, and U373MG, a human glioblastoma cell line. Clonogenic assay was performed to assess both the in vitro cytotoxicity and radiosensitizing effect. Inhibitory concentration 50% (IC_{50}) and sensitizer enhancement ratio (SER) at survival fraction of 0.2 were measured. Pharmacokinetic parameters were determined in mice by a validated LC-MS/MS assay method using non- compartmental analysis. All screened PsA derivatives were found to inhibit cell survival at the ranges of IC_{50} 16-150 μM and 15-50 μM in A549 and U373MG cells, respectively. Three PsA derivatives were confirmed to significantly enhance radiation-induced cell killing in each cell line (MA7, MA9, and MA5M for A549; MA2, MA3, and MA7 for U373MG). For A549 cells, MA3 also radiosensitized the cells with marginal significance. Only PsA, MA2, and MA3 were shown to inhibit DNMT1 activity. The average degradation $t_{1/2}$s of MA3 and MA7 were under 10 minutes, lacking biostability. We synthesized novel PSA derivatives possessing in vitro radiosensitizing effects. However, further development is needed to improve bioavailability for clinical application. [2013M2A2A7043683]

Responses to Radiation and Fate of Cells

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Abstract. Responses of cells to ionizing radiation can be damage repair, diversion into irreversible cell cycle exit (senescence) or elimination through programmed cell death (apoptosis). Besides apoptosis, there exists a type II cell death (autophagy). Autophagy can play a dual role in mediating either cell survival or death in response to various stress stimuli. Understanding cellular stress responses is of crucial importance in foreseeing the cell fate. In this study, cellular responses induced by radiation were analyzed. HeLa and MCF-7 cells were used to evaluate cellular responses after irradiation. Cells were lysed and immune-blotted. Cell cycle was analyzed using the flow cytometry. Cellular senescence was measured by staining of senescence-associated β-galactosidase activity. Immunofluorescence of γ-H_2AX, a marker for double strand breaks (DSBs), was used to detect DNA repair activity correlated with the loss of γ-H_2AX signal. The level of p53 expression was increased in dose dependent manner in both cells after irradiation. Chk1 was decreased according to p53 level. Ionizing radiation induced a drastic increase in expression of p21 in MCF-7 compared to HeLa. Significant accumulation in G2/M phase was shown after treatment of MCF-7 with radiation. Irradiated MCF-7 cells displayed cellular senescence at 10 Gy. The conversion to LC-II was checked in HeLa for monitoring autophagy. Autophagic cell death in HeLa was shown. γ-H_2AX signal was disappeared at 48h following IR in HeLa. Induction of p21 and G2 arrest by IR impedes apoptosis in MCF-7. Instead irradiated MCF-7 cells displayed cellular senescence. These data suggest that senescence-associated increase in p21 function in regulating cell fate decision. Apoptotic features were not detected in HeLa under our experimental irradiation condition. Autophagic cell death in HeLa may play an important role in cell protection and can result in cell survival.

Radiation-Induced p53 Level Determines Radiosensitivity of Cells

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Abstract. Proteins related to cell cycle arrest and cell death increases in the cells exposed to ionizing radiation. Among them, p53 makes a dual role in controlling apoptosis and autophagy mechanisms. This study was conducted to evaluate the effects of p53 on the sensitivity of cells to radiation in RKO (wild-type p53) and RKO E6 (null-type p53) cells. Cells were grown in MEM supplemented with 10% fetal bovine serum and a proper concentration of antibiotic- antimycotic at 37 with 5% CO_2 in a fully humidified atmosphere. The cells were exposed to 1~10 Gy of gamma-rays, then lysed and immunoblotted against proteins related to p53-mediated apoptosis. Cell cycle was analyzed using flow cytometry. Caspase-3 activity was measured with an colorimetric assay kit. Appearance and accumulation of acidic vesicular organelles were detected by staining with acridine orange. The expression of p53 increased in a dose-dependent manner in both RKO and RKO E6 cells. The level of p21 was up- regulated according to p53 expression in RKO cells at 48 h after irradiation while increased levels of p21 in RKO E6 cells were not significant. The p53 death signals leading to caspase activation and cleavage of caspase-7 and substrates (PARP) were demonstrated in RKO E6. An accumulation in G1 phase was observed in the RKO cells after irradiation. On the other hand, an increase in sub-G1 population was observed in RKO E6 cells. Apoptotic features were significant in RKO E6 cells. As for autophagy, acridine orange-positive cells with higher bright red fluorescence were frequently detected in RKO cells 48hr after irradiation with 10 Gy. The results indicated that p53 and p21 were required to block apoptosis and induce autophagy in RKO cells. Radioresistance of the RKO cells was associated with the increased p21 expression, resulting in autophagy induction. This study confirmed that the role of p53 in the regulation of the radiosensitivity was dependent on different p53 phenotypes. The findings might contribute to the understanding of a potential regulatory mechanism of fate decision in the cells exposed to radiation.

Development and Validation of a Multivariate Calibration Strategy for Direct Analysis of Trace Elements in Soft Tissue Utilizing Chemometric Energy Dispersive X-Ray Fluorescence and Scattering (EDXRFS) Spectroscopy

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Abstract. Energy Dispersive X-ray Fluorescence (EDXRF) is a popular and versatile technique for fairly accurate (±≤10%) analysis of trace heavy elements in low-Z matrices. However, the analytical challenges in direct rapid EDXRF analysis of "complex" biomedical samples using Fundamental Parameters (FP) necessitates development of novel methodologies (such as based on chemometrics energy dispersive X-ray fluorescence and scattering (EDXRFS) spectrometry). By "complex" matrix we mean matrices composed of mostly low-Z elements ("dark matrix") with enhanced Compton scattering and which are characterized by sample matrix inhomogeinity, extreme matrix effects, spectral overlaps, poor signal-to-noise ratio (SNR) of the normally trace analyte fluorescence peaks and irregular geometry. We have explored EDXRFS towards trace elemental analysis in model soft tissue for the purpose of developing the method for application in cancer diagnostics in soft tissues based on trace signatures of Mn, Fe, Cu, Zn and Se as the disease biomarkers. The study utilized paraffin wax based model tissue in which the X-ray fluorescence and associated Compton scatter peaks of Mn, Fe, Cu, Zn and Se (selected on the basis of their role in biopathological processes) were utilized for comparative development (and validation) of multivariate calibration strategies for direct rapid analysis of the biomarker elements in soft tissue using artificial neural network (ANN) and principal component regression (PCR). The ANN model gave more accurate results compared to PCR for prediction of most trace elements content in Oyster tissue. The concentrations for the trace elements were in good agreement with the certified values except for Se (±31.1%). This may be attributed to low levels of Se in soft tissue and enhanced spectral overlap of Br peak. The study shows that EDXRFS multivariate calibration approach based on spectral feature selection in both the fluorescence and Compton scatter domain enables direct, rapid and accurate quantitative analysis of trace elements in model soft tissue. Therefore, the method is suitable for application medical elementology and spectral diagnostics of disease in native human body soft tissue and fluids.

Radiation Shielding perfection at Design and construction Stages

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Abstract. Radiation protection aims eliminating any radiation exposure risk due to the proximity of during a medical procedure to a third party. While there are some common principles of protection that apply to all X ray imaging, and therapy procedures, many of the most significant issues and actions are related to the methods, equipment type and protocols being applied. Situation Analysis: Through the Kenya Radiation Protection Board, the Government has devolved the radiation Safety Services and Quality Controls to newly empowered Technical Support Organizations (TSO's). The teething problems of such innovations include but not limited to the following: Inadequate number of trained human resource, radiation survey equipment; Testing and calibration especially in the new devolved health set-ups; Inconsistent shielding designs and patterns, leading to inadequate shielding integrity assessments and dose calculations thus false radiation protection impressions; Over/under protection of premises resulting in unnecessary extra costs incurred or inadequate radiation protection. "Often times, the NZ principle is applied thus: - If all else fails, 2 mm lead for primary, 1mm lead for scatter!!"; Lack of financial and business plan to enable TSOs to serve the low resource facilities; Inadequate tools and equipment at the SSDL calibration centers, lack of identification and traceability of the TSOs E; Experiences in the field during assessment for leakage/scatter has been cites in the protective booth joints, overlap, between glass and the shielding sheets, and sometimes old overused lead aprons. Aims of the paper: Demonstrate the extend of Protection gains attained through Radiation Protection Board certified TSO's introduction; Demonstrate practical shortcomings and their Solutions; Explicitly display gaps in routine radiation protection processes; Outline the challenges of new technologies. EXPECTED OUTCOMES: Radiology professionals more involved in all protection matters; Ensure TSO's rigorously are assessed and monitored for compliance; Propose and implement in partnership with the International Authorities and standards bodies such as the IAEA, KEBS and RPB for practical Remedies; New techniques to entrench safety at work cultures; Radiology professionals' and engineers continuous education system developed accessible and affordable to all cadres.

Application of the Spencer-Attix Cavity Theory for Determination of Conversion Coefficient for Ambient Equivalent Dose with TLD-100 Dosimeters Calibrated in Air Kerma

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Abstract. The conversion coefficient for ambient equivalent dose $h_k^*(10;S)$ is determined experimentally using by TLD-100 calibrated in air kerma Ka, for ^{137}Cs and application of the SA cavity theory. First, thirty TLD-100 dosimeters are calibrated in terms of Ka for ^{137}Cs. The calibration curve CC (R vs Ka) covers the range: [0;250] mGy, with twelve different calibration points. Second, dosimeters are irradiated inside a PMMA type ICRU sphere at a depth of PMMA 10 mm, according definition of $H^*(10)$. Third, due to electronic equilibrium and kerma approximation: $D_{air} = Ka$; therefore, the SA cavity theory determinates absorbed dose to PMMA, $D_{PMMA}(10)$ from D_{air}. Fourth, $D_{PMMA}(10)$ is converted to absorbed dose to ICRU tissue, with the rate of mean attenuation coefficient. Fifth, for photon Q=1, then $H^*(10) = D_{ICRU}(10)$. Finally: $h^*{}_k(10;S) = m_{H*}/m_k$, here m_{H*} is the slope of the inverse CC H* vs R, and m_k is for Ka vs R; then, $h^*{}_k(10;S) = m_{H*}/m_k$ = 1.20 Sv Gy^{-1} with $u_c = 3.7\%$, where the combined uncertainty is estimated by the BIPM/ISO guide; this value is consistent with value reported at ISO 4037-3: 1.20 Sv Gy^{-1} with $u_c = 2\%$.

Evaluation of Fission Energy Deposition in the SAFARI-I Nuclear Reactor

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Abstract. The knowledge of the amount of energy released during a nuclear fission reaction is extremely important for the safety analysis of a nuclear reactor. In this work, we estimate the fission Q-Value of the SAFARI-I nuclear reactor using the MCNP-5 (Monte Carlo N-Particle) code. MCNP is a probabilistic transport code that has the capability of calculating most of the heating contributions due to particle interactions with matter. In particular, we present the calculations performed to obtain the energy deposited by fission products, prompt neutrons and photons as well as neutron induced photons. Currently, the MCNP-5 code cannot calculate the heat deposition due to beta particles and gamma rays produced during fission product decay. Such values were therefore estimated using typical values reported in the libraries. The calculations were performed for the beginning and end of cycle of a typical operation cycle of SAFARI-I. Using the ENDF-VII data, the fission Q-value for SAFARI-I was calculated as 197 MeV. Typical fission Q-values reported for nuclear reactors are around 200MeV. Further studies will focus in the improvement of the accuracy of our calculations by performing energy deposition calculations due to fission products decay of typical used fuel elements in SAFARI-1.

Lung Cancer Risk from Radon and Smoking – Additive or Multiplicative Effect

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Abstract. The aim of the presentation is an evaluation of the lung cancer risk from combined exposure to radon and smoking. Methodologically, it is based on case-control studies nested within two Czech cohort studies of nearly 11 000 miners and nearly 12 000 inhabitants exposed to high levels of radon in homes. In addition to recorded radon exposure, these studies use information on smoking collected from the subjects or their relatives. A total of 1 029 and 370 cases with smoking information have been observed in the occupational and environmental (residential) studies, respectively. Three or four control subjects have been individually matched to cases according to sex, year of birth, and age. Exposures are given in terms of WLM in the occupational study and in kBq m^{-3} year in the residential study. Similarly, smoking exposure is given in pack-years. In order to account for temporal effect, cumulated exposures are given in two exposure windows – 5-19 and 20+ years before current age. The combined effect from radon and smoking is analyzed in terms of geometric mixture models of which the additive and multiplicative models are special cases. The resulting models are relatively close to the additive interaction (mixing parameter 0.2). The impact of the resulting model in the residential radon study is illustrated by estimates of lifetime risk in hypothetical populations of smokers and non-smokers. In comparison to the multiplicative risk model, the lifetime risk from the best geometric mixture model is considerably higher, particularly in the non-smoking population. This study was supported by the Czech Ministry of Health (project NS10596).

Risk of Leukemia in Uranium Miners

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Abstract. Epidemiological studies among uranium miners have evidenced lung cancer risk in relation to radon exposure. Although leukemia is especially sensitive to induction by radiation, the assessment of leukemia risk in exposed populations is more complex as its incidence is substantially (more than 30 times) lower than that of lung cancer. So far, the significant association among uranium miners has been observed in studies of Czech uranium miners. The assessment of the risk is complex because the radiation risk in mines involves exposure to radon, external gamma radiation, and exposure to airborne long lived radionuclides arising from uranium ore dust. In contrast to radon measurements, the other two components were monitored much later in uranium mines. Recent follow-up of a Czech study of 10 000 uranium miners have resulted in 42 leukemia cases. The risk is evaluated in relation to cumulated equivalent doses from radon, long lived radionuclides, and external gamma. The mean equivalent doses to the red bone marrow in the entire study are 35 mSv from radon, 46 mSv from external gamma radiation, and 106 mSv from long lived radionuclides. Mean doses among leukemia cases are nearly twice. The excess relative risk per Sv (ERR/Sv) in this study 3.75 is statistically significant (p=0.008). This value is consistent with the leukemia risk observed in the Life Span Study among Japanese survivors of A bombing (ERR/Sv = 4). This study was supported by the European Commission and the Czech Ministry of Education (project DOREMI GA 249689, 7G13001).

Chronic Bronchitis Incidence in the Cohort of Mayak Production Association Workers Occupationally Exposed to Radiation

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Abstract. Objective. To study chronic bronchitis (CB, ICD-9 code 491) incidence in an extended cohort of Mayak workers following chronic occupational external and/or internal radiation exposure taking into account non-radiation factors (sex, age, smoking, etc.). Mayak is the first Soviet nuclear weapons production facility and is located in Ozyorsk, Russia. Methods. The study cohort included 22,377 Mayak workers (25% of whom are females) first employed at one of the main facilities (reactor, radiochemical, and plutonium production plants) in 1948–1982 and followed up to the end of 2008. The Mayak Worker Dosimetry System-2008 (MWDS-2008) was used to provide internal and external doses for the study. Relative risks (RR) and excess relative risks per unit dose (ERR/Gy) were calculated based on maximum likelihood using AMFIT module of EPICURE software. Results. By the end of 2008, 2,135 cases of CB were registered. Analysis of CB incidence RR in relation to non-radiation factors revealed significant effects of sex, attained age, facility type, age at first employment, smoking status, quantitative smoking parameters, and occupational hazards from activities preceding employment at Mayak. RR of CB incidence was found to increase sharply in the period prior to 1960. The categorical analysis revealed a significant increase in CB incidence among workers exposed at total absorbed lung dose from internal alpha radiation above 0.1 Gy as compared to workers exposed at the corresponding dose below 0.01 Gy. Significant linear associations of CB incidence with both external gamma and internal alpha radiation were found in the period of the follow-up after 1960 (ERR/Gy=0.14 (95% CI: 0.02, 0.28) and ERR/Gy=1.14 (95% CI: 0.41, 2.18), respectively). ERR/Gy for CB incidence following internal radiation exposure markedly increased with the increasing lag-period. Exclusion of adjustments for facility type, dose form external gamma- rays and smoking status provided approximately a 2.5-fold decrease in ERR/Gy. Conclusion. CB incidence was found to be significantly associated with both external gamma and internal alpha radiation.

Microdosimetric Measurements for Electron Irradiation of DNA under Physiological Conditions: Low Energy Electrons vs. Radicals

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Abstract. Radiation damage to DNA is one of the main causes for cancer and likewise a major tool in its treatment. One of the dogma of the classical radiochemistry and physics involves the opinion that radicals such as OH° produced by ionizing radiation are the most lethal agents. This scenario is increasingly disputed as secondary low-energy electrons are emerging as important, if not predominant, reductive pathway in ionizing damage of biomolecules. These electrons are generated in copious amount in aqueous environment as secondary scattering products. But until now all research concerning the quantification of the effects of low energy electrons on the biomolecular damage was either performed in vacuum with low energy electron sources or with DNA plasmids on metallic surfaces in humid environment. In this work we present detailed experimental and simulation microdosimetry data on electron damage to plasmid DNA in liquid environment: Well-defined electron energy and dosage irradiation was achieve by using an EM and the irradiation through a nanomembrane. The results are analyzed in terms of single- and double-strand break probabilities in the dependence of dose, energy, number of primary and secondary electrons. The results are important not only from the basic scientific point of view but also for the development of effective radiosensitizers, either as protecting or enhancing (radiotherapy) cofactors.

Markers of Neural Degeneration and Regeneration in Blood of Cardiac Catheterization Personals

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Abstract. The catheterization laboratory is considered an area where exposure to ionizing radiation (IR) is particularly high during fluoroscopic procedures. Neuro-vascular and cerebro-vascular damage are considered to be induced by IR. Such damage is postulated to be repaired by circulating endothelial and neural circulating progenitor cells originating from the Bone Marrow. The aim of the present study was to evaluate neural damage and rejuvenation capacity among cardiac catheterization (CC) staff. Subjects and Methods: Venous blood samples were obtained from 70 cardiac catheterization staff exposed to x-ray during fluoroscopy procedures at three busy hospitals in Cairo – Egypt vs. 40 controls. Blood was assayed for the amyloid beta peptide, the frequency of micronuclei (FMN), plasma nerve growth factor (NGF) and cell phenotype of circulating neural progenitor cells (NPCs), whose surface markers were identified as the nestin, CD45 and CD34. Amyloid beta peptide was non-significantly increased among CC staff compared to controls. The individual three month collective dose information, as measured by thermoluminscent personal dosimeters (TLD), ranged between 2.16 and 14.9 mSv/y. Results: NFG and FMN were significantly higher among CC staff compared to controls. Nestin,, CD45 and CD34 were also significantly higher among CC staff compared to the controls. Smoking seemed to have a positive effect on the FMN and SDF-1, while negative on circulating progenitor cells. Conclusion: It is found that among CC staff, the numbers of EPCs had increased indicating an increased capacity for tissue repair. This regenerative process is hindered by smoking, evidenced by increased levels of NFG and decreased numbers of PCs. Further studies are required to prove whether changes in of EPCs' levels can offer a reliable detection marker for radiation exposure.

Regulatory Culture and its Role in Radiation Protection

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Abstract. Many organizations have expressed great interest in radiation protection (RP) culture and more recently in security culture. These are important areas of development for the global RP profession. But is this the whole picture? It is proposed that "regulatory culture" also deserves attention as it is, or should be an intrinsic part of the wider RP culture. This paper explores the definition, objective and scope of regulatory culture as it could apply to RP and explains its relevance to the various levels of the profession both inside and outside of Regulatory Bodies, considering aspects such as regulatory approach, top management commitment, benchmarking, self-assessment and training of individual regulators. In addition, the approach that the regulatory authorities could adopt to support the regulated organizations on the promotion of safety culture will be addressed.

The Hybrid Analytical – Voxel Head Phantom for Activity Measurement of 241Am in Cranial Bone

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Abstract. Size, shape and the internal distribution of bone and soft tissues are varying in human heads, which significantly affects the efficiency measurement of 241Am in the cranial bone. Therefore the calibration head phantoms for measurement of 241Am should be constructed in details similar to the measured head and according to our information sufficiently precise standard head phantom is not yet made. Presented new method of the activity measurement of 241Am in a cranial bone is based on in-vivo measurements by a HPGe detector with an efficiency corrected by factors with regard to detail anatomy of actual measured head. The detector is positioned above the parietal bones of the skull. The correction factors of the 241Am measurements efficiency in cranial bone are obtained by a Monte Carlo simulation of analytical – voxel head phantom that represents measured head in relevant details. The hybrid analytical – voxel head phantom consists of two parts. Upper analytical part (that is closer to detector) is modeling neurocranium (mainly parietal and frontal bones) by parameters defining shape of skull and thickness of surface tissues and underlying bones. Determination of the thicknesses of surface soft tissue and skull bone of upper part of measured head can be performed by a sonograph. Lower part of hybrid phantom consists of the part of Zubal phantoms in outer dimensions similar those ones of measured head. By using the proposed method for activity measurement of 241Am in cranial bone by means of the hybrid analytical – voxel head phantom, the calibration of HPGe detector can be performed by a simple phantom that is similar to upper part of an analytical cranial bone which can be relative simple prepared. Presented new method of the activity measurement of 241Am in a cranial bone is based on in-vivo measurements by a HPGe detector with an efficiency corrected by factors with regard to detail anatomy of actual measured head Correction factors of HPGe detection efficiency of 241Am in cranial bone with regard to three different head dimensions with various thicknesses of surface soft tissue above different thicknesses of cranial bone are presented. Acknowledgment: The work was partially supported by the projects APVV-0-24 1-011.

Occupational and Medical Exposure: The Contribution to Carcinogenic Risk In Mayak Worker Cohort

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Abstract. Introduction: Medical exposure as a result of X-ray investigation is an important issue in radiation protection of population. It is considered that potential harm that can bring the X-ray procedure is low. In the same time, an X-ray exposure may increase cancer risk. The aim of present study is to assess the excess relative risk (ERR) for a total dose of external gamma and X-ray radiation of the nuclear workers to understand the possible harm of X-ray procedures in terms of carcinogenesis. Material and methods: The study was conducted in Mayak Worker Cohort among workers hired from 1948 to 1972. Follow-up period was since 1948 to 2000, and ended on date of migration or death from cancer. Information about the cause of death was obtained from the Mayak Worker Registry. The absorbed dose of occupational and medical exposure was obtained from the dosimetric system "Dose-2008". Based on these data in lung was calculated. Lung cancer mortality was selected to assess the contribution of occupational and medical exposure to carcinogenic risk. Excess relative risk per 1 Grey (ERR/Gy) was calculated using LNT model, created with statistical package “Epicure” (Amfit module). Results and discussion: In the period from 1948 to 2000 workers underwent regular X-ray screenings (fluorography), as well as different X-ray examinations due to health disorders. The structure of X-ray examinations is mostly presented by the chest fluoroscopy (57%) and chest X-ray filming (15.4%).Average absorbed dose in lung was about 0.6 Gy for external exposure and 0.05 Gy as for X-ray exposure. ERR/Gy of cumulative dose of external gamma exposure was 0.26(95%CI 0,09-0,49) and the ERR/Gy of cumulative dose of medical exposure was 5,2(95%CI 1,6;9,7). This fact could be explained by Reverse causation. Conclusions: Lung cancer mortality in a cohort of nuclear workers exposed to occupational and medical radiation for more than 50 years has been analyzed. X-ray dose was generally consisted of chest X-ray (72.4% of all X-ray procedures). The dose of medical exposure, accumulated in lung of workers during the follow-up period is at low dose range (about 5 cGy). ERR per 1 Gy of medical and occupational exposure has been evaluated.

Baseline Lifetime Mortality Risk from Circulatory Disease in Japan

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Abstract. Nominal risk coefficient for radiation-induced cancer mortality can be estimated based upon baseline lifetime cancer incidence with excess relative risk model and excess absolute risk model, taking lethality into consideration. But as Ogino et al. indicated, even the gender- averaged baseline lifetime risk of cancer mortality in Japan was calculated to be 25.4%, there was variation from 23.7% to 28.3% among 47 prefectures. On the other hand, International Commission on Radiological Protection issued a statement on tissue reaction in 2011, which showed lower dose threshold for circulatory disease and emphasized the importance of optimization of protection. Since Ozasa et al. reported the excess relative risk per unit absorbed dose for circulatory diseases was to be 0.11 /Gy in the 14th Life Span Study of atomic bomb survivors, uncertainty in the system of radiological protection and the risk of circulatory diseases have received a lot of attention in recent years. For this, we have calculated baseline lifetime risk of circulatory disease mortality risk in Japan and its variation among the prefectures, using national population census and the statistical database as of 2010 collected by the Ministry of Health, Labor and Welfare. As a result, the baseline lifetime risk of circulatory disease mortality for the gender-averaged population was estimated to be 30%, and the variation was approximately 7%. These results will be available for the minimum provability dose method developed by the authors, which could provide a prioritization of radiation protection measure based on detectability of radiation effect. Furthermore, understanding the variation of circulatory disease could be one of the significant information in consideration of optimization of protection.

DNA Repair Genes XRCC1 and XRCC3 Polymorphisms and the Level of Micronuclei in Industrial Radiographers

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Abstract. Ionizing radiation exposure produces a variety of DNA lesions which may enhance the cancer risk. Genetic polymorphisms in DNA repair genes may influence inter-individual variation in DNA repair capacity and thus modulate susceptibility to cancer. The aim of the present study was to investigate the association between DNA repair genes XRCC1 Arg399Gln and XRCC3 Thr241Met polymorphisms (SNP) on micronuclei (MN) frequency as a biomarker of DNA damage and a predictor of cancer in peripheral blood lymphocytes of 65 Industrial radiographers (IR) and 50 non-exposed individuals as the control group. Frequencies of MN and Nuclear bridges were significantly higher in the IR group than in the controls (34.57 ± 12.32 vs. 8.23 ± 1.92 $p<0.001$ and 1.72 ± 1.55 vs. 0.14 ± 0.12 $p<0.001$, respectively). Also, MN frequencies were higher in smokers in the both groups. In the exposed group, MN values were significantly higher in the individuals with accumulated doses of more than 50 mSv in comparison to those with exposure less than 50 mSv. Polymorphism of XRCC3 Thr241Met was associated with increased MN frequencies in IR group ($P=0.002$). However, no significant association was observed between XRCC3 SNP and MN frequencies in the non-exposed group ($P=0.37$).The analysis of different genotype interactions in the IR group showed significantly higher MN frequencies, in those carrying the mutant-types of XRCC3 and XRCC1 genotypes compared to those carrying the wild or heterozygote genotypes. The results showed that MN frequency is a reliable biomarker for the assessment of genetic effects in workers occupationally exposed to chronic ionizing radiations and XRCC3 Thr241Met alleles might contribute to increase these effects.

Mayak Worker Cancer Mortality

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Abstract. The Mayak worker cohort (MWC) includes about 26,000 workers who started their employment at the Mayak Production Association (Mayak) during the period 1948 – 1982. Mayak, located in Ozersk, Russia, is the first Soviet weapon-grade Pu production facility. This cohort has sufficiently good epidemiological follow-up and presents one of the very few opportunities in radiation epidemiology to estimate radiogenic risks related to prolonged exposure to both low-LET external exposure (primarily gamma-rays) as well as exposure to high-LET alpha-particles emitted by inhaled ^{239}Pu. Recent analyses were focused on effects of external gamma exposure on solid cancer and hematological cancer mortality. For the group of solid cancers other than lung, liver, and bone, a significant dose-response is observed in MWC. Site-specific risk estimates followed the similar pattern, although due to the lack of the statistical power, only esophageal cancer demonstrated significant dose-response. The risk estimate for the whole group was approximately half of the risk estimate in the Atomic Bomb survivors' cohort; although the two estimates are not significantly different from each other this might be an indication of reduced radiogenic risk at lower dose rates. A significant dose-response was observed for leukemia mortality; the increase of leukemia risk was primarily related to myeloblastic forms of leukemia. We also analyzed carcinogenic risks in organs of primary Pu deposition (lung, liver, and bone) and demonstrated dose-related increases of mortality due to these cancers. We discuss comparative effects of gamma and alpha exposure and the effects of radiation exposure in the MWC in comparison to Atomic Bomb survivors and other cohorts of radiation-exposed workers.

Repair of Ionizing Radiation-Induced DNA Damage and Risk of Second Cancer in Childhood Cancer Survivors

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Abstract. The study's purpose was to assess whether individuals who developed a second malignant neoplasm (SMN) after treatment for a first malignant neoplasm (FMN) had a lower ability to repair DNA double-strand breaks (DSBs) using a bioassay with γH2AX intensity as a surrogate endpoint. In a case-control study nested in a cohort of childhood cancer survivors, lymphoblastoid cell lines (LCLs) were established from blood samples collected from 94 cases (SMN) and 94 matched controls (FMN). LCLs were irradiated with ionizing radiation (2 and 5 Gy) and γH2AX intensities measured 1, 3, 5 and 24h post-irradiation. Differences in mean γH2AX intensity between cases and controls were compared using Kruskal-Wallis tests. Generalized linear models for repeated measures and conditional logistic regressions for SMN risk estimates were performed. The mean baseline γH2AX intensity measured without irradiation was 9.1 [95% confidence interval (95% CI): 8.5-9.7] in the LCLs from cases and 6.4 (95% CI: 6.0-6.8) from controls ($P < 0.001$). Markedly higher γH2AX intensity, particularly at 1 h post-irradiation, was also found in the LCLs from the cases compared with the controls for all FMNs and for different types of FMN. Chemotherapy and radiation doses received by bone marrow and thymus for FMN treatment showed a non-significant effect on γH2AX intensity. This case-control study shows that higher baseline and post-irradiation levels of DNA DSBs, as measured by γH2AX intensity, are associated with the risk of SMN in childhood cancer survivors. Further investigations in a prospective setting are warranted to confirm this association.

The Role of the Scientific Review Group in the Russian Health Studies Programs: Key Contributions and Influence and Impact on Radiation Protection

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Abstract. Projects conducted under the auspices of the Joint Coordinating Committee for Radiation Effects Research (JCCRER) are reviewed by independent U.S. and Russian Scientific Review Groups (SRG), established in 1994 by the JCCRER Agreement between the United States and the Russian Federation. The primary purpose of the SRG is to critically review and evaluate technical progress reports and proposals and recommend research priorities to the U.S. Department of Energy and the Federal Medical Biological Agency. Each SRG consists of distinguished scientists with expertise in external and internal radiation dosimetry, radiation measurements, radiological assessment, biokinetic modeling, epidemiology, biostatistics and radiological protection. The SRG critically reviews and evaluates the semi- annual technical progress reports of the ongoing projects of radiation health effects studies in 26,000 workers at the Mayak Production Association (Mayak) and in 30,000 residents in surrounding communities along the Techa River and provide written comments to the researchers for response and corrective actions. The SRG also and provides feedback to the research teams, evaluates research proposals and assists in the preparation of the strategic plan for future work (5-year Plan). The SRG goes beyond being merely reviewing progress reports to also providing insights to the researchers on computational dosimetry directions, emphasizing the importance of accounting for competing risk factors for cancer induction when evaluating the risk associated with radiation, having called for encouraging close collaboration of between the dosimetrists with and the epidemiologists and statisticians, and instigating changes as to how requests for samples from the tissue repository were evaluated and shipped. A limited number of meetings of the combined Russian and U.S. SRGs have been held and those have proven effective for onsite critical reviews and evaluation of the ongoing projects. The SRG provides an ongoing critical service to program direction and quality.

A Comprehensive Study on Tritium Release from Nuclear Accidents and Impact of Tritiated Water on Postnatal Development of Mouse Cerebellum

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Abstract. Looking at the energy situation on a total basis in a long term horizon, it is evident that nuclear energy may make a large addition to energy sources for many countries. Though, after the Fukushima Daiichi accident this concept has suffered a big blow and serious efforts are under way to reduce the number of nuclear reactors under operation world over. With the development of nuclear power programs, an additional consideration outside the existing radiation protection framework has appeared and now apart from assessing the level of exposure, considerations with regard to the accidents which could release large inventories of radioactivity have become the main focus of attention. With the expansion of the nuclear power programs, inventories of 'tritium' produced during such processes are bound to increase. Tritium production and release from nuclear detonations and thermonuclear reactors is enormously great and this may pose significant tritium management problems. Uptake studies of tritium have revealed that more tritium from tritiated water (HTO) accumulates in mouse brain as compared to the other organs of the body. Knowledge is still fragmentary on the behavior of tritium in brain incorporated during its developing stages. Swiss albino mice belonging to 1, 3, 5 and 6 weeks of age were injected with HTO at a dose 111 kBq /gm body weight. The animals from each age group were autopsied on 7 and 30 days *post- injection* and hence, qualitatively and quantitatively studied for age associated cerebellar vulnerability due to acute tritiated water exposure. In cerebellum, where the cell renewal system is lacking major cytoarchitectural changes occur mainly during the first three weeks after birth. This accounts for its high radiovulnerability and capability to repair the rendered damage during 1 week to 3 weeks of postnatal development, whereas at 5 and 6 weeks of age a tendency towards radioresistance is achieved. As the age advances relatively lesser impairments post tritiated water exposure become evident. Hence, on the whole, tritium in the form of tritiated water renders appreciable damage on the postnatal development of mouse brain which warrants further investigation. The results would be discussed in the light of tritium metabolism. Our studies suggest that stringent measures be met to ward off dangers of tritium release from nuclear reactors and policies be revised for ethical tritium use.

Current State of Pharmacologic Radioprotection for Clinical Exposure to Ionizing Radiation

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Abstract. Background: The oncogenic effect of ionizing radiation (IR) is clearly established and occurs in response to DNA damage. Many diagnostic imaging exams make use of IR and the oncogenic risk of IR-based imaging has been calculated. The increased use of these modalities has led to concern. Recently, studies have shown the feasibility of a pharmacologic approach to radioprotection in the clinic. Methods: We conducted a literature review to examine the most recent pre-clinical and clinical studies on pharmacologic radioprotection for diagnostic doses of IR. Also, we conducted our own pilot study in which 10 patients undergoing bone scans were recruited. Five patients were given no premedication. Five patients were pre-medicated with antioxidants in pill form 15 minutes before radiotracer injection. Primary antibody staining was conducted for γH2AX, a biomarker of DNA double-strand breaks (DSBs), in peripheral blood mononuclear cells (PBMCs) isolated from whole blood. γH2AX was quantified with fluorescent microscopy and software-based image analysis. Results: In the literature, a reduction in tumor multiplicity was seen in mice fed an antioxidant-enriched diet compared to control mice when both groups were irradiated with a whole-body CT weekly for four weeks. Another study showed volunteers who consumed oral antioxidants had reduced DNA DSB induction compared to controls when their blood was irradiated ex vivo. Finally, one group showed a reduced induction of DSBs in patients who were given intravenous antioxidants prior to clinical IR exposure compared to controls. Our own work showed a statistically significant increase in γH2AX foci per nucleus in PBMCs 2.5 hours after radiotracer injection in control patients. However, patients who were pre- medicated with antioxidants showed no significant increase in γH2AX foci per nucleus in PBMCs 2.5 hours after radiotracer injection. Conclusion: Studies have shown the efficacy of pharmacologic radioprotection. The next steps are to optimize the pharmacologic agents, determine the best delivery methods, and design large population studies to evaluate if there is a meaningful reduction in carcinogenic risk with this approach.

Ameliorating Effects of Bone Marrow Transplantation and Zinc Supplementation on Physiological and Immunological Changes in γ-Irradiated Rats

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Abstract. Purpose: The present study was carried out to determine the prophylactic impact of zinc sulphate administration to irradiated rats treated with bone marrow transplantation (BMT) as indicated by the hematological and immunologic response as well as oxidative stress. Material and methods: Rats were injected orally with zinc sulphate, 10 mg/ Kg body wt, daily for 2 weeks before whole body 5Gy gamma irradiation and intravenous injection of bone marrow cells, one hour post irradiation. Results: The results revealed a significant decrease in red blood cells (RBC), white blood cells (WBC), glutathione (GSH) and zinc superoxide dismutase (Zn /SOD), splenocyte count as well as bone marrow lymphocyte count and viability of irradiated rats. Regarding immunological data: tumor necrosis factor alpha (TNF-α) and interleukin 2 (IL-2) recorded a significant decrease while interleukin 6 (IL-6) and lipid peroxidation product (MDA) in the serum and spleen were conversely elevated. Zn supplementation before irradiation and BMT and showed significant decrease of serum and tissue MDA compared to the irradiated group. Lymphocytes, bone marrow viability percentage, splenocytes percentage, IL-2, IL-6 and GSH were significantly elevated compared to irradiated group. Conclusion: Protection with Zn, enforcing significant innate response, could trigger and augment adaptive immune response by BMT which suggests its use to protect against radiation hazards.

KEYWORDS: BMT; gamma irradiation; zinc sulphate; immunologic response.

Occupational Exposure to ^{7}Be – A Case Study

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Abstract. A dispersion incident occurred in the course of experimental preparations towards neutron irradiation of a ^{7}Be target in Soreq Applied Research Accelerator Facility (SARAF). The purpose of the experiment was to investigate the reaction $^{7}Be(n, \alpha)$ in the big bang nucleosynthesis. Portions from the source were dispersed into the beam corridor space. The target consisted of ^{7}Be atoms that were electro-deposited on a thin (0.75 µm) Carbon sheet covered by a thin Aluminum sheet. The total activity of the deposited ^{7}Be source was approximately 10 GBq. A few minutes after the release, de-contamination activities were conducted by several workers. Shortly after the de-contamination activities, the workers were monitored externally by hand held Geiger detectors which did not indicate any contamination. Individual equivalent dose (Hp(10) and Hp(0.07)) measurements using the workers' personal theremoluminescent (TLD) badges showed no exposure (0 mSv). Additional occupational measurements were carried out a few hours after the incident, including both in-vitro (nasal wipes and urine samples) and in-vivo (total body and lung counting). Traces of ^{7}Be were found in the urine and in the nasal as well as significant quantities (kBq) in the lungs. The uptake and dose for each of the involved workers were quantified. The biological half-life for the extraction of the ^{7}Be from the body was estimated by repeated lung counting measurements which were performed during several weeks past the event. Results are compared to published data.

Early and Late Alterations of Neurochemical, Behavioral, and Somatic Criteria in Rats Exposed to ^{12}C ions and γ-rays

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Abstract. Exposure to ionizing radiation represents a risk for individuals engaged in deep space travel or undergoing the radiation therapy of cancer. Irradiation with high-energy and charge ions may disrupt normal functioning of the central nervous system (CNS), leading to various behavior disorders. In animals, ionizing radiation was found to induce prolonged deficit in CNS observed at least during several months after exposure. The present study was designed to investigate the early and late effects of 1 Gy of 500 MeV/n ^{12}C particles and ^{60}Co γ-rays on the metabolism of monoamine neurotransmitters in the rat brain as well as to compare the neurochemical data with the behavioral and somatic outcomes. The animals were tested 30 and 90 days after irradiation. The analyses included estimating concentrations of neurotransmitters and their metabolites, the open field and grip strength tests, and measuring the numbers of the nucleated cells and leukocytes. On the 30th day after carbon ion exposure, the most pronounced changes in monoamine metabolism were observed in the nucleus accumbens, while smaller ones were detected in the hippocampus and striatum. The orienting-investigative activity of ^{12}C-irradaited animals increased in comparison with sham- and γ-irradiated rats. The grip strength was slightly stimulated. 90 days after heavy ion exposure, significant neurochemical changes persisted in the nucleus accumbens, while in other structures they became less noticeable. Under γ-rays, the metabolic pathways were altered in the prefrontal cortex and striatum. In this period, the orienting-investigative activity of ^{12}C-irradiated rats was not significantly different from that of the control animals, while exposure to γ-rays resulted in its strong decrease. On the 90th day, the grip strength was normalized back to the 30-day level. The nucleated cell number in bone marrow temporally increased on the 30th day after γ-irradiation and dropped on the 90th day. After both radiations, the number of leukocytes decreased on the 30th day and normalized on the 90th day. Our results suggest that the observed neural effects of sparsely ionizing radiations and heavy charged particles with relatively low linear energy transfer (about 10 keV/μm) are most pronounced at early periods after exposure. Later, a recovery of the induced changes is observed. Under this exposure, the assessed somatic criteria do not strongly correlate with neurotransmitter metabolism and behavior violations.

Integrating Dosimetry, Radiobiology and Epidemiology to study the Effects of Occupational Exposure to Uranium in Europe: the CURE Project

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Abstract. The health effects of chronic exposure to uranium in humans are not well known. Most available epidemiological studies suffer from limitations (dosimetry and/or statistical power). Impairments of the cerebral function, genotoxic, nephrotoxic and other biological effects were reported in animal studies but the implications of these findings to human health are not clear. Collaborative studies borrowing strengths from enhanced epidemiological datasets on the one hand, and from modern biology approaches on the other hand, will have higher potential to improve the characterization of the biological and health effects of uranium exposure. CURE (Concerted Uranium Research in Europe) was an 18-month concerted action supported by the European Commission Network of Excellence DoReMi (www.doremi-noe.net), involving 9 European institutes. It aimed to elaborate a collaborative research project on the biological and health effects of occupational exposure to uranium, integrating epidemiology, biology and dosimetry. A work-package was dedicated to each of these disciplines with strong interactions, and a further working group on uncertainty was constituted. Protocols were developed for pooled analyses of existing cohorts of uranium miners (40,000) and uranium processing workers (40,000) in Belgium, Czech Republic, France, Germany, and the United Kingdom. To allow for the study of dose-response relationships, protocols were developed to calculate organ doses due to uranium exposure using state-of-the art dosimetric methods. Feasibility studies for molecular epidemiology were worked out for sub-cohorts, and standardized protocols were developed for the measurement of several biomarkers relevant to supposed uranium effects. Methods were proposed to estimate the impacts of uncertainties at several steps of the project. Based on CURE protocols, a multidisciplinary research project will be proposed to improve the characterization of the biological and health effects associated with occupational uranium exposure in Europe. In the future, it might be envisaged to extend collaborations with other countries outside the European Union, but also to apply the proposed approach to other internal emitters and other exposure situations of internal contamination.

Investigations of radiation exposures in the aftermath of the Chernobyl accident

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Abstract. Acknowledging three decades of research on the consequences of the Chernobyl accident a short review is given on the accident, the releases of radionuclides and the radiation exposures in the highly contaminated regions. The Chernobyl accident has provided a wealth of information about the consequences of a nuclear reactor accident; e.g. UNSCEAR (2000). The past experiences must not be forgotten. They provide heuristic guidelines to estimate the consequences of large scale contaminations with Cs-137, Sr-90 and actinides; e.g. Michel (2006). The opportunities and drawbacks of the retrospective dosimetry of the I-131 exposure of thyroid glands by the long-lived I-129 are discussed taking the highly contaminated regions in Northern Ukraine as an example. After an initial investigation (Michel et al. 2005), now a comprehensive study is available (Michel et al. 2015) demonstrating the extreme exposures in some parts of Northern Ukraine and – at the same time – allowing to validate and to scrutinize the method. The findings are relevant for the application of the retrospective dosimetry after the Fukushima accident. The actual radiation exposures in the highly contaminated regions of Northern Ukraine are addressed by evaluating the exposures of returnees into the evacuated zone; e.g. Handl et al. (2006). Besides Cs-137 also the exposure to Sr-90 and actinides is taken into account. In conclusions, the opportunities for radioecology offered by the situation in the evacuated and exclusion zones for further investigations of the pathways of Sr-90 and the actinides through the environment to man are emphasized.

A New Tool for Genotoxic Risk Assessment: Re-evaluation of Cytokinesis-Block Micronucleus Assay using Semi-automated Scoring following Telomere and Centromere Staining

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Abstract. Background: The cytokinesis-block micronucleus (CBMN) assay is international gold-standard method for not only measuring DNA damage, but also a biomarker of DNA repair complexes. The high baseline of micronucleus in heathy population was compromised the sensitivity and the application of CBMN assay in the radiationprotection fields. In this study, we improved the detection of the different type of MN leading a significant reevaluation of the sensitivity of CBMN assay as well as the dose response curve using semi-automated MN scoring following telomere and centromere (TC) staining. Material and Methods: Blood samples from 15 donors were exposed to ^{137}Cs at 6 doses from 0.1Gy to 4 Gy with dose rate 0.69Gy/min and served to the reevaluation of dose response curve. In addition, blood samples from 2 donors were exposed to ^{60}Co at 4 doses from 0.01Gy to 0.2Gy with dose rate 0.01Gy/min in order to establish the sensitivity of the technique. MN were scored using semi-automated MN-TC scoring approach. Results: The introduction of TC staining offers the potential to render not only MN scoring more efficient and robust, but also permits the distinction between exposure to clastogenic (MN with only telomere signals) and aneugenic agents (MN with both telomere and centromere signals). Using semi-automated MN-TC scoring, it was possible to detect the difference between control and 0.05Gy as well as to reduce the MN baseline by excluding the MN with centromere sequences. Taking into account only MN with only telomere sequences or without any signal (interstitial deletion), linear quadratic dose response curve was established. Conclusion: The use of semi-automated MN-TC scoring has permitted a reevaluation of the sensitivity of CBMN assay as well as the reduction of MN baseline in circulating lymphocytes of healthy donors and the establishment of reliable dose response curve. These improvements market new step in the management and the follow-up of population exposed to genotoxic agent making possible the construction of a data base in order to respect the radioprotection norms and to define the risk associated with the exposure to very low doses to chemical agent and ionizing radiation.

Change in Peripheral Blood Lymphocyte Telomere Length and the Occurrence of Secondary Cancers in Hodgkin Lymphoma Patients

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Abstract. Background: The study of Hodgkin lymphoma (HL) has provided exceptional insights into several areas including late radiation-related effects. Our previous studies investigated DNA repair and telomere dysfunction in peripheral blood lymphocytes of retrospective cohorts of HL patients, in relation to radiation sensitivity, and the risk of late complications, in particular secondary cancers and cardiovascular disease. In this study, we investigate telomere length in a prospective cohort of HL patients followed >15 years after diagnosis. Patients and methods: Telomere length measurements were performed at several time points in a prospective cohort (125 patients) of stage I to stage III HL survivors diagnosed between 1997 and 2002 with a median follow-up 15.6 years. All patients were treated with radiation therapy associated with chemotherapy regimens. We evaluated the association between telomere length measured at diagnosis, after treatment and during follow-up and the change between those time points with HL cancer specific and all-cause mortality and morbidity using cox proportion hazards models. Results: There were 13 patient deaths, of which 7 were due to secondary cancer and 2 due to cardiovascular disease. Baseline and change in telomere length were associated with all- cause mortality ($p=0.02$ and $p=0.01$ respectively). The follow-up of patients who developed secondary cancer demonstrated a high variation of telomere length and the presence of a sub population of cells with drastic telomere shortening before the occurrence of secondary cancer. This telomere dysfunction was related to the presence of complex chromosomal exchanges. The variation of telomere length in patients with non-evidence disease was much lower. Conclusion: Telomere shortening was associated with increased risk of the occurrence of secondary cancer and all-cause mortality, suggesting that changes in telomere length in circulating lymphocytes over time could be biomarkers of prognosis. This study validates the concept that defects in telomere maintenance play a significant role in the initiation of genomic instability during carcinogenesis. Findings in HL have not only improved the understanding of human carcinogenesis, but have also pioneered its translation into the clinic.

Radiation Dose to the Eyes in the Risk of Cataract after Non-retinoblastoma Solid Childhood Cancers

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Abstract. Importance: Few studies have been published up to now on the relationship between radiation received to the eyes during childhood cancer radiotherapy and the risk of later cataract. Objectives: To investigate the risk of cataract after non-retinoblastoma solid childhood cancers. Materials and Methods: A retrospective cohort study on 1,833 5-year survivors who were diagnosed with solid cancer from 1945 to 1985 was set up between 1985 and 1995, and prospectively followed since by sending self-questionnaires. Radiation doses both eyes for individuals were estimated using Dos_Eg software, for all patients who had received radiotherapy. The role of the radiation dose on cataract risk was investigated using Cox's proportional hazard regression model, and using the excess relative or absolute risk (ERR or EAR) model. The role of chemotherapy was also investigated. Results: After follow-up for 37 years, 33 patients with unilateral or bilateral cataract were identified, with a total of 47 validated cataracts. Overall, in a multivariable Cox regression analysis, patients who received radiotherapy had a 4.4-fold (95% CI 1.5-13.0) increased risk of cataract compared with patients who did not receive radiotherapy. Exposure to radiation doses ≥ 10 Gy to the eyes increased the hazard ratio (HR) 42-fold (95% CI, 12.8 to 137.4), relative to no radiation exposure. Although based on few patients, a strong increase in cataract risk (HR = 31.0; 95% CI, 8.1 to 118.2) was observed in patients treated by melphalan. Conclusion: This study can directly inform guideline-based recommendations for long-term follow-up for cataract.

Risk of Subsequent Leukaemia after a Solid Tumour in Childhood: Radiotherapy and Chemotherapy Side Effects

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Abstract. Purpose: To investigate the respective roles of radiotherapy and of chemotherapy in the occurrence of subsequent leukemias after childhood cancer. Materials and methods: We have analyzed a case-control study which included 35 cases and 140 controls. The active bone marrow (ABM) was segmented into 19 compartments and the radiation dose was estimated in each of them. Doses of chemotherapy drugs were also estimated to enable adjustments. Models capable to take into account the radiation doses heterogeneity were implemented for analyses. Results: The univariate analysis showed a significant trend in the increase of secondary leukemia risk with radiation dose, when dose heterogeneity was accounted for (p- value=0.046). This trend became non-significant after adjustment for the doses of epipodophyllotoxins, alkylating agents and platinum compounds, and the first cancer types, in multivariate analysis (p-value=0.388). The role of radiation dose appeared to be dwarfed mostly by alkylating agents (OR=6.9, 95%CI: 1.9 - 25.0). Among patients who have received more than 16 Gy to the ABM, the radiogenic risk of secondary leukemia was found to be about 4 times higher in the subgroup with no alkylating agents than in the subgroup receiving 10 g/m^2 or more. Conclusions: Notwithstanding of limitations due to the size of our study population, and the quite systematic co-treatment with chemotherapy, the use of detailed information on the radiation dose distribution to ABM enables to consideration of a role of radiotherapy in secondary leukemia induction after childhood cancer.

Simulation-extrapolation Method to Address Errors in Atomic Bomb Survivor Dosimetry on Solid Cancer and Leukaemia Mortality Risk Estimates, 1950-2003

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Abstract. Analyses of the Life Span Study (LSS) of Japanese atomic bombing survivors have routinely incorporated corrections for additive classical measurement errors using regression calibration. Recently, several studies reported that the efficiency of the simulation-extrapolation method (SIMEX) is slightly more accurate than the simple regression calibration method (RCAL). In the present paper, the SIMEX and RCAL methods have been used to address errors in atomic bomb survivor dosimetry on solid cancer and leukaemia mortality risk estimates. For instance, it is shown that using the SIMEX method, the ERR/Gy is increased by an amount of about 29 % for all solid cancer deaths using a linear model compared to the RCAL method, and the corrected EAR $10(^{-4})$ person-years at 1 Gy (the linear terms) is decreased by about 8 %, while the corrected quadratic term (EAR $10(^{-4})$ person-years/Gy(^{2})) is increased by about 65 % for leukaemia deaths based on a linear-quadratic model. The results with SIMEX method are slightly higher than published values. The observed differences were probably due to the fact that with the RCAL method the dosimetric data were partially corrected, while all doses were considered with the SIMEX method. Therefore, one should be careful when comparing the estimated risks and it may be useful to use several correction techniques in order to obtain a range of corrected estimates, rather than to rely on a single technique. This work will enable to improve the risk estimates derived from LSS data, and help to make more reliable the development of radiation protection standards.

Chernobyl, 30 Years On – Health Effects

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Abstract. The Chernobyl reactor accident in Ukraine in 1986 was the worst nuclear accident in history. Of those dealing with the emergency, 134 suffered acute radiation syndrome and 28 of these died within weeks of high exposure. In total, ~14 EBq of radionuclides were released to the environment during ten days, including 1.8 EBq of iodine-131. Evacuation of people from the surrounding area was delayed, but the most serious consequences followed from children in the worst affected parts of the former USSR drinking milk heavily contaminated with radioiodine so that tens of thousands received thyroid doses >1 Gy. As a consequence, to date, several thousand excess cases of thyroid cancer have occurred among those exposed as children; fortunately, thyroid cancer has a low lethality, so relatively few deaths have resulted. Doses to organs/tissues other than the thyroid were much lower, so the evidence for other health effects arising directly from the releases is inconclusive. More than half a million people were involved in recovery and clean-up operations, and groups of these "liquidators" are the subject of studies; the average effective dose received by the liquidators was ~120 mSv. The dissolution of the USSR has been problematical for the follow-up of the liquidators: comprehensive and uniform health data are required for reliable epidemiological studies, and this had been difficult to achieve, so that comparisons of the health of liquidators (who are given regular medical examinations) with that of general populations have to be treated with caution. Dose-response analyses within groups of liquidators produce more dependable results, but even these have proved difficult, so that the indications of radiation-induced effects have yet to provide conclusive evidence. It will be important to continue to follow those exposed environmentally (especially how the excess risk of thyroid cancer develops with time) and as liquidators. Particular attention must be paid to the collection and collation of health data that are free of major biases, such as better information for those with higher exposures relative to lower exposures and variable diagnostic criteria, and cooperation between the various studies is highly desirable, but increasingly difficult. It should not be forgotten that much of the health burden of the Chernobyl accident may result from its psycho-social consequences, such as from the compulsory relocation of residence.

Immunological Monitoring of the Personnel at Radiation Hazardous Facilities

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Abstract. The study of possible mechanisms resulting in changes in the immune system after exposure to ionizing radiation is an area that has not been thoroughly evaluated during recent years. This article presents an overview of immunological monitoring studies of personnel from the radiation-hazardous factories that took place over the past 20 years in Russia. The methodology of these studies is based on: a) the pre-clinical evaluation of immune status of workers whose occupation involves potential exposure to ionizing radiation; b) selecting at risk groups according to the nature of immune deficiency manifestation, as well as; c) studying the changes of immune status of employees with regard to the potential effects of radiation exposure. The principal aim of these studies is accumulation of new data on the impact of radiation exposure on the human immune system and search for the relationship between the clinical manifestations of immune disorders and laboratory parameters of immunity to improve the monitoring system of the health status of the professional workers involved in radiation-hazardous industrial environments and the population living close to these facilities.

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Raman Spectroscopy as an Analytical Tool for Ionizing Effect Studies in Pig Lens “Ex Vivo” and “In Vitro”

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Abstract. Cataract is responsible for 50% of the world´s blindness and visual disability in human. The lens opacity can be divided in three major types according to his location in the lens, nuclear, cortical and posterior subcapsular cataract. This last is the most common in ionizing radiation-induced cataracts. Epidemiological studies have suggested that the lens is more radiosensitive than expected and a reduction of the equivalent dose limits for the lens of the eye in occupational exposure has been introduced in the International Basic Safety Standards (BSS) as well as in the European BSS, following the recommendation given by the ICRP. These recommendations suggested to reduce to 20 mSv year^{-1}, averaged over 5 years with no year exceeding 50 mSv. and have stimulated the study on the mechanisms of lens opacity process induced by ionizing radiation with the aim to improve the radioprotection of workers occupationally exposed and public. Raman spectroscopy (RS) is a non-invasive spectroscopy technique. The resulting Raman spectrum provides detailed information of the structure, composition and the changes induced in biological molecules. This system was employed to study: the characteristics of radioresistant oral cancer cells in vitro, the protein distribution in the pig lens, the identification and quantification of melanin types and others biological applications. The pig lens has been suggested as a suitable model for the human lens studies because the pig´s embryological growth and development are typical of mammals, its shape and size are similar to the human lens, there is a close sequence homology and significant antigenic similarity between human and pig crystallins. Objective: The aim was to investigate the capability of RS as an analytical tool to determine the alterations induced by gamma radiation in porcine lens ex vivo and in germinal lens cells in vitro at different doses of gamma radiation. Results: The survival curve until 5 Gy in vitro of germinal cells, and the Raman characteristic spectrum between 500 and 4000 cm^{-1} for: a) unirradiated and irradiated whole lens ex vivo and b) normal and irradiated germinal culture cells, will be presented.

Current Status of the Biological Study on Low-Dose Ionizing Radiation Effects in KHNP-RHI, Korea

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Abstract. The understanding biological response to low-dose radiation is an important issue in radiation protection field. So far, the linear non-threshold (LNT) model has been being regarded as the main theory for risk assessment of ionizing radiation. However, it is still controversial whether LNT model can thoroughly explain the biological effect of low-dose radiation. Cellular effects of low-dose radiation constitute an important area in radiation response, and differences in observed biological effects may depend on doses, dose-rates, and cell type. Thus, low-dose radiation research project has been promoted in Korea to improve the scientific and technical knowledge about health effects of low-dose radiation and to increase public understanding about it. Especially, KHNP-Radiation Health Institute (RHI) has been conducting extensive researches on the biological effects of low-dose radiation and its molecular mechanism via in vitro and in vivo study. We constructed a low-dose irradiation facility in 2005 for the first time in Korea. We have established a biological material bank for workers at nuclear power plants and a genomic identification system to examine low dose-specific genes. Currently, we are focused on the research project regarding the biological effects of low-dose radiation less than 100mSv, throughout various biological research fields such as cellular/molecular biology, immunology, bioinformatics, and cancer prevention. Five organizations, two institutes, two universities, and one industry, are participating in this project and actively working on through collaborative network. The ultimate goal of our project is to provide scientific evidence for the effects of the low-dose radiation (less than 100 mSv) and construct its database. Finally, we'd like to contribute to public acceptance about low-dose radiation.

Role of AKT and ERK Pathway in Controlling Radio-Sensitivity and Adaptive Response by Low-Dose Radiation in Human Immune Cells

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Abstract. Despite many studies of the effect of ionizing radiation, its biological process might differ greatly depend on dose, dose rate, and cell type. Recently, in spite of increasing interest in the biological effects of low-dose radiation arising from natural and environmental exposure, there remains substantial uncertainty about its biological effect. This study was performed to explore the effects of low- and high-dose radiation in human immune cell lines. We examined cell sensitivity after irradiation with 0.05, 0.1, or 2 Gy in two normal cell lines and three tumor cell lines. Low-dose radiation of 0.05 and 0.1 Gy had no effect on cell survival in any tested cell line, with the exception of IM-9 cells, whose viability was transiently increased. However, IM-9 and C1R-sB7 cells were very sensitive to high-dose radiation-induced cell death, whereas Jurkat and JM1 cells showed moderate sensitivity, and THP-1 cells were completely resistant. This radio-sensitivity was correlated with basal AKT activation. In radiosensitive IM-9 cells, priming with chronic low-dose irradiation blocked cell death induced by high-dose radiation challenge via inhibition of caspase activation and PARP cleavage. AKT phosphorylation was not altered in IM-9 cells, but ERK phosphorylation was greatly elevated immediately after chronic low-dose irradiation. These cellular adaptive responses to low-dose radiation accompanied by ERK activation were confirmed in C1R-sB7 B lymphoblasts. Taken together, our results suggest that the different responses of normal and tumor cells to low- dose and high-dose radiation depend on AKT activation, which is regulated by protein phosphatase 2 (PP2A). In radiosensitive normal cells lacking basal AKT activity, chronic low-dose radiation might inhibit cell death induced by cytotoxic high-dose radiation through modulation of the activation level of the ERK pathway, which plays an important role in the adaptive response to radiation. These results will be helpful in understanding the effects of low-dose ionizing radiation on health.

Non-cancer Effects in the Cohort of Mayak PA Workers Occupationally Exposed to Radiation

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Abstract. Objective. To study incidence and mortality from circulatory diseases (CDs) including ischemic heart disease (IHD), cerebrovascular diseases (CeVD) and lower extremity arteriosclerosis obliterans (LEASO) in the cohort of Mayak PA workers occupationally exposed to low dose rates of radiation over a prolonged period. Materials and methods. The study cohort included 22,377 workers (25% are females) first employed at the Mayak PA in 1948–1982 and followed up to the end of 2008. Individual doses from internal and external radiation used in the analysis were from the "Mayak Worker Dosimetry System–2008" (MWDS-2008). Relative risks and excess relative risks per unit dose (ERR/Gy) were calculated based on maximum likelihood using AMFIT module of Epicure software. Results. 8,717 cases and 1,578 deaths from CeVD, 7,225 cases and 2,848 deaths from IHD, 943 cases of LEASO and 5,010 deaths from total CDs were registered in the study cohort of Mayak workers. The study showed a significant association of CD incidence and mortality with non-radiation factors such as sex, attained age, smoking, alcohol consumption, hypertension, increased body weight, diabetes mellitus and others. A significant linear association of IHD, CeVD and LEASO incidence was found with dose from external gamma- rays after having adjusted for non-radiation factors and dose from internal alpha-radiation. Moreover a significant increasing linear trend in IHD and CD mortality with increasing dose from external gamma-rays was observed. Dose-response analysis for internal alpha-radiation due to incorporated plutonium showed a significant linear association of IHD and CeVD incidence with total absorbed dose from internal alpha-radiation to the liver after inclusion of adjustments for non-radiation factors and dose from external gamma-rays. Significant increasing linear trends in mortality from IHD, CeVD and CDs with increasing dose from internal alpha-radiation were revealed only for a subcohort of workers who were Ozyorsk residents exposed to internal alpha-radiation at total absorbed dose to the liver < 1,0 Gy. Conclusion. This study provides evidence of an increased risk of CD with external gamma- ray exposure and suggestive indication for the risk of CD incidence and mortality following internal radiation exposure. Validity of internal alpha-radiation dose strongly affects the dose- response for internal radiation exposure.

Micro- and Mesocosms for Assessing Ecosystem Effects of Radiation – A Review

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Abstract. The need for an ecosystem approach in environmental radiation management strategies has been repeatedly encouraged over the last decade, which up until now has relied heavily upon single species studies and reference organisms (RAPS). By extrapolating single species data to an ecosystem, researchers are not accurately representing the multiple interactions between individuals and populations of different species. Radioecological research must therefore begin to focus on the structure and functions from populations to ecosystem levels. Different species sensitives and the movement of radionuclides through food chains, soil to plant transfer and predator-prey interactions are all factors that can influence the observed responses of an ecosystem due to radiation exposure. Applying an ecosystem-based scientific approach is one of the main goals of the Centre for Excellence for Environmental Radioactivity (CERAD) and the International Union of Radioecology (IUR). CERAD is comprised of five Norwegian partners and is supported by international experts in specific fields, with the fundamental goal of improving the ability to accurately assess the environmental risks of radioactivity. One of the activities of a joint IUR-CERAD Ecosystem Approach task group is a literature review focusing on experimental ecological systems in the form of micro- and mesocosms. Micro- and mesocosms are artificial systems used to imitate natural ecosystems under controlled conditions. A large body of research has shown that microcosms often act similarly to large ecosystems when exposed to stressors. In radiation research however, micro- and mesocosms are less common, most examples are of aquatic systems and very few terrestrial ecosystems. Our review thus far has resulted in approximately 3,000 studies of potential interest, of which less than 20 studies include the term ionizing radiation. Our review includes experimental studies that have applied micro- and mesocosm experiments for evaluating ecosystem effects of environmental stressors. We, the IUR-CERAD Ecosystem Approach task group, will present highlights from our review, which will include realistic micro- and/or mesocosm ecological systems using multiple species representing different interactions in an ecosystem. The ultimate aim of this review is to highlight potential ecological systems for use within the fields of toxicology and radioecology.

An Update on a Rapid Method of Biological Dosimetry to Assist in the Event of a Nuclear Emergency

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Abstract. During emergencies where a large number of individuals have been exposed, dose assessment results are needed as soon as possible to help physicians develop a treatment strategy within a few hours of the catastrophe. The purpose of this research is to test an effective rapid technique for biological dosimetry that will enable the quantification of the amount of the radiation dose absorbed in the event of a nuclear emergency and to continuously improve the service of biological dosimetry. Blood samples collected from donors were exposed in vitro to different doses of gamma rays (i.e. 0 to 1000 mGy). The induction of double-strand breaks (DSBs) by ionizing radiation immediately results in the phosphorylation of the H2AX protein. H2AX foci formation is a consistent and quantitative marker of radiation-induced DNA DSBs. The detection and analysis of γ-H2AX foci was performed using the Metacyte software of Metafer 4 image analysis system of an automated microscope at iThemba LABS. Images captured by the system were manually analysed to validate auto results and suggested reliable results as dose response curves showed that manual data were not considerably different from automated counts. A clear relationship between the foci induction with dose was noted. For sensitivity of individuals, values ranged from 0.015 to 0.018. A very strong correlation was noted between the two scoring methods. Accuracy chart showed average dose percentage error of 0.25% and 2.14%. The automated method can produce results of about 100 exposed individuals within 2 days. For the calibration curves, two methods of analyses were used and generated two: $Y = 9.283X + 19.43X^2$ and $Y = 3.674 + 0.503\,5X - 0.014\,73X^2$ to estimate doses from foci counts at different levels. It can be concluded that the automated scoring system may be used as a reliable tool for assessing the frequency of ionising radiation-induced γ-H2AX foci in exposed individuals. These results confirm the automated assay efficiency for fast population triage in South Africa in case of large radiation accidents.

Radioiodine Transfer from Seaweed to Abalone

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Abstract. A spent nuclear fuel reprocessing plant releases various radionuclides into the environment. Iodine-129 is one of the major radionuclides released from the plant and accumulated in the seaweeds and possibly herbivorous shell fishes. Since the metabolism of iodine in those organisms has not been well known, we studied the transfer of I-125 from seaweed to abalone which is an herbivorous shellfish and an important marine product in Japan. In this study, sea lettuce (Ulva prolifera) or kombu (Saccharina japonica) labelled with I-125 were fed to abalones. The stable iodine concentration in kombu (approximately 5 mg g^{-1}) is much higher than that in sea lettuce (approximately 50 mg g^{-1}). The seaweed samples were exposed to I-125 in seawater for 16 h in an air-tight water tank maintained at 10 °C. After the I-125 activity and wet weight measured, the seaweed samples were fed to abalone samples in an air-tight water tank at 10 °C. The abalone samples were dissected 48 h after the feeding to collect muscle and hepatopancreas tissue samples followed by measurement of their I-125 concentration. In the case of I-125 ingestion through sea lettuce, approximately 10% and 15% of ingested I-125 were retained in muscle and hepatopancreas tissue, respectively. On the other hand, only 1% and 1.5% of I-125 in kombu ingested were found in muscle and hepatopancreas tissue, respectively, and much lower than those of sea lettuce. The high concentration of stable iodine in kombu may be one of the causes of those differences, if the most part of iodine in kombu was not absorbed from digestion tract and/or most of absorbed iodine was rapidly excreted as a surplus.

Clinical Features of Subacute Radiation Syndrome

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Abstract. Introduction: In published data there is a very detailed description of acute and chronic radiation. The main characteristic that determines what course - acute or chronic the radiation syndrome will take, is the magnitude of the radiation dose received per unit time (dose power). Additionally, a long-lasting version of the radiation exposure is known. It develops as result of radiation control absence in case of accidents, associated with mishandling of radioactive sources in the home or in the workplace. Subacute course of marrowy syndrome of radiation disease may develop as a result of fractionated or prolonged irradiation with dose power 0,1 - 0,3 Gy/day lasting from several days to several weeks. Material and methods: Were selected 32 patients with radiation syndrome due to fractionated or prolonged accidental exposure (the main group of patients). There has been formed two subgroups for comparison: patients with a typical marrowy syndrome of acute radiation disease and patients with a typical marrowy syndrome of chronic radiation syndrome. Clinical features and dynamics of hematological curves reflecting the dynamics of the cells of peripheral blood, the picture of the bone marrow has been studied and analyzed. Results: It has been found that subacute course of marrowy syndrome of radiation disease can develop as a result of prolonged or fractionated irradiation power of 0.1 - 0.3 Gy/day lasting from several days to several weeks. The total dose of bone marrow exposure is more than 1.5 Gy. First patients complaints of weakness, headaches, sweating, bleeding gums, etc. appeared in the earliest one month after the start of work in adverse conditions, on the average 6 months. Symptoms of the primary reaction (early vomiting) usually absent. In a blood tests lymphopenia and a transient neutro- and thrombocytopenia were determined. Conclusion: There has been described the subacute course of radiation disease by analyzing the clinical material of patients with radiation syndrome, there has been analyzed the clinical criteria that distinguish subacute radiation syndrome from acute and chronic.

The Frequency of Chromosome Aberrations in Peripheral Blood Lymphocyte Cultures and Risk of Disease Development After Radiation Exposure

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Abstract. Currently the contribution of chromosomal rearrangements in the development processes of certain cancer diseases is a well-established fact. A separate issue is the possible connection between chromosome aberration levels in cultures of peripheral blood lymphocytes and the risk of malignant and non-malignant diseases. This was due to published in 1990 and 1994 the united results of cytogenetic examinations of several Scandinavia and Danish laboratories. To overcome the existing inter-laboratory differences the method of splitting the entire data into three groups according to the detected levels of chromosome aberrations (low, medium, high) was used. The frequency of malignant disease was in 2.5 times significantly higher In the group examined persons with the highest levels of chromosome aberrations than in the groups with low and medium frequency rearrangements. Further still the bigger number of the countries was included in the considered research in which already laboratories from Italy, Hungary, Germany, Lithuania, Poland, Slovakia, Croatia and the Czech Republic also began to participate. However, generally speaking, the increased levels of chromosome aberrations found at cytogenetic investigations of the persons exposed to radiation may not indicate an increased risk for the development of malignant tumors. They are simply a consequence of the undergone irradiation and don't reflect the processes of malignant transformation, taking place in the organism and associated with chromosome instability. In scientific literature there are messages about connection of the increased levels of chromosome aberrations in peripheral blood lymphocyte cultures with risk of development of some malignant, as well as other somatic (cardiovascular, endocrine, in particular, thyroid diseases) pathologies. However the cytogenetic analysis in these works didn't precede statement of the diagnosis that significantly distinguished them from the European researches described above. Thus, in this case there can't be a speech about estimates of risk of diseases development as any illness requires the use of adequate medicinal agents. The influence of the latter on the chromosomal apparatus in most cases was not investigated strictly speaking.

Airborne I-131 detection on Internal Surface of Buildings using Common Household Products

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Abstract. Indoor airborne I-131 contamination has been a concern most recently in our Iodine Therapy Wards for treating post-surgical thyroid cancer patients. Minute amount of I-131, up to 0.015% of oral-administered radioiodine dosage, would be exhaled by patients that had been published elsewhere. Industry-used decon-gel thin film and mini-activated charcoal sampler had been demonstrated for indoor airborne I-131 detection (IRPA 2014). In this study, we would try to use consumer-used kitchen plastic wrap and aluminum foil to conduct the similar application. Plastic wrap and aluminum foil, with 30x50cm in area, are placed on top of a closet (2.3 m in height) in our Iodine Therapy Ward. Typical sampling time is 48 hours when patient, with an oral administered dose of 150 mCi, was presenting inside the ward. After the patient was discharged from the ward, the plastic wraps and aluminum foils would be retrieved immediately. Then, these thin films after exposure would be folded and rolled up in 4 cm length tubes to fit into a 2”x2” NaI(Tl) well counter for gamma spectroscopy analysis. After 5 test runs, the plastic wrap and aluminum foil have measured I-131 activity values of 167+/- 20 Bq and 157 +/- 11 Bq, respectively. In conclusion, these relative low cost plastic wrap or aluminum foil could be used for quick screening indoor airborne I-131 contamination during a nuclear emergency.

History of Ultra-Sonography Examination for Thyroid in the Residents Near Nuclear Power Plants

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Abstract. Background: Epidemiologic studies have been conducted to assess the association between thyroid cancer risk and residence near the nuclear power plants. Because many thyroid cancers are diagnosed by chance through health examination, ascertainment bias or detection bias are common in epidemiologic studies. We surveyed the history of ultra- sonography (US) examination for thyroid in the residents near the nuclear power plants. Methods: The study population were 2,421 residents near the nuclear power plants in Korea. Information on demographic characteristics including US examination history for thyroid was collected using questionnaires by interview. We divided into 3 groups (short (within 5 km), middle (5~10 km), and long distance (11~20 km)) according to the distance of village from the nuclear power plants and compared the proportions of US examination history in these groups. Results: Examination history of US for thyroid were 23.1 %, 13.7 %, 10.5 % in men (short, middle, and long distance group, respectively) and 31.3 %, 26.7 %, 18.3 % in women (short, middle, and long distance group, respectively). After adjusting for age, smoking history, alcohol drinking history, regular exercise, house income, and education level, there were still significant reverse association between US history for thyroid and distance from the nuclear power plants (P for trend = 0.001 for men and 0.017 for women, respectively). Conclusion: There were differences of US history for thyroid according to the distance of village from the nuclear power plants. Our results suggested that there may be an ascertainment bias in cohort study to examine the harmful effect of nuclear power plant and that active follow-up and examination is need to ascertain thyroid cancer in study population.

Pu isotopes in Surface Soils in China: Its Concentration and Isotopic Ratio

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Abstract. Plutonium is one of the most important actinides nuclides not only because it relates to nuclear weapon but also it can pose potential risk to the environment and human health due to its chemical toxicity and ionization radiation. The main source of Pu in the environment is global fallout which is contributed by atmospheric nuclear test carried out by nuclear countries several decades ago during the cold war, and China was one of them. China has great environmental diversity, so the deposition of Pu in soils would presumably vary from different environmental conditions such as climate condition (e.g. precipitation) and topography due to their influence on wet deposition and resuspension. On the other hand, the Chinese Nuclear Tests (CNT) in Lop Nor is another possible Pu source for the local areas through regional deposition and long-distance transportation. Although data on Pu isotopes in the environment has been reported in details in other nuclear countries, however, in China, related researches and reported data are still limited. For a better understanding on the distribution of Pu isotopes in China, surface soil sampling was carried out in different parts of China, and measurements were performed by AMS and ICP- MS methods. In our study, special attention was given to the $^{239+240}$Pu concentration and ^{240}Pu/^{239}Pu atom ratio in surface soils in Chinese terrestrial environment. A comprehensive schematic diagram was drawn to intuitively illustrate the Pu concentration and isotopic ratio in Chinese soils. The $^{239+240}$Pu concentrations in Chinese surface soils range from 0.026~2.697mBq/g and ^{240}Pu/^{239}Pu atom ratios are 0.132~0.220 which are slightly different from the global fallout value, with one exception that has an extremely low value (i.e. 0.08).

Development and Application of High Intensity D-T fusion Neutron Generator (HINEG)

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Abstract. It commonly realizes that more hard work is needed on neutronics and its radiation safety, especially for high-energy neutron protection. However the intensity of D-T neutron generators currently on operation around the world is on the order of 10^{12} n/s, severely restricting the research capability in radiation test time scale, measurement accuracy, parameter measurability, etc. HINEG (High Intensity D-T Fusion Neutron Generator) is an state-of-the-art accelerator-based high intensity D-T fusion neutron source, which is led by the Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences (INEST, CAS). The high intensity D^+ beam from ECR (Electron Cyclotron resonance) ion source get accelerated, bombard on the tritium target, and generate high yield neutrons with energy of 14 MeV. The neutron intensity will reach 10^{14} n/s, and this project can be divided into two stages: HINEG-I and HINEG-II. HINEG-I has steady and pulse dual-modes. The intensity of the steady beam could reach 10^{12} n/s. For the pulse beam, the full width at half maximum is smaller than 1.5 ns. The assembling and testing of HINEG-I will be finished at the end of 2015. Meanwhile, HINEG-II is a steady D-T fusion neutron generator with intensity of 10^{14} n/s. In order to achieve so high intensity, accelerators array and high heating load rotating tritium target will be used. HINEG- II will be finished at the end of 2020. Besides the basic research of neutronics, the characteristics of nuclear system component, and applied technology research, HINEG can be used for radiation protection. For example, in biological research field, HINEG can be applied to neutron irradiation breeding, neutron cancer treatment, biological protection. Recently, the DNA lesions and cell transformation which were induced by neutron irradiation were test, and further the chromosome aberration, tumorigenesis were examined in animal experiments to explore how the neutron irradiation act on living body and its mechanisms. The results will can contribute on developing new antitumor treatment, and further research will be sustained carried on HINEG.

ESR Dosimetry with Ceramic and Glass Materials from Electronic Components for Dose Assessment in Radiation Accident

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Abstract. Accurate dose assessment for victims in a radiation accident is necessary for both appropriate medical treatment and retrospective research. Electron Spin Resonance (ESR) measurement of tooth enamel or bone biopsy has become an approved method for accident dosimetry, with good radiation sensitivity and signal stability. However, the tooth or bone sampling will lead to irreversible damage, limiting the application of ESR dosimetry with them. Since various electronic devices, especially the mobile phones, have become an important part of personal belongings, the electronic components from these devices could be considered as potential samples for ESR dosimetry. In this paper, we investigated the ESR properties of the ceramic base material used in resistors or capacitors and the glass materials used for screen display or protection, including dose response, signal stability and effects of temperature and sunlight. Accordingly, the application feasibility of these materials for ESR accident dosimetry were discussed.

Results of RELID Study 2014 - Buenos Aires, Argentina
Retrospective Evaluation of Lens Injuries and Dose

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Abstract. High levels of scatter radiation in catheterization laboratories and the increased number and complexity of procedures may lead to opacities in the lens of the staff if protective measures and devices are not properly used. Following ionizing radiation exposure, changes generally first appear in the posterior subcapsular region of the lens and consist of small dots and vacuoles which, over time, aggregate to form larger opacities. In addition to ionizing radiation, other factors commonly associated with posterior subcapsular are diabetes and the use of systemic steroids. An international study called RELID (Retrospective Evaluation of Lens Injuries and Dose) was initiated by the International Atomic Energy Agency (IAEA) in 2008. The same study was performed in Argentina for the first time in 2010 in the context of the congress of the Latin American Society of Interventional Cardiology (SOLACI) and recently, in 2014, was carried out for the second time (SOLACI – CACI 2014, Buenos Aires, Argentina). The 2014 study included 115 participants: interventional cardiologists, technicians and nurses. Attendants completed a questionnaire and then both lenses were observed with slit lamp previous eye dilation. A score of opacity according to the scale of Merriam-Focht was assigned. Posterior subcapsular lens changes typical of ionizing radiation exposure were found in 91.5% of interventional cardiologists, in 77% of technicians and in 100% of nurses, according to the Merriam-Focht scale. This RELID study (Argentina 2014) has particular importance since allowed the follow up of 10 professionals evaluated in 2010, considering the opacity score and changes in the use of protection tools. The results obtained in the study population highlight the importance of the availability and proper use of the elements of radiation protection, as well as the staff training.

KEYWORDS: catheterization laboratory; lens opacity; interventional cardiology; accumulative lens dose; protective elements.

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Area 2: Policy, Standards and Culture

Integration of radiation safety in management systems in Swedish health care – success or distress

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Abstract. The quality of health care is sometimes described in terms of effective, efficient, accessible, patient-centred and safe. The terms are attributed to the core activity - patient care. Health care organisations also have to address further aspects of quality for example work safety and environmental impact. Clearly a quality management system is needed. Commonalities between international standards imply that an integrated management system addressing different issues is an efficient solution. Additionally, radiation safety have to be managed. In health care, radiation safety addresses a variety of issues; patient safety, occupational safety, security of radiation sources, emergency preparedness, transport safety, waste management, biomedical research, and more over assuring legal requirements. These issues have to be managed in a complex context. Including radiation safety in a joint management systems is compelling. The aim of this presentation is to describe and discuss the prerequisites for health care organisations in implementing a management system integrating radiation safety. The discourse will include an implementation project in a Swedish health care region. The implementation project revealed a number success factors. Managers – at all levels - have to be engaged in the project. Staff members at different positions, working with other parts of the management system contribute to the implementation. Other support staff such as communications is also important to involve. The medical physicist working closely to the concerned clinics have to be part of the work jointly together with those clinics. Other stakeholders such as staff representatives has to be somewhat involved. Acceptability for the approach is high amongst executive officers and worker representatives, but poorer at lower level management. The formation of an trans-professional team in the work process is essential. The dispersed legal requirements set on health care hinder to some extent the implementation and encourage treating radiation safety isolated. The work process increases awareness and visibility of radiation safety issues in the organisation. However, it is not yet quite fully acknowledged that safety issues, and especially radiation safety is an integrated part of the quality of health care. This impedes success. A prerequisite for of success is to acknowledge that to achieve and perceive good quality needs continuous improvement.

KEYWORDS: management system health care quality assurance

1 INTRODUCTION

The quality of health care is sometimes described in terms of effective, efficient, accessible, patient-centred and safe. The latter also include radiation protection and safety. Efforts have been made to improve radiation protection and safety in the medical sector. A number of concerted research projects have been conducted in different areas. The projects have for example been dealing with optimization in digital imaging and interventional radiology, early and late health risks in radiotherapy, optimization in nuclear medicine and optimization of occupational exposure in the medical sector. These projects resulted in different guidance documents [e.g. 1, 2, 3, 4].

These and other projects have improved the knowledge of technical assessments of equipment, methodology of radiation dose assessments as well as evaluation of image quality, and have raised awareness of the need for education and training. Still there is a need to improve radiation protection in health care [5] and rather poor quality is sometimes observed. The reasons for this are probably several and it is difficult to single out one. It may be needed to address the issues in a more systemic approach within the organization. The lack of engagement and awareness of radiation protection from both management and staff could also sometimes be observed. An example to illustrate the problem of

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a malfunctioning management of radiation protection and safety relate to education and training: The radiation protection expert (RPE) accidently discover that some physicians working in the operational suit lack education and training in radiation protection. The RPE sets up a training event and offers this to the orthopedic surgeons. A schedule for the training program is sent to the department in question. However, no one attend. The example – not fiction - demonstrates a lack of review activities to check that staff receives education and training. It also indicates lack of engagement from the manager of the department of orthopedics. However, the manager may not know that education and training is compulsory due to the lack of internal rules and set goals.

The consequences of an inappropriate management of radiation protection and safety are evident; there is a great risk that the radiation protection issues are not harmonized throughout the organization and the activities that should be performed are not prioritized. It is evident that it is compelling to include radiation protection and safety in the management control system, i.e. to specify responsibilities, duties and tasks within the organization.

The aim of the present paper was a) to outline a typical health care organisation and the activities performed and describe some prerequisites to integrate radiation protection in a management system b) to give examples from a project aiming at integrating radiation protection in the management system c) to discuss success factors and barriers and other challenges in the work.

2 HEALTH CARE ORGANISATIONS AND RADIATION PROTECTION

2.1 Healthcare, organization and management

A hospital is a work environment with a complex product – health care. Health care is provided for patients with a range of individual prerequisites to benefit from diagnostic and therapeutic procedures. Each patient has an individual right to affect the activities planned. The organization consists of health care professionals with individual responsibilities to their work. The daily work is managed by managers at a lower level under the provisions provided, and the top and middle managers allocate resources to different activities under the supervision by politicians in the case of public health care or by the owners of the health care company. Health care is dependent on and is influenced by the scientific development in the medical field. New technology and methodology is introduced in the clinics with a rather rapid pace.

The work activities associated with ionizing radiation are varying. The activities range from routine work that could be standardized to activities including a great element of situational decisions. The staff has a varied level of education and prerequisites to comprehend education and training and take responsibility of their own work. The activities that should be managed are very different in nature and have to be addressed accordingly. The strategy on handling risk of acute effects from ionizing radiation and effects of stochastic nature is of course very different.

The organisational structure of health care organisation varies, but a vast number of hospital organisations is govern by a hierarchical organisation structure, with top and middle management supported by lower management. The latter close to the activities responsible for the daily planning of activities and resources. The different activities involving medical exposures often require physicians, other medical staffs and different support staffs from different parts of the organization. In order to perform well teamwork is essential but not self-evident. Swedish health care is usually organized in large organizations at different geographical sites. Resulting in large and complex organizational structures. The activities involve all sorts of radiation sources and medical radiological equipment. In the larger regional and university hospitals also high activity sealed sources, linier accelerators as well as particle accelerators (cyclotrons) are in use.

Health care is regulated by a number of laws and regulations and is supervised by a number of authorities, e.g. the Health and Social Care Inspectorate, the Medical Product Agency and Swedish Work Environment Authority. Radiation protection and safety are supervised by the Swedish Radiation Safety Authority, the authority that also issues legal requirements concerning radiation protection.

2.2 An implementation project

A project implementing radiation protection and safety in a management system was carried out in large health care organization comprising a large region, govern by a chief executive officer. The organization include a university hospital governed by one hospital director. The organization also include 3 larger regional and four smaller health care providers all with separate directors. The entities are geographically separated at 14 sites. In total, 35 000 employees work in this organization of which about 4 500 is working with ionizing radiation. The work is performed in several diagnostic radiology departments, but x-ray is also used in a large amount of departments x-ray outside the radiology department, for example in the operational suites were surgical procedures, cardiology procedures and others treatments are performed. Laboratories using open radioactive sources is also placed at different hospitals. The organization hold a common licenses for the different activities – the county CEO is the license holder.

2.3 Health care and radiation protection issues at concern

Medical exposures is obviously associated with the activities performed in health care. In addition, occupational radiation protection are needed. Safety and security issues for radiation sources have to be properly taken care of. Regulatory affairs needs to be handled. The activities are diverse and it is not easy to get an overview of what has to be done and by whom and to allocate proper resources in different areas. The main processes may be categorized as follows. Patient safety, regarding the medical exposures of the patient and involves e.g. justification and optimization. Occupational safety, appropriate safety arrangement for the staff, e.g. pregnant staff. Medical radiological devices and other radiation sources that should be supervised properly. Waste produced have to be properly taken care of. Biomedical research is often performed in the health care setting. All these issues gives rise to a number of activities that has to be performed. All parts of the organization have to be engaged in order get a proper quality of radiation protection and safety. The well-known plan-do-check-review strategy the core of any quality management system is straight forward and applicable to the processes described above. But the framework – including governance and management issues and reviewing and auditing – is also of great importance and may be neglected.

2.4 Health care and management systems

All these issues have to be sufficiently organised and managed in hospitals. A way to improve risk management is to integrate radiation protection and safety in the management system [6]. A management system is a standardised framework to improve activities throughout the organisation by developing and implementing policies, description of processes, routines for work activities as well as decision on responsibilities, accountabilities, level of authority and interactions of those managing, performing and assessing work [7, 8, 9]. A management system includes a mechanism for revision and specifies audit activities including self-monitoring activities. The need for such a system for patient safety in health care has been stressed [10], but also other radiation protection and safety activities could be included. That is, a management system could include common guidelines, processes and routines supporting radiation safety activities may be beneficial.

The evolvement of operational activities in the medical sector is interesting to recall. The need for quality control (QC) of medical radiological equipment was early recognized. QC programmes were developed and implemented in the field of radiation therapy and diagnostic radiology. QC activities have changed along with technical development of the medical equipment. Furthermore, in radiotherapy the treatment process has been evaluated from a safety point of view and quality assurance programmes (QA) have been set up to make sure that sufficient barriers are in place to minimize the probability of accidents occurring and to make sure the correct dose is delivered [11]. QA programmes have also been developed in the field of radiology and nuclear medicine [12]. The integration of radiation safety in the management system has to a less extent been addressed in the health care, at least in Sweden. International standards and guides issued from the IAEA supports the work [13, 14]. The standards mentioned above leave great room for adjusting the system to local practises and to potentially existing management systems and this adjustment is also beneficial.

3 INTEGRATING RADIATION PROTECTION IN THE MANAGEMENT SYSTEM

It is assumed that it is beneficial to adopt to the management system and structure at hand. If an organisation already have a well-functioning management system the integration of radiation safety may be less difficult. Some important aspects concerning integrating radiation safety are mentioned in the following section.

3.1 Important aspects when implementing a management system

3.1.1 Efficient and effective - identify common policies, requirements and rules but local once is also needed

There are a number of activities where overall policies, requirements and rules can and should be kept common for the whole organization, for example requirements concerning occupational safety the management of radiation sources and waste. However, not all requirements can or should be common. Local routines concerning one clinic are also needed for specific activities. The work on setting up these routines is a team effort including a group of different professionals. There is a critical and difficult balance between setting up common and local routines. There is an evident risk that some important issue is forgotten or that completely different policies or routines are developed for the same issues. A radiation protection expert should be keeping an oversight and taken a holistic view.

3.1.2 Leadership management should be addressed

Managers throughout the organization should be aware of their responsibilities. The responsibilities should be clearly stated from top management down to all levels of management. The managers at the appropriate level should be able to allocate resources and organize the radiation safety work for the activities they are responsible for. This includes assigning different tasks for different issues and to see to it that these tasks are performed. It is evident that the engagement for radiation safety issues from the top management is very important. It is also evident that the top management has to have expert advice from a radiation protection expert in identifying the needs and priorities for the specific organization.

3.1.3 Internal audits and reporting to the top management

Internal audits should be carried out on a regular basis comprising key crosscutting issues. The audit should engages all levels in the organization and it very important that management at all levels should be engaged in the audits. An audit has to be carried out with the aim to improve radiation safety not only to discover discrepancies. Therefore in connection to the audit an action plan for improvement has to be settled and agreed upon by the top management. The result and resolution should be communicated throughout the organization.

3.1.4 Coordinated support activities

Coordination between medical physics experts (MPE) and radiation protection expert(s) (RPE) is important. A joint approach including priorities and ambition level should be fostered throughout the organization. This presumes the MPE and RPE have a common view on policies, guidelines, requirements and rules adopted in the organization. An appointed radiation protection expert should be adviser to the top management, conducting audits and see to it that an action plan for improvement is formulated and established in the organization.

3.2 Result of the implementation project

The implementation project was carried out for three years staring 2013. After these years the directives, requirements and common radiation safety goals was decided by the CEO of the region. Common safety reviews have been and the result was reported to the county council. The requirements state that each hospital manager should establish their framework of requirements and to adjust it to their organizational structure.

The involved hospitals now have decided local requirements and the top documents regarding radiation safety is in place. The frameworks is to some extent different in the different hospitals in order to adapt to the different local organizational structures. This was expected as the regional directive was not (intentionally) specific. Still, there is a need to develop the system further especially in the local hospital organization and to continuously revise the established requirement.

4 CONCLUDING REMARKS

International standards [15] are clearly specifying the responsibility of top management. In safety requirements the demands on the management are specifically stated [13]. Guidance, supposedly developed for the nuclear industry provide input on introducing a management system [14].

More emphasize on management issues are needed in the medical field. Specifically, more knowledge on how to include radiation safety in a complex organization in an efficient and effective manner is needed. Experience and collaboration with other fields such as the nuclear industry and aviation industry may be beneficial.

Radiation safety issues are closely linked to patient safety issues in general; for medical exposures it is hard to distinguish between the two. Thus, it would be fruitful to collaborate with expertise in the patient safety field.

Taking this holistic approach has several benefits. One of them is associated with risk assessments. When performing risk assessments including all parts of the organization and activities performed, there is a possibility to get a balanced view supporting a graded approach. Taking a graded approach is critical for the credibility of radiation safety activities. Appropriate recourses and more elaborated safety routines could be applied for the activities with the greatest risk. The management of accidents and incidents could also be performed in a similar way throughout the organization, and performed in a uniformed manner including a harmonized assessment of the radiological consequences.

Through the review and auditing system - a mandatory part of a management system – the awareness of radiation protection and safety issues on the management level will increase. The directors at different levels are informed about results and the required needs for improvement.

When clear and communicated procedures are established in a transparent way staff members and their representatives have the opportunity to influence the system. In recent years stakeholder involvement has been recognized as an important issue in the context of radiation safety in the medical field. Implementing a management system will include such stakeholders.

A management system is also a cost effective approach since not all different departments using radiation have to address the same issues and develop documented processes for all aspects of radiation safety.

4.1 Distress or success

Current legal system, in the country of concern, to some extent hinders the implementation. Documentation of a separate radiation protection organisation is required and the legal requirements also demands a quality manual for radiation protection.

Transparency could be regarded as a threat and loss of power e.g. by some radiation protection experts and one can expect opposition.

One apparent risk is that resources to continuous improvement of the system is neglected. Actually an implementation project, such as the one mentioned here, never ends it should be considered a process. Continuous improvement is always needed.

Keeping radiation safety issues and tasks isolated and performed by some secluded staff members performed in a non-transparent manner is an insufficient approach to create sufficient radiation safety. The net benefit of integrating radiation safety in health care organisations is evident.

5 ACKNOWLEDGEMENTS

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Some Suggestions to Adequate the IAEA Safety Standards Series No. 49 According to the General Safety Requirements Part 3 from IAEA

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Abstract. At that time of publication SSR49 two exposure situations were considered, namely: practices and interventions, with Naturally Occuring Radioactive Material (NORM) being considered as intervention exposures but acknowledging that some natural sources can have exposures resulting from practices. In the Ba sic Safety Standards (BSS) the exposure situations have been categorised as planned, emergency and existing. These three situations necessitate an update of SSR No.49 since NORM fits in the existing situation, i.e one in which the doses already exist and should be reduced. To reduce the doses will create radioactive waste that must be either treated or stored. This scenario raises a problem of defining the dividing line between existing and planned situations. The point of transistion from one situation to the other needs to be clarified in order to establish the necessary controls for an existing situation whilst providing the necessary controls needed for the planned situation. For the latter planned situation several questions arise as to whether certain requirements can be exempted and under what circumstances. This paper will examine what the authors consider most important in more detail with some suggestions made for further consideration.

KEYWORDS*: *NORM; mining.

1 INTRODUCTION

The aim of this paper, is to present some suggestions that envolve in a revision of the IAEA Safety Series Report (SSR) Nº49, 2006 [1], entitled: "Assessing the Need for Radiation Protection Measures in Work Involving Minerals and Raw Materials due to the recent publication of the IAEA[2]" according to the Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards Edition, General Safety Requirements Part 3, GSR Part 3, Vienna (2014) . Our suggestions are cover two important aspects namely:

a) Update recommendation of the Safety Series Report (SSR) Nº49, 2006 [1]
b) Important issues that should now be introduced to meet the demands of General Safety Requirements Part 3, GSR Part 3 they made necessary due to the radiation levels presented by the materials and their by-product.

2 DISCUSSION

We will show some arguments that illustrate the need to revise SSR49 and also some issues that could be addressed in the new publication.

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2.1 SSR49, Section 2.3.2 (a)

"… with regard to the activity concentration levels in materials below which it is usually unnecessary to regulate 1 Bq/g for uranium and thorium series radionuclides and 10 Bq/g for ^{40}K … ".
It is not clear that the exemption levels stated in paragraph (a) refer to values in which the radioactive materials are considered unnecessary to regulate from a radiological protection point of view. These values consider the scenarios of more restrictive dose which provide individuals with a dose equal to or less than 10 μSv/y. With this and the public limits from 1 mSv/y for the whole body, the exemption levels derived from the application of radiological protection regulations would increase by a factor of one hundred (100) or more.

In addition, if we consider the derived air concentration, it can be concluded with reasonable confidence that the exemption limits would also be allowed to increase by a factor of around 100 (one hundred).

In the case of ingestion, this level of intake will never be achieved since the body can only accept a limited mass of material.

Finally, if we consider the external dose exposure, the effects of self-absorption in the material will increase the quantity of the material required to produce the measured external dose.
In view of the above it becomes problematic to make a direct relationship of dose rate in mSv/h per Bq/g from Tables 10, 11, and 12 from SSR49 which would then result in an exemption level of 1 mSv/y.

2.2

It is proposed that the radiological protection regulations are revised to identify for Naturally Occurring Radioactive Material (NORM) the activity concentration (Bq/g) as a function of volume to determine a volume of the material above which the mass or volume of the material can be disregarded, with regards an external dose, due to self-absorption effects.

2.3

SSR49 was published in 2006 with two exposure situations defined as practices and interventions. Some 5 years later the IAEA published the Basic Safety Standards Interim Edition, General Safety Requirements Part 3 [Ref2] in which three exposure situations, planned, emergency and existing were defined.

SSR49 is based on the existence of two exposure situations,namely practices and interventions, and currently section 2.3.2(a) is considered to be an intervention. In the BSS published in 2011 the exposure situations were categorised as planned, emergency and existing. As a result SSR49 needs to be revised to align with the three exposure situations defined in the BSS.

2.4

The situations include those in which the radiation doses already exist and should be reduced. To reduce existing doses will generate radioactive waste and / or raw material and in this case the situation will change from existing to planned. The first problem to resolve is to establish when a situation becomes planned situation. We recall that in the existing situation the first steps to be made relate to the principles of justification and optimization of protection to verify whether it is feasible to undertake the action of decreasing doses. If the action of decreasing the dose is chosen and justified and the principle of optimization indicates implementation should begin, this raises the question at what stage of implementation of the existing situation does it become a planned situation and the requirements therefore change?

2.5

Once the dividing line is established between the two situations under consideration the next step is to check what the conditions of the material under examination that satisfies the record level, since any dose lower than this value is considered as zero or not registered. As the radiation levels are higher than 1 mSv/y personnel involved in processing the material is regarded as a worker. Internationally, both UNSCEAR and the ICRP recommend a recording level of 5 mSv/y whilst in contrast the IAEA Safety Standards recommend its member states that they determine their own levels of registration according to their own national policies, with a caveat that they could not be less than the limits of the public.

We consider in this paper the value of 5 mSv/y has a valid technical-scientific basis and therefore the materials that will not reach this dose value should not be subjected to international recommendations and national regulations for radiological protection.

2.6

For materials that produce doses than 5 mSv/y which are subjeceted to international recommendations and national higher regulations there are several problems that need to be addressed depending on the expected doses in normal situations.

For example, suppose the expected doses do not exceed the average annual limit of 20 mSv/y.
In this case we need to indicate in when individual monitoring is necessary since both the international recommendations of ICRP and SSR49 stipulate that is only needed if there are large variations in doses during the development of tasks and thus can not be predicted beforehand. But in practice it is necessary to monitor the workplace and it must be defined which of external radiation, contamination of surfaces and air contamination are required.

Dose in this region should be, undoubtedly required be subjected to the principle of optimization and other aspects of the international recommendations.

We will also need to discuss the possibility of potential exposures.

2.7

The next step is for materials which under normal working conditions have a higher than average but below the annual dose limit of 50 mSv. In this case, in addition to the principle of optimization the use of individual dosimeters and international recommendations should be implemented almost entirely dependant upon the predicted potential exposures.

Consideration of potential incidents and accidents should also be included to inform the requirement for a Radiological Emergency Plan (REP). In this case, in addition to the three types of monitoring of the workplace, individual monitoring for external radiation, contamination of skin, clothing and the potential intake of contamination should also be required.

It is understood that, as result of an incident, the potential situation is considered to be confined within the premises of the nuclear facility and are therefore only workers are affected.

2.8

Unacceptable higher than annual dose limits for both the public and workers when they are subjected to a possible potential situation can be can be considered in the context of their maximum doses and the probabilities of occurrence. In this case one can introduce two situations, the first in which the expected doses are in the region of stochastic biological effects and the second those in which the tissue reactions result in somatic effects that manifest themselves in all subjects who received higher doses above the thresholds.

In these two cases we believe that international recommendations apply fully. Regarding the radiological emergency plan, there is a need to discuss what topics should be covered and to what extent situations in which individuals need referal to specialized medical services should be included.

3 CONCLUSIONS

It is important to assess NORM to establish which materials can exceed the average annual limit for workers in normal work situations.

It is very unlikely that the doses in abnormal situations can reach the levels defined as an incident or accident nonetheless this matter should be included in a revised SSR49 report.

A revision of SSR49 is necessary to align it with the BSS. The aspects discussed in this paper are important for workers involved in processing NORM and we propose that the arguments presented in this paper raise anomalies that should be addressed clearly in a revised SSR49 to provide the correct level radiological protection under all conditions of working.

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Restoring the "R" in ALARA

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Abstract. Radiation protection philosophy is guided by the principle that radiation doses should be kept below regulatory limits, and further reduced to as low as reasonably achievable (ALARA), economic and social factors being taken into account. A challenge for radiation protection practitioners is that no universal, objective definition of "reasonable" has been provided. In the absence of such a definition, radiation protection efforts, while ostensibly adhering to the ALARA principle, often more closely resemble "as low as possible". These two philosophies are not synonymous and lead to very different policy decisions. In particular, overemphasis on hypothetical cancer risks of radiation doses far below where such risks have actually been observed has led to unreasonable policy decisions that have adversely impacted public health. Three examples are presented: (1) the choice of electricity generation method; (2) the response to radiation/nuclear accidents; and (3) dose-reduction efforts in medical imaging. The exaggerated fear of radiation has led to the premature closure of nuclear power plants. The public rationale offered for such policies frequently rests on safety arguments. However, there is a wealth of objective data demonstrating that nuclear power is safer than alternative electricity production options. Nonetheless, nuclear and radiological accidents do rarely happen. The responses to these events have focused exclusively on protecting the public from hypothetical radiation cancer risks from exposures where such risks have not been demonstrated. Failure to consider the risks of radiation protection measures themselves is at odds with the ALARA philosophy. This issue has also spread to the medical arena. In an effort to avoid a few mSv, patients have been steered away from imaging exams involving ionizing radiation and toward less effective imaging modalities that don't involve ionizing radiation. Alternate imaging modalities also often come with risks of their own, and these risks are frequently not appropriately considered. The IRPA should take advantage of every opportunity to encourage the ICRP to restore reasonability to radiation protection guidelines, as called for by the ALARA philosophy.

KEYWORDS: ALARA; nuclear power; medical imaging.

1 INTRODUCTION

Modern radiation protection philosophy is ostensibly founded on the philosophy that in addition to complying with regulatory radiation limits, efforts should be made to reduce doses below even below these limits. This philosophy has evolved over the past six decades from its early formulation, as stated by the International Commission on Radiation Protection (ICRP) "…it is strongly recommended that every effort be made to reduce exposures to all types of ionizing radiations to the lowest possible level" [1]. In 1991, the ICRP changed the focus of this philosophy "…to focus more on balancing the potentially competing priorities of the benefits of protection from radiation and the benefits of the use of radiation, rather than on constraining protection: "to provide an appropriate standard of protection for man without unduly limiting the beneficial practices giving rise to radiation exposure" [2]. Note the shift from "the lowest possible level" to achieving a balance between dose reduction and the beneficial uses of radiation. In its most modern formulation, this philosophy is expressed as the ALARA principle, which is defined as "to keep exposures as low as reasonably achievable, economic and social factors being taken into account" [3]. In practice, ALARA is implemented through the principles of justification, which states that any decision that alters the exposure situation should do more good than harm, and optimization, which prescribes that social and economic factors should be considered in balancing dose reduction efforts with achieving the benefits of the practice involving radiation [4].

All too often, this distinction is not fully appreciated, and modern radiation protection is practiced as if we are still operating under the “as low as possible” philosophy, where putative risks are inordinately prioritized over benefits. Misrepresentation of the linear no-threshold dose-response model as implying “there is no safe dose of radiation” [5] has contributed to a culture of unreasonable radiation phobia. In this environment, dose-reduction has become the prime goal even in the range of a few mGy, approximately two orders of magnitude smaller than the acute doses which produce observable adverse effects. This is at odds with the modern formulation of ALARA, which determines a residual dose where risks and benefits are considered balanced and acceptable [6]. In this paper, I relate two personal experiences where I have encountered radiation phobia, and the unreasonable outcomes it produced.

2 UNREASONABLE CHOICES IN ELECTRICITY GENERATION

I currently live in Cincinnati, Ohio in the USA. The American Lung Association has ranked the area where I live as having the eighth worst annual particle air pollution (which increases the risk of heart disease, lung cancer and asthma attacks), and the 23rd worst ozone pollution (which is linked to premature death, asthma attacks, respiratory infections, pulmonary inflammation, and possibly cardiac arrhythmia) in the United States [7]. A very significant contributor to the polluted air my family and I breathe is the ten coal-fired power plants located along the Ohio River, within 135 kilometers of my home. One example is the William H. Zimmer Generating Station (Fig. 1), which is less than 15 km away. Incidentally, Zimmer was originally scheduled to be a nuclear plant, but as a result of serious quality control issues the U.S. Nuclear Regulatory Commission ordered a halt to construction (which was 97% complete) in 1982, and the decision was made to convert Zimmer to a coal plant. Zimmer is onlyone example. Currently, 67% of Ohio’s electricity is supplied by coal and only 12% by nuclear [8]. As a result, every day my family and I breathe air polluted with benzene, toluene, dioxins, lead, mercury, and 79 other carcinogenic compounds. Even in instances where nuclear plants have been safely supplying clean energy for decades, there is public pressure to close them decades before the end of their useful operating lives. In every US state where nuclear plants have been prematurely shuttered (Table 1), their generating capacity has been replaced with fossil fuels (Table 2). It has happened in Florida [9], California [9, 10], Wisconsin [9], and Vermont [11, 12].

Figure 1: William H. Zimmer Generating Station

Producing electricity by combusting fossil fuels instead of nuclear leads inevitably to increased air pollution and negative impacts on public health. Nuclear generation is far safer than any of the fossil fuel options which have invariably filled the gaps left by early nuclear plant closures [13, 14] in the USA, yet efforts to force early closures of nuclear plants are frequently predicated on safety arguments [15].

Table 1: US nuclear plant early closure dates.

Plant	Location	License expiration	Ceased operations
Crystal River	Crystal River, FL	12 December, 2016	September 2009
San Onofre	Clemente, CA	2 February 2022 (Unit 1) 15 November 2022 (Unit 2)	January 2012
Kewaunee	Carlton, WI	21 December 2013	7 May 2013
Vermont Yankee	Vernon, VT	21 March, 2032	29 December, 2014

Table 2: Electricity generation by sector in the years (listed in parentheses) preceding and following premature nuclear plant closures. Data demonstrating replacement of nuclear by fossil sources highlighted in *italic font*.

Source	Preceding closure (%)	Following closure (%)	Difference (%)
	Florida (2009, 2010)		
Coal	24.78	26.15	*1.37*
Natural gas	54.29	56.15	*1.86*
Petroleum	4.23	3.98	-0.25
Nuclear	13.36	10.45	*-2.91*
Hydroelectric	0.10	0.08	-0.02
Wood	0.90	0.88	-0.02
Other biomass	1.09	1.04	-0.05
Solar	0.00	0.04	0.03
Other	1.25	1.24	-0.02
	California (2010, 2011)		
Coal	0.99	0.69	-0.30
Natural gas	44.31	59.98	*15.67*
Other gas	0.83	0.74	-0.09
Petroleum	0.45	0.15	-0.31
Nuclear	18.26	9.28	*-8.98*
Hydroelectric	21.19	13.45	-7.74
Other biomass	1.29	1.26	-0.03
Geothermal	6.25	6.27	0.02
Pumped storage	-0.04	0.29	0.33
Solar	0.44	0.69	0.25
Wind	94.42	93.21	-1.22
Other	0.46	0.41	-0.05
	Wisconsin (2011-2012)		
Coal	49.66	61.62	*11.96*
Natural gas	17.50	12.28	-5.21
Petroleum	0.48	0.46	-0.02
Nuclear	21.68	17.70	*-3.98*
Hydroelectric	2.31	3.00	0.69
Wood	2.36	2.36	0.00
Other biomass	0.78	0.73	-0.05
Other	0.12	0.10	-0.02
	Vermont (2014-2015)(based on data for New England)		
Coal	4.68	3.60	-1.08
Natural gas	43.13	48.52	*5.39*
Petroleum	1.66	1.82	0.16
Nuclear	34.09	29.55	*-4.54*
Hydro	8.05	7.48	-0.57
Wood	2.89	3.21	0.32
Refuse	3.20	3.07	-0.13
Wind	1.78	2.01	0.23

3 UNREASONABLE RESPONSES TO NUCLEAR ACCIDENTS

Even in the rare instances where there have been large-scale accidents at nuclear generating facilities, radiation phobia has led to unreasonable responses that have harmed public health. In the aftermath of the Chernobyl disaster in 1986, thousands of pregnancies were terminated across Europe [16-21], in spite of the fact that public doses in locations far removed from the Chernobyl plant were a fraction of natural background. Most importantly, there is no evidence of teratogenic risk in humans from low doses [22], a fact apparently not appreciated even by physicians [23]. It is impossible to view this situation, clearly originating from radiation phobia, as a reasonable response.

The 2011 Fukushima accident, and the resulting large-scale evacuation and continued exclusion of residents from their homes, is the most recent example of an unreasonable response to a nuclear accident. The public doses resulting from the Fukushima accident were very low [24] and involved no deaths directly related to radiation exposure according to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)[25]. The ICRP has recommended that care be taken to ensure that dose-reduction measures in response to an accident should achieve sufficient benefit to offset any costs or negative consequences [4]. However the evacuation itself caused increased mortality, particularly among the elderly [26-28]. Over 1,600 people died from causes related to the evacuation [29], and the continued exclusion of residents from their homes for extended periods of time. The risk from the evacuation outweighed any hypothetical risk of radiation exposure, particularly among the elderly [30]. A retrospective evaluation has concluded that the evacuation was ordered not because of radiation-related health risks, but rather to maintain public order, and was therefore unethical [31]. This over-reaction is not only evident in hindsight – it was publicly decried as early as two weeks after the accident [32], to no avail. Japan and the world were in the full grip of unreasonable radiation phobia, and public health suffered as a result.

It would be inappropriate for a professional radiation protection society like the International Radiation Protection Association (IRPA) to advocate for or against any specific industry (*e.g.* the nuclear industry). But it is certainly appropriate for radiation professionals to educate the public on the relative safety of electricity production sources, including accident scenarios, and to do whatever we can to ensure that energy choices are based on accurate information rather than exaggeration and unreasonable radiation phobia.

4 UNREASONABLE CHOICES IN MEDICAL IMAGING

I also have personal experience with unreasonable radiation phobia in the medical arena. My son, 12 years old at the time of this incident, stayed home from school on a Friday in 2014 with an upset stomach. His symptoms got progressively worse throughout the day, and my wife took him to see his pediatrician in the afternoon. The pain was localized to his right side and he had other symptoms which concerned his doctor, so she referred him to our local children's hospital – which is one of the best hospitals of its kind in the United States – for medical imaging. At the hospital, a second pediatrician examined him and advised my wife that he had signs consistent with appendicitis. The pediatrician recommended an ultrasound rather than an abdominal computed tomography (CT) exam, even though she advised that a CT provides a more consistently reliable diagnosis. She said that if the ultrasound was inconclusive, they would proceed to a CT. The doctor told my wife that CT involves radiation exposure equivalent to 1,000 X-ray exams, children are more sensitive to radiation than adults, and there are studies that show that this increases cancer risk in children. She also said the CT exam would expose my son's gonads to radiation, and she wanted to avoid any possible future reproductive effects. I later learned that the pediatrician's recommendation for an ultrasound instead of a CT was consistent with the appropriateness criteria established by the American College of Radiology (ACR)[33, 34]. These criteria have contributed to a shift away from CT to alternate imaging modalities [35] in spite of the real risks of these alternatives, which are frequently not appropriately considered [36]. There are several problems with our pediatrician's well-intentioned advice.

First, there are no reliable studies that show increases in cancer risk from CT scanning. Through pure coincidence, on the same day my son went to the hospital I submitted a revised draft manuscript to a scientific journal concluding that cancer risks from doses as low as those typically associated with diagnostic imaging are still "too low to be detectable or are nonexistent" contrary to a few highly publicized and methodologically flawed studies claiming otherwise [37]. This conclusion is shared by The Society for Pediatric Radiology (SPR)[38], the International Organization of Medical Physics (IOMP)[39], and the North American Health Physics Society (HPS)[40], among others.

Second, there is no evidence showing increases in mutations in the offspring of parents whose germline stem cells were exposed to radiation [22], even after relatively high gonadal doses associated with radiotherapy [41], and certainly not at the doses typical of a CT exam.
Third, the blanket assertion that "children are more sensitive to radiation than adults" is an oversimplification. The UNSCEAR concluded that for about 25% of cancer types children appear to be more sensitive to radiation-induced carcinogenicity than adults. But for the other 75% of cancer types, children have about the same sensitivity (15%) or are less sensitive (10%), the data are too weak to draw a conclusion (20%), or there is only a weak relationship or none at all between radiation and that specific type of cancer (30%)[41]. As a result of this and other uncertainties, UNSCEAR recommended, "…generalizations on the risks of effects of radiation exposure during childhood should be avoided. Attention should be directed to specifics of the exposure, age at exposure, absorbed dose to certain tissues and the particular effects of interest".

Figure 2: The author and his son

One of the relevant specifics of my son's case was his physical size. The ACR appropriateness criteria are based in part on the improved diagnostic efficacy of ultrasound in individuals of small stature – typical of average children - compared to its efficacy in average adults, for whom CT is preferred over ultrasound [34]. In adults, the sensitivity of CT is 91% (95% CI: 84-95%), while the sensitivity of ultrasound is 78% (67-86). The specificity of CT in adults is 90% (85-94%), while ultrasound has a specificity of 83% (76-88). In pediatric patients, CT still has superior sensitivity and specificity compared to ultrasound, but the differences are smaller [sensitivity: CT = 94% (92-97), ultrasound 88% (86-90) and specificity: CT = 95% (94-97), ultrasound 94% (92-95)]. However, my son is over the 95^{th} percentile in both height and weight for his age, and so more closely resembles an adult than a child (Fig. 2). Even if my son is considered a pediatric patient, I question whether trading a real, demonstrable benefit (6% greater sensitivity for CT) to avoid a hypothetical harm (i.e the speculative tiny increase in cancer risk associated with the CT radiation dose, which may not even exist) is consistent with ALARA.

Figure 3: Abdomino-pelvic CT scan

And finally, another circumstance particular to my son's case was the availability of imaging equipment at the time he needed it. During our discussion of the imaging options with my son's pediatrician, she told us that it is not uncommon for the hospital to receive trauma patients (e.g. individuals involved in automobile accidents), particularly on a Friday afternoon/evening (when we were having this discussion). Should that occur, it is quite possible that those patients would have imminently life- threatening injuries, and on that basis they would be prioritized over a suspected appendicitis case for receiving a CT exam.
Given the immediate availability of the CT scanner, the superior diagnostic efficacy of CT compared to ultrasound – particularly in my son's case, the faulty bases for the pediatrician's recommendation of an ultrasound exam discussed above, and the severity of the consequences of a ruptured appendix, we opted to forgo the ultrasound and proceed directly with the CT exam. My son's CT (Fig. 3) showed an inflamed appendix, and he had an appendectomy a few hours later. The medical staff said the surgery involved only minimal risks because his appendicitis was detected so early. Let me explicitly acknowledge that our pediatrician wanted to give the best and most appropriate medical care to my son. However, she admitted that she had no particular expertise in radiation effects. I contend that the advice she had been given regarding the balance of real, demonstrable benefits of CT versus its speculative, minute radiation risk (if it exists at all) was inappropriately influenced by unreasonable radiation phobia, and is inconsistent with the ALARA philosophy.

5 CONCLUSION

As radiation protection professionals, we are all familiar with our duty to reduce radiation doses to levels as low as reasonably achievable, and we uphold it faithfully. However, in practice we often fail to act in accordance with ALARA by balancing the benefits accrued from using radiation against the hypothetical risks from very low radiation doses. Instead, we attempt to drive doses as low as possible, and this imbalance unreasonably damages public health.

The pendulum has swung too far, and we have allowed a culture of unreasonable radiation phobia to take hold. Policy-makers, healthcare practitioners, and the public are making unreasonable choices, where the substantial benefits of technologies involving radiation are being abandoned in the interest of preventing doses of a few mSv (or less). As IRPA members, our Code of Ethics [42] imposes a duty to "…whenever practicable and appropriate, correct misleading, sensational and unwarranted statements by others concerning radiation and radiation protection". To uphold this duty, we must devote more attention to combatting radiation phobia, and preventing the damage it causes to public health.

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De minimis non curat lex or endless optimization?

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Abstract. Optimization is one of the ICRP-pillars of radiation protection and should be well known to radiation protection professionals. The discussions during the revision of the IAEA Basic Safety Standards, GSR Part 3, [1] resulted in a requirement that any radiation practice has to be optimized. What does that mean? Is that possible at all? What is optimized today may be no longer the optimum tomorrow. The continuing process of optimization is parallel to the management principle of "continuous improvement". What does it mean to improve radiation protection continuously? Does that mean to strive for lower and lower doses and finally end up with "Zero-Dose"? Improvement of radiation protection could also be interpreted as to reach the same exposure level using less resources. Already decades ago the radiation protection community debated the so-called de minimis principle. It is often legally incorporated as 10µSv-concept, the basis for calculating exemption and clearance values. It would make sense to apply it to occupational exposure and to exposure of members of the public from other radiation sources too. The use of calculation methods to make decisions more objective shows that often radiation exposures are reduced with inappropriate expenses. Unfortunately the question of acceptance is of growing importance. If this will not be stopped, e.g. by clear legal means, the spiral of higher and higher radiation protection expenses will go on. The possibility to do so is given now in Europe with the implementation of the Directive 2013/59/Euratom [2] into national regulations. On the other hand the process of the revision of ICRP basic radiation protection recommendations has started. This is a good opportunity to simplify the radiation protection system and make it more understandable for radiation protection practitioners.

KEYWORDS: ALARA; optimization; very low doses; cost-benefit analysis; de minimis principle.

1 INTRODUCTION

Optimization is one of the three pillars of the ICRP radiation protection system, which was originally published with ICRP Publication 26 [3] in 1977 and forms since then the basis of radiation protection in nearly all countries of the world. Although the principle is rather old even today still some questions arise about how to implement it. Optimization is often also described by the ALARA principle which is the acronym of "as low as reasonably achievable". In the original version this short form is accompanied by the half sentence "economic and social factors taken into account". Unfortunately this phrase is often not taken into account and if, the social factors are dominating, especially the fear of radiation. You could observe this in many countries in particular after the Fukushima Accident.

Since 1977 some additions have been made, probably with the intention to make the system even better: 1990 in ICRP Publication 60 [4] and 2007 in ICRP Publication 103 [5]. In reality the system looks now more sophisticated and some parts of the "amendments" may be characterized rather as "Verschlimmbesserungen" as we say in German (improvements to the worse). Often they have simply been ignored by the radiation protection daily practice. The concept of dose constraints e.g., introduced with ICRP 60, was not implemented in many regulations nor in the daily practice. Despite this it now plays a central role in ICRP 103. The interested reader can find the explanation why we do not need dose constraints at all in the proceedings of the 2010 Helsinki Conference of IRPA [6].

The following article tries to reform and simplify the radiation protection system by proposing a de minimis concept for optimization. The de minimis concept was already discussed some decades ago with regard to very low exposures of some tenth of µSv. It is based on the Latin quotation "de minimis non curat lex" or "de minimis non curat praetor" meaning that certain things are not worth to be cared of by the authorities and can be neglected. It is established for exemption and clearance values of radioactivity or radioactivity concentrations, but up to now it is not common for occupational exposure, although there was a cut-off in the former Czech Radiation Protection Ordinance of 1 mSv/a and in Switzerland there is a proposal to introduce a cut-off of 0.1 mSv/a.

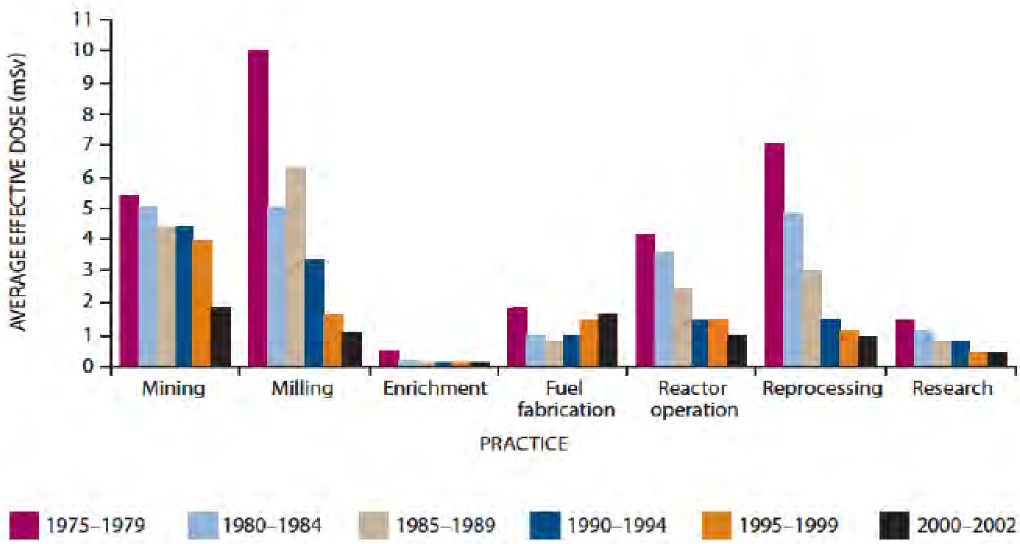
2 DIFFERENT DEFINITIONS OF OPTIMIZATION/ALARA

2.1 From ICRP Publication 26 to ICRP Publication 103

1977 was the year of birth of the radiation protection system of ICRP. It was the first time that radiation protection was presented as a system based on three pillars: justification (although this special name was not used at that time), optimization and limitation. Within 53 pages all the essential items of protection were presented in an easy to read way. At that time I started my professional carrier in radiation protection as a member of the East German radiation protection authority. My boss asked me to translate ICRP 26 into German to make my colleagues aware of this new development. You can imagine that this task was an exciting exercise and soon I became a fan of ICRP 26. Later we implemented as one of the first countries the basic philosophy of ICRP 26 into our national regulation on radiation protection. 1987 I proposed an Alpha-value of 30 000 Mark/man·Sv [today perhaps equivalent to 30 000 €/man·Sv] and performed several cost-benefit-analyses on this basis. There was the side condition not to use it as a dogma and to review this value after 5-10 years. It was also made clear that a cost-benefit-calculation is not identical with the decision based on it. However, dose reduction measures within the scope of the Alpha-value should in any case be done as well as measures which are aimed at keeping doses below the limits. So ICRP 26 was taken seriously at that time and we believed in it.

The proof of the effect of the ALARA principle is given by the statistics published regularly by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) which clearly shows that doses getting lower and lower in nearly all branches of nuclear industry.

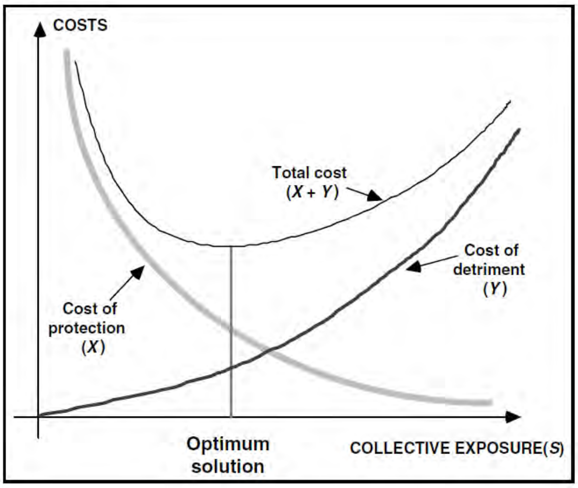
Figure 1: Development of occupational doses (from UNSCEAR 2008 [7])



At the time of ICRP 26 optimization was seen as a mathematical approach, further explained in ICRP Publications 22 [8] and 37 [9]. From the experience we have today, this approach may look a little naïve. What ICRP perhaps did not foresee was the important influence of stakeholder interests. It is for many decision makers not easy to be confronted with objective arguments for a decision. And the result of a cost-benefit-analysis would be some kind of objective criteria.

Optimization should have been performed in a way that is demonstrated in the following figure.

Figure 2: Cost-benefit analysis (ICRP 101 [10])



In ICRP 26 optimization was guided by the idea of finding objective criteria for radiation protection measures by using different decision aiding techniques like cost-benefit-analysis. The above mentioned Alpha-value was defined as the sum of money which is adequate to reduce the collective dose of one man·Sievert. This idea was soon attacked by many people alleging it as unethical to define a price of life. However, many branches and industry sectors work with cost-benefit-analyses, especially insurance companies and nobody criticises this. In any case all resources are limited and why should we devote resources to reduce risks in an ineffective way. But soon ICRP realized that this concept was not accepted and also the attempt to widen the Alpha-value by a so-called Beta-term, reflecting the fear for radiation, was not successful. So we face the situation that cost-benefit-analyses are rather seldom today, sometimes we can find them in connection with remedial measures when the budget for it is fixed and the question arises how to spend it in the most effective way. A very good example for that is the remedial project for the Wismut-contaminated areas in south-east Germany.

With the next basic recommendation of ICRP, ICRP Publication 60, although keeping the three principles alive, the first principle was now named as "justification", additional conditions were added: to keep the number of individuals exposed and the likelihood of incurring exposures where these are not certain to be received as low as reasonably achievable and to constrain the process by "dose constraints" or "risk constraints" respectively. This extended concept was called the "optimization of protection". The idea behind was to limit individual risks. A cost-benefit-analysis works with the collective dose which does not reflect the individual dose. But to restrict the number of exposed persons automatically has the effect of increasing the dose of the exposed people as now less persons have to do the same work. To restrict the higher exposures of an individual by introducing dose constraints may lead to a higher collective dose as less specialised people will get higher doses in doing specialised tasks. So what is the sense of additional criteria for radiation protection when these criteria lead to higher exposures? If one compares risks in different industrial sectors it becomes soon clear that e.g. a driver has a very diverge risk depending on the safety his car is providing and or the conditions of work, especially the time he spends behind the wheel. So from the very start to focus on inequities between exposed workers or members of the public does not consider specific situations in radiation protection and thus is a wrong chosen objective. It only creates additional work for those responsible for protection and the gain is very much questionable. Remember the basic assumption regarding radiation risk is the Linear-Non-Threshold dose effect relation (LNT), a hypothesis that is not proven at those levels encountered in normal work of exposed people and perhaps will never be.

One new feature of ICRP 60, the dose constraints, did not find the way into daily practice. And the number of exposed people was never a reason for withdrawing a license or not granting one. So these new features did not become the daily practice.

One could have expected that ICRP learned from this experience when formulating ICRP 103. But this was not the case. Instead the central role of dose constraints was propagated. The definition of optimization was now, not very much different from ICRP 60, the following:
"The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors."
Summing up we see that the originally clear concept of ICRP 26 was overpainted by a number of additional and mutually conflicting conditions which made the system more and more complicated and left those alone which had to implement radiation protection in their daily practice. The ICRP basic recommendations do not say much about the licensing procedures any radiation source or practice with a remarkable exposure has to undergo. They are on a more philosophical level which might be good for scientists. The daily practise is, however, determined by the licensing procedure and operating on the basis of this licence. One could have expected that this deficiency is outweighed by the radiation protection legislation, but unfortunately this is often not the case. We can see this from the development of the IAEA Basic Safety Standards and in Europe from the development of Council Directive 2013/59.

2.2 IAEA Basic Safety Standards

The development of the new Basic Safety Standards (BSS) of the IAEA, now named GSR Part 3, strictly followed the recommendations of ICRP 103. This was made clear by the IAEA representatives at the very start of the revision of the former BSS, Safety Series 115, from 1996 and this was not debated by the members of the involved Safety Committees. There was not any voice of critique of the ICRP 103, astonishingly, as we now see the problems in implementing the ideas of ICRP 103 into mandatory radiation protection regulations. There have been numerous discussions on the formulations of GSR Part 3, but unfortunately the definition of optimization was at the end:
"For all exposure situations, each party with responsibilities for protection and safety ***shall ensure****, when relevant requirements apply to that party, that* ***protection and safety is optimized.***[1]

Footnote: *'Protection and safety is optimized' means that optimization of protection and safety has been applied and the result of that process has been implemented."*

The demand that protection and safety "shall be optimized" is completely unrealistic. And this is not healed by the footnote. There is no formal procedure for optimization in the legislation, at least not today, and there is hope that this remains so. A formal procedure would deny the uniqueness of the radiation protection optimization. To ensure an optimized situation is in principle not possible as the situation is changing with time and with the circumstances. So you can only aim at optimization which is correctly described in para 1.13 of the BSS.

It is a pity that the members of the IAEA Safety Committees did not see the pitfall in the formulation of the IAEA BSS. But perhaps the real legislators - IAEA safety standards are not directly mandatory in the member states - could have healed this. We will see that this is not the case in Europe.

2.3 EURATOM Directive 2013/59

For members of the European Community the new directive on radiation protection was agreed upon in the European Council and set into force with the time line to be imposed into national regulation until February 2018. This imposition is now in progress in all countries of the EU. Even Switzerland intends to impose a number of provisions although not member of the EU. The European Commission wanted to incorporate the new IAEA BSS into the existing European radiation protection Directives and Recommendations and to create a single regulation combining all relevant radiation protection provisions. This was done in a relatively short time. Maybe some provisions suffer from this short period of development. Regarding optimization the EU-Directive says the following:

[1] In bold emphasized by the author

"Radiation protection of individuals subject to public or occupational exposure ***shall be optimized*** *with the aim of keeping the* ***magnitude of individual doses****, the* ***likelihood of exposure*** *and the* ***number of individuals*** *exposed as low as reasonably achievable taking into account the* ***current state of technical knowledge and economic and societal factors."***[1]
This sounds just like ICRP 103 but there is an addition: take into account the "state of technical knowledge". This may open Pandora's Box for any useful or not useful demand. Optimization should always be case specific, the state of technical knowledge is not specific. What you can do is not what you need to do. E.g. to design an entrance to a high radiation area with 10 µSv/h maximum dose rate is possible but not necessary. And you may not have the resources to do what other do. A five-person non-destructive-testing-team would like to use the same dosimeter for many years as long as it works correctly. Not each technical development has a gain for radiation protection. For simple communication telephones need not to be replaced by smart phones. The basic understanding should be to improve radiation protection on objective grounds.

The problem with such equivocal formulation is that it may be interpreted in very different ways. Somebody who wants to apply a radiation technique has to regard his economic resources which are not infinite. So if the conditions for application become too stringent the application will not be realized. It was never the intention of ICRP to ban applications of radiation sources. Today we are faced with it: the draft of the new Swiss regulation demands to accept radiation application only if there is no non-radiation alternative. This is a de-facto prohibition.

3 THE AMBIGUITY OF ALARA

ALARA is easy to understand, at the first glance. At the second glance it reveals a number of different interpretations.

Figure 3: ALARA stressing the "low", the "achievable" and the "reasonable"

This different possibilities of interpretation are a challenge and the weakest point of the ICRP-System. It does not take into account that there are different interests and interests you will not overcome with good words. For a long time the word “low” has dominated the interpretation of ALARA and still dominates. The rest of the phrase is too often and unfortunately forgotten. We should talk about reinvent the ALARA principle to give the half sentence “taking into account…” more weight.

4 OPTIMIZATION AS A PROCESS

ICRP and IAEA unison underline that optimization is a process. This implies some difficulties. Which meaning/target/endpoint has the result of optimization? Management systems demand to satisfy the interested parties. Which are the interested parties in radiation protection?

- Occupationally exposed people (the staff)
- Authorities
- Expert organisations
- Local community
- Shareholder
- Any kind of stakeholder

To satisfy them all is just like “squaring the circle“.

Taking into account social and economic factors?

- Are social factors more important than economic?
- And are these really the most important social aspects?
- Who decides? Authorities?
- Which interests count? Operator versus stakeholder?

Management systems demand continuous improvement. What does it mean to improve radiation protection and/or safety?

- Reduce doses to people, workers and the public?
- Reduce the number and consequences of incidents and accidents?
- Reduce fear of radiation?
- Reduce the use of radiation at all?
- Looking for non-radiation alternatives?

Is it allowed under the label of continuous improvement to reduce protection measures because of lack of money?

- Electricity prices in Europe are falling due to subsidised wind energy.
- There are also some other problems, like the financial crisis.

Today softening protection measures is not an option.

- Developed countries have high protection standards and low doses.
- How long will we be able to continue this way and to which price?
- Do developing countries want to follow high protection standards?

A lot of questions which may be answered very differently depending on the standpoint. But we easily find out that a process without end is not realistic or sooner or later leads to the termination of the use of radiation.

5 OPTIMIZATION: WHAT IS REASONABLE?

Coming back to the original idea of optimization: the cost-benefit-analysis. Are there up to date data on that issue? You need to have a Sherlock Holmes at your side to find some.

The money-equivalent for reducing a man·Sv, the so-called Alpha-value:

1980ies: 1000 – 100 000 $/man·Sv; highest level: 6 Mio $/man·Sv [11]

VGB, Germany, 2002: 150 000 €/man·Sv up to 10 mSv/a

(range from 50 000 – 1 500 000 €/ man·Sv) [12]

My own value 1987: 30 000 Mark/ man·Sv [today appr. 30 000 €/ man·Sv] [13]

The International System on Occupational Exposure (ISOE) reports [14] that in about two decades from 1992 to 2012 the average collective dose for operating an NPP was reduced from 1,8 man·Sv to 0,9 man·Sv. 200 000 $ in 20 years would be reasonable for that reduction. Does anyone believe that this have been the real costs? Of course not. We are far away from any reasonable costs for dose reduction.

6 THE REALITY IN RADIATION PROTECTION

To demonstrate the situation we are in for developed countries, here some facts from Germany [15].

- There are about 350 000 occupationally exposed and monitored workers in Germany.
- 30 000 are working in a NPP, collecting a collective dose of 1 man·Sv per reactor and year on average.
- 260 000 persons working in medicine.
- 87 % workers in medicine, 76% in non-medicine have no reading on the personnel dosimeter.
- 0,05 mSv/month is the detection limit for personnel dosimetry.
- 50 000 persons have a reading and an averaged dose of 0,5 mSv/a.
- 40 000 flying personal collect 80 man·Sv and an average dose of 1,9 mSv/a.
- Doses from releases of NPPs are, calculated <0,005 mSv/a, mostly < 0,0005 mSv/a (calculated) [16]

What is evident from these numbers: we have planned exposures minimized to an unreasonable level. Some people may say that it is good to have such low doses, but it is not reasonable. And we are faced with much more exposures of natural origin. The question is: do we need to restrict these sources more? Do we really want to correct the Genesis? On the other hand: UNSCEAR says, it is the sum of doses, artificial and natural, which counts. So if we want to be consistent, we need to question radiation protection caused by planned exposure situations in comparison with radiation exposure by existing exposure situations. There is still the “dichotomous” way of treatment, Lars –Eric Holm once spoke about.

7 HOW TO IMPROVE THE SYSTEM?

We should make the system simpler. Get rid of the “amendments to the worse”. And devote more attention to natural background radiation. If we do not change the philosophical background of radiation protection, especially of the ALARA-principle/optimization, we run the risk of confusion, ignorance and mistrust.

One way out may be to accept a **lower border of optimization** below which no efforts are needed to reduce doses further:

1 mSv/a (measured dose) **cut-off for optimizing occupational exposure.**
100 µSv/a (calculated dose) **cut-off for optimizing public exposure.**

Thus giving the de minimis principle a new meaning. Radiation protection may than be reduced to simple, common sense radiation protection measures.

8 ACKNOWLEDGEMENTS

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Ethics and radiation protection in biomedical research in the post-Fukushima era: *up to date*

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Abstract. International Commission on Radiological Protection (ICRP) issued in 1992 the recommendation on Radiological Protection in Biomedical Research (Pub 62), which discussed the issue of research ethics in depth. Now almost 25 years have passed and we should revisit this publication considering (1) ethical core values identified by Task Group 94 of ICRP on the ethics of radiological protection; (2) international discussion of research ethics; and (3) experiences of Fukushima in the context of research. My findings are as follows: 1. ICRP should revisit their risk-benefit assessment model to include the concept of "radiation protection culture" and "discussion and measurement model" for improvement of ethical review of research with radiation doses over 10 mSv; 2. It is necessary to develop guidelines for research in radiation emergency situations; and 3. In order to resolve the ethical dilemma between the detection of higher cancer incidence and protection of a certain population from discrimination, we should promote the concept of a "stakeholder-initiated model" of research. In conclusion, Pub 62 is a valuable document but needs to be updated. Also some of the above point 2, and 3, should be included in the revision of publication 109 on an emergency exposure situations and 111 on post-accident situations. Now it is the time for the International Radiation Protection Association (IRPA) collaborating with the ICRP to expand their scopes to discuss the ethics and radiation protection in biomedical research in the post- Fukushima era.

KEYWORDS: bioethics; research; radiation protection culture; dignity, stakeholder involvement; well-being.

1 INTRODUCTION

The International Commission on Radiological Protection (ICRP) issued in 1992 the recommendation on Radiological Protection in Biomedical Research (Pub 62) [1]. Most of the descriptions are compatible with the international standards of research ethics of this period. This Pub 62 has an Annex to reprint the 1975 version of the Declaration of Helsinki (DoH), ethical principles of biomedical research involving human subjects, issued by the World Medical Association (WMA), which was most recently revised in 2013 [2]. This Pub 62 provided a risk benefit assessment model to show the categories of risk of radiation and the corresponding levels of social benefit, which serves as a useful tool for the evaluation of research projects. This was not changed in the latest general recommendations in Publication 103 in 2007 [3]. The International Atomic Energy Agency (IAEA)'s Basic Safety Standard (BSS) in 2014 [4] suggested that the ethics committee should consider this Pub 62, along with DoH and Council for International Organizations of Medical Sciences (CIOMS) International Guidelines for Biomedical Research Involving Human Subjects (CIOMS Guidelines) [5].

Now almost 25 years have passed, and the ethical standards of biomedical research have been drastically changing during this quarter of a century. In particular, the accident of the Fukushima Daiichi Nuclear Power Station in 2011, caused by the big earthquake, raised many ethical questions including the issue of research. However, ICRP Pub 62 did not sufficiently answer these questions. In 2013 ICRP established the Task Group (TG) 94 to identify the ethical foundations of their radiological protection system and has convened a series of workshops, collaborating with the International Radiation Protection Association (IRPA), to facilitate discussion. As a result, TG 94 identified a set of core ethical values of ICRP's radiological protection system: beneficence/non-maleficence; prudence; justice; and dignity, along with procedural values: accountability and transparency; and stakeholder

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involvement [6]. In this process, the author, as a member of TG 94, found some points for which revision of Pub 62 is needed. However, revision of the existing publication is outside TG 94's scope, because their mission is to identify the ethical foundations of the (existing) system of the ICRP.

For this reason, this paper will try to answer the questions raised from the Fukushima accident within the context of research, considering the ethical core values provided by the TG 94, as well as the most recent international discussions in the field of research ethics.

2 SOCIAL BENEFIT BALANCED WITH RISK

2.1 Risk Benefit Assessment Model in Pub 62

A characteristic of ICRP Pub 62 is to provide a risk benefit assessment model as quoted in Table 1. It suggests that research projects involving use of an ionizing radiation dose over 0.1 to 10 mSv for a single exposure needs a social benefit of "intermediate to moderate". When this radiation dose exceeds 10 mSv "substantial" social benefit should be generated from the research, which means "directly related to the saving of life or the prevention or mitigation of serious disease". There is no classification of risks of a radiation doses over 10 mSv, e. g., 20 or 50 mSv, but it provides a footnote to the Table: "To be kept below deterministic thresholds except for therapeutic experiments". It states that repeated participation is not desirable but does not state explicitly about acceptable annual, total dose.

Table 1: Categories of risk and corresponding levels of benefit shown in ICRP Pub 62(a)

Level of risk	Risk category(b-d)	Corresponding effective dose (adults)(mSv)	Level of social benefit
trivial	I (～10-6 or less)	<0.1	minor
minor to intermediate	Ⅱa (～10^{-5})	0.1-1	intermediate to moderate
	Ⅱb (～10^{-4})	1-10	
moderate	Ⅲ (～10^{-3} or more)	>10(e)	substantial

(a) This table is quoted from Pub 62 (reference No. 1), with slight modification of the style. Notes (b) to (d) are quotations from the related original text and note (e) is attached to the original Table in Pub 62.
(b) The risk described here is for a single exposure. Repeated participation of volunteers is undesirable.
(c) The risk is the total detriment from the exposure; namely the sum of the probability of fatal cancers, the weighted probability of non-fatal cancers and the probability over all succeeding generations of serious hereditary disease resulting from the dose.
(d) The risk might be affected by the characteristics of the group of research volunteers, e.g., age, sex, state of health. For example, in case of children, the detriment per unit dose is 2 to 3 times larger than for adults; for people aged 50 years or over it is about 1/5 to 1/10 of that for those younger. For those suffering from serious or terminal disease, radiation-induced risk will be even lower.
(e) To be kept below deterministic thresholds except for therapeutic experiments

On the other hand, the United States Food and Drug Administration (US-FDA) established in 1975 the radiation dose limits shown in Table 2, which are defined by the law to be "safe", for their Radioactive Drug Research Committee (RDRC) Program [7]. If the radiation dose is over these limits, investigators must submit their research protocol to US-FDA for authorization of its conduct. If the radiation dose and other defined conditions, e.g., without intention of diagnosis or clinical development, are within this framework of RDRC Program, this submission to FDA is waived, and instead, they submit to a FDA-approved RDRC, and this FDA-approved RDRC should submit an annual report to the FDA. In both cases review of the institutional review board (IRB) is ordinarily required.

Because the ICRP does not provide sufficient instructions about the risk of a radiation dose over 10 mSv, it is difficult for a researcher and an ethics committee to discuss and identify in which kind of "social benefit" 20 or 50 mSv for healthy volunteers is acceptable. Actually, in recent studies using Positron Emission Tomography (PET) combined with Computed Tomography (CT), the radiation dose is increasing more than before. According to the survey conducted by the Japanese Society of Nuclear Medicine (JSNM) and Japan Radioisotope Association (JRA) [8], most of the radiation doses of the research conducted within 2 years of the surveyed institutions were below 10 mSv but there were some that exceeded this level. However, only 19/82 (23%) of the surveyed institutions referred to an international standard such as ICRP or IAEA. At the 21/82 institutes (25%) an expert of radiological science is not included in the ethics committee (6/21 will call an expert when necessary). This situation in Japan does not meet IAEA's BSS of 2014 [4]. Especially after the Fukushima accident, some of the Japanese experts come to hesitate to discuss about the implication of these radiation doses, such as the risk of 10 or 20 mSv, which has become a sensitive issue causing debates among the society.

Table 2: Radiation dose to be defined by the US FDA as "safe" to administer to human (a, b)

Organ or system	Single dose	Annual and total dose
Whole body; Active blood-forming organs; Lens of the eye; Gonads	3 rem (＝30mSv)	5 rem (＝50mSv)
Other organs	5 rem (＝50mSv)	15 rem (＝150mSv)

(a) This table is quoted from reference No. 7. If all the conditions described in this regulation are met, the investigation is waived for submission of the protocol of a clinical trial to US-FDA. Instead, it should be submitted to the FDA-approved RDRC, in addition to an ordinary submission to an IRB.
(b) The pharmacological dose should be based on some published literature on human studies, which means that first-in-human study cannot be performed within this RDRC framework. Also, only studies with objectives of a basic investigation are permitted, but studies with the objectives of diagnosis or clinical development are not permitted to be performed within this framework.

2.2 Measurement and Discussion Model in Fukushima

Meanwhile, in the case of the Fukushima accident, the government issued an evacuation order with the threshold of 20 mSv/year ("y", hereafter). It would be difficult to explain the gap between US-FDA's idea to define "safe" for the RDRC program and this evacuation order. A possible answer would be the difference in the number and variety of affected people, and that the former is based on the willingness of research volunteers and the latter is in the situation of an accident. In such a situation, many of the people in the areas around 10 mS/y have difficulty in finding social benefit of living in these areas which can be balanced with the risk of low dose radiation. Even if the radiation dose is around 2 mSv/y (1 mSv/y exceeding natural background), the impression of a "dangerous zone" crept into their daily lives and it caused their limitation of actions and distrust of the authorities [9].

Learning from the Fukushima citizen's initiatives, especially "Ethos in Fukushima", and "Dialogue" projects facilitated by ICRP, as well as through the discussion in the workshops of the TG94's initiative, we should recognize that there is no predefined implication of "social benefit" to be balanced with some categorized levels of risks, which can be standardized to be common in each situation. Only continuous activity of measurement of the actual dose, continuous efforts to mitigate radiation risks, along with continuous discussion about the implication of these measured results and impact on their daily lives would be the way to find the points of balance to enable decision-making. Such activities are called *"radiation protection culture"* [10], to assure *well-being* and *dignity* of affected people. Such a way of seeking balance can be expediently called a "measurement and discussion model".

Accordingly, the Pub 62 should be updated as summarized as in Table 3, view point (1). More consideration about risk benefit assessment for radiation doses above 10 mSv is needed, including the concepts of "radiation protection culture" and "measurement and discussion model". These concepts will activate effective discussion in the research ethics committees to mitigate the risk of volunteers, as well as to promote research generating social value to be balanced with the risk of radiation.

Table 3: Ethical consideration and proposals for biomedical research related to radiation protection

View point (1): Social benefit balanced with risk
Update of risk-benefit assessment model of Pub 62 - More consideration about the risk of radiation dose above 10 mSv. - Clear definition for an acceptable annual, total accumulated dose, in addition to instructions for a single exposure. - More comprehensible description about the risk of other populations, e.g., children, which is now only in the text of Pub 62 and the author of this paper added in the footnote of Table 1. - Update of quoted international ethical guidelines, e.g., the Declaration of Helsinki. ***Include "radiation protection culture" and "measurement and discussion model" in Pub 62***
View point (2): Social benefit balanced with ethics
Development of ethical guidelines for radiation emergency research, including: - Reflection on boundary of practice and research in emergency situations. - Explicit description of core ethical values and procedural values identified by the TG94, such as dignity, and their application to research, such as informed consent. - Information sharing and joint, central review procedure to avoid duplicated studies. - Pre-review and rapid review procedure to enable research in emergency situations. - Justifiability of research without full process of informed consent, instead, opt-out procedure, broad consent, or otherwise, without consent of study subjects. - Governance framework of biobanking and exploration of emergent transplantation.
View point (3): Scientific progress balance with social benefit
To promote awareness toward "stakeholder-initiated model" of research

3 SOCIAL BENEFIT BALANCED WITH ETHICS

3.1 Questions from Fukushima: informed consent and ethics committee

As for the consideration on ethics and radiation protection in biomedical research, some crucial questions have been raised in Fukushima, as the following examples.

3.1.1 Guinea pig claims

After the accident, many of the researchers started epidemiological, social science, psychological or behavioral studies, some of which were without ethics committee review (this issue is not limited to nuclear disasters). Sometimes duplicated questionnaire surveys were delivered to the affected people. There were voices from the residents: "Are we guinea pigs?" The researchers' ambition might take priority over the dignity of research subjects with their excuse that they were supporting them. This topic was discussed by WMA to develop a warning statement on research involving "street children" without children's informed consents, which happened in African disadvantaged areas [11].

3.1.2 Exemption considerations

At the time of nuclear accident, it is extremely important to conduct an epidemiological survey of people, using an accurate method of measurement of their radiation dose, starting just after the instance. However, in the case of Fukushima, it was extremely difficult to conduct such a survey as the people needed support far more than a survey. Such difficulty is partially because of the experience of the Hiroshima and Nagasaki bombings. It is an often stated criticism from the Japanese population that the Atomic Bomb Casualty Commission (ABCC) initiated by the US conducted a survey but never provided medical support. It is ironic that this kind of epidemiological survey provides well-established scientific evidence of the causality of the radiation dose and risk of cancer. Meanwhile, sound evidence could be generated also from a large size cohort study of radiation workers. However, it is becoming difficult to obtain accurate data of the cause of disease and death of these people, without prior informed consents.

3.1.3 Biobanking and cell transplantation

After the Fukushima accident, there was some proposal of research of the storage of hematopoietic stem cells of the workers at the destroyed nuclear power plant for future experiment of cell transplantation research, but it was concluded to be unjustifiable by the Science Council of Japan. The reason was because the research project was meaningless considering the related exposure situation, where the reference level is defined as 250 mSv, which is not estimated to cause hematopoietic injury, and cell extraction causes a burden on these workers. This statement of the Council caused a controversy, as there are some opinions that this reference level may not be kept and storage of the hematopoietic stem cells may be beneficial. On the other hand, there are some kinds of large size biobanking projects both in Fukushima and another district in Tohoku (north east) area affected by the earthquake. Both of these biobank projects are not related to radiation risk but for various causes of diseases. The latter was criticized by citizens because of insufficiency of collaborative dialogue with the citizens.

3.2 Answer: development of ethical guidelines for radiation emergency research

"Social value" to be balanced with risk is discussed in Pub 62. Not only from this perspective, should we discuss more about "social value" generated from research to be balanced with ethics. The fundamental norm of research ethics is to prohibit "using human as a *mere* tool". This norm is a corollary of *human dignity*, described by the 19th century philosopher Immanuel Kant, and it was identified by the ICRP TG94 as one of the four core ethical values of their system. The traditional framework of research ethics to define *"ethics committee review"* for assessment of justifiable risk-benefit ratio; as well as obtaining *"informed consent"* of research subjects to assure their autonomous decision. However, in the situation of an emergency, as well as in the case of large size population studies, there is a possibility that the traditional full process of ethics review and informed consent may be impracticable. Such a situation is well discussed in the recent draft revision of the CIOMS Guidelines [5]. Considering the types of research in the post-Fukushima era, we should develop more strengthened ethical guidelines for research in the radiation emergency and post-accident situations, reflecting the following as examples, as summarized in Table 3, view point (2).

3.2.1 Guinea pig claims

To avoid the cause of guinea pig claims, first of all researchers must follow a fundamental ethical norm to distinguish "practice" to provide care or support from "research" aiming to find generalizable knowledge [12]. Considering this norm, the DoH states that physicians should prioritize patient's interests over their objectives of medical science [2]. This principle of doctor-patient relationship can be applied to public health research, where both the well-being of community people and each individual must be prioritized. From this reason, even if in emergency situations, principally any types of research involving human subjects should be conducted obtaining ethics committee authorization and informed consent of study subjects. Additionally, it is necessary to develop a more strengthened ethical review procedure which goes into effect in emergency situations, e.g., (1) a qualified joint, central review procedure to avoid duplicated reviews on duplicated types of studies at each institution [13]; (2) a review procedure of a set of 1) a pre-screening of an outline of the research protocol in advance of an emergency; and 2) a rapid review of the actual protocol at the time of the emergency [14]. Both of these needs *"transparency"*, one of a procedural values identified by the TG94.

3.2.2 Exemption consideration

Recently, many of the international or national laws or ethical guidelines have strengthened the obligation of researchers to obtain informed consent of study subjects, and simultaneously expanded the conditions where this obligation can be mitigated e.g., when a full informed consent process is not practicable; social value of research could be substantial; and the risks of subjects are minor or minimal. Especially in the emergency situations, it is necessary to clarify what is the "substantial social benefit" of a research where mitigation or exemption of informed consent procedure is justifiable. In some situations, an outline of the research should be disclosed to the public to provide the study subjects an opportunity of refusal. This kind of procedure is called *"opt-out"*. This estimated risk does not usually mean physical risk but risk of infringement of their *privacy right* (to control their own information) and *autonomy* (an ability and will of self-determination). More practically it may cause a risk of damage because of an unintentional leak of personal information.

There are some cases where the researcher could hardly have access to individual information even by means of such an opt-out procedure. One example is the fact or cause of death which does not occur in a hospital or workplace where the research subject was originally involved in the research. Sometimes an epidemiologist has to negotiate and agree with a local agency to disclose a resident's information of death or move to another district. Such kind of study can be more smoothly conducted if there are some legal bases of conduct of research. The most typical example is a law on cancer registration. The Hiroshima and Nagasaki victims' study is also one example. Whether or not a full informed consent process is necessary for a cohort study of workers in nuclear facilities may be controversial. Especially in the case of a nuclear accident, it is very difficult to follow-up part-time workers at the destroyed plant. It is necessary to develop some procedure to conduct research in such situation. *"Stakeholder involvement"* must be the prerequisite for developing guidelines for such procedures.

3.2.3 Biobanking and cell transplantation

Not specific to biobanking for transplantation research on workers at a destroyed nuclear plant, the design and development of the "governance" framework of a biobank operation is a hot issue of recent bioethics and research ethics. A biobank itself is not "research" but it is a project to store human samples and associated health information, to provide these materials for researchers. This project needs participation of patients or healthy citizens who willingly trust their own materials for research, by means of a *"broad consent"* process without detailed information about future research. The most recent revision of the DoH in 2013 included the word "biobank" but they decided to develop another draft guideline, specific to health databases and biobanks [15]. In the case of a biobank project to store nuclear power plant worker's hematopoietic stem cells suggesting the future possibility of cell transplantation, we should be extremely careful not to exert undue influence on such people who are in a vulnerable position, especially when there are no sufficient prospects of direct benefit to them.

On the other hand, if there is a potential for some direct benefit, some experimental cell transplantation research in an emergency situation may be needed, without informed consent of the patient/subject or even surrogate consent of a family member. A pre-screening procedure of ethics committee may be effective for this type of study.

4 SCIENTIFIC PROGRESS TO BE IN BALANCE WITH SOCIAL BENEFIT

4.1 Questions from Fukushima: Discrimination

Principally scientific progress generates social benefit, however, sometimes it causes harmful impact to the individual, community and/or society. Apart from the "dual use" issue, e.g., developments of nuclear energy and nuclear weapons, research outcomes beneficial to society may cause some negative impact on some specific populations or individuals. For example, scientific findings of genetic research to identify some population at risk for future development of disease, without simultaneous development of a therapeutic method, have caused controversial discussions. We should be reminded of a fundamental question whether scientific progress to find a causal relationship between radiation exposure and cancer incidence may cause discrimination against people who are living in affected areas.

4.2 Answer: Stakeholders-initiated research model in Fukushima

One example to solve such issue is a patient-involvement strategy, which has been taken in the US President Obama's Precision Medicine Initiative [16]. This project aims to develop millions of cohort of US citizens to find the causality of genetic profiles, other health related conditions, and life style and incidence of diseases. Some of the patient participants appear in the President's web-site with their photos, names, and life histories. Another trend in the US is that ethical principles of research collaborating with developing countries [17] added the principles of "collaborative partnership" and "social value" to traditional principles derived from fundamental ethical bases such as "respect for persons" (autonomy), "beneficence" (and non-maleficence), and justice [12]. "Collaborative partnership" is directly related to "stakeholder involvement".

A more prominent example which Fukushima experienced was *"stakeholder-initiated"* research. Fukushima high school students collaborating with students in France and Poland and scientific experts measured and compared their individual external doses and demonstrated their estimated these doses to be within the terrestrial background radiation levels of other regions/countries [18]. In Japan there have been some trends to refuse the food coming from Fukushima and other types of harmful rumors based on a biased view of radiation effects. Beyond stakeholder involvement or collaborative partnership, a *"stakeholder-initiated model"* of biomedical research would open the door toward a new era of principle of biomedical research, activated by the Fukushima experience.

5 CONCLUSION

This paper first explored ICRP's Pub 62 for its risk-benefit assessment model, especially the classification of radiation risks and required levels of social benefit corresponding to them. Then, it reflected upon what happened in Fukushima within a research context. Some of the issues in view points (2) and (3) would be *not* the issues of Pub 62 but the issues of publications 109 [19] on emergency exposure situations or 111 [20] on post-accident situations. Some issues may be beyond the radiological protection system of ICRP, which IRPA may discuss. Or otherwise, some points should be discussed more in the field of bioethics, rather than of radiation protection. Thus, interdisciplinary collaboration should be needed.

ICRP-TG94, collaborating with IRPA, has now identified ethical core values and procedural values, but discussion on the application of these values are the future task of the ICRP, possibly collaborating with IRPA. Now it is the time for ICRP and IRPA to expand their scopes and to discuss ethics and radiation protection in biomedical research of the post-Fukushima era.

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e-Learning – Radiation Safety Training Course

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Abstract. In an effort to provide quality basic radiation safety training to people working with radioactive materials and/or radiation producing equipment in an academic or research setting, a task group of University of California radiation safety officers and trainers worked together to design an e-learning radiation safety course that could be used by anyone. The e-learning course was designed to satisfy the academic portion of the regulatory training requirements for users of radioactivity and radiation producing machines. Rather than the classic power point style presentation, the course was designed in a dynamic web-based format making significant use of video, animations and interactive learning points developed using Articulate Storyline software. The course has seven modules (called books) covering Fundamentals, Biological Effects, ALARA and Detection, Regulations, Contamination Control and Waste, Shipping and Receiving and Incidents and Radiation Producing Machine. Learning objectives, challenge tests, learning points, and exams on completion are offered for each module. The course was designed to allow for flexibility to only take those modules that meet an individual's training needs. The course is designed to be done in 1.5-2 hours depending on which books you are assigned. A summary that can be printed is available at the end of each module; a glossary of terms and a printable completion certificate are also available.

KEYWORDS: e-learning; radiation safety training.

1 INTRODUCTION

Radiation safety training has traditionally been taught by an instructor in a classroom utilizing slides and occasionally demonstrations. The classes were designed as one-size fits all and all radiation users were required to attend the class. A written test at the end of the class was typically given to verify that the training was successful. If the class material was offered online, it typically was Power Point slides that you clicked through and read. This method of teaching this topic has several disadvantages, such as:

- The users had to wait for the next available class to be trained prior to starting work;
- It was labor intensive for the instructor and the quality of the class was very dependent on how skilled the instructor was at teaching;
- The class did not typically accommodate for the different skills of the advanced learner as versus the beginner or for different learning styles.
- The class did not accommodate for other languages.

The University of California, Berkeley campus decided to team up with the nine other University of California campuses and five medical centers to jointly develop an interactive e-learning course to better meet the needs of our radiation users. Our challenge was to design the course such that it met the academic component of the regulatory training requirements for both radioactive material and x-ray machine users and to accommodate for a wide range of knowledge levels on the topic.

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2 COURSE DESIGN

A committee of Radiation Safety Officers and trainers from the different campuses and medical centers agreed to serve as the peer review committee on the course. The software chosen was Articulate Storyline 2 [1] which allowed for the level of interactivity that met our objective of having a highly engaging course, as well as a testing format from a test bank of questions. Two training developers skilled in the software and 2 part-time radiation safety specialists were dedicated to the project. The goal was to have the entire e-learning course not exceed an average of 2 hours of course time. A dynamic format making significant use of animations, pictures, videos and interactive learning points was desired. A plan to accommodate different learning styles by offering affective visuals, audio script, optional written script for reading if desired, and downloadable written summaries was decided upon. The summary documents could also be translated into other languages to accommodate a diverse audience. A bookshelf model, with 7 books covering the array of desired topics was designed to allow people to only take the modules (books) that they needed. It was also decided to offer both metric and conventional units throughout the course to accommodate everyone. A glossary of terms was designed to be accessible at any time and a course completion certificate after passing was required.

The advantages of this design were that it allowed for a set of modules to address basic concepts and additional modules for specialized topics such as radiation producing machines. The topics covered in the 7 modules are: Fundamentals, Biological Effects, Radiation Protection and Detection, Regulations, Contamination Control and Waste, Shipping and Receiving and Incidents, and Radiation Producing Machines. It was also agreed upon to have optional training information available clearly marked and not tested upon for those that would like to learn more.

3 NAVIGATION

The peer review committee of radiation safety officers discussed how best to navigate through the course. In discussions with users, we learned they do not like when it e-learning courses restrict what they can do, such as the order the materials are presented in, or the time they take on each slide. Based on this feedback, we decided to allow the user the ability to navigate any way that they chose to rather than structure the course to a set order for taking the modules. We thought it was wise to encourage users to start with the first module on fundamentals, but not mandate this order. We also decided to allow users to click through the material at their own pace and not to restrict “quick” clicking through the screens to accommodate different learning styles.

4 INTERACTIVE LEARNING POINTS

Interactive learning points, similar to the actual test at the end of the modules were interspersed throughout each module to give users an opportunity to learn by answering questions. This interactive approach helps to make the course more interesting for the user. Immediate feedback is given as to whether the answer was right or wrong in writing, and if the wrong answer is chosen, the right answer is given both in writing and verbally to reinforce the right answer. Users provided feedback that they enjoyed the learning points because they were interactive.

5 OPTIONAL TRAINING MATERIALS

Optional training material in the course was included due to questions asked by users on some topics not covered by a regulatory requirement. A symbol to alert the user that the topic was optional was provided so users could make a conscious choice as to whether to take it or not. No test questions address the optional training materials. Examples of optional training materials in the course include a background history of how radiation was discovered and how to perform a decay calculation.

6 TESTING OPTIONS

Learning objectives were established for each module and at least two test questions were written per objective for the test bank that can be randomly selected so that each test is different. The course is designed so that you can test out of individual modules by taking a challenge exam and passing it by
90%. If you do not pass the challenge test or if you simply chose to view the training material, the test at the end of each module must be completed with a passing grade of 80%.

7 SUPPLEMENTAL SITE-SPECIFIC TRAINING

The peer review committee recommended that supplemental site-specific training should be provided after e-learning is complete to address those issues not covered by online training. Brief supplemental site-specific training can be done in small groups or one-on-one in the lab at the time of issuing dosimetry. This allows for important hands-on training with a radiation survey meter, an opportunity to ask questions, and the opportunity to establish a personal contact with Radiation Safety staff for future reference if needed. Topics suggested to be covered are:

- Site-specific signs & emergency procedures
- Hands-on radiation survey meter use
- Site-specific waste handling procedures
- Dosimetry issuance
- Questions

8 CONCLUSION

Approximately 500 users have taken the completed online radiation safety training as designed to date and we have received excellent feedback on the course. Online on-demand training, versus an in-person class approach, is preferred by most users. The quality and consistency of the training has been enhanced by moving to an e-learning platform for providing the academic portion of the required training. Supplemental in-person training with each user or in small groups has helped us to still address individual needs and assure that the students receive hands-on experience with a radiation survey meter, personalized instruction on their dosimetry and confirmation of important emergency response information, while still significantly reducing our overall teaching time.

The published United States version of the course, as well as the source files are available for viewing and licensing through the University of California, Berkeley Office of Technology Licensing [2].

9 ACKNOWLEDGEMENTS

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[2] Licensing and viewing inquiries, contact: Office of Technology Licensing, UC Berkeley: Terri Sale Terri.sale@berkeley.edu +1-510-643-4219.

The Romanian Society for Radiological Protection - 25 years as Associate Society to IRPA

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Abstract. The Romanian Society for Radiological Protection (RSRP) is a non-governmental proffesional organization of the specialists in the field of the radiological protection from Romania since May 1990 and became an Associate Society to the International Radiation Protection Association (IRPA) in 1992. The education and training in radiation protection is an important objective of the society and this is demonstrated by structure and topics of the accompleshed projects, including the annual national meetings and conferences, and participations of its member to several IRPA activities. The main achievements and learns of the RSRP during the last 25 years as an Associate Society to IRPA were presented, with the occasion of IRPA 50 Year Celebration in Cape Town, South Africa (IRPA14).

1 INTRODUCTION

The Romanian Society for Radiological Protection (RSRP) is a non-governmental proffesional organization of the specialists in the field of the radiological protection from Romania since May 1990 and became an Associate Society to the International Radiation Protection Association (IRPA) in 1992.

2 ABOUT US

The Romanian Society for Radiological Protection (RSRP) is a professional association of the Romanian specialists in field of radiological protection, an nonadvocacy, nonprofit and nongovernmental organization, which was founded in May 30, 1990 and it is an IRPA Associated Society since 1992.

3 OUR GOALS

- to protect population and radiation workers against the harmful effects of ionizing radiation;
- to develop and make known the scientific, technical, medical and legal aspects of radiation protection on a nationwide scale;
- to imply the civil society in the benefit/risk analyses for the ionizing radiation uses.

4 ORGANIZATION

- 78 active members from the whole country on 1-st of May, 2016;
- a board elected every 2 years, a president, 3 vice-presidents, one secretary, 12 members and one treasurer;
- a library with more than 1100 books and journals in the radiation protection field;
- financial resources from members annual fees and donations.;
- a website : www.srrp.ro

5 MAIN ACCOMPLISHED PROJECTS

- Conference: RADIATION - BETWEEN BENEFIT AND RISK, Constanta, 22 October 2009
- National Conference: TRIAGE, MONITORING AND TREATMENT OF PEOPLE EXPOSED TO IONISING RADIATION FOLLOWING A MALEVOLENT ACT, Olanesti, 6-8 October 2009

- National Conference : PUBLIC HEALTH AND THE IONIZING RADIATION, Galati, 9-12 September 2008
- IRPA Regional Congress for Central and Eastern Europe : REGIONAL AND GLOBAL ASPECTS OF RADIATION PROTECTION, Brasov, Romania, 24-28 September 2007
- National Conference with International Participation: RADIOLOGICAL PROTECTION IN THE III-rd MILLENIUM, Vatra Dornei - Suceava, 2001.
- National Conference with International Participation: RADIATIONS, LIFE AND ENVIRONMENT, Sinaia, 2000;
- Participation at the IRPA 10 Congress, Hiroshima, Japan, 2000;
- 3 public radiation monitors with a large digital display installed in Bucharest, Craiova and Cernavoda, 1998;
- National Conference with International Participation: NATURAL RADIOACTIVITY, Tunad, 1998;
- National Conference with International Participation: RADIATION PROTECTION AND NUCLEAR SAFETY CULTURE, Sibiu, 1997;
- Distribution within an EU-ECHO Project of 1 720 000 iodine tablets to emergency personnel and the population in emergency zones 1997 and extension of their shelf life until 30.11.2004;
- Workshop: NUCLEAR ENERGY IN ROMANIA - POTENTIAL RISKS FOR ENVIRONMENT AND HUMAN HEALTH, Bucharest, 1996;
- Participation at the IRPA 9 Congress, Vienna, Austria, 1996;
- Symposium: BECQUEREL CENTENARY, Bucharest, 1996;
- Symposium: RADIOPROTECTION IN THE NUCLEAR FUEL CYCLE, Piatra Neam, 1996;
- Symposium: RADIATION PROTECTION ASPECTS ON USE OF GEOTHERMAL WATERS, Bile Herculane, 1995;
- Symposium: ROENTGEN CENTENARY, Cluj - Napoca, 1995;
- Workshop: NATURAL, MAN-MADE RADIOACTIVITY AND POST-CHERNOBYL LESSONS, Sinaia, 1994;
- Symposium: NUCLEAR ACCIDENT - MANAGEMENT AND IMPACT ON ENVIRONMENT AND PUBLIC HEALTH, Bucharest, 1994;
- Symposium: MAN MODIFIED NATURAL RADIOACTIVITY AND RISKS FOR THE HEALTH OF THE POPULATION, Oradea, 1993;

6 PUBLICATION AND RELATED ACTIVITIES

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- Artificial Radioactivity in Romania, English-Romanian version, 262 pages, Bucharest, 1995;
- 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Romanian version, 207 pages, Bucharest, 1996;
- Nuclear Energy in Romania - Potential Risks for Environment and Human Health, in Romanian, 110 pages, Bucharest, 1996;
- Radioprotection Concepts, in Romanian, 84 pages, Ed. H. Hulubei, Bucharest, 1996;
- Radiation and Life, in Romanian, 84 pages, Ed. Paco, Bucharest, 1998;
- Environmental Radioactivity Bulletin, Bucharest, 1995-1998;
- Permanent columns in Curierul de Fizică- Bulletin of scientists from Romania and abroad, Bucharest, 4 issues yearly, from 1992;
- Interventions in mass-media on Radiation Protection topics;
- Conferences, workshops and lectures on Radiation Protection in schools, high-schools, faculties, public institutions and nongovernmental organizations.

7 INTERNATIONAL COOPERATION

- American Nuclear Society Memorandum of Cooperation, from 2001;
- Canadian Radiation Protection Association Joint Association, see the WebPage http://www.crpa- acrp.ca/;
- Central European Association of IRPA Associate Societies;
- Croatian Radiation Protection Association; http://mimi.imi.hr/crpa
- Hungarian Health Physics Section of the Roland Eotvos Physical Society;
- International Radiation Protection Association; http://www.irpa.net
- Japan Health Physics Society

8 RECENT ACHIEVEMENTS

The organization of the *IRPA Regional Congress for Central and Eastern Europe,* in Brasov, Romania, from 24th to 28th of September 2007, titled "REGIONAL AND GLOBAL ASPECTS OF RADIATION PROTECTION". 330 persons from 27 countries and international organizations (IRPA, IAEA, WHO and EC) participated and its successful organization is still very much appreciated by all participants.

Within the transposition and implementation activities in Romania of the Council Directive 2013/59/Eurratom (the new European Basic Safety Standards, EBSS) a large national debate was initiated by the RSRP, the last two RSRP and 2016 Conferences being dedicated to this Directive:

- 24 October 2014: General provisions of the Directive 2013/59/Euratom;
- 09 October 2015: Directive 2013/59/Euratom on optimisation of the radiation protection of the population;
- 14 October 2016 (planned): Directive 2013/59/Euratom on protection of radiation workers.

The main purpose of these presentations and discussions on the new EBSS was to explain the new concepts and definitions, for a better understanding of the Directive, and already proved to be very useful on some practical aspects of the implementation in Romania of this important Directive.

In a statement on tissue reactions approved on April 21, 2011 the International Commission on Radiological Protection (ICRP), taking into account new scientific evidence pointing to observable health effects above a lifetime dose of 500 mSv, recommends for occupational exposure in planned exposure situations an equivalent dose limit for the lens of the eye of 20 mSv in a year (instead of 15o mSv/y), keeping 15 mSv/y for a member of the public. The RSRP has participate to the Survey initiated by IRPA President to provide an assessment of the impact on members of IRPA Associate Societies of the introduction of ICRP recommendations for a reduced dose limit for lens of the eye.

9 RECENT RSRP's PARTICIPATIONS TO IRPA CONGRESSES

- International IRPA Congress, IRPA 13, Glasgow, Scotland, 13 - 18 May 2012:
  - 14 Romanian participants;
  - Constantin MILU, Member of the International Program Committee and Raporteur to a Scientific Session.
- The 4th European IRPA Congress, Geneva, Switzerland, 23 - 27 June 2014 :
  - 13 Romanian participants (11 posters and 2 oral presentations, one within young professionals session);
  - Constantin MILU, Co-chair to two scientific sessions and a presentation on RSRP's Activities within the Forum of Associate Societies.
- International IRPA Congress, IRPA 14, Cape Town, South Africa, 9 - 13 May 2016 :
  - Minimum 5 participants;
  - Constantin MILU, Member of the International Program Committee and Co-Chair to the Panel session: International response to the Bonn Call for Action.

Radiation Safety Climate in a University Setting

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Abstract. This paper analyzes the safety climate associated with both ionizing and non-ionizing radiation use in a university setting. By fielding a survey and conducting behavioral observations, we were able to assess both the safety culture and safety climate of those working in radiation laboratories. A robust safety climate is essential in maintaining safe laboratory practices, yet studies have shown that many researchers, across disciplines, are unsatisfied with their organization's existing safety climate. Developing and maintaining a strong safety climate in a university setting is especially important as young researchers are establishing the foundations of their safety culture. To that end, our organization is working to identify characteristics of the existing climate to inform the development of clear and accessible resources and training related to safety and accountability. Initial observations in the laboratories showed that there were many inconsistencies between perception, knowledge, and behavior. Consequently, we developed and implemented strategies for rectifying associated deficiencies, which are discussed herein. The methods and results discussed herein describe how collaborative techniques can reduce risk and improve safety climate in a University setting.

KEYWORDS: Safety Climate; Safety Culture; University Research Safety.

1 INTRODUCTION

Nationwide, laser safety generally is generally given less priority than other areas within research and laboratory safety. University laser safety programs consequently receive fewer resources and less attention than other health and safety program components even though laser-related injuries and deaths occurring in the research industry surpass those caused by general use of radioactive material [1]. It is likely that explicitly incorporating laser safety into traditional university radiation safety programs will likely improve the overall radiation safety climate. Therefore, this study seeks to assess, compare, and improve safety climates in ionizing and non-ionizing radiation laboratories.

Safety climate is often perceived as synonymous with safety culture [2], however a positive safety culture does not necessarily imply a positive safety climate. Safety culture is inherent to an organization or individual whereas safety climate, which may include many factors, is an expression of safety culture within the working environment [3]. A robust, positive safety climate is essential in maintaining safe laboratory practices, as a poor safety climate may lead to otherwise avoidable safety-related incidents [4]. Beyond the personal impact to the individual, these incidents may lead to potentially significant organizational costs, both direct and indirect, such as lost time and productivity, medical expenses, and safety fines to regulatory organizations [5]. Subsequent to the occurrence of an accident in the laboratory, there is evidentiary support that the incident may lead to more positive safety behaviors in the short-term [5]. However, waiting for accidents to occur is not an acceptable approach to creating a more favorable safety climate, as an organization's goal should be zero accidents, plus, safety climate will soon revert back to pre-accident conditions. Proactively supporting a more positive safety climate has the benefit of lowering the occurrence of incidents as well as the potential for increased reporting of accidents and near-misses. This then provides the opportunity to execute corrective interventions and implement new strategies to prevent future incidents [6] as opposed to relying on a purely reactive approach to safety.

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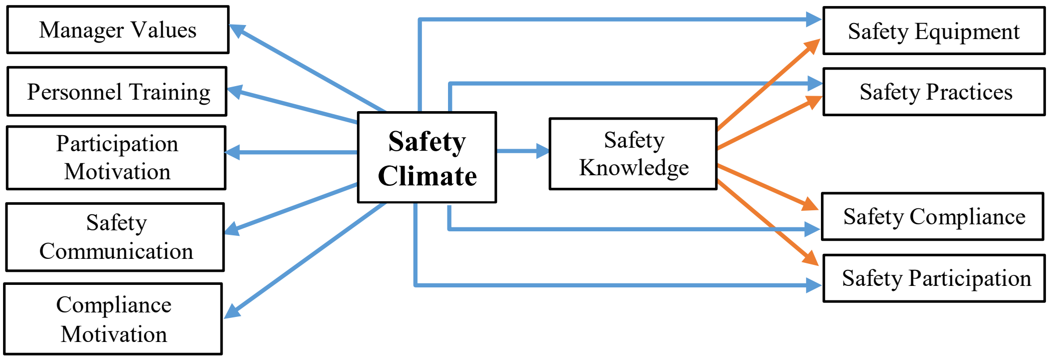
2 METHODS

2.1 Preliminary Ionizing Radiation Safety Surveys and Observations

A survey was designed to determine the radiation safety climate of our institution's radiation laboratories, with the intent to field both preliminary and post-recommendation surveys to compare how the study influenced the safety climate. Fig. 1 represents the various elements of safety climate on which survey questions were based; questions within the survey fell under different categories to gain a broad understanding of the associated safety climate as well as to potentially identify any problem areas.

Figure 1: Components of safety climate [7]



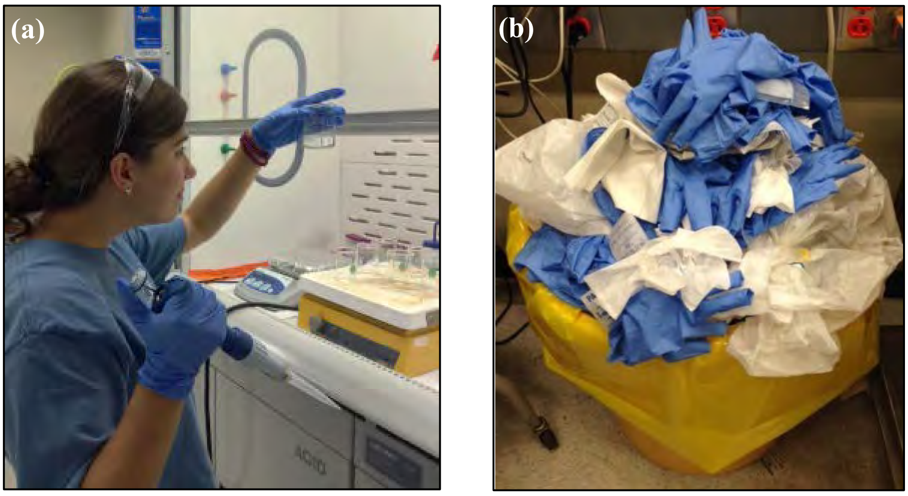
Both surveys featured questions from ten different categories: personnel training, manager values, participation motivation, safety communication, compliance motivation, safety knowledge, safety equipment, safety practices, safety compliance, and safety participation. These categories collectively enabled distinction of the safety climate and culture [7, 8]. Fig. 2 provides a few sample survey questions from the ionizing radiation survey.

Figure 2: Sample ionizing radiation safety survey questions

Statement	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5
There is appropriate and sufficient PPE available for my use in the lab.					
There is sufficient opportunity to discuss and address safety issues in meetings.	○	○	○	○	○
I help my coworkers when they are working under risky or hazardous conditions.					
I believe that promoting safety in the workplace is important.	○	○	○	○	○

Preliminary radiation safety surveys were then fielded in the radiochemistry laboratories. The web link to complete the survey electronically was sent to students working in the radiochemistry laboratories through the Clemson University branch of the Health Physics Society (CUHPS) email listserv. Additionally, hard copies of the survey were made available at CUHPS meetings and lab group meetings for students to complete. At the same time, preliminary safety observations of researchers working in radiochemistry laboratories were conducted. Regular and periodic observations were unobtrusively made of researchers working in the radiochemistry laboratories to evaluate working conditions and safety behaviors, such as availability and use of personal protective equipment (PPE), housekeeping and organization of bench tops and hoods, use of dosimetry, etc. Fig. 3 illustrates two examples of observations made during this period.

Figure 3: Sample safety observations in radiochemistry laboratories involving (a) lack of appropriate PPE and (b) an overfilled waste bin.



Specifically, these observations included a researcher actively working in the laboratory with no lab coat and wearing safety glasses on top of their head (a re-enactment with no chemicals present is pictured in Fig. 3(a)) and an overflowing radioactive dry waste bin (Fig. 3(b)).

Surveys and observations were analyzed and compared upon completion. The differences between the existing safety climate and culture were determined by this analysis. Potential deficiencies, root causes, and recommendations for improvement were compiled (discussed below) to provide assistance to the observed groups in improving the safety climate.

2.2 Non-Ionizing Radiation Safety Observations and Surveys

Clemson University requires all laser users to compete the Laser Institute of America (LIA) Laser Safety in Educational Institutions online training. Members of the research team also completed this training to gain insight to the type, detail, and extent of training laser users receive. Clemson does not yet have a dedicated laser user database, therefore monitoring and training has been challenging for the radiation safety officer (RSO). Additionally, the RSO is not informed when new lasers are acquired. An accountability system, then, is much needed, and one of the motivations for this work. The RSO provided a list of known laser users that established the beginning of a database. Internet search engines helped locate news articles featuring laser use at Clemson, and peer-reviewed journal articles provided contact information as well as detailed context of said use. Meeting with responsible principal investigators (PIs) also often yielded contact information of other laser users at the university.

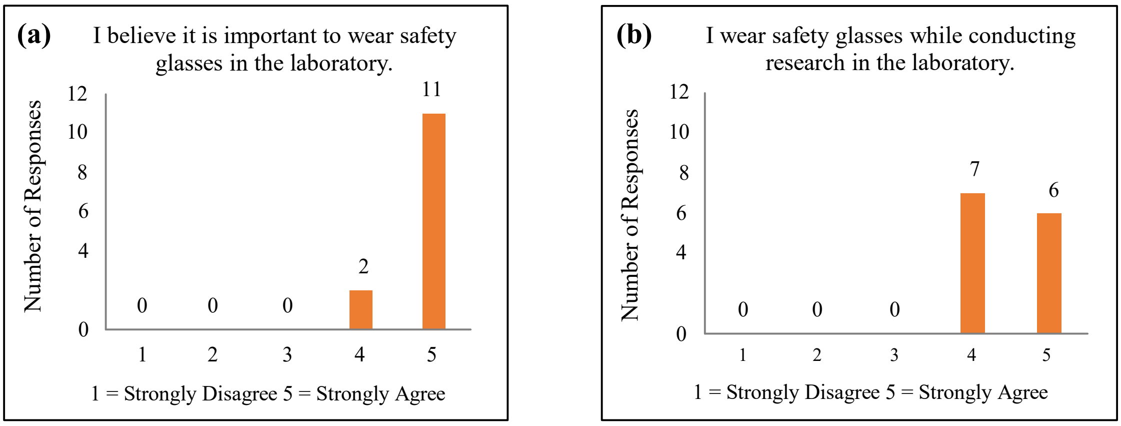
A laser inspection form was drafted to include PI contact information, laser equipment description (manufacturer, model number, location, lasing media, class, wavelength, mode, average power output, energy output per pulse, pulse length, pulse repetition rate, beam diameter, and beam divergence), laser eyewear description (wavelength attenuated, optical density, quantity, and manufacturer), additional safety features (door signage, controlled access, entry way warning light, entry way barrier, interlocks/emergency stop, and barriers to prevent stray beams), the purpose of the laser, the names and emails of users who will assist in the use of, or frequent the room, SOP for class four lasers, additional training provided by the PI, and any reflection hazards [9]. Additionally, the form included a laser safety officer (LSO) review checklist for control measures and additional safety considerations.

At this point, face-to-face meetings were conducted with PIs to discuss general (non-ionizing) radiation safety and the laser inspection form as well as to make observations of the relevant laser lab regarding safety issues specific to non-ionizing radiation. Both electronic and hard copies of the non-ionizing radiation safety survey were made available to PIs or lab managers for completion by relevant users.

3 RESULTS AND DISCUSSION

Preliminary ionizing radiation safety survey results displayed a picture of both safety climate and safety culture. Fig. 4 represents the results of several compliance survey questions.

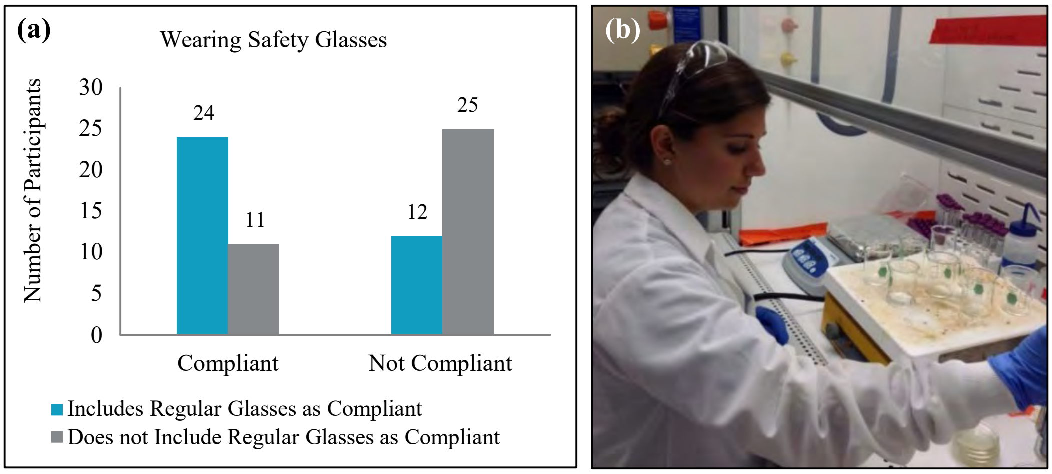
Figure 4: Preliminary survey responses showing (a) safety culture and (b) safety climate associated with the use of safety glasses in the radiochemistry laboratories.



Specifically, these survey results included personal beliefs of the importance of wearing safety glasses (Fig. 4(a)) and how often they wear safety glasses in the laboratory (Fig. 3(b)). Personal beliefs regarding the importance of wearing safety glasses indicated a positive safety culture. However, the lack of actually wearing safety glasses indicated a safety climate inconsistent with this culture.

Preliminary observations provided evidentiary support for the safety climate reflected in the survey results. Fig. 5 is a bar graph of observation results of safety glasses compliance and a re-enactment of a safety observation of a student working in the laboratory lacking safety glasses over the eyes.

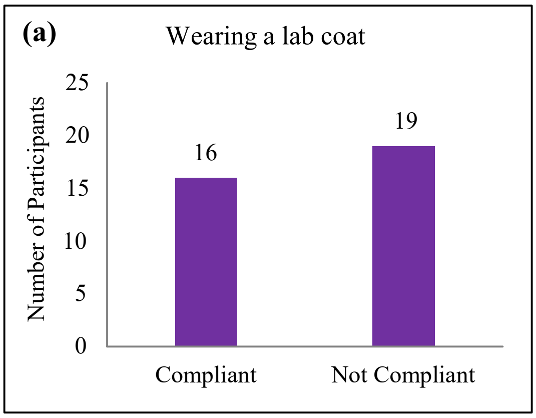
Figure 5: Observations of safety glasses compliance, where (a) is a summary and (b) is an example observation (re-enacted).



Individual PIs had different requirements for safety glasses, in that some PIs approved the use of regular eye glasses in place of specifically designed safety glasses. However, regular glasses do not offer the same protection as safety glasses, as they were not designed to shield the eyes from chemicals or projectiles (although it is possible to fit eye glasses with side shields). The Occupational Safety and Health Administration (OSHA) explicitly requires employers to ensure that all employees needing vision correction either wear prescription protective lenses or wear safety glasses over the top of their prescription glasses [10]. However, wearing both regular glasses and safety glasses together may pose a potential risk to individual safety. For example, two sets of glasses may impede vision, or an ill-fitting, larger second set of glasses may fall into an experiment when looking down. Clemson does not provide prescription safety glasses but recommends that individual departments purchase them as needed; offering prescription safety glasses as well as periodically replacing existing safety glasses (minimizing scratches and lens cloudiness) may alleviate some of the discrepancies seen.

Preliminary observations indicated that the safety climate regarding wearing lab coats and gloves was also poor in the radiochemistry laboratories. Fig. 6 and 7 display the results of observations and survey responses of researchers respectively, indicating inconsistencies between the two.

Figure 6: Preliminary observation results for wearing (a) a lab coat and (b) gloves in the laboratory.



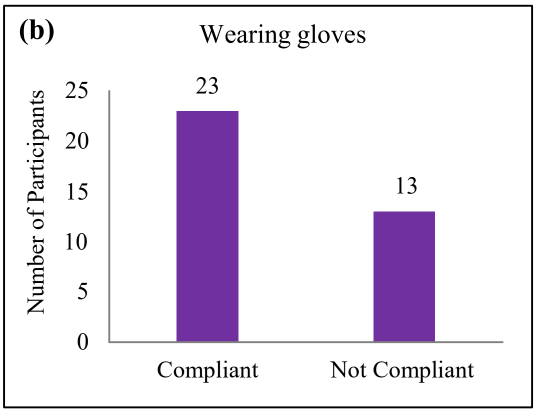
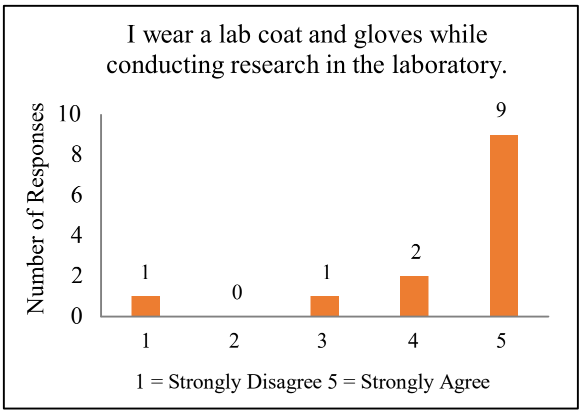


Figure 7: Preliminary survey results for wearing a lab coat and safety glasses.



It was observed that researchers wore lab coats less often (Fig. 6(a)) than gloves (Fig. 6(b)), although survey results indicated that researchers normally wear lab coats and gloves together; these results may have been more consistent if researchers were questioned about the independent use of a lab coat and gloves.

Preliminary ionizing radiation safety survey and observation results provided insight into potential deficiencies in the safety climate. Table 1 describes the possible deficiencies associated with each safety climate indicator, the suspected root causes of these deficiencies, and recommendations for improvement.

Table 1: Potential deficiencies, suspected root causes, and recommendations for improvement resulting from the preliminary ionizing radiation safety study.

Safety climate indicators	Potential deficiency	Suspected root cause	Recommendation for improvement
Safety knowledge	Safety material location unknown	Lack of communication, inspections, or accountability	Spot checks and feedback by management
Personnel training	Training does not provide confidence for working safely	Training does not prepare for an accident and is only required once a year	Live accident "drills" by management once a semester and refresher training held each semester
Safety practices	Labs with multiple safety standards	Each lab group has a different safety climate depending on the PI; Clemson does not have clearly defined rules	Each lab group may post safety requirements inside the lab
Safety equipment	Unorganized lab	Lack of PI support for good housekeeping practices; numerous users result in lack of ownership	PIs recommend twice a semester lab cleanout after group meetings
	Appropriate and sufficient PPE is not available	Communication between students and PIs is lacking	PIs ask students in group lab meetings about PPE problems
Safety communication	Not comfortable communicating safety issues	Fear of reprisal or negative peer-perception	PIs ask students in individual meetings of safety concerns; safety comment box
Safety compliance	Does not wear appropriate PPE	Lack of accountability or emphasis on importance	PIs set example; hands on trainings to demonstrate the value of PPE
	Have to take short-cuts in regards to safety	Lack of a variety of safety techniques to fit specific tasks	Talk with laboratory manager about to be efficient with regards to safety
Manager values	Research safety is not of high concern to their peers	Poor safety climate	Case study presentations to demonstrate importance of safety
Safety participation	Does not help peers working in hazardous situations	Poor attitudes and "tunnel vision" while working in lab	Encouragement by PI to help peers with higher risk activities

Many of the recommendations include improved communication between individuals, PIs, and safety management as well as encouragement of all relevant parties to take a more active role regarding workplace safety. The Occupational Safety and Health Administration (OSHA) requires employers to provide a safe workplace, but ultimately the individual controls his or her personal behaviors related to safety [11]. Therefore, collaborative techniques, such as between PIs and safety management, are the most likely to effectively reduce the risk of accidents and injuries occurring in the laboratories. According to non-ionizing radiation safety observation results, safety knowledge and training was often lower compared to ionizing radiation users. However, safety observations demonstrated non-ionizing radiation users exhibited a stronger desire for maintaining and promoting a safe work environment. That is, while the ionizing radiation safety culture appeared appreciably positive, the non-ionizing radiation safety culture was comparatively even more positive. There have thus far been few respondents to the non-ionizing radiation survey, which may be an indication of a poor safety climate [12]. Future work will more actively encourage survey response through face-to-face meetings.

4 CONCLUSIONS

Individual safety cultures as well as the overall group safety climate in radiation laboratories were assessed through survey and observation. Although safety was generally perceived as important, many improvements may be made to increase the practical reflection of this belief. Many of the potential deficiencies were ultimately attributed to lack of communication between researchers, PIs, and safety management [13]. Recommendations for improvement included encouragement from PIs and safety management to emphasize individual safety responsibilities. Non-ionizing radiation users generally lacked training and safety knowledge, however observations conclude that they were more willing to take personal responsibility for their safety than ionizing radiation users. Safe behaviors resulted from a myriad of factors, but ultimately required the active participation of all levels of an organization. In this, effective communication was essential and therefore our primary recommendation.

5 FUTURE WORK

After the implementation of safety recommendations, surveys and observations will be repeated. A quantitative analysis of safety climate pre- and post-recommendation will be performed to determine the extent of improvement. Additionally, a safety climate based risk assessment will be performed in an effort to predict potential for, and severity of, laboratory accidents [14]. Underreporting is indicative of a negative safety climate, therefore we expect more accidents (including spills and injuries) may be reported to the safety officers resulting from the implementation of recommendations [6], assuming they occur. Frequency of accidents or incidents is not currently tracked, however, so this may be difficult to quantify. Quantitative analyses of quarterly radioactive waste and dosimetry cost will also be conducted to assess expenditures related to those items. Capital may be saved from dosimetry and radioactive waste removal to purchase additional PPE and safety supplies for radiation laboratories, effectively encouraging a positive safety climate. A new electronic annual laser refresher training will be developed and implemented to account for laser use specific to the university [1, 15]. Since laser safety training is only required once, a yearly refresher training encourages a positive non-ionizing radiation safety climate. A detailed comparison between the ionizing and non-ionizing radiation safety climates at the university will also be conducted.

6 ACKNOWLEDGEMENTS

The authors would like to thank Stephanie Hoelbling, Dr. Brian Powell, and the participating students and faculty of CU's department of environmental engineering and earth sciences; Samuel Forrest of CU's research safety; and the participating students, faculty, and staff at CU using lasers. Funding for this project was provided by United States Nuclear Regulatory Commission Nuclear Education Grant #NRC-HQ-13-G-38-0002.

This study was conducted in accordance with the requirements set forth by the Clemson University Office of Research Compliance; IRB Exempt under category B2, study protocol number IRB2015-176.

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Young Scientists and Professionals (YSP) – Austria's Young Generation as best practice example

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Abstract. Austria's radiation protection association is a pioneer in encouraging young scientists to join the field of radiation protection both in medical and non-medical use. It not only helps establishing it's young scientists within its working environment through various resources and possible knowledge management but also within the international radiation protection community. The association is running a 2-step supporting program: On the one hand students can submit scientific papers or their thesis for two different awards. On the basis of the scientific quality for RP they can get some monetary appreciation. In addition they can introduce themselves to members of the radiation protection association when presenting their work during a conference. On the other hand a sub-group to the radiation protection association called "Young Scientists and Professionals" has been established in 2013. One of the main goals is to help young people interconnecting themselves. Every member of Austria's radiation protection association either younger than 35 or working in RP less than 5 years is automatically member of this group. There are no additional fees or duties. On the basis of these frame conditions young scientists can share their knowledge, their experience during different projects at university or during their employment. Therefore about 15 young professionals join the meetings up to 6 times per year. They discuss the latest news of our specialist field, about advantages and disadvantages of different measurement equipment and juridical improvement. In addition they visit research facilities, laboratories and companies. During meetings members present reports on conferences, their latest scientific papers and research. In addition they are invited to publish summaries, renarrations and interesting facts in the internal journal called "Strahlenschutz aktuell" which is distributed to all the members of Austria's radiation protection association twice a year. To encourage potential future members we try to stay connected to professors of different universities and institutes. We try to mediate and start projects with students. In addition we are connected to department managers of different companies who might look for young and motivated professionals. That way we want to show young scientists a promising future in radiation protection.

1 BASIC IDEA

The average age of radiation protection experts is raising from year to year. As their know-how and practical experience can hardly be maintained for young followers and vocational training periods are often reduced to a minimum, this old knowledge gets lost continuously. For this reason Austria's radiation protection association (OEVS – "Österreichischer Strahlenschutzverband") established a sub-group called "Young Scientists and Professionals" (YSP) in 2013.

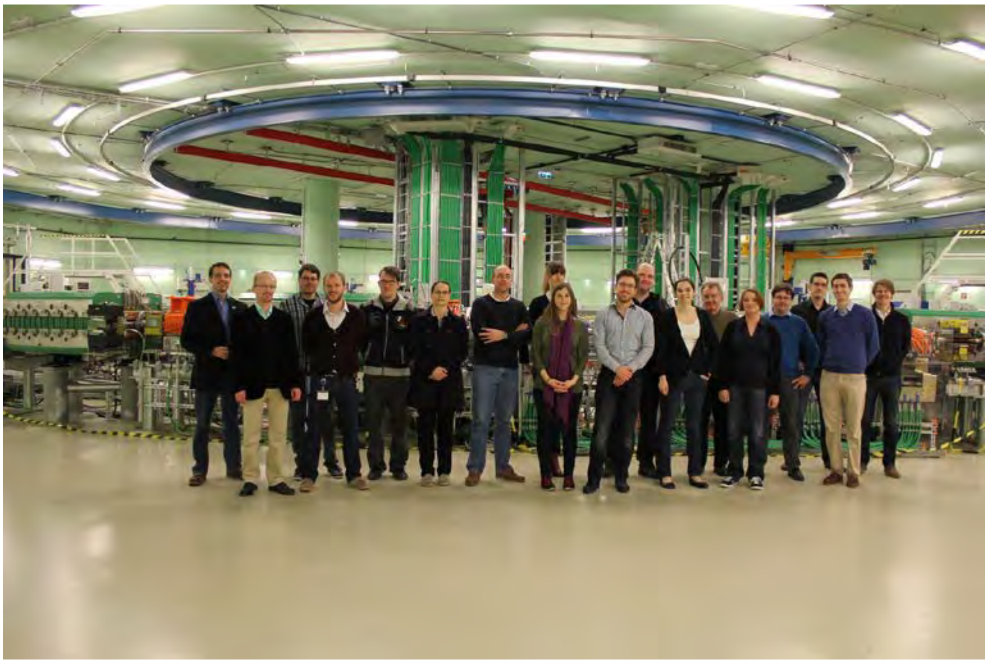
With this group the OEVS strives to encourage young colleagues to start their professional life in the field of radiation protection. The young members shall get involved within the community, benefit from the knowledge of their more experienced colleagues and introduce new ideas to support the progress of the association.

2 STRUCTURE OF THE YSP-GROUP

The group "Young Scientists and Professionals" is part of the OEVS. Every member of the OEVS either younger than 35 years or working less than 5 years in the field of radiation protection is automatically a member of the YSP-group and invited to contribute to the community. There are no additional fees or duties. During regular meetings the young members get to know each other and can share their knowledge and experience.

Currently approximately 15 young professionals join the meetings up to 6 times per year. They discuss the latest news of our specialist field, evaluate advantages and disadvantages of different measurement equipment and juridical improvement and also visit research facilities, laboratories and companies. In addition the young members have the possibility to introduce their latest research results as well as present reports of conferences during the meetings. Besides that, they are invited to submit articles for the internal journal called “Strahlenschutz aktuell” which is published twice a year.

Figure 1: YSP meeting at MedAustron (cancer treatment center at Wiener Neustadt)



3 CURRENT STATUS

The OEVS has about 200 members, 10-15 % of these members comply with the requirements to join the YSP. The OEVS provides financial support for the participation of several young members at the IRPA14 in Cape Town, so that they can meet experts from other countries. Therefore, several abstracts have been submitted by Austria’s young academics. Two of these young members are official delegates of the OEVS for voting the new executive council members of the IRPA during the conference.

In addition to the work of the YSP-group the OEVS is giving financial support to young members. Students can submit scientific papers or their thesis for different awards and get the possibility to introduce their work within the radiation protection community.

4 COMING PROJECTS

YSP has been given the privilege of organizing the 2016 spring conference of the OEVS in Linz. At this conference about 100 participants will discuss the topic of risk communication in the field of radiation protection.

The OEVS will carry on to support the YSP as a group as well as the individual members, to motivate young scientists to participate in our specialist field and improve the nuclear knowledge management. One of the major goals is to arrange an attractive start for the professional life of young colleagues and to integrate them into the association.

Figure 2: Participants at the IAEA conference of occupational radiation protection in 2014

5 ACKNOWLEDGEMENTS

Special thanks to the OEVS, that supports the YSP and gives us the opportunity to present our work at the IRPA. Many thanks to my employer Seibersdorf Laboratories for promoting my technical and vocational skills.

Carbon Molecular Sieves used in the Sampling and Monitoring Technology of Krypton in the Atmosphere

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Abstract. The experiment investigated how to establish a set of device and method that can be adapted to the environmental krypton monitoring. A set of experimental installation were designed for sampling krypton from environment normal temperature, which using carbon molecular sieves as adsorbent, based on the research of international monitoring technology and devices. In order to study the dynamic adsorption property of krypton in carbon molecular sieves, the krypton dynamic adsorption coefficients have been measured under certain conditions, including flux and krypton concentration. Under the lab operation condition of 0.08MPa, gas trapping at room temperature, and with the desorption temperature of 350 degrees celsius, the percent recovery of the device reach to 30%.

KEYWORDS: Krypton; carbon molecular sieves; dynamic adsorption coefficient; percent recovery.

1 INTRODUCTION

The radioactive noble gases are released into the atmosphere by nuclear reactor operations, fuel reprocessing and nuclear detonations. During normal operation of nuclear facilities, the disposal of noble gases in waste streams is usually handled by delay-decay techniques and dilution to reduce their concentration to values below the concentration guidelines for public exposure (GB-18871) and discharge them to the environment. Since noble gases are released to the environment. Therefore, dilution and disposal to the environment may eventually lead to a buildup of long-lived isotope Kr-85(10.76yr) that may be biologically hazardous[1]. Cryosorption is commonly used in separation of krypton in the air, but the equipment of the cold trap which used liquid nitrogen was not convenient in the wild. Monitoring of radioactive Kr in the atmosphere in wild has not routinely been done due to lack of an acceptable analytical procedure and convenient device.

The methods for the determination of the low level Kr-85 in the atmosphere have been studied. The prototype device can be regarded as composed of four distinct stages:
(1) sampling, first purification and pre-concentration;
(2) purification from radon and concentration;
(3) further concentration;
(4) Kr-85 activity and Krypton volume measurements.

The technical specifications of this method is gas-trapping at ambient temperature, that with no cryogenic cooling.

The stage (1) had been finished and the device used hollow fiber membrane to perform the pre-concentration of krypton. The step (1) removed the particles, oil, H_2O, CO_2 and other impurity. The product gas from step (1) mainly consist of N_2, O_2 and trace amounts of Kr. In the stage (2), Kr should be separated from N_2 and O_2 and in this process we would use the method of adsorption separation.

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There are several adsorbent used in air separation like 5A molecular sieve, activated charcoal, and carbon molecular sieve (CMS). Using 5A Molecular sieve for the best , that could separate noble gas from air when the column temperature is higher than at room temperature . But the samples must be no H_2O, CO, SO, and components such as H_2S. In other words, when the samples containing the components of the gas such as H_2O, CO_2, we should avoid the use of 5A molecular sieve for CO_2 can be separated under the high column temperature, while the H_2O will cause the modified molecular sieve.

Activated carbons, also called activated charcoal, or activated coal, is a form of carbon processed to have small, low-volume pores that increase the surface area available for adsorption or chemical reactions. The pore size range in 0–20 Å (0–2 nm), that is wide so it was not easy to separate the noble gas in air. But it could work well under very low temperature (as the temperature as liquid nitrogen).

Carbon molecular sieves (CMS) are a special class of activated carbons. However, pore size distribution of these materials is not always strictly discrete and furthermore, molecules are not hard spheres; they can sometimes squeeze into narrow pores. The distinction between activated or porous carbons and carbon molecular sieves is not clearly defined. Carbon molecular sieves have most of the pores in the molecular size range but some conventional activated carbons also have very small pores. The main distinction is that activated carbons separate molecules through differences in their adsorption equilibrium constants [4, 5]. In contrast, an essential feature of the carbon molecular sieves is that they provide molecular separations based on rate of adsorption rather than on the differences in adsorption capacity. The feature may make it better than 5A molecuar sieve and activated carbons in noble gas separation.

The aim of this work: try to use carbon molecular sieve(CMS) to concentrate Krypton from the atmosphere, to perform the stages (2)and (3). In order to study the dynamic adsorption property of krypton in carbon molecular sieves, the krypton dynamic adsorption coefficient have been measured under certain conditions. The recovery rates of this method with our equipment have been measured.

2 EXPERIMENTAL

2.1 Materials and chemicals

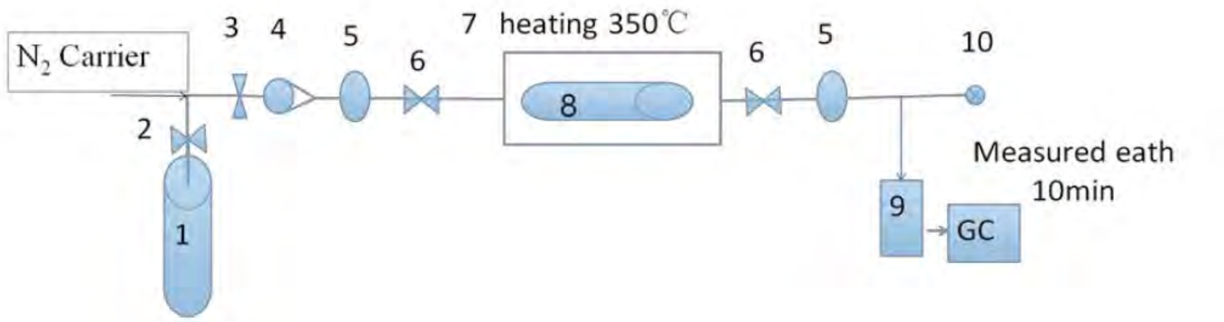
Nitrogen (99.999%) was used as a carrier. Stable krypton (0.3% , 3% and 99.999% standard gas were used as the work gas. The standard gas made of pure krypton and pure nitrogen. Carbon molecular sieves were used as adsorption trap.

2.2 Instruments and equipment

Adsorption column is 1.5 m long with an inner diameter of 0.036 m which consists of three sub-columns made of stainless steel. Each sub-column is filled with about 350 grams of CMS and located in a tubular oven. The gas chromatograph (ThermoFisher , trace1300)is used to measure the concentration of Kr in collecting gas. The chromatographic column is capillary column that is 25m long with an inner diameter of 0.5mm filled with 5A molecular sieve.

Figure 1 shows a flow diagram of the experimental apparatus used in this study. The apparatus make it possible to adjust various operating parameters such as flow rate, pressure, temperature and carrier gas. Flow was controlled by rotameter. Pressure was controlled by pressure reducing valve and pressure regulating valve. Temperature was measured and controlled by an oven with temperature control system. The volume of the gas can count by flow totalizer. The line in the system is changeable by hand valves. All interconnecting lines are made of 6mm I.D. PU tubes.

Figure 1: A flow diagram of the experimental apparatus



1-Gas bottle; 2-pressure reducing valve; 3-pressure regulating valve; 4-rotameter; 5- flow totalizer; 6-three-way valve; 7-oven with temperature control system; 8-adsorption column; 9-gas collecting bag; 10-atmospheric valve.

2.3 Experimental Conditions

The gas pressure and flow rate from outlet in the stage(1) were about 0.08Mpa and lower 0.24L/min, so we choose the experimental conditions as follows:

- Adsorption Temperature: ambient temperature;
- Desorption Temperature: 350° C;
- Adsorption Pressure: 0.08Mpa;
- Flow rate through adsorbent: 0.12 L/min and 0.24L/min; Flow volume: 10 liters and 20 liters.

2.4 Procedure

Dynamic adsorption experiment: The working gas with a certain volume was introduced to the adsorption column at a given flow under a given pressure. The concentration of Kr from the outlet of the column has been collected every 10 min and measure by gas chromatograph.

Krypton recovery: Successive heating at 350° C of each one of the sub-column which have adsorbed the work gas and performed with pure nitrogen, then the adsorption gas were collected in order to measure the Kr by gas chromatograph.

After experiments heated the column at 350° C and through with pure nitrogen 1 hours to regenerate the CMS column.

3 RESULTS AND DISCUSSION

3.1 Results of the dynamic adsorption experiment

Table 1 shows the results of the dynamic adsorption experiment. Four groups of data of Kr dynamic adsorption penetration coefficient (Kd) were obtained at Kr concentration 99.999%, 3%, 0.3% and at flow rate 0.12L/min, 0.24min/L by pulse injection respectively.

Dynamic adsorption penetration coefficient shows property of adsorption column of krypton .The equation for the Kd as follows:

$$Kd = \frac{Ft_m}{m} \tag{1}$$

Kd -- dynamic adsorption penetration coefficient, L/kg
F -- the flow rate of the work gas , L/min(STP);
t_m --, the time of break -through(when the concentration of Kr in outlet was 5% of the inlet);
m -- the weight of CMS, Kg.

Table 1: Dynamic adsorption penetration coefficient in different conditions

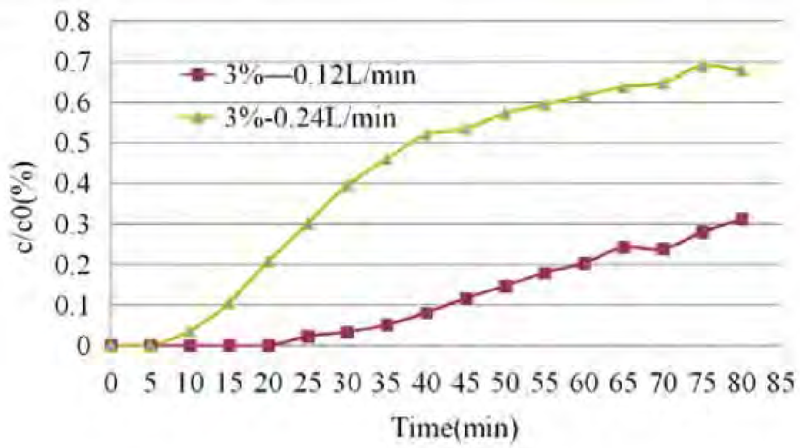
Krypton concentration of work gas	Flow rate	The time of break-through	Dynamic adsorption penetration coefficient, Kd
(%)	(L/min)	(min)	(L/Kg)
99.999	0.12	20	2.19
3	0.12	25	2.74
3	0.24	10	2.19
0.30	0.24	35	7.67

3.2 Discussions on the selection of flow rate for adsorption

Figure 2 shows the curve of adsorption break-through of adsorption column at two flow rate. c is the concentration of the Kr in the outlet, c0 is the concentration of the Kr in the inlet.

At higher flow rate (0.24L/min), the time of break-through is shorter within our experimental conditions. From the table 1, the Kd at flow rate 0.24L/min and 0.12L/min have similar value as 2.19L/Kg and 2.74L/Kg. But also the flow rate 0.24L/min is the same as that in the outlet in the stage (1). So 0.24L/min could be used as the work flow rate at stage (2) without adjustment.

Figure 2: The curve of adsorption break-through of Kr at two flow rate



3.3 Discussions on the concentration of Kr in work gas

Considering the role of the CMS adsorption column was concentrated Kr, which in the range 10^{-7} mol/L (about 2.3ppm) to 10^{-3} mol/L (about 2.3%), the influence of concentration to Kd should be studied. According to the research by FENG shujuan [5], When the noble gas concentration is below 10^{-4} mol/L (about 0.23%), the effects of a gas concentration on the Kd are not obvious. When the noble gas concentration above 10^{-4} mol/L (about 0.23%), with the increase of concentration, Kd will decline. So we chose three Kr concentration that are 0.3%, 3%, and 99.999% to determine the Kd value respectively.

The results shows that the Kd value at 3% and 99.999% were similar (2.74L/Kg and 2.19L/Kg), in our experiment conditions. Figure 3 shows the time of adsorption break-through of Kr at concentration 99.999% and 3% were similar too. From table 1, when the Kr concentration were 3% and 0.3%, the Kd value were 2.19 L/Kg and 7.67L/Kg with our experiment conditions. With the increase of concentration, Kd will decline. Figure 4 shows that at higher concentration (3%), the time of break-through was shorter within our experimental conditions. The results were consistent with the FENG shujuan's research. The result could be used to define the volume of the work gas in the further work.

Figure 3: The curve of adsorption break-through of Kr at concentration 99.999% and 3%

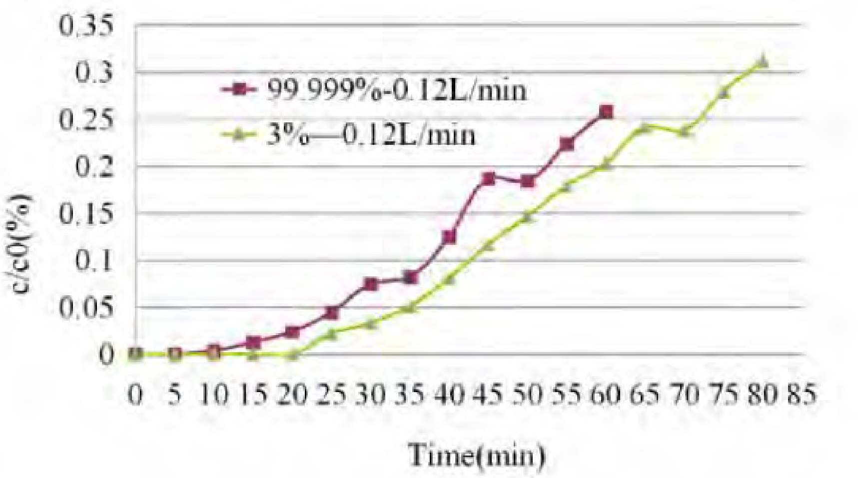
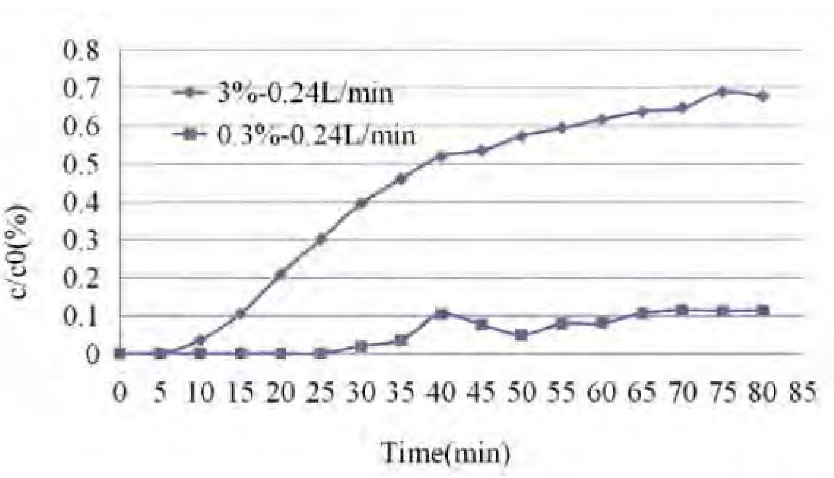


Figure 4: The curve of adsorption break-through of Kr at concentration 0.3% and 3%



3.4 Results and discussions on recovery rate

The recovery rate: the percentage for the quantity of krypton in the recovery gas compare to the inlet gas. When the concentration of Krypton in the outlet gas is greater than 2 times of the inlet gas, we star to collect the outlet gas every 0.5 liter in one gas collecting bag.

Table 2 shows the results of recovery rate of Kr were 40% and 47% at the volume of the work gas 20L and 10L in our experimental conditions. The result shows that 10L should be used as the volume of the work gas for this adsorption column.

Table 2: The recovery rate of Kr at two volume of the work gas

Volume of the work gas	Recovery rate of Kr	Recovery volume	c/c0	c0
(L)	(%)	(L)	(%)	(%)
20	40	3.8	68	3
10	47	2.3	30	3

4 CONCLUSION

In order to use carbon molecular sieve (CMS) to concentrate krypton, the dynamic adsorption property of krypton on CMS have been studied. The results shows that 0.24L/min (flow rate) and 10L (volume of work gas) are appropriate to the adsorption column system.

When the work condition with 3%, 10L krypton as inlet gas at 0.08Mpa, 0.24L/min, ambient temperature for adsorption, and 350°C for desorption, the recovery rate can be more than 30%.

5 MORE WORKS

After another researches and experiments, now the prototype device of sampling and measuring the Kr-85 in the atmosphere had been finished are showed in figure 5. More details will be published in other articles. The detection limit of the method was not below 0.5Bq/m^3. Some data of Kr-85 in the experimental environment have been measured. More tests for the device are in the progress.

Figure 5: The prototype device of sampling and measuring the Kr-85 in the atmosphere

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Public acceptance of Nuclear Technology: education and communication to transform old prejudices and inspire new thoughts

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Abstract. According to some international surveys, as Globescan and Eurobarameters, the higher the education level, the more favourable are opinions towards nuclear technology. People fear what they cannot understand and the issue divides public opinion Brazil and worldwide. Taking advantage of the growing impact of Internet, this web-based educational project aims the dissemination of nuclear technology contents to teachers and students throughout Brazil, educating educators, combating misinformation and encouraging scientific and technological research. The web-based educational project RadioAtividades (RadioActivities) aims the dissemination of nuclear technology contents for teachers and students of Elementary and High School Education. The content includes curiosities, interactive exercises and short courses that comprise the various aspects of the beneficial applications of nuclear technology, such as electric power generation, transportation, protection, art, archaeology, food irradiation and nuclear medicine, among others. The website offers basic content on radiological protection and safety, presenting some actions related to health and safety of the public, the workers and the environment. Students can learn about principles of radiological protection, principles of radiation safety to minimize exposure, different units for measuring radioactivity exposure, and everyday life actions, such as nuclear and radiological safety operations in major public events. Moreover, to enhance teachers' understanding of core in Nuclear Technology issues, this project provides pedagogical support, offering supplementary free course material to develop in class. All content can be easily accessed by any conventional internet point and there were created mobile apps, for IOS and Android Smartphones and tablets. Public opinion is based on experience of the population with the available information about risks and benefits. It is not a coincidence that more informed people favour nuclear technology. Education transforms old prejudices and inspires new thoughts. Our target is the dissemination of information, spreading knowledge for new generations, contributing to public acceptance of Nuclear Technology, combating misinformation in our society, omission of the media and knowledge fragmentation.

KEYWORDS: radiological protection; public acceptance; education and communication.

1 INTRODUCTION

This project aims to offer an interdisciplinary approach to science education, integrating economic, ethical, social and political aspects of nuclear sciences. In Information Society, where Internet is the most popular information source, most often social networks seem to associate radiation to nuclear weapons and nuclear accidents. The best known examples throughout history seem to be the big mushroom cloud in Hiroshima and Nagasaki, as well as major accidents such as Chernobyl and Fukushima. A multi- disciplinary approach to science education shall offer a wider perspective on the opportunities, as well as the dilemmas, that nuclear science presents in our daily lives. The program covers different aspects of nuclear technology, including its impact on social, environmental, economic and political aspects, enabling the public to formulate a critical understanding of the interaction between science, society and nuclear technology.

Sensitive to the fact that there is still great misinformation about nuclear technology among a large fraction of the population, and taking advantage of the growing impact of Internet, this web-based educational project is an initiative to offer opportunities for all Brazilian citizens to learn and explore the puzzles of nuclear science throughout Brazil. The challenge involves the ability to create an effective system, which pleases both youth and adults, which counts on an original and creative design, and effective pedagogical Distance Education (EAD) practices according to the most modern educational concepts. The different themes are presented through interactive activities and short courses. The web- based multimedia courses were developed using modern educational concepts

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and instructional strategies, which not only replace instructor absence, but also enable users to see and review the content with great quantitative and qualitative achievement. One of the most interesting ways to understand nuclear energy is the possibility to relate it to life itself. Therefore, in order to enrich the public's educational experience, encouraging a deeper learning, all topics are related to everyday life: safe transport, nuclear power generation, food irradiation and radiological protection, among others. This last item is particularly important, for there is still great misunderstanding about the risks involving the harmful effects of ionizing radiations. People fear what they cannot understand. Regarding this issue, different areas of this educational site offer basic content on radiological protection and security, presenting some actions related to health and safety of the public, the workers and the environment issues. The website presents the principles of radiation safety to minimize exposure: time, distance and shielding. The site brings and explains visitors about the three principles of radiological protection, known as justification, optimization and dose limits. There are presented concepts, theory and interactive activities concerning radiological protection to inform the public about different units for measuring radioactivity exposure, such as absorbed dose, effective dose and equivalent dose, as well as some units like gray and sievert.

This project aims to be a reference in nuclear science education and communication, engaging society in issues pertaining to the impact of nuclear science on social, technological, economic and political contexts.

2 METHODOLOGY

In order to successfully achieve our goals, the methodology for this global platform system development includes a comprehensive analysis of three main challenges:

1. Literature review of the official publications of ICTs access possibilities in Brazil, as well as literature review of official publications of nuclear technology and education in society.
2. Development of an effective instructional design for scientific divulgation, regarding the best didactic and pedagogical practices in order to enhance society understanding
3. Strategic definition of technological resources for scientific divulgation and a monitoring management system

2.1 Nuclear science and education: impacts on society

This project takes into account two main issues: (i) public opinion is based on experience of the population with the available information about risks and benefits, and (ii) it is not a coincidence that more informed people favor nuclear technology.

Indeed, important surveys conducted by GlobeScan (2005) and Eurobarometers (2010) report similar socio-demographic trends: the higher the education level, the more favorable are opinions towards nuclear power. Eurobarometers are used to measure public opinion in Europe and overseas. Their report, entitled Public Attitudes to Nuclear Power, was published in 2010 by the Nuclear Energy Agency (NEA) and the Organization for Economic Co-operation and Development (OECD). According to this document, "respondents with higher levels of education are more likely to think that the advantages of nuclear outweigh the risks" [1].

The Globescan survey (2005) for the International Atomic Energy Agency (IAEA), published in 2005, analyses the results of public opinion conducted among a thousand adult respondents in each of the eighteen participant countries [2]. According to this report:

"Overall, men (33%) and people with high levels of education (36%) are more inclined than women (23%) and those with low levels of education (24%) to say that nuclear power is safe and that interested countries should build new nuclear power plants. People with less education (28%) are more likely than the well educated (21%) to say that nuclear power is dangerous and that all plants should be closed down."

Nevertheless, a survey conducted by Globescan (2011) for BBC World Service following Fukushima crisis brings different trends: opposition to nuclear energy grows since 2005 [3]. The survey covered 23,231 citizens across 23 countries. In the Latin American countries that do not operate nuclear plants, opposition is well-marked. In Chile and Ecuador, respectively, 55% and 53% think that nuclear energy is dangerous and should not be used. In Panama and Peru, respectively, 38% and 30% think nuclear power generation should be abandoned in countries that have active plants. Brazil was one of the participating countries of this survey, even though only urban samples were used:

"In Brazil - which operates a few nuclear plants and was surveyed for the first time in 2011 - a plurality of 44 per cent of Brazilians says that their country should continue to use the nuclear power stations that are already in operation, but not build new ones. Thirty-five per cent say that nuclear power is dangerous and that all operating nuclear plants should be closed down as soon as possible - above the 12-country average (30%) - and only 16 per cent support the building of new nuclear plants - below the 12-country average (22%)."

According to this survey results suggest opposition to nuclear energy grows in many countries and opposition to nuclear power has increased in 5 among 8 countries that were also polled by GlobeScan in 2005. The biggest impact was in Germany where 52% of the population supported the government's new policy of shutting all the nuclear energy facilities in the country [3].

Some studies conducted in Brazil to measure public acceptance of food irradiation bring similar results, showing that most often the public does not know the difference between food irradiation and radioactive food. Population-Food Supply is one of the major Brazilian issues. Food irradiation touches human health, agriculture applications, food safety, radiological protection, environment issues, nutritional education, food waste, economic losses and international commerce. Food irradiation is a process that contributes to reduce pathogenic microorganisms and parasites that cause diseases to human health. Besides the health benefits to the consumer, food irradiation could also bring tangible benefits to the national economy: food irradiation helps to delay sprouting and ripening of fresh fruits and vegetables, extending their shelf-life, avoiding losses and waste. However, beyond these benefits there must be considered some intangible aspects: due to lack of knowledge and understanding about the difference between food irradiation and radioactive food, people fear the harmful effects of ionizing radiation to the consumers' health.

A study published in Brazil in 2008 [4] clearly demonstrates that misinformation and preconceived ideas impact heavily on the acceptance of irradiated food. This experiment to measure the level of public acceptance considering four different groups:

- Group 1. Received information and tasted foods identified as irradiated.
- Group 2. Received information and tasted food without knowing whether or not they were irradiated.
- Group 3. Received no information and tasted foods identified as irradiated.
- Group 4. Received no information and tasted food without knowing whether or not they were irradiated.

The third group showed markedly unfavourable results, demonstrating the negative impact of misinformation and prejudice.

Another survey entitled "Brazilian Consumer Views on Food Irradiation" was conducted in 2009. The information given to participants about the benefits of irradiated food impacted positively, however participants generally still proved to be fearful about the risks and possible side effects. The research provided important data about factors which affect acceptance and purchase intention by the Brazilian consumer. In the published conclusions, the authors emphasize the importance of developing an educational program for Brazilian population, explaining the principles, purposes and benefits of food irradiation [5].

Given this challenge, this educational project takes advantage of the potential of new web-based technologies to create new bridges between science and society. Any construction depends on a solid foundation and education is the foundation of every society.

2.2 Web-based system development

The web-based educational Project, entitled RadioAtividades (RadioActivities) aims the dissemination of nuclear technology contents for teachers and students of the Elementary Education and High School throughout Brazil [6]. Therefore, we conducted a comprehensive job regarding the possibilities of access to the Information and Communication Technology (ICT) throughout the country. This research work has enabled the collection of quantitative and qualitative data about our target public profile. That allowed us to define the best interfaces tools and resources for this Project.

Internet access has increased strongly all over the country. According to a publication held by the Brazilian Internet Steering Committee [6] who conducted a survey in all Brazilian States, there was an important advance in the use of ICT in Brazilian organizations. This research made use of methodological standards proposed by the United Nations Conference on Trade and Development (UNCTAD), described in the Manual for the Production of Statistics on the Information Economy, produced in partnership with the Organization for Economic Co-operation and Development (OECD), European Commission of Statistics (EUROSTAT) and together with the Measuring ICT for Development, a coalition of various international organizations aiming the harmonization of key indicators on ITC research (Information Technology and Communication) [7].

In Brazil, between years 2006 to 2008 there was a significant decrease in the use of the dial-up internet from 14% to only 5% [7]. Besides, there was significant progress regarding internal wireless network in corporations, which included only 14% of companies in 2005. Nevertheless, in 2009 41% of Brazilian companies already claimed to have wireless network. These are only few examples that demonstrate the rapid evolution of events and trends of the business market to track the latest technological trends in order to benefit as fully as possible the advances of information technology [8].

The ICT Education 2011 survey [9] comprehended interviews with 1.822 teachers, 606 directors of studies, 640 principals and 6 364 students were interviewed between October and December, 2011.

“The relationship between the frequency of activities carried out in pedagogical practices and the use of ICT suggests a challenge to incorporating technologies in education. There are signs that an increasing number of activities carried out in classrooms will create opportunities for the introduction of ICT in the teacher-student relationship. This is because ICT are used more often to carry out the least frequent activities proposed by teachers. Although there are limitations to the ICT infrastructure of Brazilian schools, the relationship between the most frequent activities and the use of these tools may be indicative that teachers are still struggling to change their teaching practices traditionally carried out without computers or the Internet.

Students in turn, incorporate more naturally the use of computers and the Internet in their school activities. The indicator on activities carried out using ICT shows that 82% of the students do school research using computers and the Internet. Furthermore, 74% of them prepare theme projects using ICT, and more than half claim to use these tools for homework assignments (60%).”

Regarding student access to the internet, this publication reports several sample profiles. Age group results show that 40% of the interviewed students are up to 13 years old and that 14 to 15 year-old students represent 29% of the sample profile. When each region is studied separately, access to internet are led by Northeast and Southeast regions with a percentage of 34%, and 33% respectively, while South region represents 16%.The Center-West and North regions have the lowest average rate and together represent 17% of students access in Brazil. Among the predominantly activities involving the use of computers and the internet for school assignments in public schools, research activities stand in first place, with 82% of the total number of students in public schools. Overall, there is a higher incidence of computer and Internet use by teachers and students in private schools: “as well as in public teaching institutions, students in the private system also use ICT in their school assignments, particularly for school research (96%).

The most recent publication of this entity up to this date [9] shows a comprehensive picture of ICT infrastructure in public and private schools, considering the relationship between the number of students per school and the number of computers in working condition. There are on average 20 operational computers in state or municipal institutions and approximately 500 students per school facility, according to the 2011 School Census. Even though 93% of Brazilian public schools claim to have access to Internet, 32% have connection speeds between 1 and 2 Mbps for the whole facility and a further 25% have speeds below that. Wireless connections are available in only 45% of the institutions. Among private schools, there is a higher incidence of computer and Internet, which increases use of ICT with students. Private institutions have on average 29 working computers, nine more than in public institutions, and count on fewer classes per grade and 4 to 5 fewer students per class.

Given these data, we were able to start the system intelligence and the development of educational technology models of nuclear technology content. The pilot project was implemented in a web environment, using the Web 2.0 tools and resources that allow the entire organizational structure. We developed a platform whose range of features and functionality suits the needs of the academic public. Our challenge involved the ability to create an effective, but at the same time flexible system, which please both children and youth.

The project uses the combination of multiple technologies, for both development and infrastructure issues, maximizing the resources available in each technology in order to achieve our goals. Taking into account this is an original project with the prospect of long-term use, it was considered the HTML (XHTML1 STRICT) patterns, according to the W3C (World Wide Web Consortium) recommendations [10]. Considering an infrastructure that supports an average volume of service access, we chose the Linux operating system and MySQL server database [11]. Whether during the implementation phase or hereafter the server has to be rescaled to increased demand, our team can easily migrate the database to a server MSQL Server [12]. For the server language development, we chose PHP [13], as it is a widespread technology, well documented with an extensive and active community, and especially for being a dynamic and flexible language. This WEB 2.0 concept project makes extensive use of CSS (computer language), allowing it to be easily adapted to new possibilities of media, like mobile access, feeds of content and information sharing. There is still a great concern for SEO (computer language) to ensure that the information is well-indexed in the best way possible in the Internet search engines. Furthermore, all content can be accessed from any traditional internet connection, either for computers or mobile technologies.

All content can be easily accessed by any conventional internet point and there were be created mobile apps, for Android Smartphones and tablets.

2.3 Instructional design for scientific divulgation

The information about the current situation of ICT in Brazil, the way people work with the resources available, the most present technologies, as well as the main challenges and trends were essential to guide the planning of this project development. Our first challenge involves providing public accessible scientific information throughout Brazil, expanding the dialogue among different segments of society. Responding to this global plural society demands creating responsive instruction design tools which can be well accessed either from computers or mobile technologies, from any conventional point internet at home, at work, on the way home or any other location. In this sense, the instructional project includes not only the adaptability to mobile media, as well as the responsibility (responsive system). This means that the system is able to identify the type of screen used by the user. According to the equipment and resolution of screens used, the layout automatically adjusts for best viewing and better use of educational resources designed for the transmission of each content. The web-based system development strategies include three essential steps: (i) to create a website; (ii) to create short courses and (iii) to develop a monitoring management system.

Creating a website involves the development of an original and creative design, created according to modern concepts, with different thematic roles which please the different segments of our society, regarding sex, age, geographic location and sociocultural aspects. This project will provide different possibilities for activities according to the various contents, such as Frequently Asked Questions, interactive short courses and a repository of supplementary support references material designed to clarify and enhance public understanding of core in food irradiation issues, providing material resources for free download.

All interactive short courses development should consider modern educational concepts and will count on last generation internet resources which not only replace instructor absence, but also enable students to see and review the content with great quantitative and qualitative achievement. The content includes concepts, definitions and theory in addition to many interactive activities [6]. The project involves the creation of computerized models that comprise the various aspects of food irradiation in daily life, with the title:

1. **Radioactivity** - Based on the story of ordinary human beings who, in contact with radiation, became superheroes or super villains, the subject introduces the atom, radioactivity, biological effects of radiation, among other curiosities related to the subject.
2. **Electric Power Generation** - The topic discusses the various forms of renewable and non-renewable energy, emphasizing the benefits of nuclear energy and explaining the nuclear energy generation and fuel cycle.
3. **Transport** - This item features transport of dangerous goods, which are essential to improve the quality of our everyday life, such as gasoline, alcohol, varnishes and also radioactive materials. Activities and short courses teach international pictograms used in the transportation of these products and present the specific signals used for Class 7 material.
4. **Everyday life** - The topic discusses how nuclear technology contributes to improve the quality of our everyday life in many more ways than people can realize, such as medicine, agriculture and industry.
5. **Nuclear Energy Museum** – The topic offers a virtual visit to the Brazilian Nuclear Energy Museum, in Recife (PE), presenting general concepts about several applications of Nuclear Technology, such food irradiation, gemstones irradiation, nuclear power and radiological protection, among others.
6. **Safety and protection** – This item offers basic content on radiological protection and safety issues, presenting some actions related to health and safety of the public, the workers and the environment. The topic introduces important concepts and applications, as well as unities and measurements. Inter-relating the theme to everyday life, this topic presents, for instance, nuclear and radiological measures applied to major public events, such as the Fifa World Cup.
7. **Art and archaeology** – This topic discusses many ways that nuclear technology can contribute to the understanding and preservation of cultural historical heritage, such as paintings and other artefacts: x-rays for pigments identification, hidden paintings and authentication of paintings, computed tomography scan of sarcophagus and mummified tissues and carbon-14 techniques for dating works are discussed in this item.
8. **To infinity... and beyond!** – The item presents the contributions of nuclear technology to the aerospace technology and last generation submarines: the contributions of electric power generation for the success of space missions and reactors for nuclear propulsion for submarines.

These eight topics were designed to meet the global interests of our plural society, providing a more comprehensive and solid information, linking technology and everyday life in order to improve public understanding of nuclear science, safety and protection issues. Making use of the latest technological resources, each short course presents the essential of the main concepts and their practical applications.

3 FINAL CONSIDERATIONS

The use of information technology for quality scientific divulgation shall contribute greatly to deliver information throughout the country, spreading knowledge to as many people as possible, minimizing geographic distances and stimulating communication and development. In order to measure the website visitors´ profiles, evaluation of the results are checked by customized reports provided by the Learning Management System (LMS) platform and also customized reports provided by Google Analytics. It is our intention to investigate the website usage profile, collecting monthly reference data about visitors' profile, gathering information of quantitative and qualitative aspects, collecting fundamental information for strategical planning of the evolution of this Project, as the WEB platform tools and functionalities must be developed according to our target public needs, regarding new possibilities of media, mobile access, feeds of content and information sharing. Moreover, monitoring data will allow us to identify our public audience: location, interests, most accessed information, among other relevant information. Still, due to constant technological innovations, our team intends to lead a constant research work and monitoring of new related technologies that may be useful for the development of this project. This is a long term project and it is our target to make it a reference on nuclear science divulgation for Portuguese spoken countries.

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Enhancing communication on Radiological Protection throughout Brazil

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Abstract. This paper focus on the potential value of Information and Communication Technologies (ICTs) to enhance communication on Radiological Protection throughout Brazil. The servers processing power added to the technology of relational databases allow to integrate information from different sources, enabling complex queries with reduced response time. It is our objective to provide radioactive facilities a complete repository for research, consultation and information on radiological protection in an integrated and efficient way. This web-based project works informatization of Radiological Protection Programs according to the positive tree published by AIEA in its Safety Series No. 102, the most generic and complete tree for an appropriate and effective radiation protection program. Up to this moment, the website counts on concepts, definitions and theory about optimization and monitoring procedures, interrelating information, currently scattered in various publications, in order to meet both Brazilian and international recommendations. The project involves not only the collection and interrelationship of existing information in the several publications, but also new approaches from some recommendations, such as potential exposures. Only few publications develop expressively the issue and, even though they provide fundamental theory, there is still lack of knowledge of failure probabilities, which currently constitutes a broad research field in radiological protection. This research proposes the development of fault trees and the analysis of different scenarios, suggesting paths to quantify probabilistically the occurrence of potential exposures, as well as probabilities to reach a certain level of dose. It is our target to complete the system in a near future, including other relevant issues, such as safe transport of radioactive materials, emergency response, radioactive waste management and decommissioning, among others. We believe the use of information technology for the radiological protection programs shall contribute greatly to provide information to Brazilian radioactive facilities throughout the country, spreading information to as many people as possible, minimizing geographic distances and stimulating communication and development.

KEYWORDS: radiological protection; ALARA; potential exposures; information and communication technologies.

1 INTRODUCTION

This paper focus on the potential value of Information and Communication Technologies (ICTs) to enhance communication and education on Radiological Protection Programs throughout Brazil. In order to establish a Radiation Protection Plan or a Radiation Emergency Plan, Brazilian facilities should take into account all procedures based on national and international guidelines and recommendations. This information can be found in several documents published by different organizations over the past decades: the International Commission on Radiological Protection (ICRP) [1], International Atomic Energy Agency (IAEA) [2] and Comissão Nacional de Energia Nuclear (CNEN) [3].

To meet national and international standards, the development of this research includes concepts, definitions and theory about radiological protection procedures in order to interrelate information, currently scattered in several publications and documents published in the last past decades. Radiological Protection Programs are developed according to the positive tree published by AIEA in its Safety Series No. 102 [4], which is considered the most generic and complete tree for an appropriate and effective radiation protection program.

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The main objective of this work is to provide Brazilian radioactive facilities a complete web-based repository for research, consultation and information. Moreover, this research involves not only the collection and interrelationship of existing information in the publications, but also further approaches from recommendations, comparing information, discussing present challenges and future possibilities towards protection and safety. This paper focus on Potential Exposure researches, which currently constitutes a broad research field in radiological protection.

2 METHODOLOGY

2.1 A web-based repository for radioactive facilities throughout Brazil

In Brazil facilities involving ionizing radiation are divided into nuclear and radioactive facilities. Nuclear installations cover the entire nuclear fuel cycle, which comprises nuclear materials mining, including power reactors and research, the production of radioisotopes for use in several human activities and also the reprocessing of fuel elements of nuclear reactors. Moreover, the radioactive facilities are those that make use of ionizing radiation in other peaceful applications of nuclear energy like in the industry, medicine, agriculture, environmental protection, among others. This division is due to the fact that the entire nuclear fuel cycle, including reactors, are government monopoly, while all other human activities involving ionizing radiation can be developed and used by the public under government supervision. Brazil is a large country with great distances between major cities and counts on hundreds of radioactive facilities located in different states. The project UNIPRORAD (Unification of Radiological Protection Programs) is a web-based tool to spread information and communication on radiological protection and safety for radioactive facilities all over the country [5].

The WEB platform tools and functionalities were developed according to target public needs, regarding new possibilities of media, like mobile access, feeds of content and information sharing. Moreover, taking into account this is a pioneer project with the prospect of long-term use, our challenge takes into account the development of a robust, effective, and flexible system, which can be easily adapted to future demands, this pioneer Project involves the combination of multiple computer technologies. That is a long term use Project that shell help greatly radioactive facilities and can be a reference for researchers in Portuguese spoken countries.

2.2 Delineation of the content

Regarding potential exposures, only few publications develop expressively the issue. The ICRP gives the first basic steps to develop potential exposures issues in Publication 60 [6]. In 1993, the same entity extends this work in its Publication 64 [7], focusing risks, probabilities, defense-in-depht and safety culture. In 1995, the International Nuclear Safety Advisory Group publishes INSAG-9 [8], a report on potential exposure in nuclear safety to complement IAEA's work on safety standards in the context of potential exposure. Discussing risks and probabilities and establishing policies for nuclear and radiation safety, this report repeats on its paragraph 34 the police also used by ICRP, literally transcribing the paragraphs about the justification of a practice, the optimization of protection and individual dose and risk limits. Later, in the same year, in December 1995, a report from CRPPH/CSNI/CNRA/RWMC Expert Group discussed the meaning and application of the concept of potential exposure [9]. This report of OECD/ NEA takes into account Publications ICRP 60, ICRP 64, AIEA SS114 and AIEA INSAG-9 [6] - [10]. According to this report, one of the principal issues considered is "an establishment of a common understanding and of agreed definitions concerning a number of terms used by the different communities sometimes with different meanings". Therefore, this report brings further discussions of some terminologies, such as individual risk, safety, probability, frequency, event, sequence, scenario, consequence, limits and constraints, among others. Later on, the ICRP brings in its new publication about Potential Exposures, Publication ICRP 76 [11], in its section 62:

"The methods for optimization of radiation protection range from simple common sense to complex quantitative techniques (see Publications 37 and 55; ICRP 1983, 1989). Optimization of protection against potential exposure is still largely unresolved, particularly when probabilities are low and consequences are big (NEA / OECD, 1995). Although the present report conceptually equates risks from normal and potential exposures, simultaneous, formal optimization of protection against both types of exposure would be difficult. However, the use of devices for protection against potential exposures, as outlined here, already includes an element of optimization. Also, the reference risk used in this report corresponds to the risk associated with the highest occupational doses in an optimized operation, rather than to the risk associated with a dose at the occupational dose limit. Still, optimal protection against potential exposures is not necessary achieved at the same level of risk as optimal protection against normal exposures. This is because the costs of reducing risks from normal exposures may be quite different."

Although this publication recognizes that these two issues should be treated separately, it does not provide specific recommendations. Indeed, despite the NEA/ OECD report affirm that optimization of protection against potential exposure is still largely unresolved, it emphasises optimization, justification and individual dose and risk limits as principles aimed at reducing the probability of accidents [9]. Taking into account the above mentioned reports and publications, as well as Brazilian publications, the web- based system UNIPRORAD presents the criteria used for control of occupational exposures, discussing normal and potential exposures [5].

The content includes concepts, definitions and theory about the optimization programs, help decision making techniques, information related to protection costs, radiation doses and detriment. The project involves the creation of computerized models that comprise the various aspects of optimization:

- Concepts and definitions whose terminology will follow the definitions provided by the ICRP publications [12], [13] and IAEA [14].
- Structured models for optimization projects of radioactive facilities and models for the facility operation, according to guidance provided by ICRP [13].
- The three basic principles of radiological protection, namely: justification, optimization and dose limitation system, according to guidance provided by ICRP [12].
- Quantitative decision making techniques, according to the ICRP publications [12], [13] and some examples through interactive virtual components, so the user can quantify and sense the extent required in practical situations. These interactive components are original and have been exclusively created for this purpose.
- Estimates of the alpha value and the international and national examples according to the guidance provided by the IAEA [14] and the publication of the Commission of European Communities [15].
- The factors that could be quantified according to the guidance given by ICRP [13], which includes the methodology necessary to implement the optimization procedure for both the project and the operation of the radioactive facility.
- The construction of the optimization process, given its features, the stakeholders and the choice of the optimal options, which means the analytical solution, and the distribution of doses over time and space, inserting the matrix of collective dose to the decision making according to publication of the ICRP [16] and following the methodology suggested by it.
- The procedures for evaluation of exposure situations, and the basic guidelines, showing the actual dimensions of each situation [14] - [16].
- The principles and means of reducing exposure that will keep the actual dimensioning of each situation [14] - [16].
- The global components to be considered to define and implement an ALARA Program [14] - [16].

Furthermore, the content includes concepts, definitions and theory discussing monitoring procedures [17] - [20], such as authority and responsibility, classification of work areas, practical implications and engineering controls, operational procedures, reference levels, types of monitoring and its functions. The system provides detailed information about workplace monitoring and individual monitoring, discussing objectives, routine monitoring and task-related monitoring in each case. Workplace monitoring for air contamination, for example, cover the following topics: conventional and more convenient structure, reference level for air contamination, routine monitoring, task-related monitoring and interpretation of results. Also, it was created exclusively for this purpose, an interactive virtual component presenting hypothetical problem-based situations related to incorporation of radioactive materials by workers. Besides workplace monitoring for air contamination, there are detailed information about workplace monitoring for external radiation, workplace monitoring for surface contamination, individual monitoring for external exposure, individual monitoring for internal exposure and individual monitoring for skin and clothing contamination.

Regarding potential exposures, only few publications develop expressively the issue [7], [8], [11] and some recommendations are not developed, making it difficult to discuss information in a complete and clear way, even from the original publications. Therefore, this web-based project promotes the discussion of this subject, introducing potential exposures in more quantitative way than national and international recommendations. Articulating ICRP and AIEA valid recommendations and official reports, in addition to some scientific works published in major international congresses, the system suggests paths to help to quantify probabilistically the occurrence of potential exposures, as well as probabilities to reach a certain level of dose. For this purpose and further discussions, the system brings the table of range of probabilities given by publication ICRP 64 [7], as seen in Table 1, and discusses the annual occurrence probability of a potential exposure suggested by Sordi equations [21], as seen in Table 2.

Table 1: Range of probabilities in a year from which constraint may be selected

Sequence of events leading to doses treated as part of normal exposures	10^{-1} a 10^{-2}
Sequence of events leading to stochastic effects only but above dose limits	10^{-2} a 10^{-5}
Sequence of events leading to doses where some radiation effects are deterministic	10^{-5} a 10^{-6}
Sequence of events leading to doses where death is likely to result	$< 10^{-6}$

Source: ICRP 64 [7]

Table 2: Range of probabilities in a year from which constraint may be selected

Maximum admissible dose for risk limits	Maximum incident probability
100 mSv	$1{,}0 \times 10^{-2}$
110 mSv	$1{,}5 \times 10^{-3}$
120 mSv	$8{,}0 \times 10^{-4}$
150 mSv	$2{,}6 \times 10^{-4}$
200 mSv	$1{,}0 \times 10^{-4}$
500 mSv	$1{,}0 \times 10^{-5}$
1000 mSv	$2{,}5 \times 10^{-6}$
2000 mSv	$1{,}0 \times 10^{-6}$

Source: Sordi [21]

Another example of further discussions beyond the original publications are the development of fault trees, suggesting new possibilities, inspiring new attitudes towards protection and safety for professionals involved in radiological protection issues. There is still lack of knowledge of failure probabilities, which currently constitutes a broad research field in radiological protection. This research proposes complete and general scenarios constructions that could be extended and applied by similarity to any radioactive facility according to its specific situation. The scenarios proposed bring the interrelationship of 3 different publications:

- ICRP 76: using the following examples: fault tree analysis of the radiotherapy device, fault tree analysis of a modern irradiator and fault tree analysis of an accelerator for isotope production [11].
- AIEA 102: regarding the positive tree, published by in 1990, which is considered the most generic and complete tree for an appropriate program of radiation protection [4].
- AIEA TECDOC 430: bringing the requirements and symbols for the correct development of a fault tree [22].

3 FINAL CONSIDERATIONS

The web-based system UNIPRORAD proved to be a useful source of information. Google Analytics is used to investigate the website usage profile, collecting monthly reference data about visitors' profile. According to Analytics most recent monitoring reports, between 05/06/15 and 04/07/15, the website UNIPRORAD counted on 251 sessions of Brazilian visitors from 10 different states, among which 32.67% were new visitors. Results were similar to the following month, between 05/07/15 and 04/08/15, when the website received 267 sessions of Brazilian visitors from 16 different states, among which 24.72% visited the website for the first time. The percentage of visitors who return to web-based system UNIPRORAD indicates it has been an efficient tool.

Indeed, the system UNIPRORAD allows to face different publications comparing similarities, understanding differences or analyzing discrepancies among the several valid recommendations. This is particularly important to Brazilian Radioactive facilities, because in order to establish a Radiological Protection Plan or a Radiological Emergency Plan, Brazilian facilities should take into account all procedures based on both national and international standards, guidelines and recommendations. For example, IAEA and ICRP suggest different values for the investigation level for individual effective dose in monitoring procedures. The IAEA [2] recommends 6 $mSvy^{-1}$, which means 3/10 of maximum average annual limit. Nevertheless, the value of the investigation level suggested by the ICRP [1] is 1/10 of the maximum permissible annual limit, which means 5 $mSvy^{-1}$. In Brazil, according to CNEN, the level of investigation is 6 $mSvy^{-1}$. In this case, the question would be: “How to achieve compliance with ICRP and CNEN to define the investigation level of individual effective dose in the case of internal contamination monitoring?” In this case, recommendations (ICRP, IAEA and CNEN) are provided and answers are given to help understand these variations. According to CNEN the level of investigation is 6 $mSvy^{-1}$ / n where n is the number of sampling periods per year. The ICRP suggests 5 $mSvy^{-1}$ / n where n has the same meaning of CNEN rules and the investigation level is the recording level itself [1] - [3].

The content has been developed and structured to provide answers to all questions that should be reasonably asked to plan a Radiological Protection plan according to each user’s specific situation. It is our target to complete the system in a near future, including other relevant issues, such as safe transport of radioactive materials, emergency response, radioactive waste management and decommissioning, among others. We believe that the potential of ICTs shall contribute greatly to provide information where it is needed, stimulating development in this large country where it is a strong challenge to ensure access to information to as many people as possible, minimizing costs and optimizing results.

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Radiation Protection Culture in Waste Management

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Abstract. Radiation Protection Culture in Waste Management is an international area of interest and has an important impact on the acceptance of nuclear technology and waste disposals by the societies independent of the nationality. Therefore, this subject is well positioned as an IRPA workshop. In 2014 and 2015 the "Working Group Disposal and RadWaste Management" the German Swiss Association for Radiation Protection (FS) has organized national seminars regarding disposals of radioactive waste, exemption and release of radioactive material which formed a very good base for an international workshop. That was the reason for the FS to organize an workshop "Radiation Protection Culture in Waste Management" in cooperation with IRPA in Switzerland in 2015. 26 participants from four countries (UK, Belgian, Germany and Switzerland) and two international organizations participated at the workshop. In 2014 IRPA established the "Guiding Principles for Establishing a Radiation Protection Culture" defining that the aim of Radiation Protection Culture is to establish a field culture in radiation protection among workers connected with our experience, knowledge, science, and information transfer which is shared and accepted by society. The FS-IRPA workshop merged Radiation Protection Culture into Radioactive Waste Management.

1 THE WORKSHOP

From August 31[st] to September 1[st] the German-Swiss Fachverband für Strahlenschutz (**FS**) in cooperation with the International Radiation Protection Association (**IRPA**) called for a Workshop on the topic **«Radiation Protection Culture in Waste Management».**
Some 26 Experts from several European countries attended the meeting. This paper is a summary of the main conclusions of this workshop. It was divided into four groups:

A) Dose reduction versus waste minimization;
B) Interim storage versus (final) disposal;
C) How to deal with safety culture deficiencies?
D) A common dose concept for clearance and release.

2 NEED OF A SOLUATION

Radioactive Waste is mainly produced in Nuclear Power Plants (NPP), but – to a smaller amount – also in Medicine, Industries and Research (MIR). The producer of the waste ─ indirectly as consumers everybody of us ─ is responsible for its long term safe handling, disposal and storage. This has to be done in such a way and for a sufficiently long time, in order to avoid that radioactive material enters in contact with the biosphere and threatens humans and environment. The time schedule is in probably of the order of 105 year, at least until it has decreased to the radioactivity level of natural uranium ore. Nuclear reprocessing would reduce storage time by a factor of roughly 25, transmutation ─ provided that this will one day be technically possible ─- would reduce storage time by a factor of 1000 and the volume of waste by a factor of 100. Actually several countries have renounced on nuclear reprocessing; in these countries the used fuel elements will be deposited without retreatment, after an intermediate storage time of some 20 to 30 years and after an adequate conditioning - i.e. in storage containers, which are suitable for this purpose - in a disposal facility.

The decision to build and operate such a disposal facility, the choice of a suitable site and the evaluation of the best suited host rock, as well as the way of conditioning is the responsibility of the national nuclear authority of each state. This body or its superior authority will also deliver the building permit and the operating licence and has in addition the responsibility to assure the necessary financing and the long-term monitoring and quality assurance of the disposal facility in terms of protection of man and environment.

In some countries like Switzerland, the relevant parliamentary decision will probably be followed by a public vote. So the task of the scientists and authorities in charge with the radioactive waste storage is to convince the population of the need of such a project and that the solution put forward by them is optimized from the point of view of safety, technology and in particular protection of man and environment. Although individual countries will renounce in the near future from nuclear energy they already have radioactive waste that needs to be disposed of. A long term surface storage as called for by certain people is, however, not a suitable long term solution as its security cannot be ensured over such a long time period.

3 OPEN QUESTIONS

Three fundamental questions need to be addressed in this regard:

1) First, an ethical one: We charge future generation with a kind of mortgage, i.e. the responsibility for our waste disposal facilities, without their consent. They will be in charge of something they haven’t caused and have to bear the expenses and the responsibility of long term safety and also the surveillance of these disposal facilities.
2) Secondly, we have to store the waste in a geological formation, which appears to us optimal from today's perspective (probably in deep geological layers) but without knowing the long term changes that will occur in geology of the earth and in regard to the evolution of human civilizations. Although 100 percent security is not possible, every effort should be made to keep it on the highest possible level and this for a time interval beyond human imagination.
3) And third, we can do it only based on scientific and technological knowledge of today. That means we cannot anticipate future developments of reuse or for new methods of treatment or conditioning of radioactive waste. In this regard, the question arises, how long should the stored waste remain accessible (retrievability) and how long should the site be monitored, and who will be responsible for it in the distant future?

4 DOSIMETRY CONSIDERATIONS

The radiation doses for population from artificial radiation sources – as recommended by ICRP and laid down in most of the national radiation protection legislation – are limited to 1 milli-Sievert per year. For Switzerland, a protection target for people living near a nuclear power plant has been fixed to 0.3 milli-Sievert per year and for those living near a deep geological disposal facility for radioactive waste to 0.1 milli-Sievert per year.

Doses received by the nuclear workers can amount up to a few milli-Sievert per year and are well below the dose limit for this category of persons, fixed in the legislation to 20 milli-Sievert per year. Real doses to the public from nuclear installations including scoping calculations for disposal facilities for radioactive waste are or will be significantly lower, typically in the range of a few micro-Sievert per year. So, there is a safety interval of 3 orders of magnitude between the protection target and the real radiation exposure.

5 COMMON DOSE CONCEPT FOR CLERANCE AND RELEASE

Clearance is defined as the removal of radioactive materials or radioactive objects within authorized practices from any further regulatory control by the regulatory body. The clearance system is based on the so called 10 µSv-dose concept. A dose for members of the public caused by clearance of materials should below some ten µSv per year. Individual radiation dose is likely to be regarded as trivial, if it is of the order of some ten µSv/year. This level of dose corresponds to a few percent of the annual dose limit for members of the public and is much smaller than any upper bound set by competent authorities for practices subject to regulatory control. This level corresponds to a few percent of the radiation of the natural background.

For the release of a site, it should be ensured by means of the optimization of protection that the effective dose to a member of a critical group is kept below the dose constraint of 300 µSv in a year. This system of clearance of materials and release of sites is very important for a national waste management programme. Clearance/release is one of the most important tools to ensure that radioactive waste generated is kept to a minimum practicable (IAEA: GSR-3 3.131). Minor modifications to the clearance/release system can influence the generation of radioactive waste in a very strong way (e.g. in Germany up to 97% of the materials from decommissioning a NPP could be cleared. If this is changed for example to 88% by modification of a clearance condition, the amount of radioactive waste is increasing by a factor of 4 from 3% to 12% and can cause a necessity for an additional disposal facility). On the other hand a dose concept of up to 300 µSv per year for release of a site should fit to other dose concepts for licensing, discharge of effluents, and exemption. In addition, it should be considered that a release of a site should not create a new legacy in the future.
During the workshop the possibility of a common dose concept for the release of sites and clearance of materials from regulatory control was checked. Actually, the description of two different concepts in two guides has a strong overlap for example for materials resulting from the release of a site on the one hand and clearance of parts of buildings or excavated soil on the other hand. Is it possible or necessary, to merge the existing two concepts together in one concept (e.g. in a single or two separate guides) or to provide more detailed guidance on the application of the two concepts for the overlapping issues?

The results were the following points: IAEA recommends a dose concept for clearance of materials 10 µSv/y and for release of sites (buildings plus areas) up to 300 µSv/y. There is an overlap in case of release of building debris or excavated material. This is a source for inconsistencies in the system and does not support a common understanding of the system. These inconsistencies can also reduce the necessary radiation protection culture. A common dose concept would be an ideal solution to repair the dose system, but includes the risk of loss of flexibility, if solutions are necessary for sites with higher contamination.

In any case different dose concepts are also existent in case of NORM and release of effluents compared to the dose concept of clearance. A detailed definition for the application of all these dose concepts and their overlaps in one guide would be very helpful and increase the acceptance of the recommended dose concepts.

6 COMMUNICATION AND PUBLIC ACCEPTANCE

Communication of the process and of the results of the safety case, especially with regard to the long-term perspective, is somehow lacking. The promise of long-term safety is ambiguous and often misinterpreted by the media and the public. In relation with communication, but also with providing the correct background information to decision-makers, there exists the wrong perception that avoiding a decision and/or not approving a final disposal strategy (including site selection) is a solution. Instead, the discussion needs always to start from the consideration that waste is already existing and mostly stored in temporary facilities, for which there is no long-term safety case. Saying no to any final disposal means automatically saying yes to existing temporary facilities with all the associated risks for man and environment.

To increase public understanding and acceptance of a waste storage concepts education (school, universities) and communication (information transfer, experience from the past) need to be improved and stakeholders should be involved in the opinion-finding process from the beginning although the final decision will be taken by political authorities.

A communication strategy promoting confidence and trust in the scientific arguments should be established. The entire decision process should be transparent and comprehensible for the concerned population. A structured engagement of stakeholders in the discussions and information sessions about waste management should be put in place taking into consideration the national culture. In particular, the communication of the periodic reviews', results and safety status of the facilities should be tackled in an appropriate form (target-oriented).

7 COMPREHENSIVE APPROACH

An optimized waste management concept should consider the whole process from the production of waste to its final disposal and not just individual steps thereof. All driving forces should be included in the search of the optimal solution, not only from the technical site but also to meet the requirements from politics, population, media and environmental organisations. Of particular importance are general aspects for communication to stakeholders in order to increase public understanding and acceptance, what is essential.

8 WASTER MINIMIZATION TO REDUSE THE OVERALL RISK

To what extent is waste minimization necessary to reduce the overall risk? Would it make more sense to set the priority on risk reduction then on dose reduction and on optimization instead of minimisation? Many countries have a law about waste minimization in force. This underruns the imperative of dose reduction, as waste minimization causes further work in controlled areas and additional irradiation doses to the involved workers. A holistic optimization process might be the right solution to get out of this dilemma, considering both the dose reduction and the waste minimization. In some cases a modification of the national legislation would therefore be necessary. Switzerland has explicit regulations for waste minimization, as Germany is still trusting in the market. So the question needs to be addressed, which level of dose is acceptable and to what extent waste minimization is necessary to lower the overall risk?

Waste minimization has the advantage of a better use of the of available disposal facility space. Such a more environmental friendly approach might to some extend increase public acceptance. The doses workers are taking by waste minimization are real, calculated doses of the nearby population are, however, hypothetical and conservative. On the base of accepted concepts an optimized waste management system should take into account costs, volume minimization of waste for different kind and activity level of the waste, technical low dose waste minimization methods and realization of final disposals. Such an optimized waste management system is based on a proper radiation protection balance, low risks and an optimal safety culture.

9 SURFACE STORAGE IS NOT A LONG-TERM SOLUTION

It is emphasized that, radioprotection professionals should explain and better inform stakeholders about the fact that the rejection of disposal options means necessarily the acceptance of existing situations and temporary surface storage facilities, that for a long term storage is not an acceptable solution and presents significantly more important risks for men and environment than a final underground storage. The public should be made aware that, however, the predicted long-term governmental control remains questionable.

10 NATIONAL OR INTERNATIONAL SOLUTIONS FOR WASTE STORAGE

Most of the countries have so far decided that waste has to be stored in the country where it is produced in order to avoid any «waste tourism». Nevertheless, in a long term perspective and in caring for an optimal solution this question should be discussed again. Therefore multinational solutions should be taken into account especially for countries with small amounts of radioactive waste or for those who have no nuclear power or plan to shut down their existing nuclear power stations in the near future. Long term surface storage of spent nuclear fuel is only an alternative, if spent fuel is considered as resource for reprocessing. Finally experience from operating and shut down of disposal facilities should be preserved.

11 INTERIUM STORAGE AND FINAL DISPOSAL

Existing radioactive waste in intermediate storage facilities: although such radioactive waste is not currently perceived as legacy by the society and/or the public, because of the time-limited safety case (e.g. with regards to the design life time of casks) or due to a change in regulations, the waste can in future become a legacy.

The commissioning of a disposal facility is often postponed due to many different reasons. Due to these delays the duration of the interim storage last much longer than planned. Often additional work has to be done to keep the interim storage safe causing additional dose for the workers. Do we need a speed up of the process for a disposal facility? Interim storage and final disposal is the strategy for most of the countries that have to dispose of the radioactive waste. Unlimited (surface) storage (as discussed in US) in order to improving public perception is a discussion topic among some critical groups. By joining their forces IRPA and IAEA could work in order to eliminate such contradictions and to provide better information of the population, in particular between retrievability and final disposal or between immediate conditioning and dose reduction.

An operating disposal facility would be the ideal situation, however, the reality is different and most of the counties have actually no available disposal facility. In these cases only interim storage facilities are available, but they will be only an interim and not a long term solution. Today the affected countries did not yet come to a common solution, i.e. to proper balance between an intermediate storage period (as this is necessary for used fuel elements so that they can cool down), time of conditioning and time of disposal. Such evaluations are depending on chemical form of the waste, if with or without nuclear reprocessing, external storage conditions, availability of waste acceptance criteria and storage capacity as well as funding.

12 OPTIMIZATION PROGRAMS BY INTERNATIONAL COOPERATION

The waste management concepts should be optimized by comparing the programs of different countries in order to benefit from their experiences. Despite the decision taken by many countries, that waste should be treated and stored in the country where it is produced, the question of sharing disposal facilities between several countries should be evaluated as an option. For optimizing security of waste disposal facilities and certainly also to increase public acceptance a comparison of the concepts established by different countries would be recommendable. Such a comparison should be based on the following information.

- amount and nature of radioactive waste to be stored;
- nuclear waste after or without retreatment;
- waste containers and conditioning technique;
- one or two storage facilities (LMW and/or HAW);
- intermediate surface or final underground storage or a combination of both;
- host rock: Crystalline, salt dome, sedimentary rock like Opalinus Clay, others;
- time schedule and licencing procedure: licencing authority, start of licencing procedure, start of construction, start of operation, operation time, sealing, monitoring period;
- monitoring programme: Monitoring authority, long term funding for monitoring,

- option of retrievability and for how long,
- financing: Estimation of the cost and who is responsible for funding and for the long term financing,
- long term security and safety concept,
- risk analyses and quality assurance programme,
- geological studies and research performed,
- dose concept,
- information concept,
- participation concept for the final decision.

13 EVOLUTION OF SAFETY CULTURE

Safety culture is not a constant standard existing in the same way at the beginning of nuclear technology as today. How to deal with legacies with radioactive waste, which we classify today as legacy but in former times they were in compliance with state of the art or due to a lack of adequate legislation? How can we avoid a general demonization of the waste management of nuclear waste today by the legacies of waste from yesterday? Obviously concept of safety culture will evolve as changes of standards and social values may occur on a long time range.

Additionally, security considerations of long-term safety of disposals for radioactive waste are often ambiguous and misinterpreted by media and public. Decisions should therefore be kept open for any future evolution, technical as well as societal and cultural, and, therefore, should have a maximum of flexibility. A systematic approach is necessary to find legacies especially from industrial site, as they need radiation protection assessments. Radioactive waste from remediation of legacies needs options for disposal. Recommendations for radioactive waste management have to be increased in a structured way with blame-free conditions in view of a long term quality assurance: periodic review, appropriate communication, qualified radiation protection personnel, periodic training, confidence and trust. Radiation protection experts should explain better, what risks for future generations arise if disposal facility projects are failing?

14 EDUCATION AND TRAINING OF STAFF

Qualified staff in radiation protection is needed in all steps of waste management. Therefore adequate plans to acquire and further educate such personnel should be offered and this should also be assured over the whole time of storage. Periodic training in safety awareness should be part of integrated safety training. In order to learn from operating experience, a blame-free reporting of events should be promoted. Experiences from disposal facilities for non-radioactive waste should be included. The responsibility for the promotion of safety culture should be clearly defined and present at all staff levels.

The education and development of young scientists in the field of radiation protection needs to be addressed with more attention. A dialog is necessary in order to transfer the safety culture to next generation(s).

15 LONG TERM SURVEILLANCE

Monitoring programs in the licensing and information process as they ensure the population of the long-term safety of the repository. Monitoring will be different in the different time periods.
- Pre-operational monitoring,
- monitoring during operation, i.e. during conditioning and storage of radioactive waste,
- Emergency monitoring,
- Live-time monitoring after sealing the repository site.

16 FOLLOW UP

The results of the workshop (s. following recommendations) are a good basis and very general for the future work to improve the safety culture in radioactive waste management. All members in the working groups are in agreement that more detailed work is necessary. The Fachverband will keep in touch with this topic and organizing a follow up meeting from 14th to 16th of November 2016 in Mont Terri, Switzerland.

17 RECOMMENDATIONS

- A waste management concept should consider the whole process from the production of waste to its final disposal and not just individual steps thereof.
- The decision process should be transparent and include all potential stakeholders.
- The licensing process should take into account changes of standards and social values that may occur in a long time range. A dynamic adaption of the process is necessary.
- The decision process should be kept open for any future evolution, technical as well as societal and cultural.
- A periodic review of the safety case of waste disposal facilities should be implemented.
- To increase public understanding and acceptance concepts of education and communication should be developed. This should in particular include the fact that waste already exists and actually in most countries stored in temporary facilities, for which there is no long-term safety case. So, rejection of disposal options means necessarily the acceptance of the existing situation.
- Education and training: Periodic training in safety awareness should be part of integrated safety training. In order to learn from operating experience, a blame-free reporting of events should be promoted.
- Despite the decision of most countries to store their waste in the country itself multinational solutions should be taken into account.
- The waste management concept should be optimized by comparing the programs of different countries in order to benefit from their experiences.
- We need a concept for the dilemma waste minimization vs. dose reduction (for the in the process involved workers).
- Common dose concept for clearance and release: A detailed definition for the application of all these dose concepts and their overlaps in one guide would be very helpful and increase the acceptance of the recommended dose concepts. In any case different dose concepts are also existent in case of NORM and release of effluents compared to the dose concept of clearance. A detailed definition for the application of all these dose concepts and their overlaps in one guide would be very helpful and increase the acceptance of the recommended dose concepts.
- Unlimited surface storage in order to improve public perception: IRPA and IAEA should join their forces in order to eliminate such contradictions and to provide better information of the population, in particular between retrievability and final disposal or between immediate conditioning and dose reduction.
- Radioactive legacies: A systematic approach, also taking into account the different legislative situations and involved authorities in each country, is missing. Radioactive materials from former nuclear activities are perceived to pose much a higher risk than existing exposure situations from former non-nuclear industries and mining, which can result in a non-optimized remediation strategy. All these legacy sites require nonetheless a radiation protection assessment. During the remediation of legacies, radioactive waste could be generated, which then needs appropriate disposal options. A systematic approach, also taking into account the different legislative situations and involved authorities in each country, is missing
- A concept for a long-term surveillance should be developed and periodically adapted.

Comments on the General IAEA Safety Requirements - Part 3 - and Suggestions for the Next Publications

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Abstract. The international recommendations in question are described 52 requirements specified from chapter 2 to 5. The first chapter states that the number of fundamental safety principles has been increased form 3 to 10. To implement these requirments, the IAEA mentions 14 main parties but it is not clear which party is responsible for each of the fundamental safety principles. Chapter 2 presents 5 general requirements for protection and safety and makes it clear the responsibilities and competence of the government and regulatory body. ; but the responsibilities and competence of the other 12 principal parties reported in requeriment 4 are not clear. Chapter 3, which includes 37 requirements, is the most extensive and deals with planned exposure situations. Due to its extension, chapter 3 is left for a future paper, in case my comments are considered of some value by the principal parties involved. Chapter 4, with 4 requirements, deals with emergency exposure situations; and in chapter 5, the 6 requirements are about existing exposure situations. As to the requirements exposed in chapters 1, 2, 4 and 5 I have verified that the responsibilities and competence of the government and the regulatory body are clearly specified, which is not true for the other 12 principal parties. It is concerning this specific matter that I have made comments and suggestions. I also discuss the matters that are not under the responsibility of the radiological protection services but of other parties. Could the radiation protection service as a whole or in part be delegated to others, including the attributions of registrants or licensees?

KEYWORDS*: *IAEA International Recommendations, Radiation Protection Requirements.

1 INTRODUCTION

Chapter 1.

In this chapter the IAEA establishes 10 safety principles that are considered fundamentals – conversely, the ICRP mentions only 3. The IAEA also says that the 3 IRCP principles were separated into 4 by the Agency.

Some of these 10 principles are not very clear as to who is the responsible for developing and implementing them, as it is shown below.

Principle 1: Responsibility for safety

According to the IAEA, the prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks. I believe it is in charge of the registrants and licensees.

It also mentions some other parties, but it looks rather as an example than all the possible interested parties given in requirement 4.

Principle 2: Role of government

This chapter is quite clear and suggests the formation of an independent regulatory body.

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Principle 3: Leadership and management for safety

The government must assure its coordination provided by a department and agencies responsible for protection and safety. Standards have to be developed by means of consultations with those who are or could be affected by them. They should serve as a guide to all the interested parties listed in requirement 4?

Principle 4: Justification of facilities

Here medical irradiations are developed in a satisfactory way and health authorities are also mentioned, but facilities that introduce new sources and professional bodies are ignored. It does not give any insight about what professional bodies shoud be. Also, it does not mention the government for the introduction of new practices.

Principle 5: Optimization of protection

The responsibility for applying this principle is not mentioned, but based on old superseded publications I believe registrants and licensees are responsible for it and the process will be developed by the radiation protection services, not listed among the interested parties. Shouldn´t this list include more interested parties?

Principle 6: Limitation of risk to individuals

None of the directly interested parties is mentioned here. A previous publication makes me believe the responsibility is in charge of the government through its regulatory body.

Principle 7: Protection of present and future generations

The IAEA made no comments about this principle. I think that limits should be established by the government, and registrants and licensees are responsible for it. Isn´t it right?

Principle 8: Prevention of accidents

The IAEA proposes some measures but does not say who is responsible for implementing them. I believe the general direction [supervision] should be given to the government. The responsibility should be given to registrants and licensees; a mixed team composed of radiation protection and facility operation people should take care of its implementation, for an accident can occur due to equipment failure or human error during the procedure. In this case the operational personnel has major knowledge about possible failures that can cause an accident. Besides, it is responsibility of the radiation protection service to correct any failure and restart normal work with safety. Am I right?

Principle 9: Emergency preparedness and response

The IAEA mentions that it is necessary to ensure that arrangements are made for an effective response at the scene and, as appropriate, at the local, regional, national and international level; but it does not inform about responsibilities and how we can maintain the preparedness. I think that in order to avoid doubts more specific details should be given.

Principle 10: Protective action to reduce existing or unregulated radiation risks

Really, no comment was made by the IAEA.; this principle was ignored. I believe the government should suggest some general lines of action including the unregulated radiations. And, under the responsibility of registrants and licensees, radioprotection services should suggest the main appropriate actions for the facility in question. The implementation of these actions should be subjected to a pertinent government body for approval. So the responsibilities would be shared. Isn´t it right?

To finish this question it should be wise to say which of the interested parties listed in requirement 4 should be responsible for implementing the actions concerning each principle. The IAEA also informs that, to perform the recommendations of these standards, the 52 requirements specified from chapter 2 to 5 need to be considered.

To comment on the 52 requirements would make this paper too long; so I have restricted my discussion to chapter 2, 4 and 5. These chapters contain 5 requirements each in average. Chapter 2, requirements 1 to 5; chapter 4, from 43 to 46; chapter 5, 47 to 52.

Chapter 3, with requirements from 6 t0 37 is left for another paper if I notice that it will be really useful for the IAEA and the associated countries.

To make this paper more clear I will mention the title of the 3 chapters to be commented, their sections and the respective requirement.

2

Chapter 2. General requirements for protection and safety.

Section: Application of the principles of radiation protection Requirement 1:

Application of the principles of radiation protection

The first item informs: “Parties with responsibilities for protection and safety shall ensure that the principles of radiation protection are applied for all exposure situations.” But in any of the 5 items that deal with this question no hint is given of which parties would be. Would it refer to all the parties listed in requirement 4, items 2.40 and 2.41?

Section: Responsibilities of the government

Requirement 2: Responsibilities of the government

This requirement is discussed in items 13 to 28 and it is clear that the government is responsible for it.

Requirement 3: Responsibility of the regulatory body

This requirement is discussed in items 29 to 38 and it makes clear that its responsibility is in charge of the regulatory body.

Section: Responsibilities for protection and safety

Requirement 4: Responsibilities for protection and safety

This requirement is discussed in items 39 to 46. The IAEA mentions, in principle, the parties really interested and that have responsibilities related to this requirement, but does not inform the protection and safety action for which each of the interested parties mentioned is responsible.

The mentioned parties directly interested are: government; regulatory body; registrants or licensees; employers; radiological medical practitioners in relation to medical exposure; persons or organizations designed to deal with emergency exposure situations or existing exposure situations; suppliers of sources, providers of equipment and software, and providers of consumer products; radiation protection officers; referring medical practitioners; medical physicist; medical radiation technologist; qualified expert or any other party to whom a principal party has assigned specific responsibilities; workers other than workers already listed in this paragraph; ethic committees.

I consider it would be very useful to show the responsibilities of registrants or licensees that can be, in principle, transferred to other interested parties.

Section: Management requirements

Requirement 5: Management for protection and safety

This requirement is discussed in items 47 to 52 and deals with protection and safety elements of the management system, the safety culture and human factors to avoid failures, but does not mention which are the interested parties and their specific responsibilities.

3

Chapter 4. Emergency exposure situations

Section: Generic requirements

Requirement 43: Emergency management system

This requirement contains 6 items and defines very clearly the government responsibilities. To demonstrate it I transcribe here its introduction and paragraph 4.6: Introduction: “The government shall ensure that an integrated and coordinated emergency management system is established and maintained.”

Paragraph 4.6: “The government shall ensure the coordination of its emergency arrangements and capabilities with the relevant international emergency arrangements.”

This requirement does not provide any information about the possible organizations and the probable responsibilities for each of them. Although emergency depends on each particular situation, there is a generic part that is common to all situations. This is helpful for maintaining international harmony, once there is already a pact of mutual help among IAEA and the associated countries in agreement with this pact.

Section: Public exposure

Requirement 44: Preparedness and response for an emergency

This question, treated in items 4.7 to 4.11, defines very precisely the responsibilities of the government but does not inform anything about the other interested parties, especially of the registrants and licensees.

Section: Exposure of emergency workers

Requirement 45: Arrangements for controlling the exposure of emergency workers

The question is treated in items 4.12 to 4.19 and defines once more the responsibilities of the government ; it also informs the responsibilities of the organizations and of the employees in charge of the response, but does not inform which of the interested parties of the organizations would be in charge of the response. It can again be concluded that it depends on each specific situation but generic situations can be treated very well.

Section: Transition from an emergency exposure situation to an existing exposure situation. Requirement 46: Arrangements for the transition from an emergency exposure situation to an existing exposure situation.

This question is treated in 2 items only: 4.20 and 4.21 and informs that the government needs to ensure that arrangements will be provided for the transition and that the responsible authority needs to make a decision to accomplish it [this transition]; but it does not inform who this responsible authority would be. It also informs that the workers involved in the recuperation duties need to satisfy each particular requirement related to occupational exposure in planned exposure situations, but it does not say anything related to the other interested parties.

4

Chapter 5. Existing exposure situations

Section: Generic requirements

Requirement 47: Responsibilities of the government specific to existing exposure situations

This question is treated in 5 items and the IAEA informs that the government must make sure that the existing exposure situations have been identified and evaluated. Also that the pertinent ones, from the point of view of radiation, were determined, in order to protect the worker and the public; those that need some actions. But it does not establish who can implement them. It also gives responsibilities to the regulatory body: to establish a safety strategy for an existing exposure situation.

As the existing exposure covers relatively great areas, it should be wise to specify some cases and inform the probable interested parties in order to solve the problem. We have already had several severe accidents involving reactors, besides natural occurrences in zones with high natural radiation.

Section: Public exposure

Requirement 48: Justification for protective actions and optimization of protection and safety.

The argument is treated in 3 items and informs that the government and the regulatory body or other relevant authority shall ensure that remedial and protective actions are justified and that protection and safety is optimized. However, it does not inform in which cases other authorities could be relevant and which are the responsibilities of the other interested parties in case they exist. It also says that these bodies need to review periodically the reference levels to make sure that they are still adequate. It is necessary to ask who is responsible for establishing these reference levels as no information was given about it.

Requirement 49: Responsibilities for remediation of areas with residual radioactive material.

The argument is long and treated in 9 items. The government shall identify the persons or organization responsible for the contamination of areas and those responsible for financing the remediation programme, and the determination the appropriate arrangement for alternative source of funding and putting in place an appropriate strategy for radioactive waste management.

The regulatory body shall take the responsibility, in particular, for review of the assessment of safety submitted by the responsible person or organization.

The person or organization must take the responsibilities for the contamination and the information to the public and for persons harmed by the contamination, as well as the recuperation procedure.

Requirement 50: Public exposure due to radon indoors

This question is detailed in 3 items. The government shall provide and implement mandatory and voluntary action levels. It does not give any information about the interested parties that, in my opinion, should be the inhabitants and owners of the indoors.

Requirement 51: Exposure due to radionuclides in commodities

This requirement is discussed in 2 items. The regulatory body or other relevant authority shall establish reference levels for exposure due to radionuclides in commodities. The regulatory body shall consider the guideline levels which are published by the joint Food and Agriculture Organization of the United Nations/World Health Organization Codex Alimentarius Comission.

Section: Occupational exposure

Requirement 52: Exposure in workplace

This argument is explored in 10 items. The regulatory body shall establish and enforce requirements for the protection of workers in existing exposure situations.

Employers shall ensure the exposure of workers undertaking remedial actions is controlled and that adequate information is released.

The regulatory body shall establish reference level of dose for the exposure of aircrew and space crew due to cosmic radiation.

5

Further suggestions

Registrants and licensees in general hold facilities aiming to implement several human practices in different areas of action, such as industry, health, environment, etc.. As their duties involve the ionizing radiation, due to the biological effect it produces, they have to maintain a radiation protection service under their own responsibility. For a registrant or licensee this service is a medium activity and not a core activity, so it can be contracted. The question is if it can be totally contracted. In my view it cannot because the IAEA as well as ICRP recommend that the responsibility to ensure the protection and safety of workers is of the employers and this responsibility cannot be delegated (see first fundamental principle mentioned in this paper).

If all radioactive protection duties of an entity are transferred to a contracted organization the registrant or licensee can trust the contracted organization to carry through its duties according to international and national standards. The regulatory body of the country, with supervision duties, will be responsible for checking if the radiation protection activity is performed according to the recommendations and rules and so, the contractor will not need to supervise the contracted nor require his accounting. This interpretation is against international recommendations, according to which this responsibility cannot be delegated.

Some radiological protection duties are generally done by contracted bodies as in the case of equipment calibration performed by facilities approved by the government. The external individual monitoring as a routine function is also generally performed by organizations with this finality. Therefore, I think it would be convenient if the IAEA discussed and made recommendations about which services should be contracted and which had to be done by registrants and licensees themselves to ensure their prime responsibility.

6 ACKNOLEDGMENTS

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5th European IRPA Congress (4-8 June 2018): *Encouraging Sustainability in Radiation Protection*

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Abstract. Since 2002, Radiation Protection professionals from all over Europe and beyond have met every four years at regional European IRPA congresses. The Dutch Society for Radiation Protection (NVS) is pleased to host the next congress in this series. The 5th European IRPA Congress is scheduled to take place from 4th to 8th June, 2018 in the wonderful city of The Hague, The Netherlands. With the theme "Encouraging Sustainability in Radiation Protection", the congress will focus on the various aspects needed to make sure that we have, and will continue to have, adequate equipment, staff and resources to protect human health and our environment against the adverse effects of ionising and non-ionising radiation. In this contribution relevant information concerning this congress is presented.

KEYWORDS: radiation protection; IRPA congress; sustainability; security; education and training.

1 INTRODUCTION

Since 2002, Radiation Protection professionals from all over Europe and beyond have met every four years at regional European IRPA congresses. The Dutch Society for Radiation Protection (NVS) is pleased to host the next congress in this series. The 5th European IRPA Congress is scheduled to take place from 4th to 8th June, 2018 in the wonderful city of The Hague, The Netherlands.

The historical city of The Hague is not only the administrative center of the Netherlands, but is also famous for its international institutions like the International Court of Justice and the Organisation for the Prohibition of Chemical Weapons. The Hague also aims to be a major player in security matters, a fact which became widely known when the city hosted the Nuclear Security Summit in 2014 in our congress venue, the World Forum.

With the theme "Encouraging Sustainability in Radiation Protection", the congress will focus on the various aspects needed to ensure that we have, and will continue to have, adequate equipment, staff and resources to protect human health and our environment adequately against the adverse effects of ionising and non-ionising radiation.

The five day programme of the congress will offer a whole range of plenary, parallel and poster sessions, refreshers on all relevant scientific and operational topics in radiation protection, as well as plenty of opportunities for exhibitors. More importantly, the congress offers radiation protection professionals the opportunity to interact and exchange experiences among each other. Furthermore, building on the experiences of previous European and International IRPA congresses and in line with the general theme of the congress, special attention will be paid to (activities for) both the young and future generations of radiation protection professionals.

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Figure 1: Logo of the 5th European IRPA Congress.

2 MAIN SCIENTIFIC TOPICS FOR IRPA 2018 (THE HAGUE)

2.1 Fundamental and/or general issues

Sustainability in radiation protection. Security of sources, installations and plants. Fundamental safety and security objectives and principles of protection, safety and security, and education and training herein. Emergency Preparedness and (risk) communication. Existing and planned exposure situations. Ethics in radiation protection. Stakeholder involvement. Presentations of radiation protection programmes and policies at the national, multi-national and international level on these issues are particularly encouraged.

2.2 Medical

All radiation protection activities and issues related to the safe, secure and economical use of radioactive isotopes and X-rays in health care applications, including education and training. Dose optimization for patients, workers and the general public.

2.3 Industry

Operational radiation protection practices at e.g. NPP's, waste storage/disposal facilities for artificial nuclides as well as for NORM, re-processing plants, decommissioning projects, etc. This item also includes industries producing materials with elevated NORM levels and industries applying sealed radioactive sources in their production process or in non-destructive testing.

2.4 Research and applications

R&D, licensing, construction, operation, effect on people and environment. Regulatory/public acceptance and radiation protection aspects of (new) developed isotopes and applications for medical and industrial use. Modelling, calculation and assessment of the radiation dose received by people and the environment (e.g. animals and plants). Low-dose radiation risk assessment and modelling. Cosmic radiation and space travel.

2.5 Non-ionizing Radiation

UV-radiation protection and UV health effects, skin cancer prevention, balancing UV-health hazards and benefits; Solar and artificial UV-exposures in environmental, medical, cosmetical and industrial situations for public, patients and workers; Laser safety and protection in medicine and industry; EMF- exposure and possible health effects in industrial, medical and environmental situations, including cell phones, power lines, MRI, RF-transmission stations etc, Public perception of risks, Regulatory principles of protection, guidelines.

3 REFRESHER COURSES AND TECHNICAL VISITS

An innovative set up for refresher courses and technical visits will be employed. The Monday morning and Wednesday will almost exclusively be devoted to refreshers and/or technical visits. Thus we offer participants the possibility to compose a coherent and concise program of refreshers. Additionally a combination of technical visit and refreshers will be developed.

4 LOCATION AND VENUE

4.1 About the Netherlands

The Dutch – all 17 million of them – live in 41,528 square kilometres, little more than half the size of Scotland. This makes the Netherlands one of the world's most densely populated countries.
The Netherlands is best known for its tulips, windmills and clogs. It is also known for its low altitude and vulnerability to flooding. Less well known is that the Netherlands has the sixteenth largest economy in the world, and ranks tenth in GDP per capita. Equally little known is that the Dutch have won Nobel prizes for chemistry, physics, medicine, economics and peace or that the world's planners and architects flock here to learn about Dutch solutions for this crowded country.

Figure 2: Map of The Netherlands; The Hague is encircled in red.

4.2 About The Hague

The Hague is the international city of peace and justice and the third largest city in the Netherlands. It is also the official seat of the Crown and government, home to hundreds of international organisations and multinationals and one of the world's top three UN cities. The Hague is a true place of deliberation and sets the perfect setting for high level conferences and business events. The Peace Palace has become an icon of international justice. In fact, the city has conferencing and high-level decision making in its DNA. The Hague offers some 9,000 hotel rooms in all price categories, including key international brands such as Hilton, Accor, Starwood, Crowne Plaza and Holiday Inn. It takes 15 to 35 minutes to arrive at The Hague from the nearest airports (Rotterdam-The Hague Airport and Amsterdam Airport Schiphol). From our neighbouring countries we however recommend transport by train. There are excellent connections that will bring you within a couple of hours to The Hague.

Figure 3: Peace Palace in The Hague.

4.3 About the World Forum

The World Forum is the leading international convention centre in The Hague and is perfectly situated between the city centre and the beach. It successfully hosted the largest summit in the history of the Netherlands: the Nuclear Security Summit 2014. This international conference was attended by the leaders or heads of state of more than 50 countries. It attracted around 5,000 delegate members and thousands of journalists to The Hague. The venue provides a safe, secure and flexible environment.

Figure 4: World Forum and its main auditorium.

5 CONGRESS ORGANIZATION

5.1 Congress officers and website

Congress President:	Hielke Freerk Boersma
Congress Secretary:	Bert Gerritsen Congress
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5.2 More information on the congress

Congress Secretariat: A Solution Events
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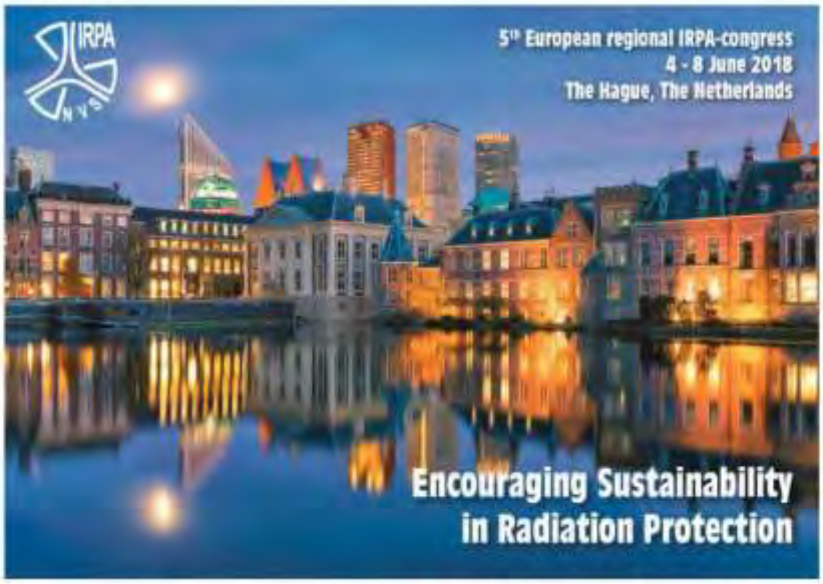
6 CONCLUDING REMARKS AND INVITATION

We are grateful to the Society for Radiation Protection (SRP) for their contribution to the core scientific programme committee.

We kindly invite everyone to disseminate the announcement of this congress as widely as possible and we want to express the hope that you will also be able to attend and contribute to the success of the 5th European IRPA Congress!

Figure 5: Branding of the congress: Court Pond with Mauritshuis and Buitenhof in The Hague.



L Band EPR Tooth Dosimetry for neutron

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Abstract. Neutron was irradiated to human teeth using NASBEE at NIRS. For comparison, simulations using Particle and Heavy Ion Transport code System (PHITS) and Electron Gamma Shower5 were carried out to evaluate energy transfer. The response to neutrons was about 8% of that from 150kV X-rays. By comparing with water, energy transfer to hydroxyapatite through recoil proton was 8% according to calculations using PHITS.

KEYWORDS: EPR tooth dosimetry; L band EPR; neutron; simulation.

1 INTRODUCTION

In case of a nuclear accident such as atomic bomb attack by terrorists, a critical accident at a nuclear fuel plant and nuclear power plant, workers and first responder will be exposed by neutron. In Japan two workers were killed by neutron irradiation at the critical accident that occurred in 1999.

Ionizing radiation generates stable unpaired electron species in irradiated tooth enamel instantly upon irradiation, persisting for a long time. The radiation-induced signal is proportional to the dose. Electron Paramagnetic Resonance (EPR) spectroscopy has been applied to perform retrospective radiation biodosimetry, following radiation accidents and exposure (e.g., Chernobyl disaster, atomic bomb in Hiroshima, Nagasaki, critical accident in Tokai-mura) by conventional EPR dosimetry, which involves the isolation of tooth enamel for measurements made at the X-band (9.1-9.5 GHz) [1-3].

While this technique has been useful for retrospective studies of exposure based on exfoliated teeth, it is not applicable as a tool for performing screening after an event where a large number of people have potentially been exposed to clinically relevant doses of ionizing radiation because of the need to have an isolated tooth.

In vivo EPR tooth dosimetry using L-band (1.0-1.2GHz) has been developed to allow measurements to be made with one or more intact incisors in situ [4-6]. This approach is adaptable to screening in case of a mass-exposure incident with acquisition times of less than 5 minutes (threshold is 2 Gy) including first responders who were exposed radiation without certain notice.

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In addition this, retrospective dosimetry such as for atomic bomb survivors is needed to be carried out by using different methods. For dose estimation of atomic bomb survivors, estimation of the neutron attribution is inevitable and this method is non-invasive for valuable samples.

The main composition of a tooth is hydroxyapatite. Hydroxyapatite is not contained much hydrogen. So that amount of recoil proton should be small then neutron dose to a tooth would be small. According to the paper published by A.M. Khailov et al, neutron dose to isolated teeth was 2% compared with dose from gamma ray [7]. On the other hand, the absorption of neutrons in the surrounding soft tissue should result in appreciable radiation dose from scatter of electrons and photons caused by recoil proton in the mouth1. Furthermore some attribution from prompt gamma ray caused by the absorption of neutrons would be expectable. Another possibility of neutron response in a tooth is recoil proton produced in dentin and radiation from radio-activated nuclides inside a tooth that would create radical continuously even though the dose would be small.

We therefore initiated a study to determine the contributions of high LET radiation to the EPR signal. The purpose of this project is to acquire the fundamental response curves for neutrons irradiation in tooth dosimetry using L band EPR to acquire basic knowledge on EPR dosimetry.

2 MATERIALS AND METHODS

2.1 Neutron irradiation to human teeth

Neutron was irradiated to human teeth using neutron exposure accelerator system for biological effect experiments (NASBEE) in Chiba (HIMAC) in the National Institute of Radiological Sciences (NIRS). Natural human molar teeth were included in the polyethylene slab phantom (N=12). These teeth were donated by Japanese subjects and were complete and intact without significant dental cavities or metal fillings. Total exposure dose was 60 Gy. The neutron source of NASBEE in NIRS was produced by Be(d,n) reaction. Linear energy transfer (LET) spectrum of NASBEE in NIRS in several mediums using LET counter were already acquired and neutron energy spectrum of Be ((25MeV) d,n) was acquired at Tohoku university in Japan.

Figure 1: Neutron exposure setting at NASBEE

Figure 2: Phantom for setting teeth

2.2 X-ray irradiation to human teeth

For comparison, a human maxillary central incisor was serially irradiated using X-rays to accumulated doses of 1, 5, 10, and 20 Gy and remeasured after each dose. Irradiation was performed using a Hitachi Medical X-ray apparatus (MBR-1505R2, Hitachi Medical, Tokyo, Japan) of 150 kV and 4 mA, with
0.1-mm copper plus 0.3-mm aluminium filtering and compared with exposure using the ^{137}C source that was provided from he EPR Center for the Study of Viable Systems at Dartmouth.

2.3 EPR measurement

Irradiated teeth were measured for detecting the EPR signal by using the 1.2 GHz L band EPR at the National Institute of Public Health (NIPH). Before irradiation, all teeth were measured using the EPR dosimeter to record their background signal amplitude.

2.3.1 Positioning of teeth

Teeth were precisely positioned using a custom-made bite block that located each tooth within the central homogeneous region of the magnet (Small Dipole Permanent Magnet for L-Band EPR, Model: BFMP-415/170-D, Resonance Research, Inc., MA, USA). Each tooth sample was placed in a dental putty mould (EXAFINE [putty type], GC Corporation, Tokyo, Japan) to ease both handling and positioning within the bite block. It was confirmed that the dental putty does not contribute significantly to the EPR signal.

2.3.2 EPR spectra acquisition

The EPR spectra were acquired using standard parameters of 20 scans, including a scan range of 2.5 mT, a scan time of 3 and a modulation amplitude of 0.4 mT. This process was repeated for a total of 3 datasets at each dose, as well as at baseline. A plastic tube containing at a concentration of 8 mM in D^2O of 4-oxo-2,2,6,6,-tetramethylpiperidine-d16-1-^{15}N-1-oxyl (^{15}N-PDT, also known as perdeuterated tempone). The ^{15}NPDT was sealed in a glass vial and was placed in close proximity to the surface loop and used as a reference standard, as well as to monitor EPR signal detection and the amplitude of magnetic field modulation. The ^{15}N-PDT EPR spectrum includes two resonance peaks that are offset from the peak of the irradiated tooth.

The spectra from each of the collected datasets were analysed using non-linear least-squares fitting to estimate the peak-to-peak signal amplitudes of the radiation-induced signals, and of ^{15}N-PDT. These were then averaged to provide a mean amplitude for each tooth and at each dose (VRIS and VPDT, respectively). In order to account for variations in RIS amplitude that result from instrumental instability or external environmental factors, the ratio of VRIS to VPDT for each measurement was calculated and normalized to the same ratio in a standard tooth irradiated to 20 Gy. Accordingly, the dosimetric relative RIS amplitude value (RelRIS) associated with each tooth was calculated using the following equation:

2.4 Measurement of photon and neutron

Photon and neutron dose inside a phantom were measured separately by using optically stimulated luminescence method being modified to coat with 25μm ^{6}LiF.

2.5 Simulation of energy transfer

For comparison, simulations using Particle and Heavy Ion Transport code System (PHITS) Version 2.770[8] and Electron Gamma Shower5 (EGS5)[9] were carried out to evaluate energy transfer. In simulation, the nuclide composition of hydroxyapatite was set to be ^{40}Ca: ^{31}P: ^{16}O: ^{1}H = 5.0: 3.0: 13.0: 1.0 setting the density as 2.0 g/cm^3.

The cut off energy was 1(MeV) except for 1E-3 (MeV) for photons, 1E-1 (MeV) for electrons and positrons.

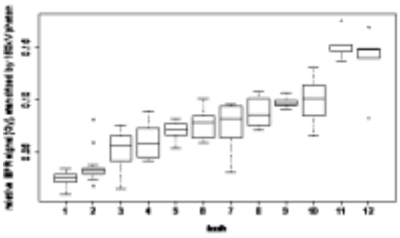
This study was approved by the Institutional Review Board of the National Institute of Public Health, National Institute of Radiological Sciences and Kagawa University. (NIPH #12071, NRS #11-019, Kagawa Univ. Heisei#24-4)

3 RESULTS

3.1 EPR measurement

Dose-response relationships with relatively wide uncertainty were observed as shown in Fig. 3. The mean response to neutron was about 8% (range: 2-15%) of that of 150 kV X-rays. Meanwhile, the relative response for diagnostic x-ray was about 4 compared with gamma ray from ^{137m}Ba disintegrated from ^{137}Cs source. Therefore mean response to neutrons was about 30% of ^{137}Cs.

Figure 3: Relative response for neutron irradiation, comparing 150 kV X-ray



3.2 Photon and neutron measurement

The result of photon and thermal neutron absorbed dose inside a phantom are indicated at Fig. 4 and showed similarity with simulation using PHITS (Fig 5). In hydroxyapatite, amount of thermal neutron was smaller due to smaller content of hydrogen.

Figure 4: Relative response for neutron irradiation, comparing 150 kV X-ray
Error bars indicate standard deviation.

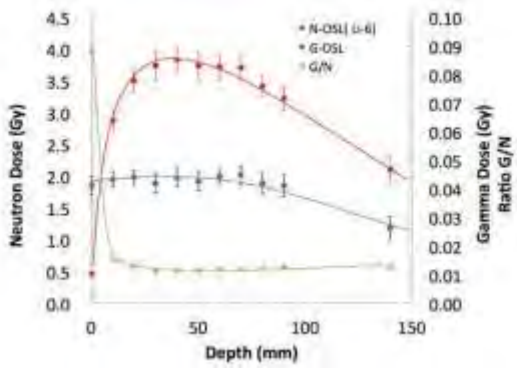
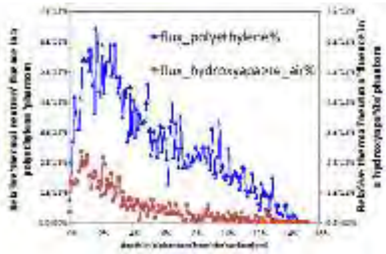


Figure 5: Thermal neutron flux calculated using PHITS comparing hydroxyapatite and polyethylene



3.3 Simulation of energy transfer

Energy deposition for neutron irradiation is indicated at Fig. 5-a. Energy deposition assuming that teeth as water is shown at Fig. 5-b. By comparing water, energy transfer to hydroxyapatite through recoil proton was 8%.

Figure 5-a: Energy deposition and tracks simulated by PHITS

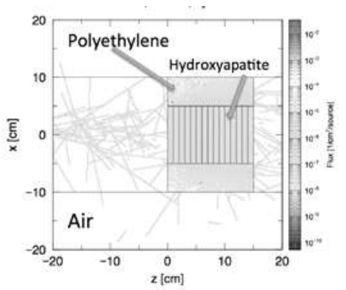
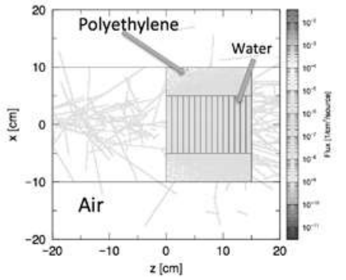


Figure 5-b: Energy deposition and tracks simulated by PHITS assuming teeth as water
In case of hydroxyapatite, the number of recoil proton is smaller than in water.



4 DISCUSSIONS

4.1 Response to neutron of L band EPR tooth dosimetry

The measured result was consistent with the previous study. According to the simulation using PHITS, energy transfer to hydroxyapatite through recoil proton was 8% comparing with water (Fig. 2). Therefore radiation dose to hydroxyapatite in a tooth was speculated that mainly from recoil proton that was generated by first neutron and it was added by secondary contaminated gamma.

Uncertainty of dose estimation was relatively high that would be caused by difference of amount of enamel for each tooth and location of measurement, shape and size of tooth, element composition.

4.2 Response to neutron of L band EPR tooth dosimetry

In case of neutron irradiation, radioactivation should be considered in terms of dose estimation. The count rate of a tooth sample was about 6kcpm after about 3 hour cooling time when using a GM survey meter with thin widow. When radioactivated nuclide was assumed to be ^{24}Na and counting efficiency was 0.5, induced radioactivity was estimated to be about 2×10^2 Bq. Therefore total dose from ^{24}Na was estimated to be about 1mGy and confirmed that radiation dose from radioactivation would be inevitable.

By establishing neutron dosimetry, neutron dose to survivors of past fast neutron therapy might be assessable. Adding this, dose to patient who receives BNCT using accelerator will be assessable in the future.

4.3 Limitations

Due to the legal restriction for radiation safety management of induced radioactivity, it was impossible to carry out measurement immediately after irradiation. Therefore we could not evaluate any prompt kinetics (i.e., due to radicals generated at the time of exposure). However we did not find any fading effect during our measurement at the NASBEE.

5 CONCLUSION

As LET radiation, neutron was irradiated to human teeth. Compared to 150 kV x-rays the signals from neutrons was about 8%. The relative response to neutron of L band EPR dosimetry was 30% compared to gamma ray of ^{137}Cs source.

6 ACKNOWLEDGEMENTS

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Promoting Radiation Safety Culture in the UK General Users Sector

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Abstract. In parallel with the development of IRPA's Guiding Principles for Establishing a Radiation Protection Culture, the UK Society for Radiological Protection (SRP) included in its Strategic Plan an objective to "promote a strong Radiation Protection Culture in the UK". To pursue this a number of sector specific Working Groups (WG) were established, together with an overarching Co-ordinating WG. This paper reports on the work of the General Users WG. This sector is characterised by radiation users that have no in-house Radiation Protection (RP) professional expertise, and have to contract in that expertise. The sector is extremely diverse, both in terms of radiation uses and the size, complexity and underlying safety competence of the organisations using ionising radiations. The WG programme covers, surveys of users approaches to radiation safety culture and stakeholder communication; working with third party influencers, such as regulators, trade and industry groups, trades unions, suppliers and contracting organisations; better use of existing resources in learning from incidents and best practices; developing "tools" for users and the soft skills of RP professionals in influencing organisations and key players. One of the outcomes of the work across the different sectors was the adoption of the term "Radiation Safety Culture", as this resonates better with stakeholders in the UK.

1 INTRODUCTION

The Society for Radiological Protection (SRP), which is the IRPA Associate Society (AS) in the UK, worked with its Partner Societies (PSs)[1] to provide input to the development of the IRPA document on Guiding Principles for Establishing a Radiation Protection Culture [1]. Section 8 of the document emphasised the role of ASs in supporting Radiation Protection (RP) professionals who are in the front line of promoting RP Culture. SRP had already recognised this by including in its Strategic Plan for 2013 to 2017, the major Goal to "Promote a strong radiation protection culture in the UK". This clearly requires working across several sectors of radiation uses; and pursuing this Goal was tasked to SRP's International Committee, which includes members from the PSs and is the main forum for interaction with IRPA.

In developing a programme of work to pursue this Goal it was felt it would be useful to produce a baseline of the then current thinking and the issues and challenges that would need to be addressed in the UK. The paper addressing this [2] reviewed the roles of management and leadership, the Radiation Protection Adviser (RPA), the Radiation Protection Supervisor (RPS), the professional bodies and the regulators. It identified generic challenges and sector specific factors; and produced outline improvement plans. In parallel to this it was decided to establish four sector specific WGs, covering Nuclear, Medical, Research and Teaching and General Users: together with an overarching Coordinating WG. Each sector specific WG would review the current level of achievement, identify the driving forces and propose a framework for improvement, including tools and goals. One of the generic points coming out of the early work in the medical and research and teaching sectors was that the term "RP culture" did not resonant with non-RP professionals, but that the term "Radiation Safety Culture" did and had more impact; being seen as a subset of Safety Culture. It was therefore decided by the Coordinating WG [3] that we would re-brand documents and papers with the term Radiation

[1] Association of University Radiation Protection Officers (AURPO), British Institute of Radiology (BIR), British Nuclear Medicine Society (BNMS), Institute of Physics and Engineering in Medicine (IPEM), Royal College of Radiologists (RCR), Society and College of Radiographers (SCoR)

Safety Culture. Some general early milestones were set; including reporting progress at the SRP 2015 Annual conference [4,5] and submitting a suite of papers from the WGs to the IRPA14 International Congress. This paper focuses on the issues specific to the General Users sector.

2 WHAT IS THE GENERAL USER SECTOR?

The General Users sector is characterised by organisations that have no in house professional expertise and have to contract in RPA services, if required. The sector is extremely diverse both in terms of radiation uses and the size, complexity and underlying safety competence of the organisations using ionising radiations. Within this mix there are industries that bring their own advantages and challenges; ranging from ones with a major focus on Quality Assurance (QA) that tends to be associated with a good safety culture, to industries where there is a significant amount of lone working with the management challenges that brings. Whilst not exhaustive, Table 1 below indicates the range of uses and industries involved.

Table 1: Indicative list of radiation uses and Industries used in

USES	INDUSTRIES and SECTORS
• Level and thickness gauging	• Food and drinks
• Moisture and density gauging	• Construction
• Non-destructive testing	• Petrochemicals
• Irradiators	• Manufacturing
• Baggage and security inspection	• Aerospace
• Source detection in ports	• Research organisations
• Analytical X-ray devices	• Agriculture
• Tracers and laboratory uses	• Product sterilisation
• Smoke detectors	• Health care
• Dental radiography	• Air and sea ports
• Veterinary radiography	• Prisons
• Radon	• Security of buildings etc

Across these sectors of use RPA providers have to interact with a range of safety cultures. Each client has its own profile, ways of operating – and idiosyncrasies. In broad brush terms they could be characterised as one of

- Well established and effective safety infrastructure and culture to plug into.
- Safety structure and culture there, but variable effectiveness: may rely on individuals rather than corporate driver
- Organisation may not recognise benefits of having a safety culture: depends on the influence of a few enlightened people and not have a management champion
- Compliance with advice, but no real understanding or commitment
- Lip service only

3 INITIAL ASSESSMENT OF KEY FACTORS INFLUENCING THE SECTOR

We were far from starting from a complete lack of radiation safety culture; and it was important to recognise what has been done well and has been effective. This is not to say that these aspects should not be questioned; indeed a questioning attitude is an important trait of safety culture. However recognising these effective aspects does provide a bedrock to build on and to identify areas where there are challenges and we can seek improvements. In the first instance it was felt useful to look at four broad areas of influence that we should explore for our work programme.

3.1 Regulatory Context

A good regulatory infrastructure is key to setting the context in which a safety culture can be developed and maintained. At the very top-level safety culture can be self-sustaining, but the regulatory infrastructure will have been important in its development to this stage.

The UK has a good track record in this area, with much of the legislation being the UK implementation of the European Basic Safety Standards (BSS). This process of transposition is important to get the correct balance of regulatory control without undue burdens on the users of radiation. Equally important are the supporting Codes of Practice and Guidance Documents, which explain and flesh out the necessarily precise language of legislation. This is part of a wider dialogue, or stakeholder engagement, of regulators, professional bodies, trades associations, users and others. Having good communications, leading to clear messages is important in setting the context for Radiation Safety Culture: without it radiation safety will not get the appropriate attention of managements and safety infrastructures.

Equally important is the regulatory presence in terms of inspections, advice and ultimately prosecutions. For example the annual inspections of source inventories by the Environment Agencies is known to have a positive effect in raising the profile of radiation safety and getting onto management agendas [4,5]. However, the current major constraints in funding in the public sector obviously pose a challenge to the regulatory presence and its impact. It is therefore incumbent on professional bodies to press for maintenance of important regulatory practices, to maintain stakeholder dialogue and to try and fill any communication gaps that might arise. Indeed the programme of work across the WGs has resulted in the initiation of a dialogue with one of the regulators on inspection regimes

3.2 RP Professional Competence

The importance of having standards of competence for this role, recognised by the competent authority, has long been recognised; and has been incorporated into UK legislation for over 30 years. For example, any person wishing to act as a RPA, has to gain a Certificate of Core Competence from an Assessing Body recognised by the Health and Safety Executive (HSE); and be deemed 'suitable for appointment' by the Radiation Employer appointing that RPA. The Assessing Body is currently RPA2000 and covers a range of specialisations [6]. It was set up in 2000 as a non-profit making company, by four Professional Societies, namely the Association of University Radiation protection Officers (AURPO), the Institute of Physics and Engineering in Medicine (IPEM), the Society for Radiological Protection and the Institute of Radiation Protection (IRP), which has since been incorporated into SRP.

Successful applicants are awarded the appropriate Certificate of Competence, which is valid for a period of five years and which can be renewed. A crucial aspect of attaining a Certificate of Competence is that it requires not only demonstration of relevant knowledge, but demonstration of the experience to have effectively put that knowledge into practice in a variety of areas. This requires the building of a portfolio of evidence. Around the world it is not universally accepted that experience is a pre-requisite for recognition of competence within national systems. In the UK we believe that this focus on experience helps inculcate an approach in young professionals that looks to identify good practices and to transfer these from one area to another. This is a basic trait for radiation safety culture and one that is a positive influence on the clients that the professional advises.

Overall the Co-ordinating WG believes that radiation protection professionals in the UK are of a good standard and well supported. However from across the sectorial WGs it was identified that there could be benefit to be derived from expanding the skill set to encompass "soft skills". Here one is looking at the skills required to influence managements and others, especially in situations where radiation safety culture is having to compete for attention and resources, with high profile considerations such as financial, commercial and core activities. The Societies are therefore in the process of organising a Workshop on this, out of which it is hoped to develop training courses.

3.3 Managements, Radiation Protection Supervisors (RPSs) and Staff

Ultimately it is the management of an organization that is responsible for the standard of safety culture. As identified earlier, RP professionals have to interact with a wide range of safety cultures. It is one thing to provide appropriate advice, it is another to have assessed the management and safety structures, identified key individuals and pressure points, so as to target and couch the language of the advice to achieve the best effect. This is where the soft skills mentioned above come into play.

Whilst the professional is contractually providing advice and services to the organisation, in practice this is channeled through one or more individuals; often RPSs. Their training and skills are crucial in getting things done at a practical level, and in fostering a radiation safety culture. They need to be proactive in engaging with the workforce and promoting good ways of working. The workers actually using the radiation sources are clearly important and need to have the opportunity to engage with RPSs and management on maintaining, and improving, safety and efficiency; which are often interlinked. “A brain comes free with a pair of hands, so make use of it”. What emerges from this is that the ongoing attention given to the programmes of training of the various stakeholders and the internal systems of communication on safety are key and warrant further attention within our programme of work.

The format of the service provision by the RP professional is also important in conveying the wider context of radiation safety culture, rather than just legal compliance. One approach used by Public Health England (PHE) is the “RPA Operational File” (can be physical and /or electronic), which both the RPA and the client have identical copies of. This has a structure designed to ensure all relevant aspects are covered, provides definitive descriptions of the safety structure and how RP fits within this, operational data on dosimetry and surveys, safety documentation and crucially the effectiveness of pursuing ALARA. The very act of compiling it usually provides the opportunity to interact with a range of people across the organization – and influence them. The output is not just advice from specific assessments, but also includes an Annual overview report to the organisation’s top safety structure.

3.4 Third Party Influencers

Third party influencers are potentially a broad group of organisations that through diverse routes can cause radiation users to improve their safety culture. Examples of these are:

- *Users Clients*: if a significant part of an organisation’s income is with a major client or group of clients, then there is a commercial imperative to adopt a safety standard that the client may impose. An example would be in the NDT sector, where few companies carrying out site radiography would be viable without contracts in the petrochemical and nuclear industries; both of which because of their own driving forces require a high standard of safety. In the 1990s NRPB worked with the petrochemical industry to provide training and safety audit material for their staff, so that they could influence the standard of safety in the NDT contractors [7].

- *Peer pressure from Trade and Industry Associations*: These groupings provide a route to influence a whole industry. Some initiatives come from within an Association, possibly driven by energetic enlightened individuals, or sadly as a result of some calamity / accident that has a significant impact. The latter often gives emphasis to the adage “if you think safety is expensive, wait until you experience the cost of an accident!” Associations can also promote the positive impacts on efficiency and productivity associated with safety culture.

  SRP and the British Institute of Non Destructive Testing (BINDT) recently combined to produce a leaflet on Managing Industrial Site Radiography [8]. The document is a guide for both Client and NDT provider detailing best practice when utilising radiography as a tool for inspection and what both parties may experience.

- *Suppliers of Equipment Using Radiation:* Suppliers get a golden opportunity to provide users with clear and effective safety advice both about the routine use of equipment, but also about its care and maintenance. Maintenance is an important area, because a significant number of accidents occur either during maintenance, which often involves the removal of some engineered safety features; or shortly after return to routine use, because the engineered safety features have not been fully reinstated.

  In some organisations, if appropriate measures are not in place, or ignored, it is possible for staff to purchase equipment with an integral radiation source, without the RPS or any part of the safety structure being aware. In such cases there are clearly issues for the RP professional and the user to address. However, suppliers also have a role to play in their documentation and procedures.

- *Trades Unions:* one of the pillars of the work of Trade Unions is the health and safety of its members. They work with all of the above, regulators and individual companies to improve safety. How managements and trade unions interact on safety is often a barometer of safety culture. If it is the stereotypical confrontational situation of the last century, then the inherent safety culture is poor. If however there is clear evidence of stakeholder engagement with both the management and the workforce having the same "Attitude" then there is likely to be a good radiation safety culture.

4 HOW TO IMPROVE RADIATION SAFETY CULTURE

There are at least four effective ways to impact radiation protection culture:
- by educating and training the people involved in RP applications;
- by creating positive and total awareness of RP in workplaces, establishing adequate and proper communication processes among all the stakeholders involved in RP applications;
- by engendering the capacity to learn from accidents, near misses and safety performance indicators and bring about continual improvement; and
- by learning from other sectors and industries

The following sections expand on these.

4.1 Training

Radiation Safety training, as with other health and safety related training, is an essential part of an organisation's commitment to achieving a safe and healthy workplace for staff, contractors and visitors. Staff must be provided with sufficient information, instruction and training to ensure that they are aware of radiation hazards and know what safe working procedures to follow to reduce the risk of injury or work related ill health, to themselves and others. Training is also essential in raising the level of staff awareness of health and safety policies and procedures, such as Local Rules, and to ensure their effective implementation. All new staff or those that have been redeployed or relocated must receive general health & safety induction from their line manager or other appointed person, and specific induction from the Radiation Protection Supervisor (RPS) in the area in which they will be working. This requirement also applies to those on temporary contracts and agency staff.

The importance of knowing what health and safety training is needed is a key element of safety culture. These needs should be assessed on appointment, when members of staff take on a new role with increased safety responsibilities, or new equipment is introduced. Training needs should also be reviewed as part of staff appraisals, from reviews of radiation safety performance and risk assessments.

The experience of the WG was that there were still many organisations that approached training as "ticking the box" without ongoing review. In particular it was felt that there was a need to focus on the need for refresher training; and that training for new roles needed to be improved.

4.2 Communication

Communication is key to the promotion of good safety practice. It should build on the training above and provide a mechanism to reinforce aspects of safety, whilst also providing a forum for staff involvement. Communication can be in many forms from the traditional safety posters, newsletters and weekly bulletins to the modern day emails, texts and Twitter messages. The profile of communications that is appropriate for each organisation will vary and should be capable of adapting to the feedback from the workforce.

The WG felt it would be useful to assemble data on the different approaches used by organisation in this sector, to provide a learning route. It is intended to cover this in a Questionnaire to the radiation users where members of SRP act as RPA. It was also noted that the very act of putting out a questionnaire can have a beneficial impact in raising awareness of issues.

4.3 Learning from our mistakes

Much of what is known about safety has been learned from accidents, incidents and near-misses. By using a lessons-learned approach, organisations are able to engage with staff and provide a challenge to think about how safety measures could have prevented an accident or incident, or at least have minimised the consequences. It is important therefore to establish robust accident/incident reporting systems and investigation procedures to identify root causes and formulate plans to implement mitigating actions.

The OTHEA database [9] is provided by a network of radiation protection stakeholders across Europe who have a joint interest in sharing feedback and experience from radiological incidents, in order to improve the protection of persons working with similar radiation sources. More generally, the aim is to encourage good practice within different sectors including medical and veterinary, industrial, research and education sectors, etc. Incidents and reports are selected on the basis of the value of sharing the lessons learned and therefore the database includes a wide variety of incidents: not just accidents and incidents, but also any situation, event, behaviour or anomaly with the potential to cause an unplanned radiation exposure, or a significant decrease in the existing standard of radiation protection. This could include 'near misses', contamination spills as well as more serious radiological incidents.

The WG believe more use could be made of this existing resource in the provision of formal training and also as the basis for occasional articles in internal safety newsletters.

4.4 Learning from others

The European ALARA Network (EAN) [10] was created 1996 to further develop topics dealing with the radiation protection principle of Optimisation, or as it is often referred to "ALARA" (keeping doses As Low As Reasonably Achievable). In addition it had the objective to facilitate the dissemination of good ALARA practices within the European industry, research and medical sectors. One early key conclusion was that whilst tools, processes and procedures could help there was a need for an overarching "ALARA Attitude" across all the stakeholders involved. Whilst there are differences in terminology with Radiation Safety Culture, the two are very closely linked, and the work of the EAN was a significant input to IRPA's development of its Guiding Principles.

The work of the EAN continues [10], with it having a number of sub-networks, and producing 6 monthly Newsletters and an annual 3 or 4 day Workshops. Whilst the target audience is the RP professional, it provides many examples of good practice that can be used to further Radiation Safety Culture. The WG believe more use could be made of this resource.

5 ASSESSING RP SAFETY CULTURE

There is a long history of the development and use of assessment tools to assess the safety culture (in its wider context) of an organisation. A mixture of quantitative and qualitative tools can be used to benchmark performance and to detect changes or issues. Examples are; audits against regulatory requirements, review of key performance indicators, attitude surveys and a variety of HSE tools e.g. "Plan, Do, Check, Act', the Safety Climate Tool, Corporate Health & Safety Performance Index Tool (CHaSPI). The use of these tools is covered in more detail in references [2,11].

The WG will explore the use of these tools, but in the first instance will focus on the use of questionnaires and attitude surveys to develop an overall picture of the sector, and to inform the development of the programme of work.

6 SUMMARY OF PROPOSED PROGRAMME OF WORK

- A Workshop on expanding the professionals skill set to encompass the "soft skills" is being planned This will look at the skills required to influence managements and others, especially in situations where radiation safety culture is having to compete for attention and resources, with high profile considerations such as financial, commercial and core activities. Out of this it is hoped to develop training courses for RP professionals.
- Influencing senior management is considered a priority area. In conjunction with the point above, senior management briefing resources will be developed. These could include sets of standard slides and /or a short video, together with documentation to facilitate the briefing(s).

- Discussions will be held with "Third party Influencers", such as Trade and Industry Associations, Equipment Suppliers, and Trade Unions to develop appropriate programmes of work.

- A questionnaire will be developed to send to RPA clients to ascertain the different forms of internal safety communication they use, their perceived effectiveness and any issues that can be identified. From this guidance will be developed and linked to other resources

- We will promote a greater use of existing resources for training and information purposes. In particular:
  - the use of existing material on the SRP website such as;
    - posters originally developed for schools but which may be useful in explaining the basics of radiation protection; and
    - sector guidance leaflets.
  - the use of the radiation incident database OTHEA
- We will be working jointly with the other WGs to explore the potential for use of existing tools to assess and improve radiation safety culture; and if needed, develop other tools. In particular it would be useful to have an adapted Attitude survey tool that RPA Clients could use.
- In the longer term we will be looking to bring together the experience from the WGs and produce a set of Radiation Safety Culture Packs.

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Promoting Radiation Safety Culture in the UK

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Abstract. In parallel with the development of IRPA's Guiding Principles for Establishing a Radiation Protection Culture, the UK Society for Radiological Protection (SRP) included in its Strategic Plan an objective to "promote a strong Radiation Protection Culture in the UK". This has been taken forward by SRP's International Committee, which is the focus for interaction with IRPA and which includes members from UK Partner Societies (PSs) with interests in radiation protection in the UK. The concept of radiation protection culture is no different whatever the sector, and is a subset of general safety culture. However the challenges and potential ways of addressing them varies with the context of the sectors of radiation use. Thus sector specific Working Groups (WG) were established for the medical, research and teaching, nuclear, and general users sectors. In addition, an overarching Co-ordinating WG was established to oversee the work programme, ensure there is learning from best practice across the sectors and to identify and address common themes or issues. This paper reports on the current outcomes and takes a forward look.

1 INTRODUCTION

The potential to improve how radiological challenges are addressed through the development or enhancement of a strong Radiation Protection (RP) safety culture was a key topic at several International Radiation Protection Association (IRPA) Congresses. In response IRPA set up a Working Group (WG) to produce a document on Guiding Principles for Establishing a Radiation Protection Culture [1], which was published in 2014. The Society for Radiological Protection (SRP), which is the IRPA Associate Society (AS) in the UK, worked with its Partner Societies (PSs)[1] to provide input to the development of the document. In particular the input was aimed at building on significant existing initiatives on Safety Culture in general, and the radiation protection orientated "ALARA Culture", which can be traced through the European ALARA Network (EAN) Newsletters and Workshops [2].

Section 8 of the IRPA document emphasised the role of ASs in supporting RP professionals who are in the front line of promoting RP Culture. SRP had already recognised this by including in its Strategic Plan for 2013 to 2017, the major Goal to "Promote a strong radiation protection culture in the UK". This clearly requires working across several sectors of radiation uses, and pursuing this Goal was tasked to SRP's International Committee, which includes members from the PSs and is the main forum for interaction with IRPA.

2 OVERALL WORK PROGRAMME

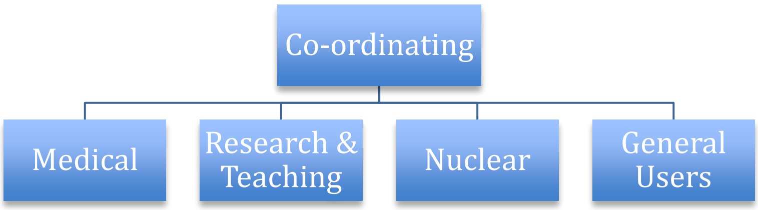
In developing a programme of work to pursue this Goal it was felt it would be useful to produce a baseline of the then current thinking and the issues and challenges that would need to be addressed in the UK. The paper addressing this [3] reviewed the roles of management and leadership, the Radiation Protection Adviser (RPA), the Radiation Protection Supervisor (RPS), the professional bodies and the

[1] Association of University Radiation Protection Officers (AURPO), British Institute of Radiology (BIR), British Nuclear Medicine Society (BNMS), Institute of Physics and Engineering in Medicine (IPEM), Royal College of Radiologists (RCR), Society and College of Radiographers (SCoR)

regulators. It identified generic challenges and sector specific factors; and produced outline improvement plans.

In parallel to this it was decided to establish four sector specific WGs, covering Nuclear, Medical, Research and Teaching and General Users: together with an overarching Coordinating WG.

Figure 1: Structure of Working Groups



Each sector specific WG would review the current level of achievement, identify the driving forces and propose a framework for improvement, including tools and goals. Some general early milestones were set; including reporting progress at the SRP 2015 Annual conference [4,5] and submitting a suite of papers from the WGs to the IRPA14 International Congress in Cape Town, May 2016. The papers from the Medical, Research and Teaching, Nuclear and General Users WGs can be found in references [6,7,8,9] respectively, whilst this paper provides an overview.

The "baseline" paper [3] for the project identified common elements of Radiation Safety Culture across the sectors and the links to the overall approach to Safety Culture in general. However to develop effective programmes with a view to improving Radiation Safety Culture, each sector was tasked with reviewing the characteristics of their relevant sector that posed the greatest challenges and the driving forces of the various stakeholders. The following sections briefly summarise these.

3 EARLY OUTCOMES

3.1 What is in a name?

Does the terminology used matter? Yes it does; especially in the early stages of developing any aspect of safety culture. If you cannot get the attention of managers and other stakeholders, either because they do not understand the terminology or because they cannot link it to something they are familiar with, then it makes it much more difficult to make progress.

One of the generic points coming out of the early work in the medical and research and teaching sectors was that the term "RP culture" did not resonate with non-RP professionals, but that the term "Radiation Safety Culture" had more impact; being seen as a subset of Safety Culture. It was therefore decided by the Coordinating WG that we would re-brand documents and papers with the term Radiation Safety Culture.

3.2 Regulatory Context

A good regulatory infrastructure is key to setting the context in which a safety culture can be developed and maintained. At the very top level safety culture can be self sustaining, but the regulatory infrastructure will have been important in its development to this stage.

The UK has a good track record in this area, with much of the legislation emanating from the UK implementation of the European Basic Safety Standards (BSS). This process of transposition is important to get the correct balance of regulatory control without undue burdens on the users of radiation. Equally important are the supporting Codes of Practice and Guidance Documents, which explain and flesh out the necessarily precise language of legislation. This is part of a wider dialogue or stakeholder engagement with regulators, professional bodies, trades associations, users and others. Having good communications, leading to clear messages is important in setting the context for Radiation Safety Culture: without it radiation safety will not get the appropriate attention of managements and safety infrastructures.

Equally important is the regulatory presence in terms of inspections, advice and ultimately prosecutions. For example the annual inspections of source inventories by the Environment Agencies is known to have a positive effect in raising the profile of radiation safety and getting onto management agendas [4,5]. However, the current major constraints in funding in the UK public sector obviously pose a challenge to the regulatory presence and its impact. It is therefore incumbent on professional bodies to press for the continuity of important regulatory practices, to maintain stakeholder dialogue and to try and fill any communication gaps that might arise. Indeed the programme of work across the WGs has resulted in the initiation of a dialogue with one of the regulators on inspection regimes.

3.3 RP Professional Competence and Developing Soft Skills

The importance of having high standards of competence for the RP professional role which is recognised by the competent authority, has long been recognised in the UK and has been incorporated into UK legislation for over 30 years. For example, any person wishing to act as a Radiation protection Adviser (RPA), has to gain a Certificate of Core Competence from an Assessing Body recognised by the Health and Safety Executive (HSE); and be deemed ‘suitable for appointment’ by the Radiation Employer appointing them. The Assessing Body is currently RPA2000 and covers a range of specialisms [10]. It was set up in 2000 as a non-profit making company, by four Professional Societies, namely the Association of University Radiation Protection Officers (AURPO), the Institute of Physics and Engineering in Medicine (IPEM), the Society for Radiological Protection (SRP) and the Institute of Radiation Protection (IRP), which has since been incorporated into SRP.

Overall, the Co-ordinating WG believes that radiation protection professionals in the UK are of a high standard and well supported. However from across the sectorial WGs it was identified that further benefit could be derived from expanding the skill set to encompass “soft skills”. Here one is looking at the skills required to influence managements and others, especially in situations where radiation safety culture is having to compete for attention and resources with other high profile considerations such as financial, commercial and core activities. The UK Societies are therefore in the process of organising a Workshop on this, out of which it is hoped to develop training courses.

4 NUCLEAR SECTOR

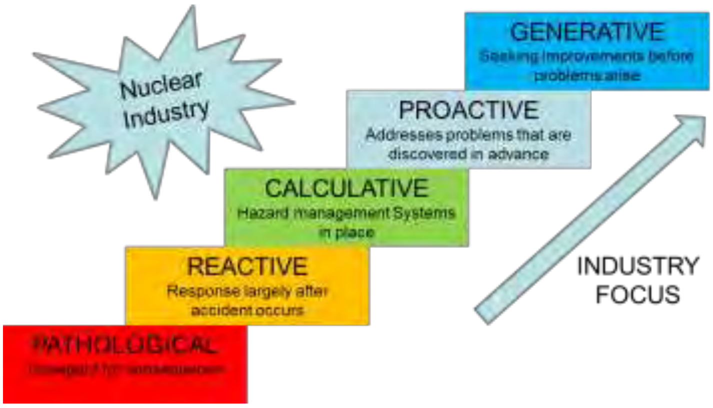
This sector has a long history of addressing Safety Culture in general and the subset that relates to radiation protection. Much work has been done on developing international standards [11,12]. These have been integrated into the approaches of the various nuclear employers; with the regulators in the UK, the Office for Nuclear Regulation (ONR), taking a keen interest in how employers practically implement Safety Culture. The ONR are currently engaged with the nuclear community through a culture network programme to assess and develop the generic culture at a high level. This top down approach is being driven via the nuclear industries Safety Directors Forum and provides a hugely supportive background.

The challenge for the SRP WG was to tap into existing programmes and structures and develop a complementary work programme that was not “reinventing the wheel”. The outcome has been a bottom up programme, focusing on radiation safety culture through the Industry Radiological Protection Coordinating Group (IRPCG), which is a sub-committee of the Safety Directors Forum.

In developing the programme the WG took note of the changing profile of the industry. It was particularly noticeable that the industry had changed from one dominated by a relatively small number of organisations, to one with many more smaller organisations, with nuclear sites having a range of contractors working for the nuclear site licence holder. It was also noted that there could be significant variations in safety culture within an organisation, often driven by the quality of leadership within the different divisions.

The initial exploration of culture by the working group involving RP professionals from a selection of nuclear sites led to an early assessment of culture performance against what is known as the '5 Box model' [11]. The model is pictured here and rates the industry's position as typically calculative with evidence of elements ranging from reactive through to generative.

Fig 2: 5 Box model for safety culture development



The proposal is to carry out a more detailed and evidence based assessment to rate its placement against these criteria. The WG assessment of the main influencers within a Radiation Safety Culture assessment concluded there to be eight focus areas: event tracking, rewards and sanctions, unified safety, work planning, human performance, communication, effective influencers and training.

5 MEDICAL SECTOR

The medical sector provides some unique challenges to radiation safety culture and, in many ways, seems to lag behind the nuclear sector in this respect. The focus within healthcare is the diagnosis and treatment of patients, and there are many associated safety concerns, which usually take a higher priority than radiation safety. The medical sector working group has been collecting data to provide an assessment of the current state of radiation safety culture in the UK medical sector, and has also started to look at ways of improving this culture.

Data collection methods have included review of regulatory inspection reports, analysis of data from staff radiation dosimetry services, consideration of radiation safety information available on professional body websites and, finally, a UK wide survey of hospital staff. The information gathered demonstrates the range of current knowledge about, and attitudes to, radiation safety.

Methodology for improving radiation safety culture in this sector has followed both a top down and a bottom approach. The latter has focussed on identifying potential areas of improvement in staff training, and also in public knowledge of issues such as patient doses. The top down approach has included discussions with a number of management and regulatory groups and consideration of how to incorporate radiation safety metrics into both inspection regimes and hospital safety policies. The metrics have been developed as a set of 'ten points' for radiation safety, with each point or metric being accompanied by a number of performance indicators. These points have been cross-referenced to both the IRPA guiding principles on safety culture and the Bonn 'Call for Action'.

6 HIGHER EDUCATION AND RESEARCH SECTOR

SRP's Partner Society, the Association of University Radiation Protection Officers (AURPO) took on the work of the WG for the sector. In the UK, this sector encompasses 162 institutions, with around 378,000 staff and approximately 2.5 million students. An initial assessment of the sector has been published by the WG [13]. This identified that the sector represents a unique challenge in the establishment and improvement of a strong safety culture. The reasons for this include:

- A higher percentage of young and inexperienced persons involved when compared to a non-educational work environment;
- A higher 'turnover' of personnel involved in hazardous work: indeed most under-graduate student courses have a three year cycle duration, and short term contracts are becoming more common in research companies;
- Academic attitudes are often more focused on the recruitment and retention of students, research goals and outcomes, than on safety and radiation protection;
- The research work carried out in these sectors is often very diverse;
- The research is often extremely novel in its nature, if not unique, and this leads to challenging hazards;
- There is chronic under-funding that leads to a process of 'grant optimisation', which may not place safety as a priority.

The key will be getting leaders in the sector on board by emphasising the benefits of a strong safety culture and the risks of getting it wrong. With regard to the latter, image is important to many institutions in their fight to secure funding for research and other activities.

The WG propose to design and produce a number of tools that can be used to develop a good RP culture, or to enhance an existing one, within higher education and research institutions. Such tools could be made available in a 'culture pack' of resources distributed via, for example, AURPO. The pack could reasonably include:

- A senior management briefing (or set of briefings), which would emphasize the contents of this practical matter article. This would include a set of standard slides and a short video to facilitate the briefing(s);
- Training resources such as slides, videos, suggestions for practical exercises, exam questions, and quizzes for use by RP workers and other RP trainers/coaches;
- Tools to help promote a good safety culture e.g. templates for feedback questionnaires and suggestion forms, methods for establishing and running an RP discussion forum on the organisation's website, and instructions on how to use Twitter to garner RP comments from staff and students;
- Information about RP professional societies, the benefits of membership, and instructions on how to join (including membership application forms);
- A newsletter of topical RP articles, links to further RP information, notices of forthcoming RP events, etc.
- Contact details for RP Culture 'mentors' in the UK.

7 GENERAL USERS SECTOR

The General Users sector is characterised by organisations that have no in-house professional expertise and have to contract in RPA services, where required. The sector is extremely diverse both in terms of radiation uses and the size, complexity and underlying safety competence of the organisations using ionising radiations. Within this mix there are industries that bring their own advantages and challenges; ranging from ones with a major focus on Quality Assurance (QA), such as the pharmaceutical industry, that tends to be associated with a good safety culture; to industries where there is a significant amount of lone working and the management challenges that brings.

Across these sectors of use, RPA service providers have to interact with a range of safety cultures. Each client has its own profile, ways of operating – and idiosyncrasies. Whilst the professional is contractually providing advice and services to the organisation, in practice this is channeled through one or more individuals; often Radiation Protection Supervisors (RPSs). Their training and skills are therefore crucial in getting things done at a practical level, and in fostering a strong radiation safety culture.

As with the other WGs an initial assessment, based on experience to date, was made and came to similar conclusions:

- The importance of the regulatory context and the visibility of the regulators;
- The importance of having appropriately qualified RP professionals;
- The importance of training of the various stakeholders, including management.

With regard to last bullet point, it was felt some early gains could be made by promoting a greater use of existing resources for training and information purposes. In particular:

- the use of existing material on the SRP website such as;
    - posters originally developed for schools but which may be useful in explaining the basics of radiation protection; and
    - sector specific guidance leaflets.
- the use of the radiation incident database OTHEA [14]

It was concluded that the sector was far from starting from a complete lack of radiation safety culture; and it was important to recognise what has been done well and what has been effective. This is not to say that these aspects should not be questioned; indeed a questioning attitude is an important trait of safety culture. However recognising these effective aspects does provide a bedrock to build on and to identify areas where there are challenges on which we can seek improvements. Here the WG also looked at the importance of working with what was termed "third party influencers". These included:

- *Major client groups:* for example the safety culture inherent in some large organisations in the petrochemical and aerospace industries. If you want their business you have to meet their safety standards!
- *Trade and Industry Groups:* they often develop their own industry guidance and if you can embed aspects of safety culture in these documents it provides a form of peer pressure. For example SRP and BINDT recently combined to produce a leaflet on Managing Industrial Site Radiography [15]. The document is a guide for both Client and NDT provider detailing best practice when utilising radiography as a tool for inspection and what both parties may experience.
- *Suppliers of Equipment Using Radiation:* Suppliers get a golden opportunity to provide users with clear and effective safety advice both about the routine use of equipment, but also about its care and maintenance.
- *Trades Unions:* One of the pillars of the work of Trades Unions is the health and safety of its members. They work with all of the above, regulators and individual companies to improve safety. How managements and Trades Unions interact on safety is often a barometer of safety culture.

Influencing senior management is considered a priority area. In conjunction with the other WGs senior management briefing resources will be developed. These could include sets of standard slides and/or a short video, together with documentation to facilitate the briefing(s). Another aspect identified was the need to optimise the internal communication processes on safety. To this end a questionnaire will be developed to send to RPA clients to ascertain the different forms of internal safety communication they use, their perceived effectiveness and any issues that can be identified. This will provide a resource for learning from good practices.

8 CONCLUSION

SRP and its Partner Societies have made significant progress in establishing sector specific programmes of work on this subject. Some key early Outcomes have been identified.

- Rebranding the work as Radiation Safety Culture to resonate better with stakeholders;
- Initiating a dialogue with regulators regarding the benefits of regulatory presence;
- Looking to develop RP professionals in the area of Soft Skills to influence management.

Completion of the programme of work will take several years and it is intended to report progress at the next IRPA regional Congress in The Hague in 2018.

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Radiation Protection Quantities for the Assessment of Stochastic Effects: *Should we be more Papal than the Pope?*

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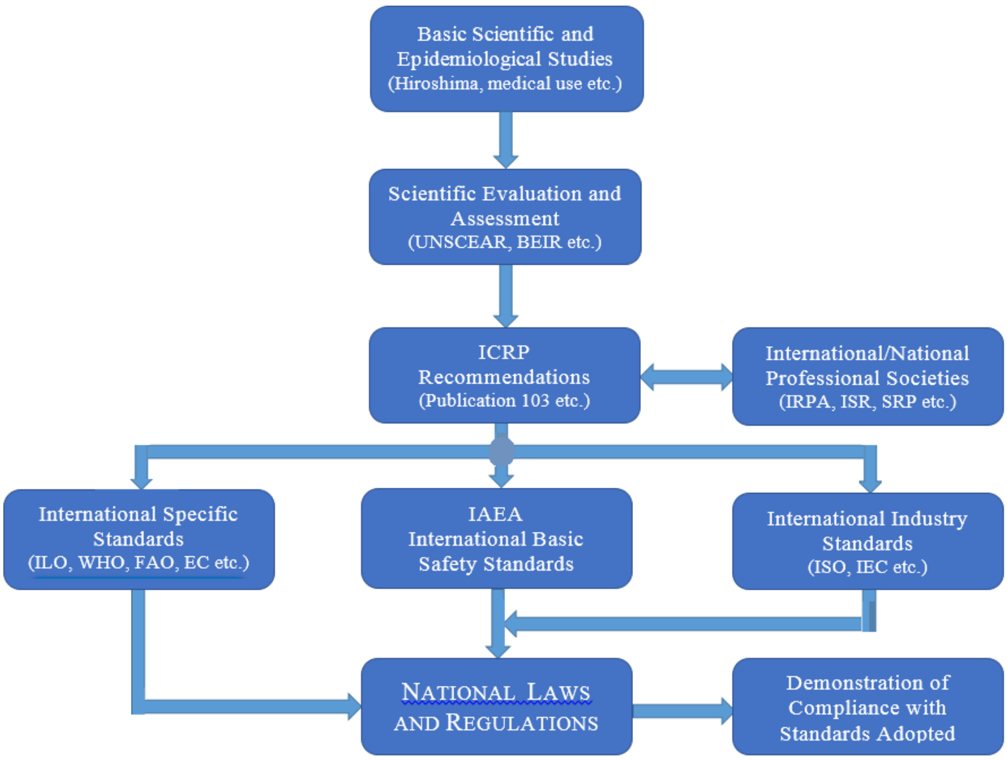
Abstract. The current system of radiation protection, based on the use of rather complicated quantities introduced for the assessment of the biological stochastic effects of exposure from ionizing radiation, presents some problems. One of the main purposes of ensuring adequate protection of persons against harmful effects of radiation lies with the application of the principle of the limitation of exposure which, under normal circumstances, should be as much below the dose limits or dose constraints as is possible in practice, taking into account technical, economic and social conditions. However, the quantification of radiation exposure is defined in terms of quantities which cannot be readily measured. This is why it is virtually impossible to confirm in a reliable way the compliance with the regulatory standards, which rely on such radiation protection quantities as the effective dose (for the assessment of the whole body exposure) and the equivalent dose (for the assessment of the exposure of individual organs and tissues).

***KEYWORDS:** radiation protection; quantities; stochastic effects; quantification of exposure; regulatory standards.*

1 INTRODUCTION

The present system of radiation protection relies mainly on the recent ICRP recommendations [1], which took into account scientific findings evaluated by the reputable expert bodies and were further elaborated and modified by such international organizations and agencies as IAEA [2], in a form feasible for the national regulations of individual countries (Fig. 1).

Figure 1: The origin and basis of the present system of controlling radiation exposure to ensure the adequate control of the exposure of persons.

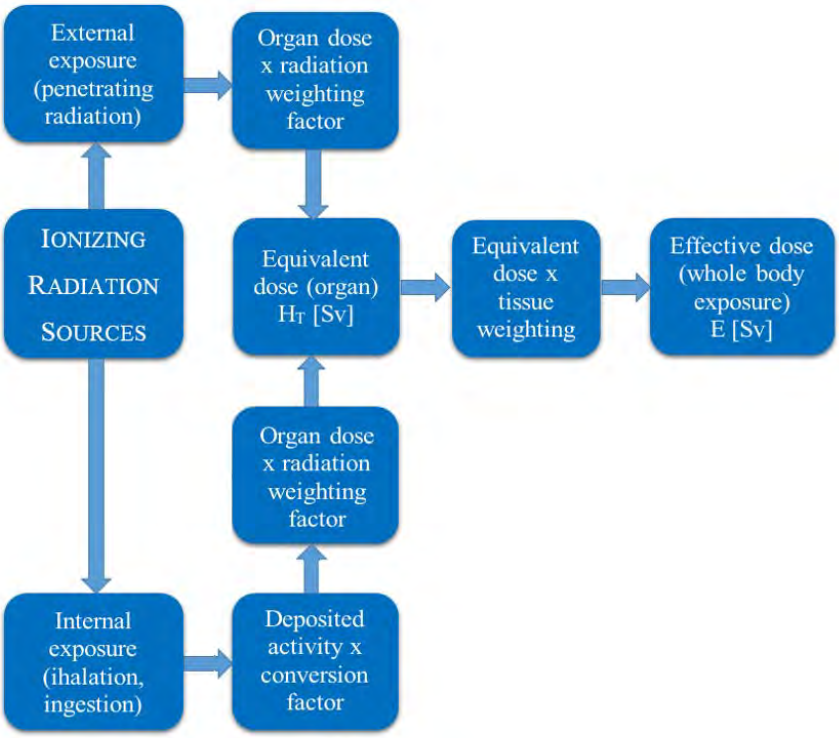


2 PRESENT APPROACH TO QUANTIFY AND CONTROL RADIATION EXPOSURE

Many attempts have been made to define a universal quantity to quantify the exposure to a person in order to assess the probability of detriment regardless of the type of radiation (or irradiation conditions), including nonhomogeneous exposure of individual organs. The quantity of the effective dose has been adopted for this noble purpose and extensive effort has been made to associate its value with the whole-body stochastic effects. In principle, this has been achieved by the introduction of relevant weighting factors – the radiation weighting factor and the tissue weighting factor, which convert a physical quantity - the absorbed dose - into a bio-physical quantity expressed in Sv. These factors, based largely on epidemiological studies, have often been changed (and presumably this process will continue also in the future) in order to match the value of the effective dose with the impact of the exposure in terms of stochastic effects based on the latest scientific findings. A similar concept, relying on the quantity of equivalent dose, has also been adopted for the stochastic effects occurring in an individual organ or tissue exposed to ionizing radiation.

In principle, the stochastic dose has to consider both components, namely from external and internal exposure. (Fig. 2).

Figure 2: Illustration of ionizing radiation sources and the resulting exposure in terms of the effective dose reflecting the total stochastic effects due to external and internal exposure.



The present system has been developed through many phases reflecting available information and scientific knowledge at that time. The primary aim of the system was based on the effort to fully assess harmful stochastic effects. Obviously one had to have considered some important biological factors related to the harm caused by different types of ionizing radiations in individual tissues or organs. Consequently, the quantity, which would adequately represent stochastic effects, would no longer be a physical quantity, but rather a bio-physical quantity, which apparently could not be assessed using only pure physical principles. This is why the effective dose as well as the equivalent dose cannot be measured directly. These quantities can only be approximated using specifically defined operational quantities. Even here one experiences some problems in measuring or monitoring operational quantities directly.

The effective dose is obviously supposed to reflect a whole-body exposure taking into account the contributions from external radiation and internal radioactive contamination due to the intake of radionuclides. These two contributions should be additive and present independent components to the total effective dose. Because of the difference in choosing the relevant weighting factor (in the case of external radiation, this factor is related to the quality of the particles and photons striking the surface of the body, while as to internal exposure this factor represents the properties of the radiation actually absorbed in the organs). For example, in case of neutrons, the particles striking the surface of the body, may interact inside the body in such a way that the resulting particles delivering the energy to some organs would differ from the incident particles.

There have been too many quantities introduced in radiation protection and definitions are rather complicated and in some cases inconsistent (e.g., the dose to the skin as an organ) suffers from difficulties in interpreting the nature of the equivalent dose to the skin). This may cause some confusion not only in reporting the radiation situation to the public, but even among some professionals who are supposed to be responsible for the implementation of relevant standards ensuring adequate protection of workers, members of the public as well as patients. These complications make the risk communication to the public rather difficult, especially in the case of radiation or nuclear emergencies.

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In radiation protection too many quantities have been introduced which have been defined in a rather complicated way. Moreover, in some cases these quantities have been used inconsistently (e.g., the dose in the skin as an organ, which implies difficulties in interpreting the nature of the equivalent dose to the skin). These inconsistencies may cause some confusion not only in reporting the radiation situation to the public but even among some professionals, who are supposed to be responsible for the implementation of relevant standards that ensure the adequate protection of workers, members of the public, and patients. These complications make risk communication to the public rather difficult, especially in the case of radiation or nuclear emergencies.

3 PROBLEMS IN THE QUANTIFICATION OF RADIATION EXPOSURE

The main difficulties in radiation protection, causing confusion and inconsistencies, can be summarized as follows:

- There are too many quantities defined in a way that even some officers, responsible for the implementation of the radiation protection programme, may not fully understand and have problems to correctly interpret and use them;
- The so-called operational quantities (ambient dose equivalent and personal dose equivalent) introduced for the assessment of external exposure are also not readily measurable according to their definition;
- The personal dose equivalent, related to the skin exposure, is rather confusing: it is supposed to be based on the relevant organ (skin) dose, where the mass of the skin volume has never been clarified. In addition, two different concepts are considered as to the areas over which the equivalent dose is supposed to be averaged (1 cm^2 set by ICRP, 10 cm^2 adopted by some countries);

- Both main radiation protection quantities, i.e. the effective dose and equivalent dose, cannot be directly assessed by the measurement;
- Strictly speaking, the total effective dose, reflecting the contributions from external and internal exposure, cannot be considered as an additive quantity. In case of external radiation, the radiation weighting factors depend on the quality of the radiation striking the body, while in the case of internal exposure this factor depends on the parameters of the radiation depositing the energy inside the body. The same dose, received by a particular organ or tissue, exposed to external and internal radiation, may be weighted by two different radiation weighting factors.

4 AN ANALOGY AND A POSSIBLE SOLUTION TO SOLVE CURRENT DIFFICULTIES

The present philosophy of radiation protection quantities may be compared with the protection approach adopted in ensuring adequate safety on roads, where the most appropriate limiting quantity would obviously be the *braking distance* as a universal measure of the safety, regardless of the type of vehicle, road conditions or driver's skill (Fig. 3). Such a quantity, which cannot be readily monitored, would be an ideal quantity reflecting *traffic risk* [3]. Nevertheless, nobody would dare to introduce traffic limits expressed in the braking distance. Instead, a measureable quantity – the speed – is used for this purpose.

Is the breaking distance not a parallel to the *effective dose* in the way of trying to express the harmful consequences resulting from the radiation exposure of a person? This concept would only be justified in cases where we have full information about all parameters and factors which may affect the overall biological effects of radiation exposure of an exposed persons. However, in practical situation such information is not readily available (Fig. 4).

Figure 3: *Speed* is used as a limiting quantity with some additional parameters and no one would consider it practical to use the braking distance, although it would be much more relevant to assess the transport risk compared to the speed which, for practical reasons, is used as a limiting quantity.

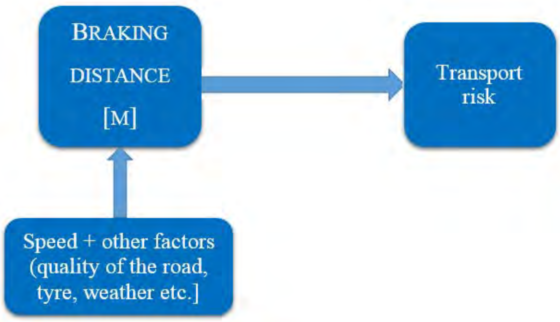
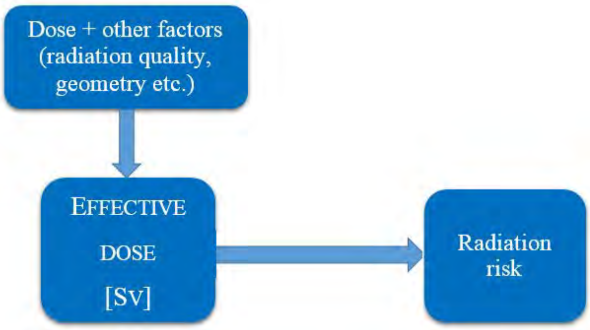


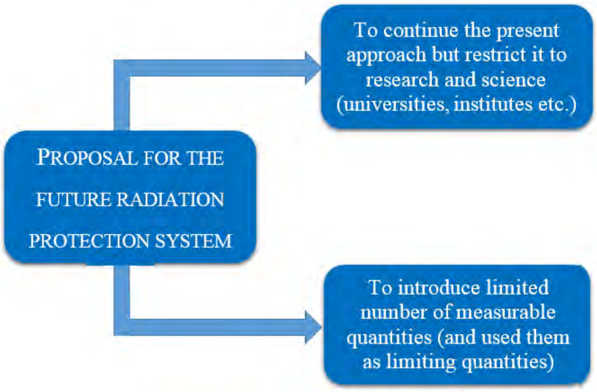
Figure 4: *Effective dose* is used as a limiting quantity perfectly (at least theoretically) related to the risk, but difficult or rather impossible to monitor and thus to comply with the regulatory requirements.



5 CONCLUSION

One of the possible solutions to the current difficulties may be splitting the present approach into two systems which can be used in parallel (Fig. 5).

Figure 5: An alternative way how to overcome the difficulties caused by inconsistencies in the current system of quantities in radiation protection.



The proposed suggestion can be formulated as follows:

- We may continue refining the current radiation protection philosophy in order to further improve/modify the present quantities accordingly. One can even introduce some other more sophisticated quantities which can quantify biological risk as closely as possible (at least theoretically). However, this approach should be left to specialists in research institutes and universities.
- Based on the above research and experience acquired, we should introduce a simplified radiation protection system, which would preferably rely on readily measurable quantities. These quantities can be easily understood and monitored with available instrumentation. This approach will obviously necessitate some changes in the regulatory requirements, which would be based on the newly introduced simple and unambiguous quantities, the number of which would have to be kept to a minimum.

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"A North-American first: a state-of-the-art fully functional Linac for teaching to the next generations of therapists and physicists in a college"

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Abstract. In 2013, a medical linear accelerator (linac) capable of producing high-energy beams of photons and electrons was installed in a Canadian college to improve both the radiation therapist and the graduate medical physics education programs, in addition to contributing to research in radiation therapy. A linac is a class II nuclear device regulated by the Canadian Nuclear Safety Commission. A rigorous radiation safety program is therefore essential for a safe use and for the security of the users. Establishing a radiation safety program in a teaching facility not used to such a large-scale radiation device was a challenge. Some of the difficulties encountered include: the wide range of users with a broad spectrum of expertise and the continuous arrival of completely inexperienced students (i.e. new students). The past two years of experience represent an important partnership of different organizations. Many types of activities were carried in this facility, from teaching to research and the radiation safety program implemented could assure a safe usage for everyone involved.

KEYWORDS: linear accelerator, Linac, Radiation safety, Radiation therapy; medical physics, training and education.

1 INTRODUCTION

A non-clinical Linac dedicated to research and teaching is used as an extremely motivating and exciting way to introduce students to radiation therapy and medical physics. The context of teaching radiation therapy in Quebec city, Canada was difficult before 2013 because a single radiation oncology department had to support two teaching programs in addition to an important clinical workload and research activities. At the time, the patients were treated from 7 am to 7 pm, which let only a limited amount of time for teaching. The dedicated teaching facility was officially inaugurated in 2014, but first courses began in August 2013. The facility is equipped with a fully functional state- of-the-art Varian TrueBeam Linac with a complete set of physics instruments and QA phantoms for the Linac and the onboard imaging system. To complement this important piece of equipment a functional, but refurbished CT scanner is also available on the premises and a laboratory composed of
21 state-of-the-art Eclipse treatment planning systems.

2 MAJOR PROJECT STAGES

2.1 Born from a partnership

A tri-institutional collaborative effort composed of a major university, a technical college (radiation therapist training) and the Department of Radiation Oncology of a University Hospital lead to the building of the new infrastructure and the acquisition of Linac fully dedicated to the teaching of therapists and medical physicists, as well as research projects by the institutions involved.

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Figure 1: Parternship organizations

2.2 Regulatory requirements

The Canadian Nuclear Safety Commission (CNSC) regulates all the device that are able to produce radiation starting from 1.5 MeV or more, and a linear accelerator (linac) capable to produce energy beams up to this range is considered as a class II nuclear device even if no radioisotope are present in this kind of facilities. There is specific information to provide to the CNSC before the installation and the use of a linac in Canada. The main steps are:

-The Radiation Safety Program with the radiation safety policies and procedures
-Facility Planning and Design Parameters
-Class II Prescribed Equipment, Operating License to Commission
-License for Routine Operation

2.3 Bunker building

The infrastructure and bunker all meet and exceed the same radiation safety regulation as any clinical treatment linac and mirror perfectly all of the features found in hospital settings. The bunker building began in June 2012 after 8 months of planning. The room was ready for the linac delivery in March 2013.

Figure 2: June 2012, the beginning of the excavation.

Figure 3: August 2012, construction milestone

Figure 4: September 2012, concrete casting

Figure 5: October 2012: concrete casting.

Figure 6: Delivery in March 2012.

Figure 7: Bunker at different stages

A part of the bunker shielding is made with steel to reduce the shielding thickness.

Figure 8: 17500kg steel shielding section

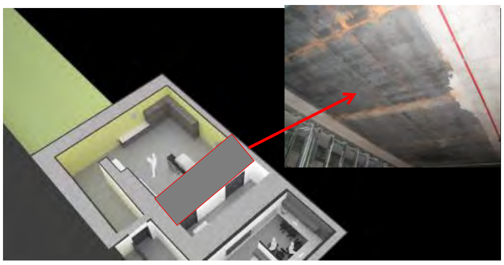


Figure 9: 17500kg steel shielding section

2.4 Installation and commission

The commission and the installation of a dedicated teaching and research Linac is shorter than it would be in a clinical context. The Linac was ready for teaching and research in August 2013 after a complete inspection of the installation by the CNSC in July 2013 with complete shielding test and approval of the radiation safety procedure and policies. All the shielding tests reveal as planned that at any point outside the room in an intense irradiation context, the measures were always under 0.25 µSv/hour and 0.05 mSv/year.

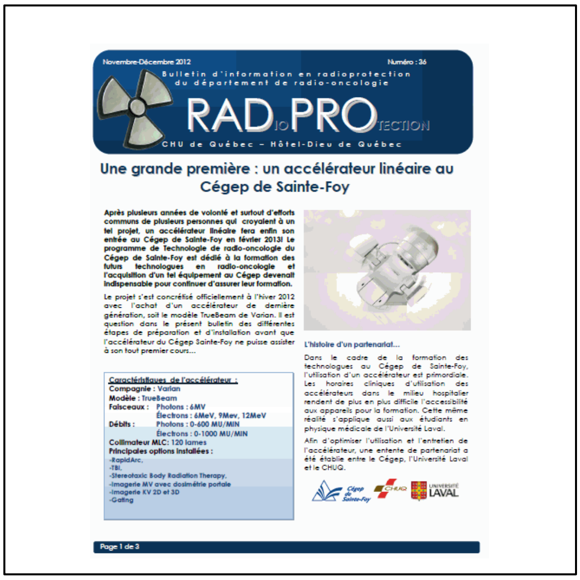
Figure 10: The ion survey meter employed to conduct the shielding test: Detection specifications Beta>1 MeV Gamma >25 KeV

Since then, daily and trimestrial tests are stricly done to follow the CNSC requirements and a complete quality assurance program is followed even if it's a non-clinical facility.

2.5 Radiation safety program

Establishing a radiation safety program in a teaching facility not used to such a large-scale radiation device was a challenge. Some of the difficulties encountered include: the wide range of users with a broad spectrum of expertise and the continuous arrival of completely inexperienced students. The past two years of experience represent an important partnership of different organizations to assure a safety use of the Linac at CÉGEP Sainte-Foy. There are 2 categories of users, students requiring constant supervision and users with complete autonomy like teachers and experience graduate students.
Every new user must complete training about general radiation safety and specific radiation safety policies and procedures of the Linac. At least once a year, users have to complete refresh training and at the end of all types of training, an evaluation is done. An important aspect of the partnership between the radiation safety program at CHU de Québec and CÉGEP de Sainte-Foy is the collaboration for the redaction of a radiation safety journal that is published every two months for users.

Figure 11: Radiation safety journal RadPro #36



Novembre-Décembre 2012 Numéro : 36

Bulletin d'information en radioprotection du département de radio-oncologie

RADioPROTECTION

CHU de Québec – Hôtel-Dieu de Québec

Une grande première : un accélérateur linéaire au Cégep de Sainte-Foy

Après plusieurs années de volonté et surtout d'efforts communs de plusieurs personnes qui croyaient à un tel projet, un accélérateur linéaire fera enfin son entrée au Cégep de Sainte-Foy en février 2013! Le programme de Technologie de radio-oncologie du Cégep de Sainte-Foy est dédié à la formation des futurs technologues en radio-oncologie et l'acquisition d'un tel équipement au Cégep devenait indispensable pour continuer d'assurer leur formation.

Le projet s'est concrétisé officiellement à l'hiver 2012 avec l'achat d'un accélérateur de dernière génération, soit le modèle TrueBeam de Varian. Il est question dans le présent bulletin des différentes étapes de préparation et d'installation avant que l'accélérateur du Cégep Sainte-Foy ne puisse assister à son tout premier cours...

Caractéristiques de l'accélérateur :
Compagnie : Varian
Modèle : TrueBeam
Faisceaux : Photons : 6MV
Électrons : 6MeV, 9Mev, 12MeV
Débits : Photons : 0-600 MU/MIN
Électrons : 0-1000 MU/MIN
Collimateur MLC: 120 lames
Principales options installées :
-RapidArc,
-TBI,
-Stereotaxic Body Radiation Therapy,
-Imagerie MV avec dosimétrie portale
-Imagerie KV 2D et 3D
-Gating

L'histoire d'un partenariat...

Dans le cadre de la formation des technologues au Cégep de Sainte-Foy, l'utilisation d'un accélérateur est primordiale. Les horaires cliniques d'utilisation des accélérateurs dans le milieu hospitalier rendent de plus en plus difficile l'accessibilité aux appareils pour la formation. Cette même réalité s'applique aussi aux étudiants en physique médicale de l'Université Laval.

Afin d'optimiser l'utilisation et l'entretien de l'accélérateur, une entente de partenariat a été établie entre le Cégep, l'Université Laval et le CHUQ.

Cégep de Sainte-Foy CHUQ Université Laval

Page 1 de 3

2.6 After 2½ years of experience

After a few years of use, this non-clinical facility enhanced teaching and research activities that are not possible with a clinical device for 96 radiation therapy students, 32 medical physics grad students (MSc and PhD) and 15 students undergrad physics (since 2015).

Figure 12: The linac room: The TrueBeam Linac with cover-off can be seen in the backgorund. The room is large enough to provide formal teaching space with students seated.

Figure 13: The treatment console with oversized monitor on the wall, mirroring the two small monitors and the treatment console allows for demonstration to a large group.

3 CONCLUSION

Full access to and control of a dedicated non-clinical facility enhance significantly teaching and research activities that are not possible with a clinical device. The experience of the past years show that teaching and research with this non-clinical Linac is an extremely motivating and exciting way to introduce students to medical physics and radiation therapy. This was clearly shown in the enhanced, multi-days Linac laboratory course for different undergrad and grad students. The success of the linac activities rest on the quality training, the efficiency of its implementation and the safety culture implemented for that kind of nuclear facilities operated within a school.

Figure 14: Radiation therapy program students in a radiation therapy simulation with the Linac.

4 ACKNOWLEDGEMENTS

All the people from CEGEP Sainte-Foy, Université Laval and CHU de Québec who took part of the project.

5 REFERENCES

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2015 IRPA survey of professionals on the new dose limit to the lens of the eye, and wider issues associated with tissue reactions

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Abstract. A reduction has been introduced regarding equivalent dose limits for the lens of the eye in occupational exposure in the International Basic Safety Standards (BSS), as well as in the European BSS, following the recommendation given by the ICRP in the statement on tissue reactions on April 2011 and further elaborated in the ICRP Publication 118. In January 2015, the IRPA launched a task group (TG) to assess the impact of implementing the revised dose limit in the work place. IRPA Societies (ASs) were asked to provide views and comments on the basis of a questionnaire addressing four topics: implications for dosimetry; implications for methods of protection; wider implications of implementing the revised limits, and legislative and other general aspects. Twenty-two ASs contributed actively, giving views and comments on the impact relating to implementation of the new limit for the lens of the eye. The TG members analyzed the collected data in order to define clusters of contents from the different responses, and to discuss common points as well as the specifics and the issues emerging from the concerned topics. The main results of the analysis are presented and discussed.

KEYWORDS: Radiation dose limit; Lens of the eye; Occupational Radiation Protection.

1 INTRODUCTION

In the April 2011 statement on tissue reactions and in Publication 118 of the International Commission on Radiological Protection[1)], a reduction in the equivalent eye dose limit in occupational exposure was recommended. This revised limit was incorporated into the International Basic Safety Standards (BSS) [2)] as well as into the European BSS[3)].

IRPA established a task group (TG) in December 2012 to provide an initial view by the ASs on the impact of implementation the reduced limit for the lens of the eye.

IRPA agreed to keep up constant monitoring and to ensure that the findings and concerns highlighted in the work done by the first TG were an integral part of the ongoing international discussion on the implementation of the revised dose limit to the lens of the eye.

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In fact, in January 2015 IRPA established a TG Phase 2, whose first aim was to create positive and complete awareness about radiation protection (RP) in the workplace, with attention given to exposure of the eye lens. Its second aim was to evaluate the response of the RP community following the first TG report, which was approved by the IRPA Executive Committee in July 2013[4-7].

The TG Phase 2, with members nominated by: AIRP Italy, SERP Spain, CRPA Croatia, SRP UK, HPS US, SARPA South Africa, SAR Argentina and JHPS Japan, defined and promoted a survey with reference to: i) the best applied methods for monitoring dose to the lens; ii) the updated and optimized methods used to reduce dose to the eye; iii) the ongoing path towards implementation in the different countries at a legislative level. At the same time, this TG provides an opportunity to obtain the views of professionals of the IRPA ASs, concerning and related to the wider generic issue of tissue reactions.

2 TARGETS AND METHODOLOGY

IRPA Associate Societies (ASs) were asked for their views, with the use of a questionnaire to aid structuring and harmonization of the answers. There were 22 questions addressing four topics within the different areas of practice: 1) Implications for Dosimetry. This topic concerns the implications for monitoring and assessing eye lens dose and interpretation of the resulting data; 2) Implications for Methods of Protection. This topic addresses the implications of the methods of protection used to reduce dose to the eye, in the context of optimizing protection; 3) Wider Implications of Implementing the Revised Limits. This topic aims to identify any direct or indirect impact on current practice, which would result from implementation of the revised dose limit. 4) Legislative and other general aspects. The target for this topic is to highlight the activities, at a national level, for preparing guidelines to address eye monitoring, and progress along the pathway of the legislative process regarding the new limit. Moreover, this topic addresses the wider issue of tissue reactions with attention given to circulatory diseases.

Twenty-two ASs, covering 40 countries from Africa, North and South America, Asia, Australia and Europe, contributed actively by applying their own internal procedures while collecting views and comments from their professionals regarding the impact of implementing the new eye lens limit. TG members analyzed the collected data to work out clusters of answers and to discuss common points as well as specific items and particular issues emerging from the concerned topics. A complete presentation and discussion of the results of the analysis will be presented in the IRPA Report of the Task Group on the impact of the Lens of the Eye Dose Limits [8)], and the main key issues which emerged are discussed here, with particular attention given to: direct implication for dosimetry and protection, health surveillance, the legislative processes regarding the new eye lens limits, and the wider issue of tissue reactions. As a result of the analysis, some recommendations which were directly expressed in, or derived from, the responses received from the ASs, are also reported.

3 RESULTS AND COMMENTS

3.1 Implications for dosimetry and protection

From the answers given by the ASs, most attention is devoted to the area of medical applications, and specifically to interventional radiology and cardiology.

An active or passive dosimeter worn close to the eye is recognised as an ideal method for eye dose monitoring, to assess Hp(3). However, its use is essentially limited to the clinicians in some centers, or dedicated to interventional procedures, or in specific pilot studies. The use of Hp(3) is also limited, considering that such a dosimeter is not widely available and therefore the more common Hp(0.07) and Hp (10) dosimeters are used.

A number of ASs consider that taking measurement close to the eye is not practicable, or that the dosimeter is not robust enough for routine use. Moreover, it is expected that it would be difficult to get interventional radiologists and cardiologists to comply regularly and wear the dosimeter, although they are more likely to receive eye doses approaching the new dose limit. Indeed, wearing a dosimeter close to the eye requires a particular device which has been created to keep it in an appropriate, well-defined position, and if the set is uncomfortable or tends to obstruct vision, then only a low level of compliance will be achieved. Definition of the optimal location for a head dosimeter is still a question which has not been completely addressed, and the ASs are also emphasizing the need to keep the dosimeter and its holder sterile, if they are used on a daily basis.

The majority of ASs stated that dedicated eye dosimeters would only be required for the more highly exposed workers who are likely to approach the eye dose limit. In general, there is widespread use of a collar dosimeter worn outside the lead apron, to provide indicative values for the eye lens dose. Such use of a collar dosimeter is considered to be a satisfactory approach for monitoring the dose levels which most of the personnel are exposed to.

With regard to the use of collar dosimeters, the ASs note that there needs to be general agreement as to which category the dose should be recorded under in the national dose register. In fact, the readings will only give an indication of eye dose and the appliance of correction factors will include large uncertainties.

In the Questionnaire, evaluation of the eye lens dose in relation to contamination, was also considered. It is unlikely that the medical sector will need to evaluate doses to the lens of the eye from personal contamination, and in other areas experience is also very limited regarding the contamination of individuals or the workplace. In centres where contamination could be a risk, it was suggested that a surface contamination meter could be used to assess possible contamination of dosimeters, before returning them to the dosimetry service.

As for protective equipment for reducing dose to the eye in the medical field, protective shielding systems are considered, such as leaded glasses, ceiling suspended shielding and table curtains. From the answers received, it is quite evident that such protection methods are not always available and they are used at different levels from hospital to hospital, even within the same country. Moreover, attention has been placed on the importance of using such means of protection correctly whenever they are available.

In nuclear installations, shielding masks, glove-boxes and remote systems were already in use before the introduction of the new dose limit, and no major changes are foreseen.
One general problem which is frequently highlighted, is the discomfort associated with using lead glasses, since they are heavy and often not properly fitted for each individual.

It is predicted that both the aspects of dosimetry and the additional protection measures to reduce eye dose will increase costs. Also, in general, any arrangement or protective measure which requires an extra dosimeter or the purchase of protective eyewear will generate additional costs and so may be a further obstacle to implementation of the dose limit. Even more so if we consider the additional time required by radiation protection officers to evaluate whether the measurements need to be corrected.

3.2 Health surveillance

Half of the ASs who answered predict changes in health surveillance. It is argued that the lens dose should be the object of explicit attention in the health surveillance of workers, who are likely to receive high exposures to the lens of the eye. It has been pointed out that it is difficult to organize annual routine examinations of the lens because the worker needs to be referred to an ophthalmologist and will not be available for work later in the day after the necessary pupil dilatation. Therefore, taking also into consideration the possible additional costs, such examinations should be restricted to workers with high potential exposure or with symptoms of possible cataract formation. A mandatory examination has been specifically indicated before a radiologist or cardiologist starts interventional work. The ASs also noted the need to recognize uniform methods of identification and documentation in investigating lens opacities, in order to define specific training for ophthalmologists operating in the field of radiation-exposed workers.

In European countries, health surveillance is carried out for workers classified as Category A, i.e. for workers who, according to the new EU Directives, are liable to receive an effective dose greater than 6 mSv per year or an equivalent dose greater than 150 mSv per year for skin and extremities, or greater than 15 mSv per year for lens of the eye. For the same Category A, the previous EU Directives considered a dose greater than 45 mSv per year for the lens of the eye. With the new eye lens limits there will probably be an increase in classified workers and this will likely lead to an increased number of workers covered by health surveillance. Licensed physicians would therefore most probably indicate the need for further specialist ophthalmologic examinations.

3.3 Legislative processes regarding the new limits

Most of the ASs are involved with governamental or regulatory advisory bodies that are consulted about legislation concerning radiation protection, while some ASs have members who are part of the regulatory body or who participate in regulatory working groups. Legislative processes addressing the new limits for the lens of the eye have been initiated in most of the countries represented by the ASs who replied.

It must be noted that the Euratom Directives 2013/59 include the new occupational dose limits for the lens of the eye, and the European Member States must be compliant with the Directives by February 2018. Therefore the legislative process regarding the new eye lens limit is at an advanced stage in the European member states, even if it is at different levels of development at the moment.

The process of considering the new eye lens limits at a legislative level is also at a good stage in most of the ASs in non-European countries: consultations, engagements, feedbacks from stakeholders and draft regulations are under consultation for comments in most cases. One country also considered introducing the new eye lens limits in two stages: a first stage of at least 5 years with a limit of 50 mSv/y for the equivalent dose to the lens, in order to analyse its implementation and the results before a second stage, when the recommended limit of 20 mSv/y would be applied (averaged as 100 mSv in 5 years, not exceeding 50 mSv in one year). Moreover, one country which was already in the process of reviewing stakeholder inputs, decided to block the development of revisions to the regulatory standards, which will include a reduction in the dose limit to the lens of the eye. Within this diverse frame of different legislative processes, the guidelines for monitoring the eye lens with regard to the reduced dose limits for workers, are under development, completed or at least planned for future development by the vast majority of ASs.

3.4 Consideration on tissue effects other than eye lens effects

In the survey, the ASs were asked if they had analysed and taken into consideration the wider issue of tissue reactions, and in particular circulatory disease, because of recent evidence of higher incidences of injury occurring at lower doses than had been previously reported.

The answers received made it clear that there is awareness of the association between low-moderate-dose exposure, late occuring circulatory diseases and the related nominal threshold dose, which is lower than previously estimated, but also that very few actions have so far been carried out in this field, and no actions are foreseen in practice at this stage. The various ASs express various related lines of argument and current points needing attention, including: the role of uncertainties in the available data and studies supporting the question; the lack of resources and means available to the ASs to allow them to conduct independent analyses or research on the subject; the existence of many potential factors, other than radiation dose, that may contribute to tissue reaction, such as psycho-emotional-stress, non-ionizing radiation, chemical substances, etc. Moreover, it is pointed out that the

ASs have the opportunity to first of all settle the different aspects related to the lens of the eye dose, and then move their attention to the wider issue of tissue reactions.

4 SUGGESTIONS FROM THE IRPA ASSOCIATIONS

Presented below is a series of specific suggestions and recommendations expressed directly or derived from the responses sent by the ASs.

4.1 Scientific, regulatory and implementation aspects

For a number of countries there is general concern about: the need for suitable dosimeters to be made available; the lack of established calibration facilities for Hp(3); the associated arrangements for regulatory approval.

Issues which need still to be addressed are: harmonization of the approach to monitoring the dose to the lens of the eye; agreement on the optimum location of dosimeters, i.e. the use of head dosimeters; consensus about suitable methods for evaluating the protection provided by lead glasses; the use of dosimeters outside glasses. Some countries suggest the application of a correction factor, while others suggest the provision of measurement data under the protection. Agreement must be found regarding a suitable category under which eye doses could be recorded in the national dose register. In some ASs, the reading on the collar dosimeter can be directly recorded as eye dose, and there is a general consideration that this reading can only give an indication of the eye dose; at the same time, the application of correction factors is considered as largely uncertain.

By far, the attention of the ASs and of the reported pilot study programs is focused on medical applications, but some of the addressed issues also relate to exposures of the lens of the eye in the nuclear industry: for instance, the need to make protective tools like lead glasses more wearable and comfortable.

The need for good practice recommendations clearly emerges in the survey. A large group of ASs highlighted their great appreciation for specific guidelines in relation to: i) calculations and methods in operational practice for lens of the eye dose, i.e. in CT and x-ray examinations; ii) practical estimations based on the actual exposure compared with the new limits, as well as the consideration that measurement by a dedicated dosimeter may not always be necessary; iii) the need to apply a preventive risk assessment and stratification of workers into high and low risk groups, regarding exposure of the lens of the eyes.

The majority of ASs consider that there are significant implications related to dose recording for itinerant workers, and new issues are emerging. ASs reported a variety of practices with regard to keeping monitoring records. The issue of itinerant workers is thought to present a significant problem for the medical sector, especially when clinicians work in both public and private hospitals.

In some countries, the use of multiple service providers for dose-monitoring could increase the administrative burden of cross checking and collating results. Greater cooperation among respective management teams is recommended, with regard to positioning the dosimeter correctly, ensuring that the correct dosimeters are worn, and sharing information about doses.

In general, some of the ASs suggested that the radiation protection community will dedicate additional attention to the uncertainties accompanying the scientific evidence, the definition of the threshold dose for cataractogenesis, and the option to apply an average annual dose limit of e.g. 30-50 mSv instead of 20 mSv.

By addressing the wider issue of tissue reactions, the survey revealed the need for adequate international guidance, specifically on the implication of circulatory disease in radiation risk and addressing the different areas of practice. Moreover, considering that uncertainty tends to inhibit a direct impact on guidelines, research needs to continue towards a better understanding of the mechanism of circulatory diseases following exposure to low-moderate dose, and to examine the impact of possible confounding factors.

4.2 Economic issues

It is commonly understood by the ASs that application of the new limit will generate additional costs. In order to achieve the necessary reduction of dose to the eye, protective methods must be made available in all the facilities, where relevant. The costs would be high: apart from the extra dosimeters, there is the additional time required by radiation protection officers to evaluate whether corrections to the measurements are needed. Economic issues are associated with methods of protection, additional training, and implementing the additional dosimetry. Any cost involved in implementing arrangements may, in general, be a further obstacle to implementing the new dose limits.

Proper preventive risk assessment and adequate stratification of workers are indeed recommended to reduce the cost of dosimetry to an acceptable level. Particularly in the European countries, attention is given to possible reclassification of workers from B to A on the basis of eye dose, which will increase administrative activities and surveillance costs.

4.3 Awareness and Culture

Because of the comparatively poor appreciation of the risk, e.g. in the medical sector, significant problems are expected in ensuring that staff will use protective equipment and will wear dosimeters correctly and consistently. There is still the need to agree on a standard system for investigating lens opacity. This will also require the organization of specific training dedicated to ophthalmologists in view of a uniform identification and categorization, as well as an agreed standard evaluation for occupational assessments.

Awareness and culture are integral components for the actual implementation of the new dose limits, and provide a great incentive to use the best procedures for maintaining exposure to radiation as low as can reasonably be achieved.

In order to ensure optimized use of protective equipment, it is considered that implementation of radiation protection culture and awareness of the risks are the main relevant methods. Some ASs also pointed out the usefulness of audit procedures, enforcing the law, engaging managers or experts, dosimetry analysis, risk assessment studies or dissemination of research results.

Particularly in the medical field, it is well recognized that awareness among workers who may be exposed needs to be improved, by investing in their education and training and by obtaining further support from specialists such as radiation protection services. The best ways to persuade staff to wear the additional dosimeters, where relevant, are conceived to be: substantial programs of education and motivational training which emphasize the benefits of a strong radiation protection culture; inducing proper use of protective equipment and increasing awareness about lens of the eye dose.

The radiation protection community is facing a real challenge with the new dose limit and ASs should take charge and strongly promote developments in line with 'IRPA Guiding Principles for Establishing a Radiation Protection Culture' [9]. This encompasses the development of a pattern of knowledge and behaviors as a combination of science, values and ethics, and includes not only the well-established justification, optimization and dose limitation principles, but also the sharing of competence by training and education.

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Introducing on-line modules in the Swedish Master's Degree Programme for Applied Radiation Protection 14

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Abstract. To complement the existing university courses in radiation physics in Sweden, a new master programme in radiation protection at the University of Gothenburg was launched in 2012. The programme includes five mandatory courses on advanced level, and has attracted interest of many students. Even though admission to these advanced level courses requires a bachelor degree the requirement is not constrained to bachelor degrees within physics or even within other science subjects. It has been an ambition to also recruit students with a background in e.g. rescue service and fire engineering. To prepare students with BSc in subjects not containing radiation physics, online courses have been developed including recorded lectures, quizzes, calculation exercises, and recommendations to future reading. The aim of these courses is to efficiently teach the basics of radiation physics and measurement methods, including rudimentary gamma spectrometry. The course structures follow that of many Massive Open Online Courses (MOOC), which are currently offered by several universities. Typically, these courses consists of short recorded lessons (3-15 min) followed by quizzes or other interactive exercises. It is expected that the students have passed the on-line courses before the gatherings (often 1-3 days per course), where the traditional lecture series and practical exercises are being run. To pass the courses, a written examination is also required. The first online course: *Detectors and measurement methods in radiation protection and emergency preparedness* was launched in the autumn of 2015. The first version were given in Swedish, but the material are continuously being translated into English. The benefit of using preparatory on-line lectures prior to the gatherings will be evaluated by comparing the outcome of the student results with those from the previous year's 2012-2014.

KEYWORDS: Massive Open Online Courses; master programme; applied radiation protection.

1 INTRODUCTION

The Swedish emergency preparedness organization for radiological and nuclear emergencies and incidents is today built around a network of experts at the authorities, universities and county administrative boards and a number of medical physicists, specially trained physicians and nurses at the major hospitals, and specially trained first responder personnel. The authorities provide support for exercises and material but as the methods and measurement systems used in radiation protection have developed the need for special competence has grown.

Most of the experts have an academic background in e.g. medicine or physics but not in applied radiation protection and emergency preparedness. New threats in form of terrorism imposes completely new situations for those experts and the generation who remember the atomic bomb threat during the cold war and the radioactive fallout over Sweden after the Chernobyl accident in 1986 will soon be retired.

In an effort to increase the national competence, a master programme specially focused on the various applications of radiation protection in normal as well as emergency situations was started at the Department of radiation physics, Sahlgrenska academy at the University of Gothenburg, Sweden. The courses were developed in close collaboration between the Gothenburg University and the department of Medical Radiation physics at Lund University in Malmö and were financed by grants from the Swedish Radiation Safety Authority. The first course started at the fall of 2012 and was run in a 2 year cycle.

The master programme is aimed not only to physics students, but is open to anyone with a Bachelor's degree. However, to understand even the basics of radiation detectors, dosimetry and radiation physics, a fair amount of basic knowledge in physics is required. To prepare those students who lack the basics in radiation physics, special preparatory courses are developed.

Encouraging people from a non-natural-scientific background to work with radiation protection could potentially benefit the field as new ideas in the philosophy behind radiation protection could be expressed. The strictly logical academic view on the main cornerstones of radiation protection such as justification and optimization might not always represent that of the general community. Still, it is important to acknowledge radiation protection as a field based upon science which is why an effective way of learning the basics of radiation physics before starting the education on an advanced level is important.

2 DEVELOPMENT OF MASTER PROGRAMME COURSES

2.1 Master Programme courses during the first two cycles 2012 to 2015

The education in medical radiation physics at university level in Sweden has a history from the early 1960s. Today, the programme consists of five years of studies, leading to a Master of Science degree and an eligibility to apply for a Medical Physics licence by the National Board of Health and Welfare. Since the development in medical applications of radiation is so rapid there is little room in the schedule for providing the students good training in radiation protection dealing with situations outside the medical sphere. However, some of the Swedish universities include courses in environmental radioactivity and emergency preparedness within the programme. There are also other courses within programmes of Nuclear Technology and Nuclear engineering, which contain vital elements of radiation protection issues, which are run in other Swedish universities.

In 2011 it was recognised in a report by the Swedish Radiation Protection Authority that many of existing programmes provide too little radiation protection skills to be applied outside the hospital environment. A demand was found for a broader education programme in Radiation protection. Also a need was found for intensive radiation protection courses. If this situation was not amended it was anticipated that in the future there would be 1.) an increased risk of radiation exposure to humans and environment, and 2.) a loss of capability to manage severe radiological or nuclear emergency.

Figure 1: Overview of the Master Programme in Applied radiation protection at the Sahlgrenska Academy, University of Guthenburg, in Sweden.

<table>
<tr><td rowspan="2">Year 1 Autumn</td><td rowspan="2">Recommended introductory course in radiation and radiation protection
7.5 ECTS (depending on prior knowledge)</td><td rowspan="2">National emergency preparedness for radiation protection
7.5 ECTS</td><td colspan="2">Radiation protection and environmental impact of the nuclear fuel cycle
7.5 ECTS</td></tr>
<tr><td>Elective courses
3.25 ECTS</td><td>Elective courses
3.25 ECTS</td></tr>
<tr><td>Year 1 Spring</td><td>Elective courses
7.5 ECTS</td><td>Scientific methods
7.5 ECTS</td><td>Elective courses
3.25 ECTS</td><td>(available: Environmental radioactivity)
7.5 ECTS</td></tr>
<tr><td rowspan="2">Year 2 Autumn</td><td colspan="2" rowspan="2">Detectors and measurement methods in radiation protection and emergency preparedness
15 ECTS (including field exercises)</td><td colspan="2">Radiation protection in medical emergency preparedness
7.5 ECTS</td></tr>
<tr><td>Elective courses
3.25 ECTS</td><td>Elective courses
3.25 ECTS</td></tr>
<tr><td>Year 2 Spring</td><td colspan="4">Individual work (Master Thesis)
30 ECTS</td></tr>
</table>

An application by the Medical Physics department in Gothenburg and Lund University of starting a new Master program in Applied radiation protection was approved by Gothenburg University in late March of 2011. In the autumn of 2012 the first cycle of the Master's program in Applied Radiation in Gothenburg begun.

The Master programme is based on four mandatory courses, that all have similar structures which enable participation of remote/distant students, requiring a limited physical presence (Figure 1). These four courses are built on so-called continuing professional development (CPD) courses that the departments of Medical Physics in Gothenburg and Lund had elaborated during the years 2006 to 2011. Those courses were made for Medical Physicists who wanted a more in-depth knowledge and training within radiation protection and emergency preparedness. These CPD-courses were individually adapted to fit into advanced university courses in the new Master in Applied Radiation Protection. In order to achieve a Master in Applied Radiation Protection, the student needs to pass all four mandatory courses with a total credit of 37.5 ECTS, pass the Scientific methodology course given by Gothenburg university (15 ECTS), write a MSc-thesis (corresponding to 30 ECTS) and then complement with elective courses (in total of 120 ECTS).

The structure of the mandatory courses all follow a common pattern, with an introduction session for 1-2 days, followed by a 3-day session of intensive lectures, and a third concluding session where individual assignments of the students are presented. The following four courses are given during the education:

- *National emergency preparedness for radiation protection* (7.5 ECTS): This course was given in fall 2012 and 2014 and focuses on the role of various authorities and stakeholders in the society. The course is given as a distance course with six mandatory meetings. The first meeting consists of introductory lectures dealing with radionuclides and inventory in nuclear power plants, radiological and nuclear threats, radioactive fallout, radiation doses to the public and the linear-no-threshold relation between dose and response. On the second day of the first meeting, the students follow a demonstration of some of the calculation tools used in the emergency preparedness; examples are: calculation of ambient dose rate from deposition on ground and calculation of air activity concentration and deposition from a release of radionuclides from e.g. a nuclear power plant. During the second day, they will also make some measurements with instruments used in the emergency preparedness, e.g. hand-held instruments and solid-state detectors.

  During three days in the middle of the course, the students will attend the corresponding CPD-course described above. The topics in this course are e.g. optimization in radiation protection, the role of Swedish local hospitals in emergency preparedness, action strategies, personal dosimetry, co-operation between authorities, the role of the rescue service, risk evaluation and risk communication, the role of the Swedish local hospitals, the university, the defence forces, the National Board of Health and Welfare, and the Swedish Radiation Safety Authority. They will also visit the County Board of Administration in a county with nuclear installations. In Sweden, these counties have a responsibility to maintain an extended emergency planning for nuclear accidents. The students will attend presentations by the medical physicists, taking the CPD-course, of accidents that have previously occurred. This is a task that is assigned to the medical physicists before the course.

  The course is examined by individual and/or group tasks that are sent to the course leaders for evaluation. The assignments consist of essays and calculations. At the end of the course, the students are gathered together with the course leaders for a discussion seminar. This structure of examination is presently used at all four courses. In most of the courses the participants are given an assignment, which will also be useful for the emergency preparedness at their workplace. We have noticed that many hospitals now have emergency plans where the role of the medical physicist is becoming more obvious than before and that discussions with the lecturers and the other participants have been very fruitful in this work.

- *Radiation protection and environmental impact of the nuclear fuel cycle*, (7.5 ECTS): The course was given during fall 2012, also as a distance course. During the first meeting introductory lectures are given, e.g. overview of the nuclear fuel cycle, biosphere modelling and different kinds of nuclear reactors. The second meeting consists of the three days together with the medical physicists taking the corresponding CPD-course. The lectures start with geological aspects of uranium mining, followed by the medical issues connected to occupational exposure to uranium. Other examples of topics that are covered during these three days are nuclear fuel fabrication, risk assessment at nuclear facilities, environmental surveillance and authority control, release scenarios, nuclear weapons, reprocessing and storage of spent nuclear fuel.

- *Detectors and measurement methods in radiation protection and emergency preparedness* (15 ECTS): The detector course was given during fall 2013 and is divided into two parts. Part 1 consists of lectures and is mostly theoretical. Part 2 is given at the shut-down nuclear power plant at Barsebäck in southern Sweden. The nuclear fuel has been removed from the plants, but the facilities are still used as a training centre. At some areas inside the reactor and turbine building the radiation level is still be rather high. Since the area is closed from public access the participants can make measurements in a high-background environment, search for hidden sources and make mobile measurements. The radiation safety for the participants is provided by the regular radiation protection organization at the plant, according to the Swedish regulations.

  The part taking place at Barsebäck is combined with the corresponding CPD-course and given during three days. Due to the regulations, the participants have to take a basic course in radiation safety at nuclear power plants in order to gain access to the facilities. Thereafter, the exercises described above can take place.

  Topics that are covered during the three days in part 1 (also in combination with the CPD-course) include basic detector knowledge, analogue and digital detector electronics, measurement techniques for alpha/beta/gamma, personal dosimeters, spectroscopy, detection limits, in-vivo measurements techniques, instruments for first-responders and mobile measurement systems. The aim is to provide the participants with the ability to understand the features of different detector types and to be able to choose the right instrument for the situation.

- *Radiation protection in medical emergency preparedness* (7.5 ECTS): This course is done in close co-operation with Medical Physics in Linköping and the Disaster Medical Centre in Linköping. The three days meeting in this course is organized in co-operation with Centre for Teaching and Research in Disaster Medicine and Traumatology, which is a directly subordinated to the County Council of Östergötland and the University of Linköping, and in co-operation with the Division of Radiological Sciences at the University of Linköping. The lectures start with an introduction to the system developed to deal with large accidents from a medical point of view, followed by the expectations of the National Board of Health and Welfare on the medical physicists in emergency situations. Biodosimetry and methods to assess the extent of internal contamination are also covered in lectures.

  During this course we also have group sessions where the students and medical physicists discuss cases related to radiological emergencies. The problems are discussed using the TMT Handbook as reference (Rojas-Palma et al., 2009).

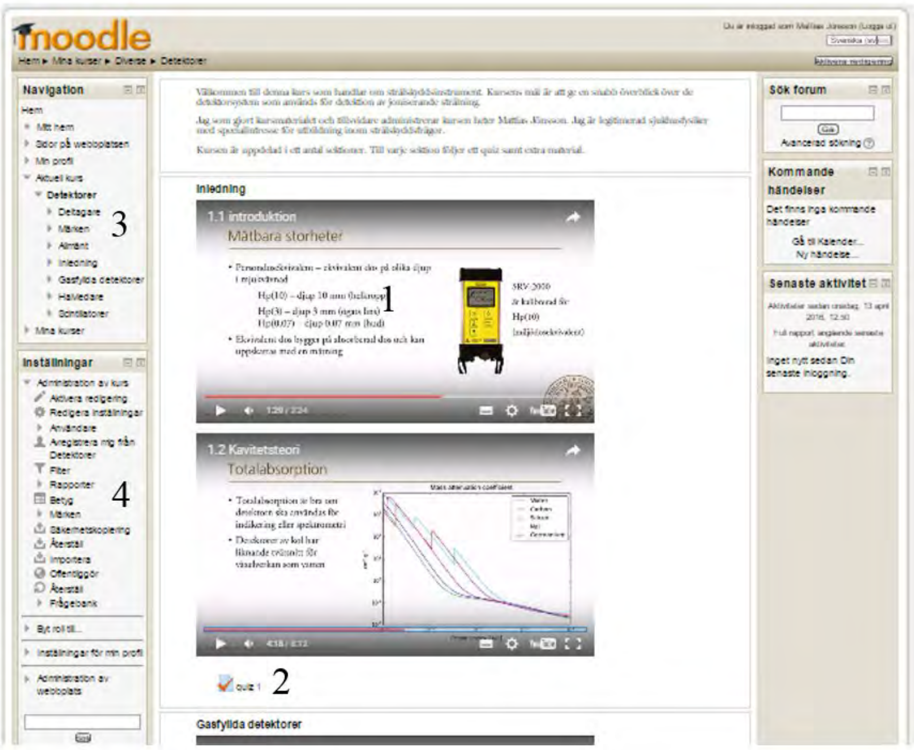
  In addition to the lectures, laboratory work and scenarios are included in the course. This course includes a scenario with an airplane crash at a local airport. The plane is carrying a radioactive source and the participants discuss, together with representatives from the rescue services, police and hospital, how this accident ideally should be handled. They will also try on protective clothing and participate in an exercise in a dedicated decontamination facility, to get a feeling for what it is like to work with that equipment during monitoring and de-contamination of a patient. The laboratory exercises deal with radiometry on samples from the patient (urine and hair), EPR-measurements and calculations of internal doses with the software IMBA (Birchall et al., 1998).

2.2 Introduction of on-line preparatory courses

To prepare students for the master's programme, preparatory courses were developed. The aim of the courses was to give students a basic understanding of radiation physics before the first semester. Although radiation protection is not an ordinary academic profession, it is important to recognize radiation protection as a field based upon science. Radiation protection experts may not necessarily need to have a deep theoretical understanding of physics, but to assess a radiation hazard using advanced detectors and simulations requires some degree of knowledge of physics, chemistry and engineering. The scoop of the online courses must be well balanced and not include too much of the underlying physics or specific properties of detector components, however important they may be for a full understanding of the field, but still not give the student misleading or confusing ideas.

The basic structure of the courses followed the same design as the MOOC (Massive Open Online Course) given at many major universities. The course consists of short recorded lesson followed by a quiz or other interactive exercise as demonstrated in Fig. 2. Each clip is 3-15 minutes long. The material was recorded using a web camera, headset and screen capturing software. The course was to some extent based upon material previously developed for education. However, since the existing material were designed to be used during ordinary lectures, most of the material had to be remade for the purpose.

Figure 2: Overview the course page as seen in a web browser showing the first module which is an introduction to the course and some general aspects of radiation detectors. The present module contains of two embedded links to clips uploaded to YouTube (1) and a short quiz (2). The different parts of the course can be accessed in the navigation menu (3). As administrator of a course different tools such as quiz results, registration of participants and degrees can be administered at the settings menu (4).



During examination in an on-line course the student has access to the internet and there is no possibility for the course administrator to check that it actually is the student who takes the exam. This limits the credibility of a passed test. In this case the students will take written exams at the university during the semester. Thus, just passing the online-course will not give any credits.

The course is assessable via any web browser. If a computer is used, no software has to be downloaded specifically for the course. However, if a mobile device is used, an app must be downloaded. The downside of any internet based service is the need for a constant access to internet. The student must have access to an internet connection while taking the interactive tests. However, the video lessons can be downloaded from YouTube using various free software and viewed later.

3 LAUNCHING OF CORSES

The first course “Detectors and measuring methods in radiation protection” was launched before the fall semester in the year 2015. The scoop of the course covered the basics of radiation detectors used in for radiation protection. In total, 88 minutes of recorded material divided into 13 clips were uploaded to YouTube. Four quizzes were uploaded on the Moodle site. The clips were narrated in Swedish but subtitles in both Swedish and English were provided and available via YouTube.

4 CONCLUSION

Developing an on-line course is time demanding even if the material is based on previously used lectures. The result of the work can be reused year after year, although an active course administration is needed both for keeping the material up to date and for registering new students on the course. On-line courses can be beneficial for some students both as the student can be more active with the interactive parts and as the student does not need to relocate during the course.

One must not forget the value of hand-on experience with the instruments. This means that the students will have to participate in field exercises, preferably with real radioactive sources or in environments with an elevated radiation level. Field exercises is therefore a fundamental part of the master’s programme. However, a basic theoretical understanding of the physics and techniques is needed for getting the most out of the field exercises.

5 ACKNOWLEDGEMENTS

The development of the on-line courses have been founded by the Swedish Radiation Safety Authorities.

Management of Radioactive Waste: Public Perceptions Versus Scientific[1] Views

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Abstract. The current work was prompted by the prominent place occupied by radioactive waste management in the wide ranging debate on public perceptions versus technical aspects. It is generally known that society has a growing environmental awareness and is very concerned about the impact that the nuclear technology might have on its health, safety and well-being, including the possible effect on future generations. There is no doubt that the public's perception of the nuclear industry and its future is heavily contingent upon its perception of radioactive waste management. For various reasons, such as the effects of ionising radiation on living organisms, the long half-life of specific radioisotopes, the military background and implications of nuclear technology, or the accidents which have occurred at facilities, the public, generally speaking, attaches higher risk to radioactive waste than to waste from any other type of industry. The research explores the intricacies of Radioactive Waste Management within the South African environment and argues that the technical aspects of radioactive waste management are perhaps less complex than the socio-political ramifications.

1 INTRODUCTION

1.1 Institutions and governance

The following are the key role players in the management of radioactive waste in South Africa:

(i) **The Department of Energy**: The Nuclear Energy Act of 1999 assigns responsibility to the Minister of Minerals & Energy for the production of nuclear energy, the management of radioactive waste, as well as South Africa's international commitments.

(ii) **The National Nuclear Regulator (NNR)**: is the national authority responsible for exercising regulatory control over the safety of nuclear installations, radioactive waste, irradiated nuclear fuel, and the mining and processing of radioactive ores and minerals. The primary function of the NNR is to protect workers and members of the public from the harmful effects (i.e. nuclear damage) arising from exposure to ionizing radiation.

(iii) **The South African Nuclear Energy Corporation (NECSA)**: established in terms of the Nuclear Energy Act of 1999, operates and manages the National Radioactive Waste Repository for low and intermediate level radioactive waste, at Vaalputs in the Northern Cape Province on behalf of the State.

(iv) **The Radioactive Waste Institute**: The 2008 National Radioactive Waste Disposal Institute Act provides for the establishment of a National Radioactive Waste Disposal Institute which will manage radioactive waste disposal in South Africa.

1.2 Storage and disposal of radioactive waste

Necsa is operating the national repository for low and intermediate level waste at Vaalputs in the Northern Cape commissioned in 1986. Low and intermediate level waste from Koeberg is disposed of in metal drums steel and concrete containers respectively at the National Radioactive Waste Repository Vaalputs, some 600 km north of Cape Town, in trenches.

Spent fuel is stored on site at Koeberg, most of it in wet storage in spent fuel pools, although some is stored on site in dry casks. The storage racks in the spent fuel pools are designed to allow for the storage of all spent fuel for the design life of the station.

2 RESEARCH METHODOLOGY

2.1 Research questions

A total of 130 structured interviews were conducted with respondents from the communities residing in the proximity of Necsa (i.e. within 5 km radius), scientist from Necsa, and the scientists from the National Nuclear Regulator. The data was collected by adopting the structured interview schedule (i.e. telephone).

The research questions arrived at were:

- What are the important radioactive waste management issues that impact on the **safety** of radioactive waste?
- Would it be better to proceed now with the final **disposal** of radioactive waste or to wait and see what new technological developments the future brings?
- What **symbolic meanings** of radioactive waste are reflected in public perceptions and scientists views?
- How public and scientists reflect upon **participation and responsibility** issues regarding radioactive waste issues?

2.2 Research design

For the current study, the research design, in using a critical-realist intellectual underpinning, is oriented to the qualitative paradigm so as to facilitate the objective of theory development. The qualitative approach can serve the following purposes, namely: description, interpretation verification and evaluation. Also, the nature of the research problem and the associated research questions essentially drove the choice of methods. The imperatives of the critical realist tradition suggest that the qualitative research methods would be a more suitable approach to select for this study.

2.3 Selection of respondents

The broader grouping from which the respondents were selected was defined as follows:
A total of 130 structured interviews were conducted with respondents from the communities residing in the proximity of South African Nuclear Energy Corporation (Necsa), scientists from Necsa, and the scientists from the National Nuclear Regulator (NNR).
Based on the above, the following categories of respondents were identified:

- Nuclear and Radiation scientists employed by the NNR.
- Nuclear and Radiation scientists employed by Necsa.
- Members of the public residing in the proximity of Necsa.

2.4 Data collection method

There are several types of research methods that can be used to collect primary data. Interviewing is probably the most common data gathering method in qualitative research. In qualitative studies, interviews are often quite open-ended; however in survey research interviews are fairly structured [9].

2.4.1 Questionnaires

The questionnaire was used as the data gathering tool. This allowed the collection of data and its analysis to determine patterns and relationships.
In conducting the interviews we had a list of questions on fairly specific topics to be covered on management and safety of radioactive waste. The questionnaire was geared to answering the research questions. Also, prospective respondents were provided with a credible rationale for the research. In order to maximize the number of responses to the questionnaire, the number of questions was limited to few questions.

Leedy and Ormrod [9], also supports the fact that questions should be as brief as possible and solicit only that information essential to research project. The questionnaire used in the current study has been employed by other researchers, however, some aspects of the questionnaire have been customized for the current study.
According to Bryman and Bell [2], an advantage of using existing questions is that they allow you to draw comparisons with other research or may allow you to explore whether the location of your sample appear to make a difference to the findings.

2.4.2 Sampling method

In the current study, a simple random sampling was applied. In this case each member of the population had the same chance of being included in the sample. According to Bryman and Bell [2], the simple random sample is the most basic form of probability sample.
Leedy and Ormrod [9] assert that how you identify a sample must depend on the research questions you want to answer. If you want to draw inferences about an entire population or body of objects, you must choose a sample that can be presumed to represent that population or body.
More often, qualitative researchers are intentionally nonrandom in their selection of data sources. Instead their sampling is purposeful, hence they select those individuals or objects that will yield the most information about the topic under investigation [9].

2.5 Ethical considerations

According to Leedy and Ormrod [9], whenever human beings or other creatures with the potential to think, feel, and experience physical or psychological distress are the focus of the investigation, we must look closely at the ethical implications of what we are proposing to do. Therefore in the current study, care was taken to ensure that the following categories of ethical issues are addressed: protection from harm, informed consent and right to privacy.

2.6 Limitations

Bryman and Bell [2], argues that telephone interviewing suffers from certain limitations when compared to personal interview:

- People who do not own or who are not contactable by telephone obviously cannot be interviewed by telephone. Lower income households are more likely not to own a telephone.
- The length of a telephone interview is unlikely to be sustainable beyond 20-25 minutes, whereas personal interviews can be much longer.
- Telephone interviewers cannot engage in observation (i.e. they are not in position to respond to signs of puzzlement or unease on the faces of respondents).

3 DISCUSSION

3.1 Summary of the study

The purpose of this study was to determine the public perceptions versus scientific views on safety of radioactive waste management.
The study covered the topic on the perceptions of members of the public residing in proximity of Necsa as a nuclear facility (i.e. 5km radius) versus the views of Scientists in the field on Nuclear Safety and Radiation Safety towards management of radioactive waste, and in particular looked at:

- Their wish for involvement in decision-making about managing radioactive waste.
- How informed the public and scientists feel about radioactive waste.
- Their subjective and objective knowledge of radioactive waste and ways of managing radioactive waste.
- Their trusted sources of information about radioactive waste.

To gain a deeper insight in the scientists and public's opinion regarding radioactive waste, the questionnaire, with key variables, has been used while analyzing the research questions.
A total of 130 randomly selected respondents (65 scientists & 65 members of the public) participated in the survey. With respect to gender per group, there were more males respondents in scientists group than in public group. (i.e. there were 35 male respondents in scientist category and 24 males in public category). Looking at females, there was a different picture as compared to males per groups, there was more female respondents in public category than in scientists category. (i.e. there were 41 females in public category and 30 females in scientist's category).

3.2 Response to research questions

The findings of this reserach in relation to each reasearch question will now be discussed. Each question is captured in bold and followed by a discussion of the findings relating to it.
What are the important safety issues that impact on the management of radioactive waste?
Table 1 depict that Scientist group are more concerned about the possible effects on the environment and health than other risks as compared to Public group, this is supported by table 1 with 19 responds out of 65 (29%) responds for Scientists. Again scientists are also more concerned about transport of waste to the disposal, which contributes 21% of the respondents. On the other hand the Public tend to differ in terms of perception regarding the risk of waste disposal as they are more concerned about the transport of waste and risk of radioactive leaks while the site is in operation.

Table 1: If a disposal site for radioactive waste were to be built near your home, what would worry you most about?

	Scientists	**Public**
Transport of waste to the disposal	14	22
The risk of radioactive leaks while the site is in operation	4	26
The risk due to a terrorist attack	9	3
The possible effects on the environment and health	19	9
A major drop in local property prices	4	1
None of these	15	2
Don't Know (DK)	0	2

Would it be better to proceed now with the final disposal of radioactive waste or to wait and see what new technological developments the future brings?
The table 2 below reveals that the Scientists group and Public group tend to totally agree on the solution for high level radioactive waste should be developed now and not left for future generations. This is explained by the highest frequency or number of responds per each group (46 and 65) respectively.
They also believe that deep underground disposal represents the most appropriate solution for long-term management of high level radioactive waste as we see that only 8 responds from Public group and 1 respond from Scientists group totally disagreed which is the lowest number of respondents per group.

Table 2: Frequency about whether the respondents agreed on the statements

		Totally Agree	**Tend to Agree**	**Tend to disagree**	**Totally disagree**	**DK**
PUBLIC	A solution for high level radioactive waste should be developed now and not left for future generations	46	7	1	6	5
SCIENTISTS		65	0	0	0	0
PUBLIC	There is no safe way of getting rid of high level radioactive waste	40	9	3	10	3
SCIENTISTS		44	7	1	13	0
PUBLIC	Deep underground disposal represents the most appropriate solution for long-term management of high level radioactive waste	39	5	6	8	7
SCIENTISTS		59	3	1	1	1

What symbolic meanings of radioactive waste are reflected in public perceptions and scientists views?

From table 3 we can conclude that scientist and public members tend to agree on that there is several categories of radioactive waste for example low, intermediate and high level radioactive waste, since out of 65 respondents public members rate 83%(54 out of 65) and scientists rate 100%.

Overall we can conclude that in the above statements scientists and public members have the same perception in terms of characteristics of radioactive and also some radioactive waste discharge.

Table 3: Public and Scientists Respondents on whether statements are true or false

		True	**False**	**DK**
PUBLIC	There is several categories of radioactive waste for example low, intermediate and high level radioactive waste	54	0	11
SCIENTISTS		65	0	0
PUBLIC	Some hospitals produce low level radioactive waste	53	2	10
SCIENTISTS		64	1	0
PUBLIC	Some non-nuclear industries produce low level radioactive waste	47	2	16
SCIENTISTS		64	0	1
PUBLIC	Some scientific research centres produce radioactive waste	52	1	12
SCIENTISTS		65	0	0
PUBLIC	High level radioactive waste is produced only in nuclear reactors	47	4	14
SCIENTISTS		64	1	0
PUBLIC	Radioactive waste is produced in similar quantities to other waste such as chemical waste	44	3	18
SCIENTISTS		59	6	0
PUBLIC	All radioactive waste is very dangerous	50	3	12
SCIENTISTS		60	5	0

From the table 4 we observe that scientists group is more informative compared to public members about how radioactive was dealt with in South Africa. By looking at every statement we observe in every respondents that says it is true Scientists have large number of respondents as compared to Public members, for example 65 responds from Scientists group say it is true that radioactive waste is currently placed deep underground at special disposal sites, while only 53 out of 65 from Public members says it is true about the above statement.

Table 4: Respondents on how radioactive is dealt in SA

		True	False	DK
Public	Some radioactive waste is currently placed deep underground at special disposal sites	53	3	9
Scientists		65	0	0
Public	Some radioactive material is put into solid form and packed in steel drums	33	17	15
Scientists		62	3	0
Public	Some radioactive waste is sent to other countries for disposal	32	17	16
Scientists		49	15	1
Public	Some radioactive waste is stored temporarily, pending a final decision on disposal	34	14	17
Scientists		54	11	0
Public	Some radioactive waste is dumped at sea	32	10	23
Scientists		45	20	0

How public and scientists reflect upon participation and responsibility issues regarding radioactive waste issues?

Table 5 depict that the Scientists responds tends to agree with the Public responds in terms of whether they would like to be directly consulted and to participate in the decision making process. From the Scientists group, 92% needs to participate in the decision making while 60% of Public also needs to participate in the decision making when a disposal site is built near their home.

Table 5: Thinking about the construction of a disposal site for radioactive waste near your home, with which of the following do you agree the most?

	Scientists	Public
You would like to be directly consulted and to participate in the decision making process	60	39
You would like local non-governmental organisations to be consulted and to participate in the decision making process	2	14
You would leave the responsible authorities to decide on this matter	2	4
None of these	1	5
Don’t Know (DK)	0	3

3.3 Limitations

This study has been limited to the assessment of the perceptions on management of radioactive waste as it relates to a nuclear facility. Participants in the study consisted of randomly selected members of the public residing in the proximity of Necsa and their views were compared to those of randomly elected Nuclear and Radiation Scientists sampled from the NNR and Necsa. Further country wide study has not being considered within the scope of this research.

4 FUTURE RESEARCH

This study contributes various opportunities for further research, notably:

- A country wide study on the attitudes of members of the public on Radioactive Waste. A similar study has been conducted in 2012 by Human Sciences Research Council (HSRC) on behalf of Necsa, however, it broadly covered aspects on Nuclear Energy and not Radioactive Waste in particular.
- Follow-up studies must be conducted at intervals of three to four years so as to establish trends in improvements of public attitudes towards safety of Radioactive Waste.
- Necsa should conduct a study on the effectiveness of the capacity building initiatives they carry out in increasing public knowledge versus the changing perceptions on radioactive waste of the communities who live within 5km of the facility.

5 CONCLUSION

This study examines perceptions of members of the public and their knowledge levels regarding radioactive waste and the ways of safely managing it. The study most notably shows that the public feel poorly informed about radioactive waste. Also, there is an overwhelming consensus in the public and scientists that a solution for managing high-level radioactive waste should be found now, rather than leaving it for future generations. Deep underground disposal is seen as the most appropriate solution for long-term management of high level radioactive waste.
There are primarily two aspects that worry the public: the possible effects on the environment and on health and the risk of radioactive leaks.
Both the public and scientists have a “pro-active” attitude when it concerns decision-making in the field of radioactive waste. In the event of a disposal site for radioactive waste being constructed in their immediate locality, both the public and scientist want to be directly informed and given an opportunity to be involved in the decision-making process.

Mourogov *et al* [10], further argue that public concerns on nuclear waste, safety and non-proliferation are also hindering the development of nuclear power globally. If nuclear power is to contribute in significant ways to meeting future energy demands, the above issues, real and perceived, must be addressed.
According to Riotte [13], there is widespread recognition within the technical community that the broader community increasingly determines the critical path towards implementation of disposal facilities. In the past, the waste management community has been mostly focused on the technical competence. In future, it should be involved in reaching out to other stakeholders.
Based on the above arguments, we therefore conclude that, as well as meeting stringent technical and environmental safety requirements, the safety of radioactive waste management must also pass the test of the strategic area of public perception and confidence.

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New EU-Regulations for Radon at Workplaces and their Consequences on the Regulatory Radiation Protection in Bavaria

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Abstract. In 2014 the new European Council Directive 2013/59/Euratom containing comprehensive radiation protection regulations came into force. All objectives of the directive have to be implemented into national law by 2018. For example, a reference level for the mean radon concentration at workplaces of up to 300 Bq/m³ has to be established by the member states. As a result, new German regulations for radon at workplaces are currently in preparation. These regulations will cover requirements for the measurement of radon and obligations for graded remediation measures if the reference level is exceeded. Companies with employees exceeding an effective radon dose of 6 mSv/a will be continuously supervised by the competent authority. The EU member states are also required to set up programs to identify areas where the radon concentration in a significant number of buildings is expected to exceed the reference level. Only in these areas will measurements at workplaces be mandatory. Since 2001, radon exposure at specific workplaces has been regulated by the German Radiation Protection Ordinance. Consequently, every single workplace of these specific types in Bavaria has been surveyed with regard to radon concentrations in the indoor air and the radon exposure of the staff. Especially in water supply facilities, elevated exposure levels of the staff were detected. Remediation measures adjusted to local conditions were implemented and typically led to a considerable reduction in the exposure. The measurement, the remediation measures and the success of the measures are supervised by the Bavarian competent authority. It is stipulated by the new European Council Directive that all workplaces with elevated radon concentrations have to be subjected to regulatory supervision in addition to the specific workplaces mentioned above. Measurements in a large number of offices, diverse types of shops and public buildings and, when appropriate, subsequent regulatory monitoring of these workplaces will be necessary.

KEYWORDS: radon; workplaces; remediation measures; reference level; Council Directive 2013/59/Euratom

1 INTRODUCTION

In 2014 the new European Council Directive 2013/59/Euratom [1] containing comprehensive radiation protection regulations came into force. All objectives of the directive have to be implemented into national law by the EU member states by February 2018. A reference level for the mean radon concentration at workplaces of up to 300 Bq/m^3 has to be established by the member states. As a result, new German regulations for radon at workplaces are currently in preparation.

2 RADON EXPOSURES AT BAVARIAN WORKPLACES

Since 2001 the German Radiation Protection Ordinance [2] (GRPO) contains regulations for radon exposures at specific "radon-exposed workplaces". According to the definition in the GRPO, "radon-exposed workplaces" are underground mines (including visitor mines), caves, radon spas and water supply facilities. For workers at these specific workplaces the radon exposure has to be measured. Workers exceeding an effective dose of 6 Millisievert per year (mSv/a) have to monitor their radon exposure continuously (action level). The legal limit for the maximal annual effective dose is 20 mSv, equal to the limit for the approved handling of artificial radioactive material e.g. in NPPs.

For all other workplaces as well as for dwellings there are currently no legal regulations concerning radon exposure.

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In Germany the competent authorities of the federal states, such as Bavaria, are responsible for compliance with the Radiation Protection Ordinance. Consequently, these authorities have to supervise the companies with radon-exposed workplaces and to ensure that every workplace is checked with regard to the radon concentration in indoor air and the radon exposure of the staff. Generally the exposure was measured over a period of at least three months with individual track etch detectors worn by the staff during working times. This is a cheap and simple method to measure individual radon exposures. During time off the individual detector is stored at a ventilated place with low radon concentration. The disadvantage of this simple detector system is that the detector cannot be switched off. To subtract the radon background level during time off a reference detector at the storage place of the individual detector is used. After the measurement both detectors were sent back to the radon laboratory to make the detectors available for simultaneous evaluation.
The second possibility to get an estimation of the individual radon exposure is to measure the indoor radon concentrations of all workplaces of the worker. Taking into account the monthly duration of stay of the worker at the different workplaces the monthly effective dose of the worker can be calculated. This method is only used if the duration of stay at the workplaces of a worker is short.

At present there are 33 facilities with underground workplaces in Bavaria: 5 mines, 17 visitor mines and 11 visitor caves. Radon concentrations, measured over a period from two to four weeks, range from less than 100 Bq/m³ up to 12000 Bq/m³. In one case up to 170000 Bq/m³ were measured. As the duration of stay of the staff is rather low in visitor facilities (10 to 900 hours per year), only in one mine, two visitor mines and one visitor cave did the exposure exceed the action level of 6 mSv/a. In these facilities exposure has since been monitored continuously.

In all three Bavarian radon spas measurements of the radon concentration as well as of radon exposure at different workplaces were performed. Due to high air exchange rates the radon concentration in the treatment rooms does not exceed 2000 Bq/m^3. Because of the short stay of the staff the exposure of the staff is in all cases below the action level of 6 mSv/a. The GRPO does not include regulations for patients. Nevertheless there are some measures like a special cover for the patient's bathtub to minimize these exposures.

A study in 500 Bavarian water supply facilities [3] revealed that there is no strong relationship between the indoor radon concentration in the water supply facilities and the radon content in the ground water. The reason is a variety of additional parameters that influence the indoor radon concentration, e.g. the design and ventilation of the supply facilities, the construction, the water flow rate and the different operational states of the plants. Therefore to get a reliable estimate of the radon exposure of water supply facility workers, the exposure of the staff of all approx. 2500 water supply facilities had to be measured directly by means of staff track etch detectors. Before remediation measures were taken the staff exposure level exceeded the action level of 6 mSv/a in 88 facilities.

Figure 1: Distribution of the 88 water supply facilities in Bavaria where the staff exposure level exceeded the action level of 6 mSv/a.

The exposure level of this staff is constantly monitored. 60% of these water supply facilities are located in the East Bavarian Crystalline Region with mainly granite bedrock. High radium concentrations in these granite structures lead to high radon concentrations in the soil air and in the ground water. Even if there is no strong relationship between the groundwater radon level, indoor air level and radon exposure levels of a specific water supply facility, it is not surprising that in this region higher radon concentrations in indoor air and radon exposures of the staff were found more frequently than in other regions. Due to poor ventilation, high water flux and high radon transfer rates from the water into the indoor air very high radon levels were measured in some facility rooms. Even short stays of the staff in these rooms can lead to an exceeding of the action level of 6 mSv/a.

Remediation measures have been developed by the Bavarian competent authority in cooperation with the water supply facilities exceeding the action level of 6 mSv/a. The remediation measures were planned with regard to the local conditions of each water supply facility. A variety of measures such as using a blower fan to ventilate wells and collecting galleries as well as the installation of complex ventilation systems in purification and water storage buildings were tested and implemented. Sometimes simple measures can be also very effective in reducing the radon level. Relocating offices into buildings without connection to the water supply and remote control of the plants can reduce the radon exposure of the staff effectively. Also an air-tight separation of purification or water storage rooms from other rooms can reduce the radon exposure of the staff. The implemented remediation measures have been very successful. Only in 6 of the initial 88 water supply facilities is the exposure now (at the beginning of 2016) above the action level of 6 mSv/a. For these remaining facilities it is strongly recommended by the competent authorities to step up efforts to reduce their radon exposures. Compliance with the limit of 20 mSv/a is achievable at any workplace.

Measurements were also carried out in breweries with their own water supply, in the beverage industry as well as in dairies and in the paper industry (process water). All exposure levels were well below the action level of 6 mSv/a.

3 RADON REGULATIONS FOR WORKPLACES IN THE COUNCIL DIRECTIVE 2013/59/EURATOM

In 2014 the new European Council Directive 2013/59/Euratom containing comprehensive radiation protection regulations came into force. All objectives of the directive have to be implemented into national law by 2018. This Council Directive contains regulations for radon exposures at all workplaces. A reference level for the indoor radon concentration at workplaces has to be established (Art. 54) in national regulations. The reference level for the annual average radon concentration in air shall not be higher than 300 Bq/m^3, unless it is warranted by national prevailing circumstances.

Areas have to be identified where the radon concentration in a significant number of buildings is expected to exceed the national reference level (radon action plan, Art. 103). Radon measurements have to be carried out in workplaces within these areas that are located on the ground floor or basement level (Art. 54). On principle radon measurements also have to be performed in specific types of workplaces e.g. mines, caves, water supply facilities, no matter if they are located within these radon areas or not.

In areas within workplaces where the radon concentration as an annual average exceeds the national reference level, despite remediation measures being taken to lower the radon concentration, this situation has to be notified and managed as a so-called "planned exposure situation"[1] except if due to short stays in rooms with high radon concentrations the exposure of the worker does not exceed 6 mSv/a (Art. 35). When the effective dose of the workers is less than 6 mSv/a, the competent authority shall require of the company management that the exposures of the workers are kept under review.

4 IMPLEMENTATION IN GERMAN LEGISLATION

For the implementation of the Council Directive 2013/59/Euratom in German legislation, major alterations to the existing German radiation protection regulations are necessary. The German federal government decided to create a new Radiation Protection Act independent from the existing "Atomic Act". The new Radiation Protection Act covers all radiation protection topics in a general manner. More detailed regulations will be provided by new additional ordinances. As before, the competent authorities for the licensing and supervision of radiation protection regulations will be the authorities in the German federal states.

A reference level for the annual average radon concentration in indoor air for all workplaces will be applied. The exact value of the reference level is currently subject to discussion.

Initial ideas have also been put forward on how to identify areas where the radon concentration in a significant number of buildings is expected to exceed the national reference level. The radon concentration in soil gas and the soil permeability will be the major criteria. It is in discussion that these areas (regions with “enhanced radon potential”) will be identified by the competent authorities of the federal states.
A list of specific types of workplaces, e.g. mines or water supply facilities, where measurements have to be carried out regardless of their affiliation to a region with "enhanced radon potential" already exists in the current Radiation Protection Ordinance. There will be no change effected by the new regulations. The existing regulations for radon exposed workplaces will be included in the new Radiation Protection Act or in the new related ordinances.

[1] The new sytem of basic safty standards of the EU Council Directive 2013/59/Euratom is grouped in three exposure situations: planned, existing and emergency exposure situations. "Planned exposure situation" means an exposure situation that arises from the planned operation of a radiation source or from a human activity (e.g. licensed activities). "Existing exposure situation" means an exposure situation that already exists when a decision on its control has to be taken and which does not call or no longer calls for urgent measures to be taken (e.g. radon exposures, gama radiation from building materials)

For the workplaces in the regions with "enhanced radon potential", it is expected that measurements in a large number of offices, diverse types of shops and public buildings will be necessary. Therefore, specific protocols have to be developed for measuring large buildings.

Currently it is not predictable how many buildings and company facilities will have to be remediated and in how many workplaces subsequent regulatory radon monitoring will be necessary.

In addition to the regulatory framework, education plans for various stakeholders such as safety engineers, public health departments and employers liability insurance associations should be established as part of the national radon action plan, the implementation of which is stipulated by the European Council Directive.

5 CONCLUSION

The new requirements of the European Council Directive 2013/59/Euratom oblige the EU member states to revise their radiation protection systems by the beginning of the year 2018. For most of the member states as well as Germany the radon regulations of the Council Directive will lead to challenging alterations for the supervision of radon exposure at workplaces. New requirements of the Council Directive concerning indoor radon concentrations will surely increase the awareness of the public for the health effects caused by radon exposure. Providing accurate and appropriate information for the public and the affected companies is essential. The aim of this information should be to increase public awareness for unacceptably high radon exposures without stoking fears. The companies should be informed about the new legal situation concerning their duties to comply with the reference level. Private homeowners should be encouraged to measure the radon concentrations in their dwellings.

On principle, the EU member states can also implement a reference level below 300 Bq/m³. But a lower reference level correlates with considerably greater efforts in performing remediation measures. Regarding the potentially great number of affected companies in Bavaria, a reference value of 300 Bq/m³ is constructive and feasible. Even this value is ambitious in consideration of the expected extent of necessary remediation measures. However, Germany has not yet made a final decision on the value of the reference level.

Following the implementation of the new regulations, the situation in Germany will be that at every workplace within a region with "enhanced radon potential" measurements have to be performed. Every workplace in an office or other type of room in the basement and ground floor will be affected. Currently only measurements at specific workplaces like mines and water supply facilities are compulsory.

The challenge will be to define a procedure to identify regions with "enhanced radon potential" which is scientifically resilient and generally accepted. This will increase the public acceptance for the regions which are identified by this procedure.

All these new requirements shall be implemented by 2018 in a new Radiation Protection Act and additional ordinances.

In comparison to the other 15 German federal states, Bavaria has one of the highest average radon exposure levels in Germany due to the geological situation. In this regard, especially the regions in East Bavaria are affected. Therefore, the impact of the new radon regulations on the radiation protection will be substantial.

However, the competent authorities in Bavaria have great experience in the field of radon. They provide a variety of brochures for download on the web. Details on basic radon aspects as well as information on remediation measures are available. Special meetings on radon have been organized for radiation protection and building experts as well as for the general public. Research projects have been set up in this field e.g. to develop a strategy for measurements in large public buildings.

The competent authorities in Bavaria are currently preparing themselves thoroughly for the new tasks.

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Contributions from Women to the Radiation Sciences

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Abstract. Contributions from men to radiation science are well known, particularly the early contributions from such luminaries as William Roentgen, James Chadwick, Niels Bohr, Robert Oppenheimer, and the like. Although not ignored per se, beyond Marie Curie and Lise Meitner, the contributions of female nuclear scientists are not as widely recognized. This paper provides a concise historical summary of contributions to radiation science from the discovery of radiation through the current status of international leadership within the radiation protection community. Beyond lead scientists and academics, this paper also considers support personnel as well as the role women have played, albeit inadvertently, in the advancement of radiation epidemiology.

KEYWORDS: gender; history; radiation protection.

1 INTRODUCTION

We consider here a timeline of the contributions women have made related to the broad field of radiation science. Studies have shown that having a role model to identify with is an important factor in the recruitment and retention of women (or other minorities) in the sciences, where women are still an underrepresented group [1, 2]. Recognizing the historical contributions from women, then, is important not just for the history of science, but for communicating the value of and continued need for women in science. Beyond providing stories of inspiration, considering this history of accomplishment, and in many cases sacrifice, also provides insight into how and why things have changed as well as the potential for identifying legacies of past events in current situations [2]. A summary of the milestones discussed herein is included as Figure 1.

Figure 1: A brief timeline of selected contributions of women to the radiation sciences

1901 – Harriet Brooks discovers radon
1903 – Marie Curie wins the Nobel Prize in Physics for her work with radiation and radioactivity
1911 – Marie Curie wins the Nobel Prize in Chemistry for the discovery of radium and polonium
1934 – Ida Noddack is the first to predict that uranium would fission into smaller atoms
1935 – Irene Joliot-Curie wins the Nobel Prize in Chemistry for the discovery of artificial radioactivity
1936 – Edith Quimby adds physics to the American Board of Radiology examination
1937 – Marietta Blau discovers “disintegration stars” in photographic emulsions
1939 – Lise Meitner provides the first theoretical explanation, and coins the term, for nuclear fission
1942 – Gertrude Sharff Goldhaber proves that a beta particle is identical to an electron
1949 – Elda Anderson becomes the first chief of education and training in Health Physics at ORNL
1949 – Liane Russell, with her husband Bill, take the lead of Mammalian Genetics at ORNL
1956 – Alice Stewart begins the Oxford Survey of Childhood Cancer
1957 – Chien-Shiung Wu proves experimentally that parity is not conserved in beta decay
1963 – Maria Goeppert Mayer wins the Nobel Prize in Physics for developing the nuclear shell model
1972 – Margaret Butler becomes the first female fellow of the American Nuclear Society
1972 – Patricia Durbin develops the biokinetic model for plutonium excretion
1973 – Dixy Lee Ray becomes the first (and only) female Chairperson of the US Atomic Energy Commission
1977 – Rosalyn S. Yalow wins the Nobel Prize in Physiology or Medicine for radioimmunoassay
1980 – Z.M. “Nettie” Beekman becomes the fifth (and first female) president of IRPA
1991 – E. Gail de Planque becomes the first female Commissioner in the USNRC
1992 – Kim Kearfott becomes the first woman to be awarded the HPS Elda E. Anderson Award
1995 – Shirley Ann Jackson becomes the first female Chairperson of the USNRC
2009 – Clair Cousins becomes first female chairperson of ICRP
2011 – Ryoko Ando becomes one of the prominent voices in promoting recovery in Fukushima
2012 – Renate Czarwinski becomes the second female president of IRPA

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2 THE WOMEN

2.1 The early years: 1895-1930

Early female scientists, and women in general, encountered many barriers in pursuit of their occupational field of choice due to their gender. Even exceptionally talented and qualified women had very limited educational opportunities, particularly in higher education. Also, even after receiving an advanced degree, most women had to take unpaid positions [3]. For perspective, at the time of Roentgen's discovery of x-rays in 1895, New Zealand (a British colony at the time) was the only country in which women had the right to vote. Only two more countries (Australia and Finland) granted women the right to vote by the time Marie Curie, a Polish-born French physicist and chemist, won her second Nobel Prize in 1911. Between 1915 and 1920 thirteen more countries granted this right, with twenty more between 1920 and 1945 [4]. As France granted women's suffrage in 1944, Marie Curie (1867-1923) was never allowed to vote in her lifetime, despite the fact that she was, and still remains, the only person to be a Nobel laureate in two scientific disciplines [5].

Marie Curie shared her first prize, the 1903 Nobel Prize in Physics, with her husband Pierre for their combined research on radiation and radioactivity, along with Henri Becquerel, who was awarded one-half of the prize for the initial discovery of radioactivity; as an aside, Marie was the one to coin the phrase "radioactivity." This was the same year she became the first woman in France to receive a doctorate. Five years later, Marie became the first female professor at the Sorbonne in Paris, having taken her husband's place after his untimely death in 1906. Soon after she was independently awarded the 1911 Nobel Prize in Chemistry for the 1898 discovery of polonium as well as the discovery and isolation of radium [5-7].

Although Marie Curie is the most recognized female radiation scientist, and arguably one of the most famous historical figures in science in general, there were other women who made related discoveries. For example, Harriet Brooks (1876-1933), a Canadian nuclear physicist and a student of Ernest Rutherford, discovered radon in 1901 and in 1904 became the first person to observe nuclear recoil following radioactive decay [8]. She worked as a tutor at a women's college for two years after, at which time she became engaged and was promptly asked by the dean to resign her position. Harriet found this ultimatum highly inappropriate, and the stress of the situation led her to leave both the position and the engagement. She worked briefly in Marie Curie's lab, but ironically ended up forming a second engagement and leaving research, seemingly for the social and financial stability marriage provided [3, 8].

With a similar view on the supposed incompatibility of marriage and science (for women, at least) Lise Meitner (1878-1968), an Austrian-born German physicist, never married and devoted her life's work to nuclear physics; she was of the mindset that science required one's complete dedication [9]. Lise discovered protactinium in 1917, in collaboration with the radiochemist, and her close friend, Otto Hahn. The same year Lise became head of the physics section at the Kaiser Wilhelm Institute for Chemistry and then a professor in 1919; no other women were given permanent scientific positions at this institution during Lise's tenure there, and only three are listed as authors on the institutions' publication list. Lise herself never published with another woman nor graduated a female doctoral student [9]. One of the women who was a student in Lise's section was Tikvah Alper, a South African who would become a prominent radiobiologist, although she had a broad range of expertise and experiences [10]. About five years later, Lise offered one of the first explanations (albeit not quite right) for the Auger effect, named for the French scientist Pierre Auger who experimentally observed said effect in 1923 and offered its complete theoretical explanation [11].

Many of these early discoveries found medical or commercial use. One of the now infamous examples is the so-called radium boom. For a while, radium was marketed as a medicinal cure-all, and even today, "radon caves" remain a tourist attraction in several areas [12]. A second utility emerged when it was discovered that radium could be combined with phosphorescent material to make luminous paint. From 1917 to 1926, the U.S. Radium Corporation extracted and purified radium to produce such paints. More than one hundred workers (~1,000 industry wide), mainly women, painted instruments (such as clocks) with radium, licking the brush tip to get a fine point. Although such "tipping" was prohibited starting in 1926, many young women had spent years ingesting radium, in some cases on the order of 40 μg. The subsequent health effects had a significant historical impact on industrial safety standards, and eventually (1941) a tolerance level for radium was established from dial painter data. Clinical studies of those exposed to radium, particularly dial painters, have resulted in major contributions to the understanding of radium's behavior in the body as well as the disease processes, including tumor formation, that result from ingestion of radium [13, 14].

On the medical side, diagnostic radiography also led to some significant exposures. In many instances, it was radiologists and technicians who received the highest doses, due to the frequency with which they were exposed. Such exposure may have even contributed to Marie Curie's anemic condition, as she served as a radiologist during World War I [3, 5]. Another group with fairly extensive exposures were those being treated for tuberculosis in the mid-1920s through the mid-1950s. Treatment at the time included collapsing the lung with subsequent inspection using x-ray fluoroscopy, which was repeated several times a month for up to five years. This resulted in considerable exposure to the chest. The increased risk of breast cancer in groups of such women helped identify the breast as a particularly radiosensitive tissue. Moreover, epidemiological analysis found that fractionation of dose had little impact on the risk of induced breast cancer, such risk remained high for a long time after exposure, and that age was a significant risk factor, with younger women being much more susceptible to radiation-induced breast cancer [15, 16]. The specific benefit of these risk estimates, compared to those from high dose scenarios, is that each examination resulted in a fairly low exposure, but the long-term continuation of said exposures resulted in measureable excess risk. As such, the corresponding risk estimates may be more relevant to realistic exposure scenarios, such as those seen occupationally or in diagnostic medicine [15].

In 1928, to address the health implications of effects starting to become evident from exposure to radiation, the International X-Ray and Radium Protection Committee (predecessor to the International Commission on Radiological Protection) was established, consisting of only five members [17]. The predecessor to the National Council on Radiation Protection and Measurements (NCRP), the United States Advisory Committee on X-Ray and Radium Protection, was established a year later in 1929 [18].

2.2 Pre-war developments: 1930-1945

Although the years leading up to World War II saw significant discoveries and progressions in the radiation sciences, this time was also tarnished by the rapid spread of anti-Semitism. Many scientists, of both genders, were forced to flee their homes and institutions to escape racial persecution. Even the Nobel committee has been accused of interpreting a lack of productivity due to forced emigration as a lack of dedication to the field, coloring the prize results of that time [19]. World War II also marked the first attack utilizing an atomic bomb. The road to the atomic bomb was remarkably fast, taking only 13 years from the initial discovery of the neutron to fully develop and deploy.

The formal discovery of the neutron was made by James Chadwick in 1932, by adapting experiments conducted by Irène Joliot-Curie (1897-1956) and her husband Frédéric. Irène, Marie and Pierre's daughter, and Frédéric were also close to discovering the positron and nuclear fission, having observed all of these experimentally, but they were unable to formulate a comprehensive explanation of their results. The pair were, however, awarded the 1935 Nobel Prize in Chemistry for the discovery of artificial radioactivity [3].

Nuclear fission had been observed by several groups, although was not identified as such for several years. In 1934 Ida Noddack (1896-1978), a German scientist, was the first person to suggest that the fission event might involve a large atom splitting into smaller atoms. Without a theoretical basis or experimental verification, this prediction was largely ignored [20]. As an aside, Ida Noddack also played an important role (along with her husband) in the identification of rhenium (1925) and technetium (1933), which have found use in both therapeutic and diagnostic nuclear medicine [21].

Experiments conducted by Otto Hahn in 1938 revealed that Ida Noddack's theory was true; fission did result in the splitting of the atom into fragments. Lise Meitner provided intellectual input regarding these experiments, but having fled Germany three months prior, she was not physically present for their completion. For related political reasons, she was not included on Otto's corresponding publication. She did provide the comprehensive theoretical explanation for the experimental results in 1939, publishing her results accordingly [9]. It was this paper that first used the phrase "nuclear fission" which was subsequently adopted by the community as a whole. Otto alone received the 1944 Nobel Prize in Chemistry for this discovery, even though Lise had long been his collaborator and her theoretical explanation considered seminal. Despite being nominated several times, she never received a Nobel [22].

In 1942 the Manhattan District began to develop the atomic bomb, following Enrico Fermi's demonstration of the first self-sustaining nuclear chain reaction. The Manhattan Project included in its ranks several female scientists as well as numerous female support staff [23]. The first atomic bomb was detonated at Trinity Site in 1945, followed by the bombings of Hiroshima and Nagasaki 3 weeks later.

Although much of the work during this time contributed to the development of peaceful nuclear power as well as the atomic bomb, work was also being done with other applications in mind. For example, nuclear medicine begin to grow as a field, with Edith Quimby (1891–1982), an American medical physicist, considered as one of its founders. She pioneered various brachytherapy and internal dosimetry systems, and even added physics to the American Board of Radiology examination in 1936 [24]. In 2011 the American Association of Physicists in Medicine (AAPM) lifetime achievement award was renamed in her honor to the Edith H. Quimby Lifetime Achievement Award [25].

Marietta Blau (1894-1970) was an Austrian-born Jewish physicist who did quite a bit of work in fundamental particle physics. She worked for more than a decade at the Radium Institute in Vienna, although her position was unpaid. The first two directors of the Radium Institute were known for supporting and encouraging women in science, with nearly a third of the scientists at the institute women. She pioneered the use of photographic methods for imaging high-energy nuclear particles and events, such as those originating in cosmic radiation [3, 19]. Protons were of particular interest to Marietta, and following the discovery of the neutron, she was able to quantitatively determine incident neutron energy through the resultant tracks of recoil protons. Her most famous accomplishment, though, was that she, with her associate and former doctoral student Hertha Wambacher (1903-1950), discovered "disintegration stars" in 1937, paving the way for the discovery of the pion. Marietta and Hertha were both nominated for the 1950 Nobel Prize in Physics by Erwin Schrodinger, which controversially went only to Cecil Powell for his follow up work with photographic emulsions and the discovery of the pion. Marietta was nominated at least twice more for the Nobel, but never received one; although there was evident, purposeful omission of Marietta from genuine consideration for these awards, it is unclear whether this is based in gender or race (or a combination of both). Marietta's situation was more difficult than most, as her closest collaborator, Hertha, was a member of the Nazi party, as were at least three other of her colleagues, who all actively worked against her starting in the early 1930s; Marietta left Vienna the day before Austria was annexed into the German Reich. From then on, the remaining physicists at the Radium Institute attempted to obscure any contributions Marietta made, even blatantly taking some of her work as their own [3, 19].

2.3 The Atomic Age: 1945-1980

This Atomic Age was the time of the Cold War, with many atomic weapons tested in the atmosphere, underground, and underwater throughout the world. However, this time also saw many other advancements in the radiation sciences, from fundamental principles to medical applications. This section reflects such variety in the radiation sciences, as different branches start to form within the broader field.

Gertrude "Trude" Scharff Goldhaber (1911-1998) was a German physicist, who experienced tremendous personal hardship in her lifetime, from having to eat bread made with sawdust during World War I to enduring her parents' death in the Holocaust in World War II [26]. She left Germany in 1935, as soon as she finished her PhD, and ultimately ended up in the United States at the University of Illinois. The interpretation of nepotism laws at the time prevented the hiring of spouses, so Trude's only option for work was to take an unpaid position in her new husband's laboratory and shift her research focus to his field: nuclear physics (her dissertation focus was in magnetism). It would be fifteen years post-doctorate before Trude would receive a regular, paid position on the staff at Brookhaven National Laboratory. She nonetheless flourished and is said to have been very cheerful. One of her early accomplishments was the discovery that spontaneous fission is associated with the emission of neutrons (1942), although this finding was held back until after the war. In collaboration with her husband, she also demonstrated that beta particles emitted in radioactive decay are identical to electrons (1948) [3, 26]. Some of her later work in nuclear physics was conducted in collaboration with her son, potentially the first of that particular familial pairing in physics collaborations. Brookhaven National Laboratory awards the Gertrude and Maurice Goldhaber Distinguished fellowship to early career scientists in the couples' honor.

A charter member and the fourth president (1959-1960) of the Health Physics Society (HPS), Elda "Andy" Anderson (1899-1961) was an American physicist who was instrumental in the formation of the HPS as well as the establishment of professional certification for health physicists in the United States [27, 28]. After working on the Manhattan Project, she became the first chief of education and training in the Health Physics Division at Oak Ridge National Laboratory (ORNL) in 1949 and was well-known for being a dedicated teacher and mentor. The Health Physics Society established the Elda E. Anderson Memorial Fund in her honor, from which the Elda E. Anderson Award was formed. This award has evolved to annually recognize a young member of the society for distinguished contribution to the profession of health physics [29]. Ironically, the first 30 years following the award's inception saw no female recipients; the first woman to receive the award was Kimberlee J. Kearfott (currently a professor in the Department of Nuclear Engineering and Radiological Sciences at the University of Michigan) in 1992 [30]. Andy's appointment at ORNL happened to coincide with the establishment of Mammalian Genetics Section (Mouse House) at ORNL, led by Liane "Lee" and Bill Russell. Among their many accomplishments was the demonstration of both dose-rate effects and radiation-induced hereditary effects in mice. In addition to Lee, many of the support staff, particularly technicians, were also women [31]. Oak Ridge National Laboratory currently awards an early career fellowship named in Lee's honor.

1956 saw the initiation of the Oxford Survey of Childhood Cancers, led by the medical doctor Alice Stewart (1906-2002). Although some of Alice's work has been criticized, this particular study was the first to bring attention to the potential risks of in-utero exposure to ionizing radiation and thus resulted in the general adoption of alternate obstetric imaging modalities [32].

Chien-Shiung Wu (1912-1997) was a Chinese-American scientist who is regarded as a founder of nuclear and particle physics. She made many contributions to the Manhattan Project, including uncovering the source of the reactivity loss experienced by Hanford reactors, but she is best known for her experimental work that proved parity is not conserved in beta decay (1957). She became the first female president of the American Physical Society in 1975 [3].

Maria Goeppert Mayer (1906-1972) was a Polish-American physicist who was the second, and only, woman behind Marie Curie to win the Nobel Prize in Physics (1963) for the 1948 discovery of magic numbers and development of the nuclear shell model. Her portion of the prize was shared with J. Hans Jensen, as they each independently proposed the nuclear shell structure of the atomic nucleus in the late 1940s. The American Physical Society created the Maria Goeppert Mayer Award in 1986 in her honor as an annual recognition of an outstanding early career female physicist [4]. That same year Dixy Lee Ray became the first female and last person to chair the US Atomic Energy Commission, which was abolished in 1974 in favor of splitting AEC responsibilities between different organizations to avoid the current conflict of interest (ultimately, these were the US Nuclear Regulatory Commission and the US Department of Energy).[1]

The NCRP in the United States was formally chartered the following year (1964). Both Edith Quimby and Rosalyn S. Yalow were among the charter members [18]. The International Radiation Protection Association (IRPA) began formation the same year, and was officially established in 1965 with its first congress subsequently held in 1966.[2]

Rosalyn "Ros" Sussman Yalow (1921-2011) was a nuclear physicist whose research focused on medical applications of radioisotopes. She became the first American woman to win the Nobel Prize in Physiology or Medicine (1977), awarded for developing radioimmunoassay (RIA) and which she shared with her long-time collaborator and friend Solomon Berson [33, 34]. RIA has found wide-ranging, far-reaching applications, from drug measurement and delivery to investigation of infectious diseases; RIA was truly revolutionary, but rather than patent their discovery, Sussman and Berson made every effort to make RIA accessible to anyone interested [34].

In 1972 Margaret Butler (1924-2013), an American mathematician and computer scientist, became the first female fellow of the American Nuclear Society. Argonne National Laboratory awards a computational science fellowship to early career scientists in her honor. Patricia Durbin (1927-2009), an American biophysicist, developed what has come to be referred to as the Durbin model for plutonium excretion in 1972, utilizing data from (ethically questionable) human injection studies conducted by the U.S. government in the 1940s [35, 36]. Pat's career largely focused on biodistribution and biokinetic models of various radionuclides, and she also made significant contributions in the development and improvement of chelating agents [36]. Also in the same year, Title IX of the Educational Amendments, which banned gender discrimination in federally-funded educational institutions, was signed into law in the United States [37].

2.4 The recent years: 1980s – 2010s

From the late 1940s, radiation protection began to evolve to be its own, diverse field. In recent years, the number of women actively pursuing careers in radiation protection and making significant contributions has increased dramatically, happily more than can be included here. As opposed to specific scientific contributions, then, this section focuses on the progress women have made in terms of leadership positions within selected sections of the current community.

Z.M. "Nettie" Beekman (1927-2013), originally trained as a medical doctor and radiologist, was the first female (and fifth overall) president IRPA, serving from 1980-1984. She was also one of the foundering members of the Dutch Society of Radiation Protection (1960), and is known for being essential to the development of radiation protection in the Netherlands [38]. The second female IRPA president behind Nettie is the current, outgoing president Renate Czarwinski, who took office in 2012, some 30 years later.[2] Also in international leadership is Claire Cousins, an interventional radiologist from the United Kingdom. Taking office in 2009, she is the current chairperson of the International Commission on Radiological Protection (ICRP) and the first woman ever to hold the position.[3]

In the United States, E. Gail de Planque was a nuclear physicist and health physicist who became the first woman to serve as a Commissioner (1991) of the US Nuclear Regulatory Commission (NRC). Her specialties included, among others, environmental radiation metrology and dosimetry. Shirley Ann Jackson is a theoretical nuclear physicist and the current president of Rensselaer Polytechnic Institute. She was the first African American woman to earn a doctorate from the Massachusetts Institute of Technology (1973), and was the first female to serve as chairperson of the USNRC (1995-1999).[4]

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[1] www.nrc.gov; http://energy.gov
[2] www.irpa.net
[3] www.icrp.org
[4] www.nrc.gov; www.rpi.edu

2011 saw the tragic natural disaster and subsequent nuclear accident at Fukushima-Daiichi. Although scientists researching in Fukushima are predominantly male, it is often women leading community support and education initiatives, from public health professionals to community members. One of the most notable of these women is Ryoko Ando, of Fukushima Ethos, who is very active in promoting the collaborative yet autonomous recovery of the area.[5]

3 FINAL THOUGHTS

There are many women, and many accomplishments, not captured here, particularly internationally. However, we hope to have presented an interesting timeline from a perspective not often seen in radiation protection. Beyond that, there are also undoubtedly many women whose accomplishments have been lost in the pages of history. Also, although there has been tremendous progress in societal reception of women in science since the discovery of radiation and radioactivity, and subsequently the number of women in the field, gender representation remains uneven, seemingly due to lingering issues associated with prior history of discrimination and stereotypes [39]. Most of the women mentioned here came from supportive families and/or had supportive colleagues, which is a tradition that will continue to be important in the inclusion and encouragement of young women (and men) across disciplines; that is, the recognition and communication that gender doesn't limit one's potential.

4 ACKNOWLEDGEMENTS

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Argentine Plan for strengthening occupational radiation protection infrastructure framed in the RLA 9075 IAEA project

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Abstract. In this work, Argentine national plan is presented, aimed to strengthen occupational radiation protection infrastructure for end-users of the Nuclear Regulatory Authority's controlled installations, framed in the RLA 9075 IAEA project. The RLA 9075 project was created with the objective of strengthening in Latin America an adequate infrastructure for end-users that allows promoting compliance of requirements and regulations for radiation protection of workers and patients, as well as the implementation of national education and training strategies. The preceding project RLA9066-TSA 2, advanced on these issues exclusively for the occupational area, highlighting the need to enhance adequate implementation of radiation protection programs. It detected that in most of Latin American countries, technical support services do not meet the demand in terms of coverage of monitored individuals and required quality of analytical techniques. A revision of Argentine's current external and internal individual monitoring situation and the activities associated with NORM and radon is presented. Four interest areas were identified: external dosimetry, internal dosimetry, safety culture, radon and NORM. Coordinators of these areas were appointed. Within each of the areas, activities related to the objectives and challenges of the RLA 9075 project were defined, which should be developed over the period 2014-2017. Finally, it is presented the action plan for ensuring that end-users adequately comply with regulations and radiological protection requirements established in the International Safety Standards, its progress and prospects that should be held at local and regional levels.

KEYWORDS: RLA 9075 IAEA project, radiation protection programs, technical support services.

1 INTRODUCTION

The RLA 9075 project was created with the objective of strengthening in Latin America an adequate infrastructure for end-users that allows promoting compliance of requirements and regulations for radiation protection of workers and patients, as well as the implementation of national education and training strategies. In Argentina the project was separated in two parts constituted by the radiation protection in occupational and patient exposures.

The preceding project RLA9066-TSA2, advanced on issues exclusively for the occupational area, highlighting the need to enhance adequate implementation of radiation protection programs. It detected that in most of Latin American countries, technical support services do not meet the demand in terms of coverage of monitored individuals and required quality of analytical techniques. In this work, Argentina's national plan is presented, aimed to strengthen occupational radiation protection infrastructure for end-users of the Nuclear Regulatory Authority's (ARN, acronym in Spanish) controlled installations, framed in the RLA 9075 IAEA project.

A revision of Argentina's current situation of external and internal individual monitoring and the activities associated with NORM and radon is presented. Four interest areas were identified: external dosimetry, internal dosimetry, safety culture, radon and NORM. Coordinators of these areas were appointed. Within each of the areas, activities related to the objectives and challenges of the RLA 9075 project were defined, which should be developed over the period 2014-2017.

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2 CURRENT SITUATION IN THE COUNTRY OF OCCUPATIONAL RADIATION PROTECTION OF THE ARN'S CONTROLLED INSTALLATIONS

Argentina has a broad spectrum of radioactive and nuclear installations distributed throughout the country. The facilities regulated by the ARN have different purposes such as electricity generation, manufacture of nuclear fuel, radioisotope production, sterilization of medical equipment, use and application of the ionizing radiation in medicine, industry, among others. They are classified as shown in Table 1.

Table 1: Classification of facilities regulated by ARN

Facilities		
Class 1	Class 2	Class 3
nuclear power reactors, production and research reactors, critical facilities, nuclear facilities with potential of nuclear criticality, particle accelerators with E> 1MeV (except accelerators for medical use), fixed or mobile irradiation plants, production plants of open or sealed radioactive sources, radioactive waste management facilities, mining manufacturing facilities that include the site of final disposal of radioactive waste generated in its operation	particle accelerators with E <1 MeV, linear accelerators for medical use, teletherapy and brachytherapy facilities, nuclear medicine facilities, self-shielded irradiators, industrial gammagraphy, mining facilities that do not include the site of final disposal of radioactive waste generated in its operation, nuclear facilities without potential of nuclear criticality, industrial meters, research and development in biomedical and physiochemical areas, import, export and storage of radioactive material, fractionation and sale of radioactive material.	*in vitro* diagnostics for humans, use of open sources of very low activity in research or other applications, use of sealed sources of very low activity in research, teaching or other applications.

2.1 Occupational radiation monitoring of facilities controlled by ARN

The ARN establishes in its basic radiation safety standard [1] that individual dosimetry monitoring should be performed in all staff that works on a routinely way in controlled areas.

2.1.1 External individual monitoring

The ARN does not exercise direct control over the technical services that provide dosimetry services, but it does indirectly through requirements for regulated facilities related to the services they choose.

Until 2014, the ARN established that the external individual monitoring could only be carried out by dosimetry services involved in periodic intercomparison exercises made by recognized entities. Later, it was found that the requirement of participation was not sufficient to ensure the reliability of dose assessments, so were added the following requirements:

(a) The service participates at least in biennial dosimetry intercomparison exercises organized by the ARN or in equivalent periodic exercises organized by an internationally recognized institution, which must be accepted, case by case, by the ARN.
(b) The service meets the requirements of Item 7 "Performance Limits" of the IRAM-ISO 14146 [2]. (The performance of a laboratory is considered acceptable if it meets the criteria established in the IRAM-ISO 14146 standard, which mentions "it is recognized that at most one tenth of irradiated dosimeters can exceed the limits given").
(c) The service has a quality management system in which the technical and administrative aspects of personal dosimetry are included, taking into account national and international recommendations.

Comments on the General IAEA Safety Requirements - Part 3 - and Suggestions for the Next Publications

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Abstract. The international recommendations in question are described 52 requirements specified from chapter 2 to 5. The first chapter states that the number of fundamental safety principles has been increased form 3 to 10. To implement these requirments, the IAEA mentions 14 main parties but it is not clear which party is responsible for each of the fundamental safety principles. Chapter 2 presents 5 general requirements for protection and safety and makes it clear the responsibilities and competence of the government and regulatory body. ; but the responsibilities and competence of the other 12 principal parties reported in requeriment 4 are not clear. Chapter 3, which includes 37 requirements, is the most extensive and deals with planned exposure situations. Due to its extension, chapter 3 is left for a future paper, in case my comments are considered of some value by the principal parties involved. Chapter 4, with 4 requirements, deals with emergency exposure situations; and in chapter 5, the 6 requirements are about existing exposure situations. As to the requirements exposed in chapters 1, 2, 4 and 5 I have verified that the responsibilities and competence of the government and the regulatory body are clearly specified, which is not true for the other 12 principal parties. It is concerning this specific matter that I have made comments and suggestions. I also discuss the matters that are not under the responsibility of the radiological protection services but of other parties. Could the radiation protection service as a whole or in part be delegated to others, including the attributions of registrants or licensees?

KEYWORDS*: *IAEA International Recommendations, Radiation Protection Requirements.

1 INTRODUCTION

Chapter 1.

In this chapter the IAEA establishes 10 safety principles that are considered fundamentals – conversely, the ICRP mentions only 3. The IAEA also says that the 3 IRCP principles were separated into 4 by the Agency.

Some of these 10 principles are not very clear as to who is the responsible for developing and implementing them, as it is shown below.

Principle 1: Responsibility for safety

According to the IAEA, the prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks. I believe it is in charge of the registrants and licensees.

It also mentions some other parties, but it looks rather as an example than all the possible interested parties given in requirement 4.

Principle 2: Role of government

This chapter is quite clear and suggests the formation of an independent regulatory body.

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In relation to radon in dwellings, the Argentine's Basic Radiological Safety Standard, AR 10.1.1 rev 3 [1] establishes a radon gas action level of 400 Bq / m^3 above which, actions must be taken. Currently the ARN is in the process of reviewing and updating its standards. This includes radon and is oriented to a value of 300 Bq/m^3 equivalent to approximately, 10 mSv/y, according to the new recommendations of IAEA and ICRP [5, 6].

Also ARN has performed radon measurements related with nuclear fuel cycle activities. These are considered planned exposure situations and therefore dose limit for workers apply. Standard AR 10.1.1 establishes in this sense that the limit for workers exposed to Rn-222 is 4 Working Level Months in one year [1].

For both radon exposures (residential and occupational) the impact of future changes of radon dose conversion factor has to be assessed.

3 CHALLENGES AND OBJECTIVES

The main challenges expected to be achieved at the end of the RLA9075 project in occupational radiation protection are the following [7]:

(a) Ensuring radiological protection of workers in medical and industrial applications.
(b) Achieve recognition of the technical competence of dosimetry services.

The general objectives to be achieved during the RLA9075 project in occupational radiation protection are the following [7]:

1. Establish occupational radiation protection programs for end users including optimization and safety culture.
2. Strengthen dosimetry services, individual and area monitoring, and calibration services.

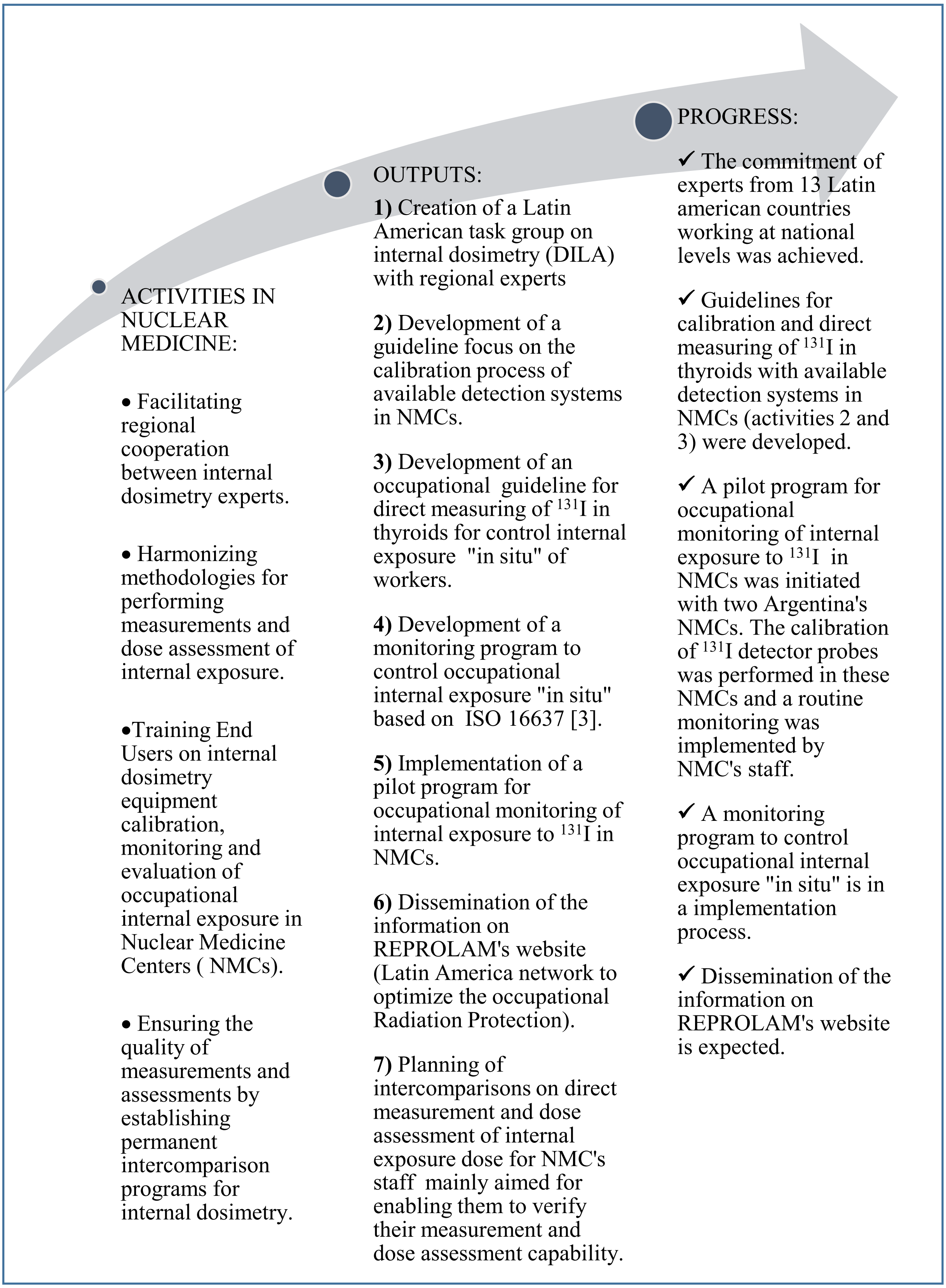
Regarding these general objectives, they were proposed specific objectives related to four topics that were identified of interest among the ARN's controlled installations. The specific objectives were oriented to achieve the optimization of protection program and promotion of safety culture in nuclear medicine, in industrial application, in NORM and radon and strengthening monitoring services. These specific objectives are:

a. Strengthening capabilities for surveillance of occupational internal exposure in Nuclear Medicine Centres (NMCs).
b. Achieve the improvement of prior risk assessment in industrial applications.
c. Providing training to stakeholders related to NORM and radon.
d. Ensuring the quality of measurements and assessments provided by dosimetry services.

4 ACTION PLAN AND ITS PROGRESS

Activities were proposed with the aim to achieve the optimization of protection program and promotion of safety culture in nuclear medicine, in industrial application, in NORM and radon and for strengthening of monitoring services. These activities were grouped by each topic and are shown in the Figures 1, 2, 3 and 4 with their respective outputs and progress.

Figure 1: Action plan in nuclear medicine, outputs and progress



New EU-Regulations for Radon at Workplaces and their Consequences on the Regulatory Radiation Protection in Bavaria

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Abstract. In 2014 the new European Council Directive 2013/59/Euratom containing comprehensive radiation protection regulations came into force. All objectives of the directive have to be implemented into national law by 2018. For example, a reference level for the mean radon concentration at workplaces of up to 300 Bq/m³ has to be established by the member states. As a result, new German regulations for radon at workplaces are currently in preparation. These regulations will cover requirements for the measurement of radon and obligations for graded remediation measures if the reference level is exceeded. Companies with employees exceeding an effective radon dose of 6 mSv/a will be continuously supervised by the competent authority. The EU member states are also required to set up programs to identify areas where the radon concentration in a significant number of buildings is expected to exceed the reference level. Only in these areas will measurements at workplaces be mandatory. Since 2001, radon exposure at specific workplaces has been regulated by the German Radiation Protection Ordinance. Consequently, every single workplace of these specific types in Bavaria has been surveyed with regard to radon concentrations in the indoor air and the radon exposure of the staff. Especially in water supply facilities, elevated exposure levels of the staff were detected. Remediation measures adjusted to local conditions were implemented and typically led to a considerable reduction in the exposure. The measurement, the remediation measures and the success of the measures are supervised by the Bavarian competent authority. It is stipulated by the new European Council Directive that all workplaces with elevated radon concentrations have to be subjected to regulatory supervision in addition to the specific workplaces mentioned above. Measurements in a large number of offices, diverse types of shops and public buildings and, when appropriate, subsequent regulatory monitoring of these workplaces will be necessary.

KEYWORDS: radon; workplaces; remediation measures; reference level; Council Directive 2013/59/Euratom

1 INTRODUCTION

In 2014 the new European Council Directive 2013/59/Euratom [1] containing comprehensive radiation protection regulations came into force. All objectives of the directive have to be implemented into national law by the EU member states by February 2018. A reference level for the mean radon concentration at workplaces of up to 300 Bq/m^3 has to be established by the member states. As a result, new German regulations for radon at workplaces are currently in preparation.

2 RADON EXPOSURES AT BAVARIAN WORKPLACES

Since 2001 the German Radiation Protection Ordinance [2] (GRPO) contains regulations for radon exposures at specific "radon-exposed workplaces". According to the definition in the GRPO, "radon-exposed workplaces" are underground mines (including visitor mines), caves, radon spas and water supply facilities. For workers at these specific workplaces the radon exposure has to be measured. Workers exceeding an effective dose of 6 Millisievert per year (mSv/a) have to monitor their radon exposure continuously (action level). The legal limit for the maximal annual effective dose is 20 mSv, equal to the limit for the approved handling of artificial radioactive material e.g. in NPPs.

For all other workplaces as well as for dwellings there are currently no legal regulations concerning radon exposure.

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Figure 3: Action plan in monitoring services, outputs and progress.

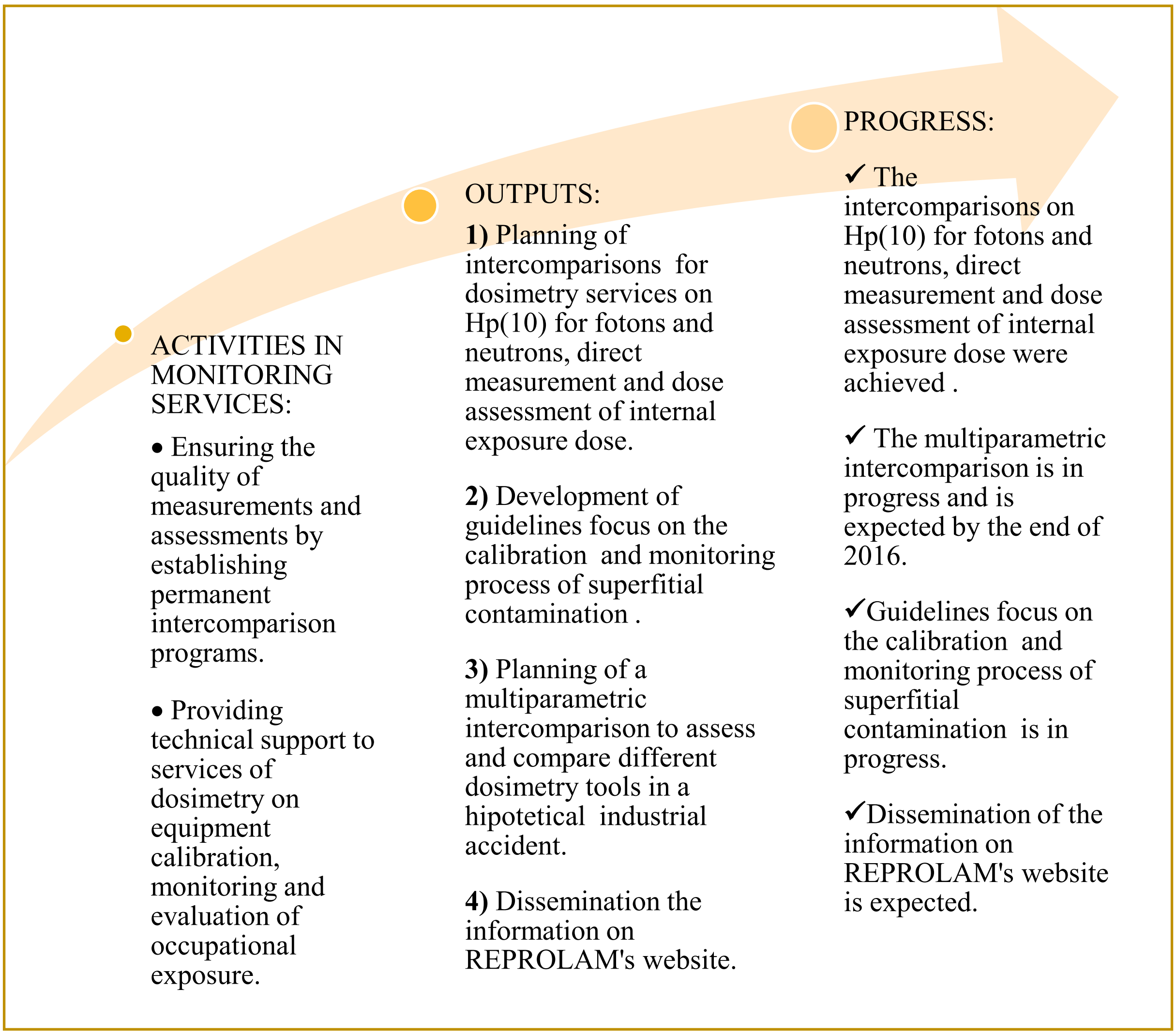
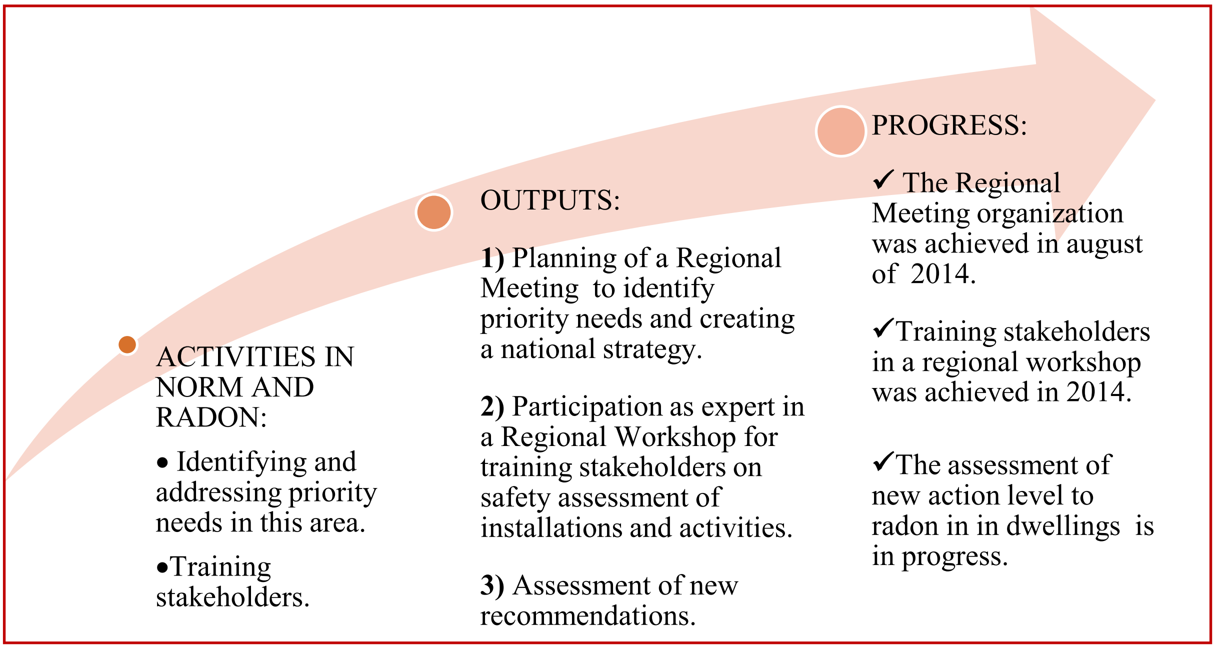


Figure 4: Action plan in NORM and Radon, outputs and progress



5 CONCLUSIONS

They were presented specific objectives, action plans and their progresses for four topics that were identified of interest, which were: the optimization of protection program and promotion of safety culture in nuclear medicine, in industrial application, in NORM and radon and strengthening of monitoring services. Up to now, the implementation of programmed activities has been successful and it is expected to meet the following outcomes: capabilities strengthened for surveillance of occupational internal exposure in NMCs, improvement of prior risk assessment in industrial applications, ensured quality of measurements and assessments provided by dosimetry services and trained stakeholders related to NORM and radon.

6 ACKNOWLEDGEMENTS

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Activities of EUTERP, the European Training and Education in Radiation Protection Foundation

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Abstract. The platform for European Training and Education in Radiation Protection (EUTERP), originally an initiative of the European Commission, was transformed into a legal entity as a Foundation under Dutch law in June 2010. The main objective of the Foundation is to encourage and support harmonization of education and training requirements for Radiation Protection Experts (RPEs), Radiation Protection Officers (RPOs) and radiation workers (RW), facilitating the mobility of these professionals. The EUTERP Foundation aims to facilitate information exchange between all stakeholders in education and training in radiation protection through the website www.euterp.eu; the publication of newsletters and the organization of workshops. EUTERP is also an active partner in the European Network on Education and Training in Radiological Protection (ENETRAP III 7Framework Programme project- 7FP). It contributes to the new formulation of guidance for the implementation of education and training of the RPE and RPO, in accordance with the revised European Council Directive 2013/59/Euratom [1]. In close collaboration with the association of the Heads of European Radiological protection Competent Authorities (HERCA), EUTERP strives towards a common understanding and approach in education and training of RPEs and RPOs whilst respecting the differences that exist in the different European Member States.

KEYWORDS: EUTERP Foundation; education and training; radiation protection; ENETRAP.

1 BACKGROUND

Since June 2010, when the EUTERP Foundation as a legal entity under Dutch law succeeded the EUTERP Platform that had been a project of the European Commission, it has been operating as a focus for European education and training in radiation protection. The Foundation has been run on a not-for-profit budget supported by a growing number of Associates who are taking an increasingly active part in EUTERP projects and actions. There are currently 20 Associates including two Europe-wide organizations, from 12 countries. The Associates recently elected the Board of the EUTERP for the next three years.

2 OBJECTIVES

The objectives of the EUTERP are:

- to encourage and support harmonization of education and training requirements for Radiation Protection Experts (RPEs), Radiation Protection Officers (RPOs) and radiation workers (RW), facilitating the mobility of these professionals;
- to encourage and support harmonization of education and training requirements for Radiation Protection Experts (RPEs), Radiation Protection Officers (RPOs) and radiation workers (RW), facilitating the mobility of these professionals;
- to promote the integration of radiation protection education and training systems into general vocational training and education infrastructures; and

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- to act as a central focus for the sharing of information on training events, standards, developments, and all other related information.

3 STAKEHOLDERS

The EUTERP Foundation has contacts in every European Member State and potential states, except Estonia with whom contact has been made to include them shortly. These 34 contacts are designated as National Contact Points (NCPs) for the dissemination of information about their country's situation with respect to legislation, education and training in radiation protection.

The major EUTERP stakeholders are the Associates. These institutions or organizations have a vested interest in the EUTERP, contributing to the work programme, projects, Board elections and budget. The EUTERP now has 20 Associates, two being from European-wide organizations. Their ideas and opinions are invaluable to the functioning of the Foundation. All institutes, universities and other organizations involved in radiation protection education and training in Europe are invited to become Associates. The benefits, listed on the EUTERP website, are becoming more widely recognised and the President is always willing to give talks about the work of the EUTERP during national events. He can be contacted through the website.

4 ACTIVITIES

The EUTERP Foundation activities are based around its website, newsletters workshops and collaborative projects, as described here.

4.1 Website

The EUTERP website at www.euterp.eu is constantly being updated, having been revamped twice since 2010. Currently it features information about its background and objectives, daily news bites, Associates' pages, National pages and National Contact Points for each European country, the latter in detail where such information exists. The NCPs are contacted with a view to updating their pages.

Another tab takes you to the career centre for information on relevant legislation, qualification frameworks and some information about professional meetings. A recent title will include research and job opportunities as the EUTERP is informed about these. The following tab is the main education and training tab, which will have access to the ENETRAP database in the near future. At the moment there is information on various training courses.

The final tab enables the website to have direct links into related projects and networks. The concept of a discussion forum has also been included and it is hoped to develop this in the future, depending on demand from Associates and NCPs.

4.2 Newsletters

The EUTERP Foundation has now issued eleven newsletters that are archived on the website. The most recent one was issued in April 2016. Every Associate and NCP contact is encouraged to submit items to include in the newsletters and on the website. The readership is much wider than the EUTERP "contacts" and indeed the number of people receiving each newsletter directly is currently 236 while many items are tweeted or otherwise referenced or forwarded, and the dissemination is wider than Europe. Persons interested in receiving the newsletter directly can subscribe on the website.

4.3 Workshops

EUTERP organizes workshops and also collaborates with other organizations that have an interest in education and training in radiation protection.

4.3.1 The 6th and most recent EUTERP workshop "*Legislative change in Europe: the implications for training in radiation protection - Rising to the challenge*", was held from 30 September to 2 October 2015, in Athens. This workshop focused on the required changes in legislation in the European Union and the associated training implications, as a result of the new Basic Safety Standards (BSS) Directive (2013/59/Euratom) [1]. Member States are required to bring into force the laws, regulations and administrative provisions necessary to comply with the new BSS Directive by February 6, 2018. This will be a challenge, requiring changes to national legislation, major revision of training activities and new approaches to the qualification and recognition of Radiation Protection Experts and Medical Physics Experts (MPE). This workshop was divided into a series of sessions focussed on specific topics associated with the new BSS.

Session 1 looked those sections of the new BSS of specific relevance to training including the provision of information and training of workers potentially exposed to orphan sources, emergency workers, outside workers, the training of operators of non-medical imaging equipment, information to workers and members of the public potentially exposed to radon, and the training requirements for the new roles of Radiation Protection Expert (RPE) and Radiation Protection Officer (RPO). Session 2 looked at communicating risks, and a series of very good presentations prompted an excellent discussion on the difficulties associated with expressing the concept of risk to non- scientific persons and members of the public. The session concluded that it is essential for trainers to be objective and unbiased in the presentation of facts, to follow a balanced approach and to structure their approach to the nature of the audience. Target audiences and the training objective can be subdivided into:

- Professionals who need radiation protection information to carry out their work: e.g. solicitors, engineers – *information provision*.
- Exposed persons and workers – *trying to achieve changes in behaviour*.
- Members of the public - *provision of information to enable informed judgements*.

The training must be carefully designed to meet the needs of each of these audiences noting that an appropriate course for one group may not be suitable for another.
Session 3 covered occupational exposure and inevitably prompted much discussion on the roles and associated training requirements for RPEs and RPOs. Most Member States already have persons carrying out these roles, although they are not named as such. There is clearly a strong desire to minimise legislative change and countries are likely to incorporate existing roles defined within their legislation to carry out the RPE and RPO functions. The outcomes of the ENETRAP III project were discussed in Session 4 and presentations were given on the new specialised training modules for RPEs in the medical, nuclear reactors, geological disposal and NORM (naturally occurring radioactive material) sectors. The guidance currently being developed on the roles of the RPE and RPO was presented and it was agreed that this should provide helpful but not mandatory guidance on best-practice methods for implementing the RPE and RPO requirements. Further sessions covered occupational exposure in the medical sector, an area where there is clearly well-established training programmes in place for a wide range of staff, and emergency response arrangements. Three working groups looked at the topics of stakeholder involvement in training development, train the trainers, and risk communication. The groups identified a number of critical issues associated with the topics and these issues were discussed in detail in the plenary session. The very constructive discussions that were held over the three days provided much food for thought and should provide useful input into the efforts of Member States to address the training requirements associated with the new BSS. Further information on the workshop, including copies of the presentations and the book of abstracts, may be found on the EUTERP website: http://www.euterp.eu/EUTERP2015/.

4.3.2 Next to the organization of its own EUTERP Workshops, the Foundation is also very much involved in the organization committee of the international ETRAP conference (Education and Training in Radiation Protection), which is the leading European conference on education and training in radiation protection matters, held about every four years and organized by the European Nuclear Society in collaboration with International Radiation Protection Association (IRPA) and International Atomic Energy Agency (IAEA). The next conference is planned for spring 2017 in Spain.

4.3.3 The EUTERP will also chair the education and training session of the upcoming *Radiation Protection Week* (RPW) being organized in Oxford, from 19 to 23 September 2016. The Radiation Protection Week is a 'must' for all scientists and decision makers participating in high-level radiation research globally. For the first time, RPW2016 will bring together complementary strands of radiation protection research, education and training with the established European platforms MELODI (Multi-disciplinary Low Dose Initiative), EURADOS (European Radiation Dosimetry Group), NERIS (European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery) and ALLIANCE (European Radioecology Alliance) as co-organizers, along with other relevant areas. The RPW2016 will extend the highly successful MELODI workshops (http://www.melodi-online.eu/index.html) in the light of greater integration of European research on radiation protection demonstrated by the European Joint Programme for the integration of radiation protection research (CONCERT) (http://www.melodi- online.eu/CONCERT.html).

4.3.4 Recently, EUTERP has also been invited to contribute to the education and training session of the next regional European IRPA conference, to be held in The Hague, Netherlands in 2018.

4.4 Projects

The most important project in which the EUTERP is currently involved is ENETRAP III under the framework programme, FP7, of the European Commission. This is a four-year project and one of the critical deliverables is the incorporation of the ENETRAP III course database, together with links to others, in the EUTERP website. The project is currently on track, another deliverable being the production of guidance for the implementation of education and training of the RPE and RPO, in accordance with the revised Council Directive 2013/59/Euratom [1].

5 CONCLUSIONS

The EUTERP Foundation provides a central focus and forum for all radiation protection education and training activities in Europe. It liaises with other European organizations and participates in projects and events with the aim of developing and enhancing training activities, and promoting a common understanding of training needs and requirements of all persons involved in activities using ionizing radiation. The EUTERP Associates contribute to the policy development and implementation of education and training activities in radiation protection.

6 REFERENCE

[1] European Council Directive 2013/59/Euratom, laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation.

A model for determining risk constraints for potential exposures of the public and limitations of the activity of radionuclides released by accidents in nuclear facilities

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Abstract. While regulating authorities in different countries generally apply unanimous values of dose constraints for public exposures from normal operation of nuclear facilities, regulations concerning acceptance levels for potential releases of radionuclides from accidents are varying and occasionally not given as explicit values. The paper proposes a model for calculation of dose constraints for different potential accident events. The model is based on the general principles of radiation protection given by ICRP. This includes the assumption of a linear non-threshold hypothesis for stochastic radiation effects below 100 mSv and that the frequency of accidents can be made small by high safety requirements, but never zero. The model uses three additional principles; (i) the sum of all of the best-estimate values of accident event frequencies multiplied by the corresponding integrated effective dose should be less than a certain dose constraint per year, where (ii) the dose constraint should be chosen not higher than the dose constraint for public exposures from normal operations and in relation to society's perception of risk from other comparable sources such as the natural radiation background. This, however, is not enough when it comes to severe accidents with very low frequencies, which could result in releases that could cause deterministic radiation effects in the population. To tackle this problem, (iii) the solution could be a robust defence-in-depth principle or a "peoples´ release defence insurance system" that prevent emissions of radioactive substances to become so large that they could inflict deterministic injuries in people or cause large land areas to be contaminated with long lived radionuclides. This robust defence-in-depth barrier should be applied regardless of how low the probability of the accident is assumed to be. How dose constraints for different classes of accident events can be calculated is shown in the paper together with a discussion on pros and cons around these principles. The idea is that a regulatory authority should be able to use the model to obtain dose constraints and calculate activity release constraints for accidental releases of different frequencies and if necessary impose additional requirements on barriers to reduce large potential exposures of the public and the risk of contamination of large areas with long lived radionuclides.

KEYWORDS: Potential exposure, dose constraint, activity release, nuclear accidents, probabilistic safety assessment, event classes, defence-in-depth.

1 INTRODUCTION

What is an acceptable long-term dose to the public from potential nuclear accidents in the future? The question does not have a straightforward answer. ICRP Publication 103 [1] considers planned exposure situations, existing exposure situations and emergency exposure situations and provides recommendations in the form of numerical values of dose limits, dose constraints and reference levels. However, for accidental exposures that may arise in the future because of deviations from planned procedures, there is not so much numerical guidance given. Such potential exposures are not normally expected to occur, but can be anticipated when a practice is continued over a long time and their occurrence can be forecasted by probabilistic safety assessments. ICRP Publication 64 [2] has provided a conceptual framework on how to use probabilities and dose estimates to obtain risk constraints for potential exposures. In ICRP Publication 76 [3] it is demonstrated how this could be applied to incidents with radiation sources. For major accidents in nuclear facilities that could lead to releases of radioactive material to the environment, ICRP has not yet given explicit numeric values that could be used for setting constraints to limit potential exposures. IAEA has taken up the aspects of risk and the concept of potential exposure in nuclear and radiation safety and pointed out that not only individual risks but also societal risks should be considered [4]. Regulating authorities in countries with nuclear power plants have generally issued requirements on systematic identifications of sequences of events and conditions that can lead to uncontrolled releases of radioactive material to the

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environment. Some countries have given explicit target values for frequencies and effective doses to the most exposed in the public, among others for example UK [5] and Sweden [6]. Other countries have given certain numerical values in combination with the description of a philosophy to reduce, as far as reasonably achievable, releases and their impact on the public and the environment.

This work is an attempt to suggest procedures for calculation and selection of values of risk constraints to limit potential exposures down to levels that may be acceptable to the public in the long term. From the decided constraints for potential exposures it is shown how to obtain activity release constraints. The suggested procedures could be useful for a regulatory authority in the process of examining design proposals and setting requirements on the construction and operation of new nuclear facilities.

2 BASIC PRESUMPTIONS

2.1 The ICRP framework

The acceptance criteria suggested here for the potential dose per year to the most exposed public is based on the ICRP framework [1] for which the principles of justification, optimisation and application of dose limits form the basis for radiological protection. For planned exposure situations, such as occupational exposure and public exposure from practices, ICRP have defined individual dose limits. For public exposures the dose limit is 1 mSv/a. In addition to this, site specific dose constraints can be applied.

ICRP uses the concept of dose constraint to restrict individual doses for specific types of sources and their use. Dose constraint is not a dose limit. Countries have generally chosen dose constraints for public exposures from planned operations of nuclear energy facilities to be in the range of 0.1 – 0.3 mSv/a. Exposures from accidents are not included.

Accidents resulting in releases of radionuclides will give rise to emergency exposure situations that can affect the public. Such exposures are not planned to occur, but if their probability is not zero they could occur sometime in the future. This is called potential exposure by ICRP. The frequency of events leading to uncontrolled release of radionuclides and potential exposures of the public can be made very low by high demands on safety and security, but not always zero.

The ”linear-non-threshold” hypothesis is assumed for effective doses below 100 mSv. In this region, an increment in dose is assumed to produce a directly proportional increment in the probability of incurring cancer and heritable effects (stochastic effects). This means that all potential doses below 100 mSv can be added to give a total probability of stochastic radiation effects as long as the sum will be lower than 100 mSv.

Table 1: Example of event classes that can be used to classify accidental events in nuclear facilities that could lead to release of radionuclides to the environment.

Event classes. The sum of all events in a class leading to accidental release	Frequency (events per year*)
H1 (normal operation)	
H2	10^{-2} - 10^{-0}
H3	10^{-4} - 10^{-2}
H4	10^{-4} - 10^{-6}
H5	$< 10^{-6}$

* A frequency per year of 10^{-2} strictly means that the event probability in any one year is $1 - e^{-0.01} = 0.00995 \approx 10^{-2}$.

2.2 Frequencies of events leading to accidental releases

Probabilistic safety assessments (PSA) are used in the nuclear industry to calculate the probable frequency of accidental events leading to releases of radionuclides (PSA level 2) and their impact on the public and the environment (PSA level 3). Events can be sorted into event classes. An example of event classes is given in Table 1.

2.3 Dose calculation for accidental release events

For each potential event leading to an accidental release of radionuclides from the facility a dose calculation should be made. The dose calculation for potential exposures of the most exposed public should include:

- Effective dose from external exposure from radionuclides in the passing cloud.
- Integrated effective dose from inhaled radionuclides.
- Integrated effective dose from external exposure from radionuclides deposited on the ground and on various structures and items.
- Integrated effective dose from intake of radionuclides in foodstuffs and drinking water.

Since an accidental release can affect people of all ages and since the average life expectancy is slowly increasing in the world, an integration time of 70 years could be justified.

3 ACCEPTANCE CRITERIA FOR DOSE CONSTRAINTS

3.1 Calculation and limitation

From the probabilistic safety assessments and the calculation of effective dose for each event an expected average value of the potential dose can be calculated. As long as all doses are kept below the threshold of deterministic effects the doses weighted by their frequencies can be added.

3.1.1 Expected value of the potential dose per annum to the most exposed public

The probabilistic expected value of the potential integrated annual effective dose from all accidental events leading to public exposure can be written as a sum of products of the frequencies and doses:

$$\bar{\dot{E}}(\tau) = \sum_{i=1}^{n} E_i(\tau) P_i \qquad (1)$$

where P_i is the frequency (per year) of accidental event number i leading to the potential integrated effective dose $E_i(\tau)$ over the time period τ, and n is the total number of events.

3.1.2 How to choose a limiting value for the potential dose

The expected potential integrated annual effective dose $\bar{\dot{E}}(\tau)$ should be limited by good technical design that keeps the number of potential adverse events, their frequencies and their resulting doses low. Let us say that it should be less than or equal to δ.

$$\bar{\dot{E}}(\tau) = \sum_{i=1}^{n} E_i(\tau) P_i \leq \delta \qquad (2)$$

The limiting value δ must be decided. A number of factors will influence the decision. The following considerations should be taken into account when selecting the δ-value:

(1) Since the δ-value represents a maximum average dose per annum to the most exposed public for a long future time interval using a practice, the value should be lower than the annual dose limit for the public, otherwise the ICRP basic rule of dose limitation is set aside. So, in any case, $\delta < 1$ mSv/a.
(2) The value should preferably be lower than the dose constraint for normal operation of nuclear facilities, which implies $\delta < 0.3$ or $\delta < 0.1$ mSv/a, otherwise the long-term use of nuclear facilities will on the average increase doses to the most exposed public above what the public has been told.
(3) Choosing a sufficiently lower value than the dose constraint for normal operation, maybe a value of 1/10 of the value for normal operation could be acceptable to the public. This would be about 1% of the average external annual dose from natural radiation. So one choice could be to set $\delta =$ 0.01 mSv/a.

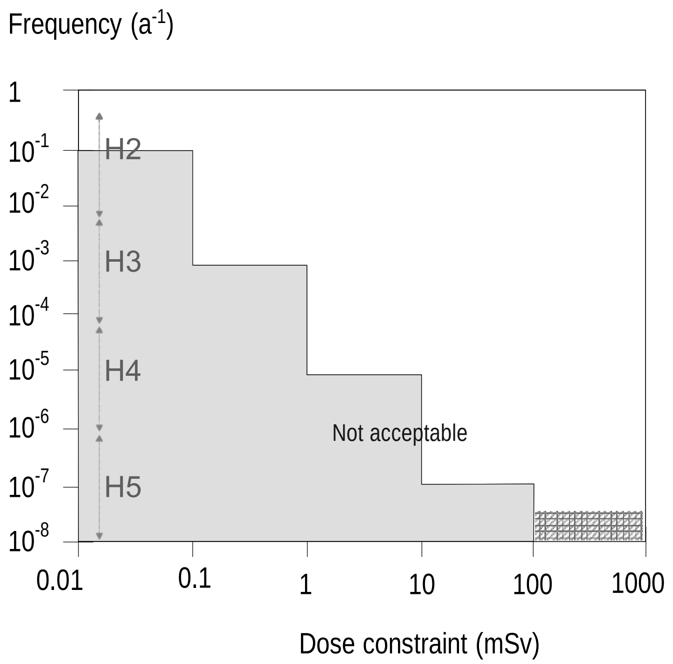
This will give a suggested limiting value of the expected potential dose per annum to the most exposed public.

$$\bar{\dot{E}}(\tau) = \sum_{i=1}^{n} E_i(\tau) P_i \leq 0.01 \qquad (3)$$

3.2 Dose constraints for different event classes

In principle there exists an infinite number of combinations of low frequencies of accidental events and doses that satisfy the inequality 3. To be acceptable to the public, however, one would prefer to choose combinations where higher doses are combined with lower frequencies. One solution would be to use the logarithmic middle of the frequencies for the event classes H2 – H5 as the P_i values, and a decade step for the potential integrated effective dose $E_i(\tau)$. A distribution of frequencies and doses for this case is shown in Fig 1. The expected potential dose per annum will be $10^{-1}\cdot 0.1 + 10^{-3}\cdot 1 + 10^{-5}\cdot 10 + 10^{-7}\cdot 100 = 0.01111$ mSv/a, which approximately satisfies a limiting value of $\delta = 0.01$ mSv/a.

Figure 1: One solution of event frequencies versus dose Constraint satisfying a limiting value of $\delta \approx$ 0.01 mSv/a for the expected value of the potential dose per annum to the most exposed public. Values of dose constraints above 100 mSv are not acceptable because they are not definitely below the threshold for deterministic effects.



3.3 Unacceptable doses and a "release defence insurance system"

According to ICRP Publication 103, absorbed doses below 100 mGy will not give rise to any clinical relevant functional impairment in human tissue. Above this value tissue effects cannot be ruled out. A small fraction of the population could be very radiosensitive, having threshold doses just above 100 mGy/a for protracted exposures [1]. Events leading to potential exposures, which could cause tissue effects (also called deterministic effects) are unacceptable, especially if the effects are severe. Mortality due to bone marrow syndrome can occur for the most sensitive part of the population for doses above 1000 mGy. Therefore, potential exposures above this level must be avoided at all costs, when designing a nuclear facility.

Events that could lead to accidental releases, giving rise to effective doses above 100 mSv can be caused by
- Technical failures beyond safety design
- Human or organizational failures

For events leading to unacceptable doses, the facility should have a robust ”defence-in-depth” structure to ensure that whole-body doses to the public are kept below 1000 mGy (dose to red bone-marrow, colon, lung and stomach) whatever happens and preferably below an effective dose of 100 mSv. Because human error is generally known to occur more often than technical error, a robust "defence-in-depth" structure should be designed to work without human intervention and assure, as far as physically and technically possible, that releases of radioactive material will be below levels that can cause deterministic health effects in the public. Such a robust ”defence-in-depth” structure could be seen as a "peoples´ release defence insurance system" against large uncontrolled releases from a nuclear facility. This technical solution does not necessarily contribute to the normal operation of the facility, but should be there in place as a final barrier to prevent catastrophic releases if everything else goes wrong.

An example of such a "peoples´ release defence insurance system" is the pressure relief release filter (generally known as "FILTRA") that was built at the Barsebäck nuclear power station in Sweden in 1985 [7]. It was the first of its kind. It contained 10,000 cubic meters of pebbles and could reduce the overpressure in the reactor vessel in case of a core melt accident by condensing radioactive steam to water. It was designed to retain 99.9 percent of the radioactive particles in the pebbles filter, thereby reducing the release of radioactive particles to the atmosphere. This would primarily reduce the doses to the public from inhalation of radioactive particles and from deposited radioactive substances. Most important, it would reduce the amount of long-lived radionuclides that could cause widespread contamination. The filter was connected to both units in Barsebäck until the power station was permanently shut down in 2005. From 1986 all Swedish nuclear power stations were required to have release filters, although of another lighter construction than the Barsebäck filter [8].

4 ACTIVITY RELEASE CONSTRAINTS

4.1 How to calculate acceptance levels for activity releases for different frequencies of nuclear accidents

Dose constraints for potential releases related to event classes are generic and their fulfilment cannot be measured or easily controlled. A more direct way to verify their fulfilment would be to convert the dose constraints to activity release constraints that can be technically controllable. The conversion procedure is as following:

1. The licensee identifies all events (1,... n) leading to releases of radioactive substances to the environment and uses PSA level 2 to calculate their event frequencies (probabilities), P_i, i = 1, n

2. The licensee uses PSA level 3 to calculate all potential integrated annual doses from all exposure pathways and events, $E_i(\tau)$, i = 1, n, over the time period τ. The result can be displayed in tables

showing events classes with frequencies, all related events, their associated release of radionuclides, activities, time courses and potential integrated annual doses to the most exposed individuals in the public.

3. The licensor uses the tables as input values and calculates the expected value $\bar{\dot{E}}(\tau)$ of the potential integrated annual dose, using Eqn 1.

4. The licensor decides the limiting value δ. Two cases can occur:

- If $\bar{\dot{E}}(\tau) > \delta$, the licensee must improve the safety, i.e. reduce P_i, $E_i(\tau)$ or n, and go back to step 1.
- If $\bar{\dot{E}}(\tau) \leq \delta$, continue to step 5.

5. The licensor identifies if unacceptable potential doses to the public could occur due to
- technical failures beyond safety design, or
- human or organizational failures.

If so, the licensor should require the licensee to furnish the facility with a robust "release defence insurance system" to certify that potential public exposures are kept below 1000 mGy whole-body dose whatever happens and preferably below 100 mSv effective dose, even if the technically estimated frequencies of failures causing these doses seem to be extremely low.

6. The licensor decides on activity release constraints for all event classes using the information from the tables derived in step 2 and, if applicable, the dose constraint in step 5.

5 DISCUSSION

The principle of calculating dose constraints for potential exposures to the most exposed members of the public builds on the fundamental principles of the linear non-threshold hypothesis for stochastic radiation effects and that it is possible to agree on a limiting δ-value for the expected effective dose per annum. The δ-value should be chosen so that it is expected to be acceptable to most people in the society. It is not the maximum dose that people can obtain from accidents. It is an average expectation value for the dose per year that may occur if nuclear energy is used for a along time, let us say several hundred years. In that sense it can be compared to the dose constraint for normal operation, which also is given as a dose per year. The limiting δ-value, should not be chosen larger than that for normal operations, because the potential releases from accidents are expected to happen in the long run, even if it is impossible to predict when they will happen. One could even question if the δ-value should be chosen as high as the same value as the dose constraint for normal operation, because then the actual dose constraint for long term operation would be double the value. This would be to hide the actual long-term exposure impact if only the dose constraint for normal operations is mentioned. A reasonable choice could be to select a value that is at least to some degree smaller than the dose constraint for normal operation. The final choice will be depending on public acceptability, in which the well-being, values and decisions of future generations should be considered.

Frequencies of technical failures are obtained from PSA-analysis. However, all technical failures may not be identified. Moreover, human and organizational faults are not included, because they are totally unknown. If they would have been known, actions should have been taken to remove them. These faults will underestimate the actual frequency of events, especially for low frequency events, which cannot be observed in a short time period. This is the case for severe core damage accidents. The accidents at Three Mile Island 1979, Chernobyl 1986 and Fukushima Daiichi 2011 [9], although very different in the amount of radionuclides released to the environment, were all the result of human misjudgments. Together they show an observed frequency of human faults leading to severe core damage accidents in the order of 1 in 10000 reactor years. This is at least 100 times more frequent than expected from technical fault assessments made in 1975 [10].

The calculation of effective doses from all pathways depend on a number of assumptions, some of which can lead to very different dose levels. Assumptions of wind speed, atmospheric stability and wet precipitation can give differences in calculated doses up to ten times or more [11]. It is therefore necessary to take the probability of different weather conditions into account in the dose calculations. This can, for example, be done by using statistical weather observations as a basis for choosing representative average weather parameters for the calculation. One can choose a set of weather parameters that will give doses somewhat above what the most frequent weather situations will give, but not chose parameters for extreme weather situations that occur with very low frequencies. This means that dose calculations should not be "over conservative", because the calculation of expected doses should be a best estimate. Too conservative assumptions could lead to distorted choices of technical safety solutions.

In the example given in Fig 1 the calculated expected potential dose per annum is 0.01111 mSv/a. The main contribution comes from events with the frequency 10^{-1} per year leading to maximum doses of 0.1 mSv. Events with lower frequencies will contribute less. This implies that there would be “space” for allowing somewhat higher doses for very low frequencies of events. But since these frequencies could be underestimated (this will not be revealed by observations in a short time period), it would be better to choose a solution with a safety margin for low frequency events.

It should be observed that supplying the facility with a “peoples´ release defence insurance system” to limit large scale releases of radionuclides also should be intended to limit releases in the "residual risks" situations, which are assumed to occur with extremely low frequencies. It can be argued that the defence insurance system itself could have some frequency of failure. It is true, but this does not detract it from the need of such a system.

This method of obtaining dose constraints and activity release constraints is primarily aimed to be used when new nuclear facilities are planned. It can be difficult to fully apply to existing facilities, because of their structural design. The method is not necessary restricted to be used for nuclear energy facilities. It can also be applied to other facilities where accidents can cause public exposures. One such facility is the European Spallation Source (ESS) that is under construction close to the city of Lund in Sweden [12].

6 CONCLUSION

The paper describes a model to calculate target values for dose constraints to the most exposed public from potential releases of radioactive substances in nuclear facilities. The method is specifically aimed to be a tool for use in the licensing process when new nuclear facilities are planned. It builds on probabilistic safety assessments to obtain a best estimate of frequencies of accidental events that should be used as input to the calculations. From the estimated frequencies of accidental events and their corresponding doses, the expected mean value of the potential dose per annum to the most exposed public is calculated. This value should be limited below a selected δ-value. The selection of δ is a matter of judgement where not only radiation protection principles but also societal values should be weighted in. When doing this, it is clear that δ cannot be chosen larger than 1 mSv/a effective dose and it is reasonable to choose it lower than the dose constraint used to limit exposures to the most affected public from normal operations, which generally is in the order of 0.1 – 0.3 mSv/a in most countries. An example of calculated target values used in this work applies δ = 0.01 mSv/a.

For a regulatory authority it is easier to check compliance with restrictions on potential exposures when the target dose constraints are translated into maximum allowed activity releases for selected frequencies of accidental events. How to calculate these maximum activity releases is described in a general way in this work. The calculations depend on a number of parameters such as weather data, radionuclide composition, deposition velocities and dose conversion coefficients. These have to be prescribed by the regulatory authority so that the calculations can be made unambiguously and comparable for all cases.

Cases with potential releases that could cause effective doses above the threshold for tissue (deterministic) effects must be treated separately, because above the threshold the sum of adverse effects are not linear and cannot just be added. To limit the possibility of large releases that can cause deterministic effects in the most affected population, special defence-in-depth structures have to be to implemented in the nuclear facility. This could be called a “peoples´ release defence insurance system” that prevent emissions of radioactive substances to become so large that they could inflict deterministic injuries in people or cause large land areas to be contaminated with long lived radionuclides. The barrier should be applied regardless of how low the technically calculated frequencies of accidents appears to be, because human or organizational failures tend to dominate over pure technical failures when the frequency of technical failures appears to be very low. Pressure relief release filters is one solution that has been chosen in Sweden and in a number of other countries with nuclear power. However, at least the current Swedish solution is not completely operator-independent, which still could result in high potential exposures to the public because of operator failures.

There are a number of questions that can be discussed when applying the proposed model. The advantage with the method is that it defines calculation procedures to obtain target values for potential exposures and activity releases in a way that can be explained and scrutinized. It can thereby identify potential problems in the design of a facility that could lead to unacceptable releases of radioactive material. In this way it can be used by a regulatory authority as a tool in the licensing procedure. This will also be of help in the process of explaining to the public how safety systems are designed to limit radioactive releases in the rare occasions when things go wrong.

7 ACKNOWLEDGEMENTS

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The Advantages of Creating a Positive Radiation Protection Safety Culture in the Higher Education and Research Sectors
A report from the Working Group on Culture in Research and Teaching

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Abstract. The safety culture of any organisation plays a critical role in setting the tone for both effective delivery of service and high standards of performance. By embedding safety at a cultural level, organisations are able to influence the attitudes and behaviours of stakeholders. To achieve this requires the ongoing commitment of heads of organisations and also individuals to prioritise safety over other competing goals (e.g. in universities recruitment and retention are key) in order to ensure the protection of both people and the environment. The concept of culture is no different whatever the sector (i.e. medical, nuclear, industry, education, research etc.) but the higher education and research sectors within the UK represent a unique challenge in developing a strong safety culture. This paper provides an overview of the challenges presented by these sectors, the current status of radiation protection culture in universities, examples good and bad practice in this sector, and goes on to suggest the potential practical methods to influence change.

1 INTRODUCTION

The International Radiation Protection Association (IRPA) has recognised that there is potential to improve how radiological challenges are addressed through the development or enhancement of a strong Radiation Protection (RP) safety culture in all relevant sectors. As the international voice of radiation protection professionals, IRPA has initiated a process which has provided a medium for discussion on this topic throughout the world. As part of this process, the UK professional radiation protection partner societies (see Appendix 1) have responded to the decision to enhance RP culture among RP professionals in all relevant sectors and as a key element of this, recognise the need for programmes and tools to assist with the development and improvement of radiation safety and protection at a cultural level within an organisation, as an effective mechanism for delivering aspirational performance.

1.1 What is safety culture?

The Chernobyl disaster of 1986 highlighted the importance that safety culture has on an organisation and in particular the impact that management and human factors have on safety performance. Since then there have been a number of widely-used definitions of safety culture. In simple terms, the safety culture of any organisation is a reflection of the attitudes, behaviours and actions of its stakeholders towards safety. In an educational/research setting, these stakeholders would include academic staff, students, managers, supervisors, technical support, administrators, contractors, visitors and members of the public.

1.2 Why have strong safety cultures?

A strong safety culture is essential to protect staff but it is equally important in protecting the high percentage of young and inexperienced persons (students) based in education and research establishments, and the reputation of academic/research institutions. Safety culture encompasses the entire organisation, from the top and needs to be integrated throughout the organisation which is why successful and sustained safety cultures take a comprehensive effort. These efforts will vary, and include: identifying problems with a safety management system; maintenance of rules and regulations; testing to make sure education is being consistently maintained; and promoting positive reinforcement. Audit, inspection and review must also fit the relevant industry.
Safety culture can be broken down into a number of key elements:

1. **Leadership & Management**
   The management style of leaders within an organisation can have a substantial effect on the safety culture, positively or negatively (Health & Safety Executive, 2005). To build a strong culture of safety, leaders need to inspire others to value safety; build trust through open and transparent communication; lead by example; accept responsibility for safety; and hold others to account for their safety performance.
2. **Learning Culture**
   To maintain and improve the safety culture within an organisation, there should be a continuous professional development of staff in safety knowledge. Staff should be encouraged to contribute ideas for improvements and develop an awareness of what good safety performance actually means in their own jobs. In universities, a strong safety ethic should be embedded into taught courses, so that students can develop their own safety skills.
3. **Attitude & Awareness**
   As well as a positive approach to safety at an institutional level, it is important that individuals have the same attitude or 'safety ethic'; "*to value safety, work safely, prevent risky behaviour, promote safety and accept responsibility for safety*" (American Chemical Society, 2012).
4. **Taking Ownership – Responsibility & Accountability**
   The acceptance of safety responsibilities needs to be implemented from the top of the institution, to all employees.
5. **Learning from Our Mistakes**
   Much of the progress in improving safety has come from the desire to prevent repeat mistakes or incidents. It is important that when incidents occur, they are investigated to determine the direct, indirect and root causes. The findings (and corrective actions taken) should be publicised to the institution, or even across institutions, so that they can be used as case studies. Near-miss reporting also provides valuable input to inform this process.
6. **Promoting and Communicating Safety**
   The best way to promote safety is through personal example. However, this only extends to those people close by. Wider promotion across the institution is needed to raise awareness of safety issues. A method to achieve this should be put in place, using electronic communications, printed materials, seminars or events and a recognition system for good safety performance.
7. **Collaboration & Best Practice**
   Even if a department or service area has made excellent progress in changing its safety culture, if the rest of the institution does not follow suit then any benefits will have minimal impact.
   The Health & Safety at Work etc. Act 1974 requires that in certain circumstances an institution-wide Safety Committee be set up to review the measures being taken to ensure the health and safety of employees.
   It is good practice to include a representative cross-section of employees to participate in this committee. Under this main committee, a network of local committees can be set up (faculty, department etc.) to encourage collaboration and the sharing of best practice across the institution.

8. **Funding & Resources**
   It is important that any safety management system is adequately funded. Each department or service area should allocate a budget for safety-related equipment and activities, rather than absorbing it into general budgets.

1.3 What are the RP Cultural Issues?

The higher education and research sectors within the UK represent a unique challenge for the establishing and improving of a strong safety culture. The reasons for this include:

- There will be a higher percentage of young and inexperienced persons involved when compared to a non-educational work environment.
- There is a higher 'turnover' of personnel involved in hazardous work, indeed most undergraduate student courses have a three year cycle duration, and short term contracts are becoming more common in research companies.
- Academic attitudes are often more focussed on recruitment and retention of students, research goals and outcomes than on safety and radiation protection.
- The research work carried out in these sectors is often very diverse.
- The research is often extremely novel in its nature, if not unique, and this leads to challenging hazards.
- There is chronic under-funding that leads to a process of 'grant optimisation' which may not place safety as a priority.

It is important though, that we do not consider the safety pressures of academia and research to differ from those of industry. The maintenance of a high level of productivity and safety applies to both. In industry a number of high profile major accidents have resulted from failures compounded by production demands e.g. Piper Alpha oil platform, the Challenger space shuttle (Cowing et al, 2004). It seems that many senior managers perceive safety and productivity as competitors whereas in truth they go hand in hand.
A review of serious and fatal accidents in university labs, mainly from US, (Van Noorden, 2011) concludes amongst other things that in some cases "*… academic freedom is more important than safety.*" A recent survey on laboratory safety (Evans, 2014) revealed that academic researchers often engage in unsafe laboratory practices.
In the Guardian newspaper on 4th December 2014, the Science Editor, Ian Sample, reports on "*Revealed: 100 safety breaches at UK labs handling potentially deadly diseases.*" This report revealed failures in procedures, infrastructure, training and safety culture at some British laboratories.
Obviously, these references do not directly relate to radiation safety. However it is reasonable to assume that such lack of culture extends to all types of work in laboratories – including that involving sources of ionising radiation.

2 THE ETHICAL REASONS FOR HAVING A STRONG RP SAFETY CULTURE

A. Protecting the Workforce (Staff and Students)

Whilst a strong safety culture is essential to protect employees, it is equally essential in protecting students and is a significant factor in the promotion of safety awareness and the development of safety skills.

B. Protecting the General Public and the Environment

The Public's perception of radiation risk can be greatly affected by the context in which the radiation is used and this perception can be skewed significantly by poor knowledge of benefit and detriment. Therefore it remains as important for us to communicate risk factors as it is the many benefits to society that can result from research using radioactivity.
To continue to increase public knowledge we must:

- define the concepts of risk in lay terms;
- use a simple vocabulary to explain radiation; and
- educate the public and the media about radiation and its benefits and risks.

However, increased public knowledge will not necessarily lead to an increase in public trust. Organisations and individuals can positively affect public perception by being seen to work closely with the regulators to strive for continual improvements in environmental and health and safety compliance.

2.1 Doing safe and scientifically robust research

Many organisations depend on universities and R&D companies undertaking robust and trustworthy scientific research, publishing learned articles founded on good science, developing products, and enhancing humanity's knowledge.
Many good practices can be viewed by academics and researchers as mundane and of low priority or simply interference in research productivity. As a result, they can be performed incompletely, incorrectly or just not at all. Frequently there is a lack of understanding of how crucial routine laboratory tasks can be to obtaining reliable measurement data. In addition, this lack of understanding can be promulgated amongst junior staff and students by the importance of such tasks being treated glibly, overlooked and missed during in-house training.

3 THE RISKS OF HAVING A STRONG RP SAFETY CULTURE

a. Business Continuity

Business Continuity Management is about establishing and maintaining an organisation's capability to retain continuous critical business processes, regardless of what disruptive event may occur.
Continuity of activities (teaching, learning, research, support services and other business activities) is a priority in education and research. It is the responsibility of all component areas (University Councils/Research Boards, Committees, Directorates, Schools and Services) to take all reasonable steps to avoid any foreseeable incident that may require an emergency management or business continuity planning response. If such an incident does occur, component areas will need to minimise any impact on the organisation and its stakeholders.
The establishment of a radiation protection policy that includes a regularly-reviewed radiation risk register is a significant step towards a good radiation protection culture and will secure better contingency plans and thus business continuity.
Although policies, plans and registers may not cover every conceivable contingency in a crisis, responsible decision-making, good judgement and good communication are paramount in a crisis to protect the organisation's ability to meet its mission of teaching, research and public service.

b. Financial implications

In university and research organisations, crises can result not just in the loss of vital resources such as buildings, equipment, infrastructure, technology and personnel, but also in teaching downtime and loss of manpower due to injury or stress, not forgetting the cost of remediation and the potential for significant damage to institutional reputation (see the next section). A poor radiation protection culture can lead to bad practices which may adversely affect the health of staff, students and members of the public. This can lead to costly civil litigations and negative media coverage.
Likewise, a poor radiation protection culture may result in non-compliances with the radiation legislation, notably the Ionising Radiations Regulations 1999 (Health & Safety Executive, 2000) and the Environmental Permitting Regulations 2010, amongst others. This can lead to regulatory actions such as prohibition notices and prosecutions by the Health and Safety Executive (HSE) and the Environment Agency (EA). This might escalate to significant fines being levied against the organisation, the severity of which will reflect the level of transgression.

c. Reputational Damage

Significant reputational damage may emanate from adverse media coverage, for example, from reporting of legal action and fines to compensation claims or clean-up costs - which can lead to loss of trust resulting in falling student numbers and loss of revenue. This can also result in an adverse change in the attitudes of potential collaborators and grant funding bodies leading to a lowering in research rating, smaller number of grant awards and the inability to attract the best academic staff. Bid documents for commercial contracts invariably ask for details of any such legal actions, in preceding years, across the whole organisation.

3.1 How to improve radiation safety culture?

Radiation safety culture is a subset of general safety culture which in turn is rooted in, and must integrate with, the wider aspects of culture within any organisation. It is therefore essential that this topic is not considered in isolation because much work has been done, and good practice identified, in other subsets e.g. chemical-safety culture.
Expanding on these ways:

1. **Training**
   Radiation Safety training as with other health and safety related training is an essential part of the University's commitment to achieving a safe and healthy workplace for staff, students and visitors.
   Staff must be provided with sufficient information, instruction and training to ensure that they are aware of radiation hazards and know what safe working procedures to follow to reduce the risk of injury or work related ill health, to themselves and others. Training is also essential in raising the level of staff and students awareness of health and safety policies and procedures, such as Local Rules, and to ensure their effective implementation.
   All new staff or those that have been redeployed or relocated must receive general health & safety induction from their line manager or other appointed person, and specific induction from the Radiation Protection Supervisor (RPS) in the area in which they will be working. This requirement also applies to those on temporary contracts and agency staff. The importance of knowing what health and safety training is needed is key to the selection and design of workshops. These needs should be assessed on appointment, when members of staff take on a new role with increased safety responsibilities, or new equipment is introduced. Training needs should also be reviewed as part of staff appraisals, from reviews of radiation safety performance and risk assessments.
2. **Communication**
   Communication is key to the promotion of good safety practice and in learning environments such as universities and research establishments, leading by example is especially important as students will follow examples set by academics and senior research staff. Communication can be in many forms from the traditional safety posters, newsletters and weekly bulletins to the modern day emails, texts and Twitter messages.
3. **Learning from our mistakes**
   Much of what is known about safety has been learned from accidents, incidents and near-misses. By using a lessons-learned approach, educational and research organisations are able to engage with staff and students and provide a challenge to think about how safety measures could have prevented an accident or incident, or at least have minimised the consequences. It is important therefore to establish robust accident/incident reporting systems and investigation procedures to identify root causes and formulate plans to implement mitigating actions.
4. **Learning from other sectors and industries**
   Safety cases were developed by the oil, nuclear and rail industries in response to high-profile accidents and disasters. In a strong safety culture, members of staff collect evidence from a range of sources to build a sound safety case, with supporting evidence that systems are safe and risks are controlled and monitored.

The core of the safety case is typically a risk-based argument and corresponding evidence to demonstrate that:

- all risks associated with a particular system have been identified;
- appropriate risk controls have been put in place; and
- there are appropriate processes in place to monitor the effectiveness of the risk controls and the safety performance of the system regularly.

By applying safety case methodology in the university and research settings, institutions would be able to:

- promote structured thinking about risk amongst academics and researchers;
- integrate evidence sources;
- aid communication among stakeholders; and
- make the implicit explicit.

The OTHEA database *(http://relir.cepn.asso.fr)* is provided by a network of radiation protection stakeholders who have a joint interest in sharing feedback and experience from radiological incidents, in order to improve the protection of persons working with similar radiation sources. More generally, the aim is to encourage good practice within different sectors including medical and veterinary, industrial, research and education sectors, etc. Incidents and reports are selected on the basis of the value of sharing the lessons learned and therefore the database includes a wide variety of incidents: not just accidents and incidents, but also any situation, event, behaviour or anomaly with the potential to cause an unplanned radiation exposure, or a significant decrease in the existing standard of radiation protection. This could include 'near misses', contamination spills as well as more serious radiological incidents.

3.2 Learning from 'Bright Spots'

'Bright Spots' are those institutions which have made successful progress towards a goal and are worthy of being emulated (Heath & Heath, 2010). With regard to radiation safety culture, institutions which are bright spots will most likely share the following traits:

- Established lines of authority for safety, via senior management, Radiation Protection Advisers (RPA), Radiation Protection Officers (RPO), and Radiation Protection Supervisors (RPS).
- Safety policies in place, covering the use of all ionising and non-ionising radiation (unsealed sources, sealed sources, x-rays, particle accelerators, lasers, ultraviolet, etc.).
- Safety responsibilities defined in job descriptions and performance/appraisal plans. There will be a set of responsibilities and duties for the specialist radiation safety personnel (RPA, RPS, RWA, RPO).
- Senior management demonstrate a care for radiation safety in their actions and have a commitment to funding radiation safety programmes adequately.
- A strong, effective radiation safety management system is in place.
- Safety skills are integrated into taught courses and the skills are assessed.
- All those with radiation safety responsibility have received appropriate training and recognised safety qualifications (e.g. Strathclyde certificate in RP, NVQ Level 4 in Radiation Protection).
- Prior risk assessments include all phases of a research project including source procurement and disposal. Grant applications should be 'forward-looking' and incorporate funding, e.g. to pay for any specialist contractor fees.
- The costs of radiation safety education and training are included in research grant proposals and contract bids.
- All accidents and near misses are investigated, recorded, communicated and acted upon.
- Established a series of safety committees from the highest level to the departmental level or lower. Each of these committees report on radiation safety to a committee which is higher in the institution's hierarchy.

- Specialist radiation protection members of staff have close working relationships with departments using ionising and non-ionising radiation, collaborating on implementing safety programmes.
- A system is in place to promote radiation safety within the institution. Information is published on their website, a regular bulletin is sent out to staff, regular training sessions and presentations on radiation topics take place.
- A reporting system for safety concerns is in place, allowing staff to feedback directly to senior management.
- A close relationship with local emergency providers has been developed (e.g. taking part in joint exercises).
- Good working relationships with regulators.

The various RP Societies play an important role in the 'Learning from Bright Spots', in that their programmes of meetings facilitate the dissemination and discussion of good practice from across the sectors. Equally there is a need for the employers of RP professionals to support attendance, both for professional development and to ensure organisations are aware of practices that could impact on the organisations work.

3.3 Methods for Assessing RP Safety Culture in Higher Education and R&D Sectors

The assessment tools used to examine the radiation safety culture of an institution can be a mixture of quantitative and qualitative tools. This is so that in addition to measuring the culture against set criteria, the attitudes and beliefs of staff can be investigated. The assessment tools should be used over time to pick up any positive or negative drifts in radiation safety culture. Such methods might include:

1. **Audit against the legal requirements in IRR99 and EPR2010**

   Within this audit there needs to be ongoing assessment of the radiation protection management structure. There must be a mechanism to identify and then encourage the removal of any disconnect that exists between: (a) the management of radiation protection at the 'coal face' and (b) senior site management (see management structure performance indicator below). The engagement of an external auditor to examine periodically the current state of culture (and its development) against recognised standards may be expensive, but is no doubt beneficial in testing the culture, and it is impartial.

2. **Review of Key Performance Indicator**
   It is important to assess whether initiatives to develop and improve RP safety culture are making any difference. Only in this way can one evaluate strategies for improvement so that managers use the most effective methods.
   As highlighted by Cole et al (Cole et al, 2014) such indicators might include the:
   - Annual collective dose of radiation workers.
   - Annual number of radiation-related incidents or near-misses.
   - Number of non-compliances with permit conditions (e.g. leading to prosecutions, notices, or RASCAR [Radioactive Substances Compliance Assessment Report] points) or in-house rules.
   - Number of persons attending radiation safety training (including refresher training) as a percentage of those registered/intending to attend.
   - Number of late and non-returned personal dose-meters.
   - Number of outstanding actions identified from audits/inspections.

This data needs to be garnered from surveys of all staff and areas within the organisation, and students. Information needs to be recorded and databases interrogated to produce periodic reports on the organisation's website. Comparing trends in RP indicators against overall safety indicators for the organisation may also show up comparisons that could be helpful in identifying areas of relative success or failure.

3. Attitude Surveys

Universities and research establishments are increasingly interested in retaining the right talents whilst targeting new talents; measuring attitude provides an indication of how successful they are in fostering a working environment which is conducive to nurturing a positive culture amongst both staff and students. The more that senior management know about their staff and student's feelings, the easier it is to manage their behaviour. Surveys can also be a powerful tool for management to demonstrate that they value staff and student input and that it will be integrated into decision making processes.

It may not be easy to illicit weaknesses in RP culture in an organisation, for example, fear of blame will suppress reporting near-misses, and fear of unfair disciplinary proceedings will inhibit staff expressing concerns on poor attitudes to safety by line managers. An attitude survey, if carried out so that staff are confident the data will be anonymised (such as through an independent external body), will provide senior managers with useful insight into the weaknesses of RP culture perceived by employees. Exit interviews can also give useful data.

4. Employee Engagement

As a knowledge-driven sector, higher education is essentially people-driven and employee engagement levels are therefore very important. The quality of HE employees' contribution to teaching, research, enterprise and the various supporting activities are key to the success of individual institutions and the sector's reputation as a whole. Employee commitment is vital to meeting student and other HE stakeholder expectations and satisfaction, and without an engaged workforce, HE would not meet the significant challenges currently facing the sector. For this reason, the Universities and Colleges Employers Association (UCEA) and Universities Human Resources (UHR) have commissioned a joint web-based toolkit on employee engagement *(http://www.ucea.ac.uk/en/publications/eetoolkit/index.cfm).* This toolkit provides institutions with the essential advice and guidance on how to secure, maintain and develop employee engagement with their institutional visions and missions.

5. Plan, Do, Check, Act

Whatever the size or nature of the organisation, the key factors to manage for health and safety are:

- leadership and management (including appropriate business processes);
- a trained/skilled workforce; and
- an environment where people are trusted and involved.

The HSE guidance INDG417 (Health & Safety Executive, 2013) sets out an agenda for the effective leadership of health and safety by all directors, governors, trustees, officers and their equivalents in the private, public and third sector. It applies to organisations of all sizes. The guidance is based on the HSE's approach to health and safety of 'Plan, Do, Check and Act'.

6. The Safety Climate Tool

The Health and Safety Laboratory's Safety Climate Tool *(http://www.hsl.gov.uk/products/safety-climate-tool)* can be used to gauge corporate safety culture. It measures key areas of health and safety climate, giving a snapshot of the underlying safety culture. Using the Tool helps organisations benchmark their performance against similar organisations in the industry and shows where to target resources, providing a baseline to measure improvements in safety culture.

3.4 Practical methods to implement cultural change

It is proposed by the authors to design and produce a number of tools that can be used to develop a good RP culture, or to enhance an existing one, within higher education and research institutions. Such tools could be made available in a 'culture pack' of resources distributed via, for example, AURPO or USHA. The pack could reasonably include:

- A senior management briefing (or set of briefings) which would emphasize the contents of this paper. This would include a set of standard slides and a short video to facilitate the briefing(s).
- Training resources such as slides, videos, suggestions for practical exercises, exam questions, and quizzes for use by RP workers and other RP trainers/coaches.
- 'Tools' to help promote a good culture e.g. templates for feedback questionnaires and suggestion forms, methods for establishing and running an RP discussion forum on the organisation's website, and instructions on how to use Twitter to garner RP comments from staff and students.
- Information about RP professional societies, the benefits of membership, and instructions on how to join (with membership application forms included).
- A newsletter of topical RP articles, links to further RP information, notices of forthcoming RP events, etc.
- Contact details for RP Culture 'mentors' in the UK.

The RP system already established at an organisation may benefit from compliance with an external Quality Management System such as that provided by ISO9000. This might seem onerous, but it is certainly comprehensive and robust. It would act to promote the implementation of an organisational RP Committee, the inclusion of RP as a standing agenda item in top level H&S committee meetings; the RPA (or RPO) could present a 'culture and compliance' report to senior management who are then more informed and better able buy into radiation safety, and the incorporation of incident case studies and lessons learned into both end-user and management training.

4 CONCLUSIONS

This paper asserts that creating a good RP culture has good outcomes for research projects, finances and reputation in universities and research organisations. This assertion must be embraced by all stakeholders but in particular senior management who may not be RP conversant. Short-cuts in safety may seem attractive, but the 'benefits' at best are short-term. An immediate saving may be made, but the costs when things go wrong are orders of magnitude greater. Excellence in education does not go hand-in-hand with sub-standard safety attitudes. Poor RP culture and poor educational and research quality have a strong positive correlation.

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6 APPENDIX 1: UK PARTNER SOCIETIES

The Society for Radiological Protection (SRP); The Association of University Radiation Protection Officers (AURPO); The Institute of Physics and Engineering in Medicine (IPEM); The Royal College of Radiologists (RCR); The British Institute of Radiology (BIR); The Society and College of Radiographers (SCoR); The British Nuclear Medicine Society (BNMS).

Education and Training of Workers for Development of a Safety Culture in a Radioactive Facility

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Abstract. The analysis of radiological occurrence in the Centre of Isotopes (CENTIS) of the Republic of Cuba shows 54 % of registered events happen due to human fails during 1997-2015. Then this requires the promotion of safety culture and the systematic labor of education of staff with responsibilities for protection and safety is the key tool for this purpose. Since beginning, a conceived education system included three basic courses and taking into account the CENTIS' functions as importer, producer, carrier and exporter, are designed courses for all practices and technologic working means. In addition, it is executed every 2 years an updating activity. However, this last activity take place annually and maintain analysis of lesson learned from events, with the combined adoption of measures for avoid their repetition, contribute to increase the adoption of better attitudes for security. The trainers are three specialist of the Radiation Protection Department of this center that have between 10 and 22 years of experience in this plant, received the International Atomic Agency, and participate as teachers in initial courses in 1998 and in the updating courses. Following themes considered are state of the art for studies of biologic effects of ionizing radiations, new national regulations, and operational experiences and in the transport of radioactive materials and those obtained from radiological occurrence and the management of radioactive wastes. The preparation and execution of education should respond to results of assessment of safety culture in the facility for to be able to impact in the significant reduction of the negative paper of the human factor.

KEYWORDS: Education and training; safety culture; safety performance indicators.

1 INTRODUCTION

The purpose of this paper is to share our experiences from the education and training system of a radioactive facility in Cuba (Centre of Isotopes (CENTIS)) which is focusing in development of safety culture.

The Culture is a combination of habits and knowledge. Among them, there are beliefs, values, and assumptions of the founders of an organization, learning experiences of group members as the organization evolves (Groups of people who have shared significant problems, solved them, observed the effects of their solutions, and who have taken in new members) and beliefs, values, and assumptions brought in by new members and leaders.

Safety Culture is "the assembly of characteristics and attitudes in the organizations, its managers and workers which assures that, as an overriding priority, safety issues receive the attention warranted by their significance". Safety is understood "as the protection of people and environment against the associated risks of ionizing radiation and also the radiological safety and the security of radiation sources", assuming that they are inextricably linked [1].

Monitoring the safety culture through indicators identifies trends that are very beneficial for an early alert on potential or imminent deterioration of safety in the organization.

Education and training of staff is an internal action to promote safety culture in our organization itself.

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2 MATERIALS AND METHODS

Taking into account the Regulatory Body regulation and IAEA recommendations [2-3] is created and maintained an education and training system for the staff of CENTIS. The analysis of this for improvement is carrying out with safety performance indicators (SPI) and does not concern the method reported in [4].

3 RESULTS

In the Table 1, show the list of courses executed in CENTIS. The CNSN recognized their competence and elaborated the respective certificates with permanent validity [5-6]. Two conferences on security of radioactive sources and security in the transport of radioactive material were in 2009 for the staff related with the transport and they are not included in Table 1 for the specific of these topics and their realization in another time with respect the training in radiation safety.

Despite is required a highest percent of accepted answers of the total points (70%) for the staff related with production and transport, all of persons have obtained good results in tests. For the periodical retraining of staff is introduced the analysis of SPI as a tool for get better the feedback process and training. For assessment the efficiency of these courses following are analyzed the radiological events happened and the occupational exposure.

There is a maximum of five events by year during 2001-2002 and 4 events in the period of 2006-2007; this can be observed in Figure 1. Can be seen the reduction of this SPI during the rest of the time. In the Table 2 presented the relationship between the behavior of annual handling activity of ^{131}I, ^{99}Mo and ^{32}P, radionuclides of the main contribution to occupational exposure, and S.

In spite of increasing 1.45 times for the sum of activities of ^{131}I and ^{32}P in the last two years, S has an increment up to 1.78 times. Figure 2 shows S' liaison with the number of monitored workers. The increase of personnel implies the same behavior of S, but reduces E.

The increment of individual radiation doses ^{32}P contributed to 75.4E-03 man-Sv y^{-1} in 2003. Besides, it should be observed in this figure the appreciable reduction of the individual exposures determines the decreasing of S during 2006-2008. In spite of this, there is the highest value 98 man-mSv y^{-1} in 2011 due to the increment of ^{131}I activity.

Table 2 allows seeing the highest figure of S is 0.49 times lower than estimated annual collective dose [7]. This is caused by CENTIS yet does not reach to the maximum activity of the basis its design for ^{99}Mo and ^{32}P. The highest contribution to occupational exposure belongs to production of Technetium generators. For the majority of workers (equal or more than 63 %), there is E below 2 mSv y^{-1}.

The relationship between the maximum annual value of dosimetric magnitudes and their respective dose constrains can be observe in Table 3. It should be observed that a new recommended limit for Hp(3) is adopted [8]. In 1996 and 1997 it is indicated as not controlled (NC) for Hp(3). The highest values appear in year 2000 for E, 2006 for Hp(0.07) and in 2003 for Hp(3). It should be appreciated that dose constrains are overcame in these two first moments.

A worker of the group of Inspection and Trial made all of the elutions of generators and received E higher than the limit as average for 5 years [9]. The workload was redistributed and a shielding of lead with 5 cm was situated. In the second case, the procedure of intervention in hot cell with ^{131}I was analyzed. There was an incorrect manipulation for part of worker and this is the cause of the highest value of Hp(0.07).

The Cuban Regulatory Body established its point of view on safety culture [10]. In that document appears 10 basic elements of the safety culture among them there are following culture on the continuous learning, report and communication on safety. With our education and training activities, allow to improve the conduct respect safety of the staff in CENTIS.

Table 1: List of radiation safety courses executed in CENTIS.

Number	Year	Course	Time (hours)	Amount of participants
1	1998	Elements of radiation protection	40	21
2		Basic course of radiation protection for workers	60	31
3		Radiation safety for the transport of radioactive material	5	20
4	1999	Radiation safety for staff with safety and protection responsibilities	60	11
5	2002	Current in radiation safety aspects for workers and staff with safety and protection responsibilities	60	52
6	2005	Current in radiation safety aspects for workers and staff with Safety and Protection Responsibilities	96	60
7		Current in radiation safety aspects for the staff related with the transport of radioactive material	60	11
8	2007	Current in radiation safety aspects for workers and staff with safety and protection responsibilities	96	53
9		Current in radiation safety aspects for the staff related with the transport of radioactive material	40	9
10	2008	Current in radiation safety aspects for the staff related with the transport of radioactive material	40	9
11	2009	Current in radiation safety aspects for the staff related with the transport of radioactive material	40	16
12		Current in radiation safety aspects for workers and staff with safety and protection responsibilities	96	9
13	2011	Current in radiation safety aspects for workers (including them related with the transport of radioactive material)	20	57
14	2012	Current in radiation safety aspects for workers related with the process of production	20	30
15	2013	Workshop on Safety Culture and Good Practices	32	30
16	2014	Workshop on waste water management in the radiopharmaceuticals production	20	30
17	2015	Current in radiation safety aspects for workers (including them related with the transport of radioactive material)	60	30

Figure 1: Amount of radiological incidents by year in CENTIS.

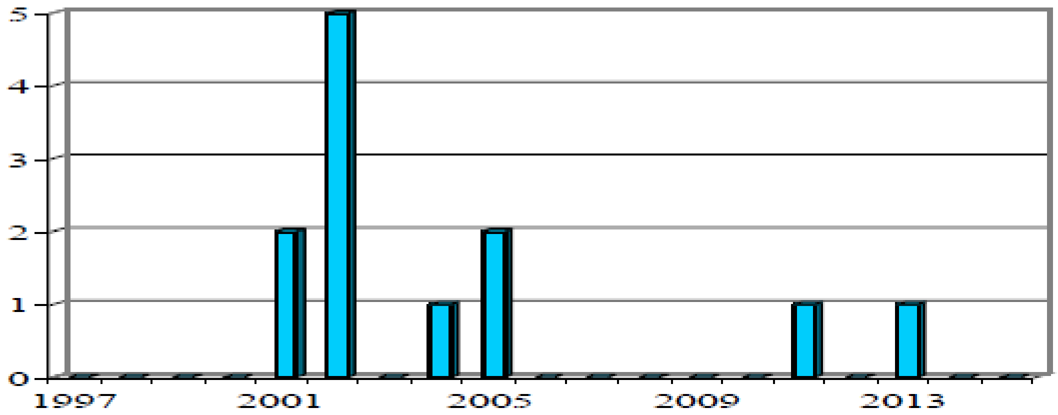

Table 2: Annual activities of the main radionuclides and collective doses (S).

Year	Activity ^{131}I (Bq y^{-1})	Activity ^{99}Mo (Bq y^{-1})	Activity ^{32}P (Bq y^{-1})	S (Man Sv y^{-1})
1996	Not handled	3.20E+11	Not handled	0.025
1997	7.33E+11	5.92E+11		0.016
1998	4.90E+12	5.39E+11		0.039
1999	4.87E+12	6.60E+11	1.19E+10	0.030
2000	4.84E+12	5.35E+11	**3.64E+11**	0.054
2001	4.88E+12	1.38E+12	3.43E+11	0.036
2002	4.60E+12	1.59E+12	2.35E+11	0.063
2003	3.94E+12	1.49E+13	2.35E+11	0.075
2004	4.71E+12	2.73E+13	1.93E+11	0.026
2005	4.08E+12	2.77E+13	9.75E+10	0.035
2006	3.28E+12	2.29E+13	5.45E+10	0.022
2007	4.91E+12	2.52E+13	8.27E+10	0.017
2008	4.33E+12	2.32E+13	2.03E+11	0.018
2009	5.76E+12	4.01E+13	2.24E+11	0.042
2010	7.09E+12	3.19E+13	3.17E+11	0.055
2011	1.05E+13	3.19E+13	3.12E+11	0.098
2012	1.54E+13	**4.42E+14**	1.68E+11	0.095
2013	1.86E+13	6.79E+13	2.65E+11	0.077
2014	**2.13E+13**	6.77E+13	1.16E+11	0.047
2015	2.02E+13	1.19E+14	1.58E+11	0.057

Figure 2: Collective doses and annual monitored workers.

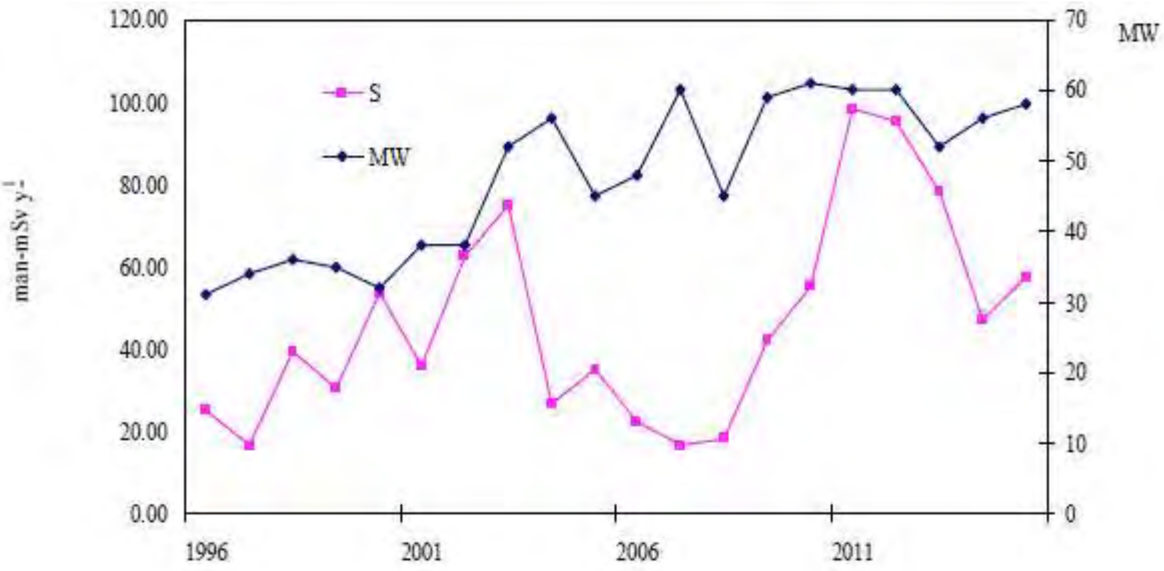

Table 3: Maximum values of dosimetric magnitudes and relationship with the dose constrain.

	E (mSv)	Hp(0.07) (mSv)	Hp(3) (mSv)
Dose constrains	12	200	15
1996	4.73	8.15	NC
1997	4.02	8.56	NC
1998	10.27	17.85	2.60
1999	4.85	49.38	4.38
2000	**25.77**	65.43	1.27
2001	3.22	117.97	1.90
2002	7.06	97.94	8.47
2003	5.89	91.47	**12.09**
2004	4.17	73.41	5.14
2005	6.52	145.17	5.89
2006	6.09	**232.71**	3.49
2007	2.96	117.70	3.86
2008	4.28	168.38	2.18
2009	5.32	172.49	4.85
2010	5.14	60.68	3.85
2011	9.13	194.60	12.05
2012	12.56	116.59	9.95
2013	13.23	159.23	7.49
2014	5.46	97.00	6.95
2015	6.68	125.14	8.75

4 CONCLUSIONS

The education and training system described in this paper allows maintaining the preparation of the staff in radiation safety in accordance with its safety function and the Regulatory Body in Cuba certified it. Assessment of the efficiency and effectiveness of education activities requires analyzing the behavior of SPI related with occupational exposure and radiological events.
The objective focusing in a safety culture is permanent in our organization since this is a lingering process. The analysis of SPI behavior in the training of the staff is a good experience since this allows improvement the feedback process and contribute to perform different aspects related with the optimization of radiation safety. The education and training system is a tool for the achievement of safety culture in the organization and accomplishment and maintaining of the ALARA principle in the diary labor of CENTIS. Culture on the continuous learning, report and communication on safety are continuously improved.

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Assessment of radiation science studies in 4 successive years

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Abstract. Finding the statistics of the studies which perform in a special field of science can be very useful to detect which part of that field progressed faster and which part needs more attention to develop. In this study, 2470 articles from 4 creditable journals were investigated in order to find the statistics of medical radiation science field studies. Results revealed that almost 70% of articles were about radiation oncology physics (37.76%) and medical imaging (35.30%). In radiation oncology field most of the studies were respectively about dosimetry (23.47%), imaging in radiotherapy (19.69%) and IMRT (14.6%) and in medical imaging filed most of the studies were about nuclear medicine (29.84%), CT (27.2%) and MRI (18.13%). Almost 28% of articles were about biology and some biomedical engineering topics. The least studies were about radiobiology (0.93%) and non-ionizing topics (3.44%). Results have shown that fast progressing topics such as radiotherapy and imaging could more interest scientists but despite that these days' non-ionizing fields such as wi-fi modems, mobile and wireless phones, microwaves and etc surround us, unfortunately less studies have performed in this field. This study revealed that radiobiology and non-ionizing radiation studies needs more consideration.

KEYWORDS: radiation science; journals; medical imaging; radiation oncology physics.

1 INTRODUCTION

Radiation has different applications in medicine and industry so that the world of radiation researches is very wide. If the researches in a field would be observed during several years, useful information can be extracted. In this way, it can be realized that which part of that field interest more researchers and which areas need more attention to develop.
The usage of radiation in medicine has a long history. Radiotherapy and its related sciences called radiation oncology physics, different fields of medical imaging, radiobiology and radiation protection are some of the braches of radiation researches in medicine. It can be helpful if the published papers in these fields assessed in order to evaluate current status of these areas of research. In this study, 2470 articles from 4 creditable journals were investigated in order to find the statistics of medical radiation science field studies.

2 MATERIALS AND METHODS

In this study, the published papers in 4 international medical physics journals were investigated during 2010-2013. Three of the journals were ISI journals (Physics in medicine and biology (IF= 2.76), Physica medica (IF= 2.40), Journal of applied clinical medical physics (IF= 1.17)) and one of them was a pubmed indexed journal (journal of medical physics) [1-6]. The original papers of these journals assessed from the first issue in 2010 to the last issue in 2013 (2470 articles). The papers were divided into some groups and subgroups (Figure 1).

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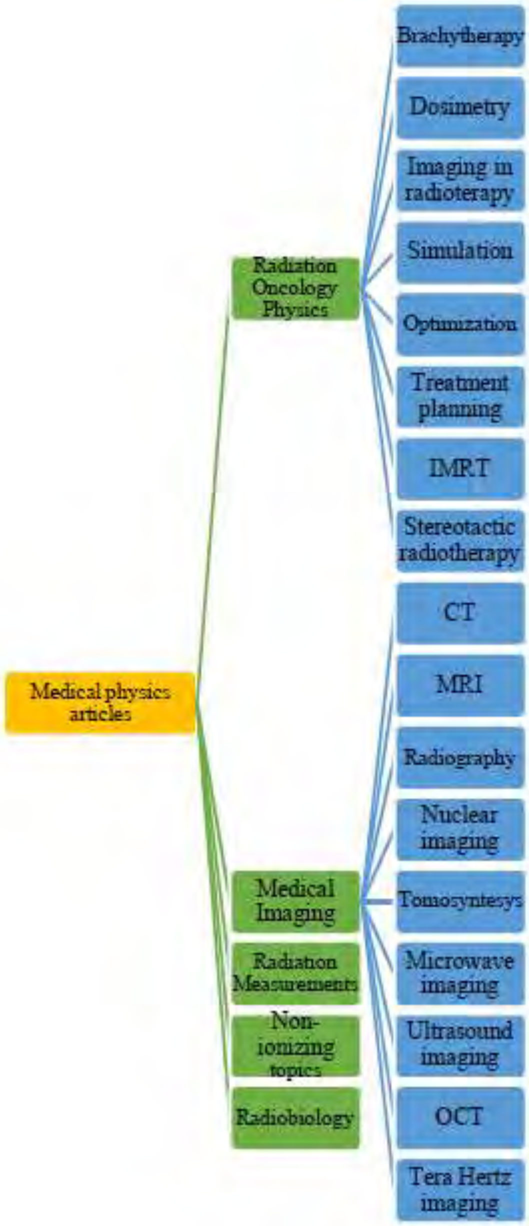
Figure 1: Groups and sub groups which considered for medical physics papers.

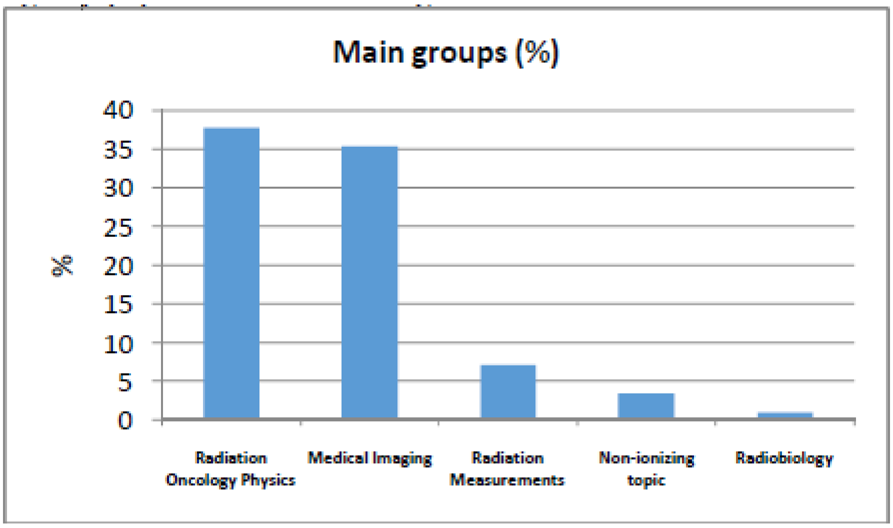


IMRT= Intensity modulated radiotherapy
CT= Computed tomography
MRI= Magnetic resonance spectroscopy
OCT= Optical coherent tomography

3 RESULTS

Percentage of main group papers was shown in figure 2.

Figure 2: percentage of main groups papers



Percentage of subgroup papers of radiation oncology physics and medical imaging was shown in figures 3 and 4.

Figure 3: Percentage of radiation oncology physics subgroups papers.

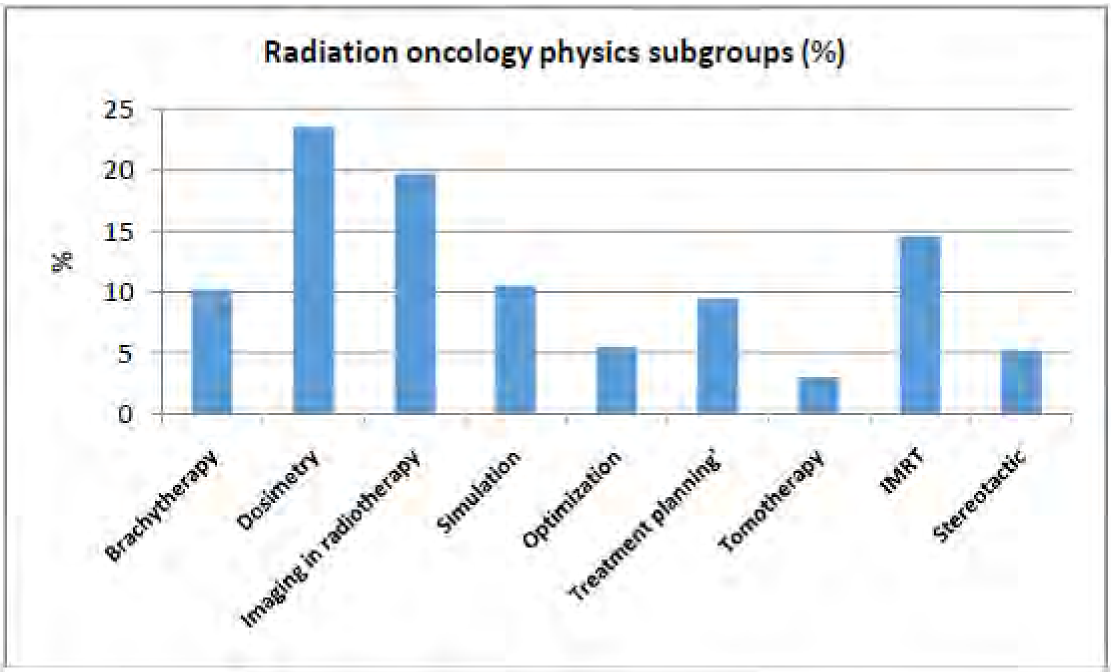
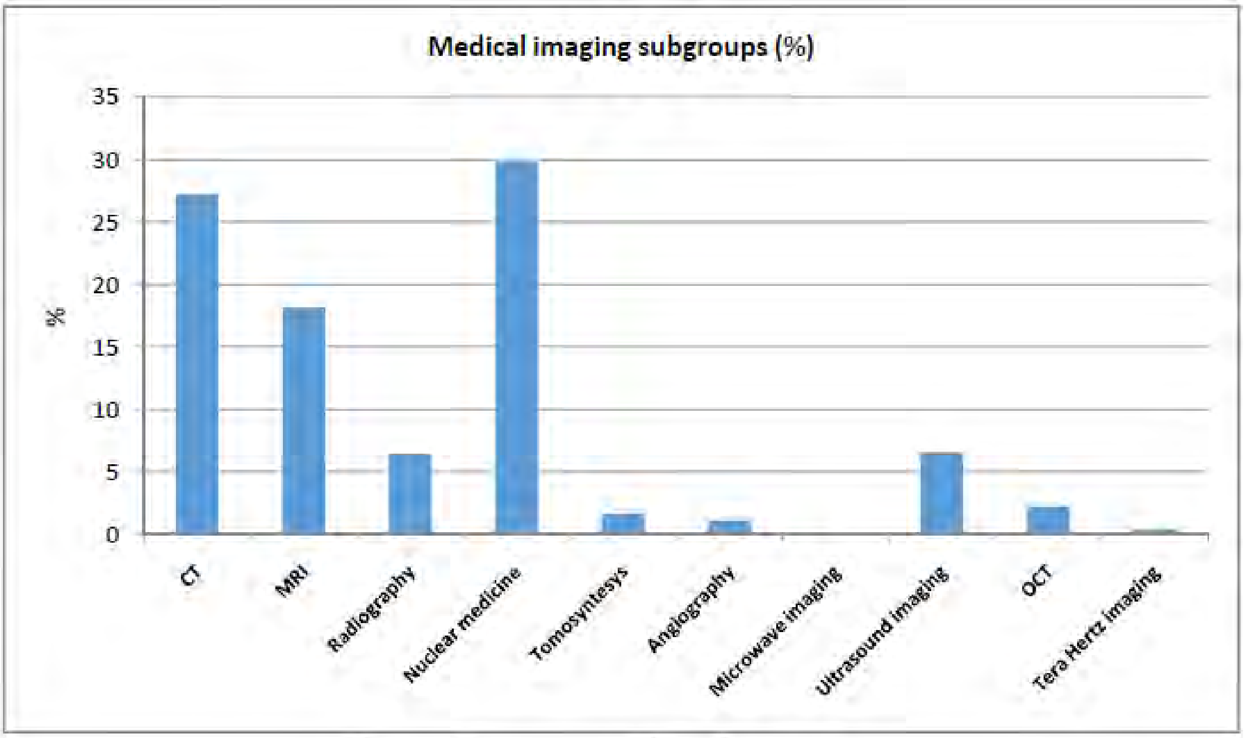


Figure 4: Percentage of medical imaging subgroups papers.



4 DISCUSSION CONCLUSION

According to table 2 radiation oncology physics and medical imaging papers were more than the other areas of research. It reflected that these fields could more interested researchers. The papers of non-ionizing topics and radiobiology papers were less than the other groups, so that these fields need more researches in order to progress more.

Figure 3 demonstrated that dosimetry, imaging in radiotherapy and IMRT are the most investigated areas of research respectively in radiation oncology physics. In medical imaging nuclear medicine, CT scan and MRI are the most interesting fields for general community of medical physicists.

Results have shown that fast progressing topics such as radiotherapy and imaging could more interest scientists but despite that these days' non-ionizing fields such as wi-fi modems, mobile and wireless phones, microwaves and etc surround us, unfortunately less studies have performed in this field.

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Gender demographics in radiation protection

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Abstract. The rapidly changing demographics of the United States workforce includes a large number of women and members of minority groups that are currently underrepresented in science and engineering related education and careers. Various organizations are working to recruit and retain women, as well as minorities, with the goal to offset this underrepresentation. To address how this issue affects those in radiation protection, we review the current status of women in the field compared to their male counterparts, from salary to advanced degrees to positions in scientific bodies, with primary focus on American women and institutions. Preliminary findings indicate that women are underrepresented in multiple aspects of education, research and management. While gender diversity is the focus of this research, it should be acknowledged that similar research could be performed to investigate other diversity factors including age and ethnicity, which are as equally important; diverse perspectives have been documented in collective problem-solving to lead to more innovative solutions.

KEYWORDS: gender; nuclear science; history; radiation protection.

1 INTRODUCTION

1.1 Background

Women have made tremendous strides in narrowing the gender gap in Science, Technology, Engineering, and Mathematics (STEM) related fields, but many disparities still exist, particularly in higher education, professional leadership, and compensation. There is no question that, historically, gender bias has played a role in STEM gender disparity, but although there will always be singular incidents of sexism, some recent studies have shown that in many scenarios direct gender discrimination is not readily apparent [1, 2]. On the other hand, such research also indicates that various, subtle biases are still present, such as societal pressure associated with traditional gender roles and familial responsibility. Such "indirect," and often unconscious, gender bias is one significant reason for women's underrepresentation in the STEM education pipeline and associated careers [3]. Legacy effects of generations of gender bias have led to stereotype threat, perceived lack of ability and value for (hard) science, as well as a lack of female role models and mentors [4-6]. Additionally, many of the women who are in senior positions are Caucasian, who may not be as relatable to female minorities. Women of color, so-called "double minorities" because they experience both gender and racial biases, are more under-represented and face unique challenges when compared to women in general, and even to men of color [3].

1.2 Objective

Considering that women are underrepresented across STEM fields in the broad sense, this paper considers where women stand in our fairly specialized field. We first provide examples of women, historical and modern, whose accomplishments have opened doors to future generations of women. This is followed by a summary of various metrics associated with gender equality. Representation is an important, but not the only indicator of equality, so we have also considered salary, education, and leadership. Where available, we have separated the data by race. Although not comprehensive, as true equality gives consideration to, among other things, personal experiences (of both genders), it provides a starting point for discussion about how to make our education pipeline, workforce, and professional bodies more inclusive.

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2 HISTORICAL PERSPECTIVE

Since the discovery of ionizing radiation in 1896, women have made numerous contributions to the field of radiation science. Many faced significant personal and professional challenges, particularly the women living in the early to mid-twentieth century who provided the foundation of nuclear science. We first consider two early, and prominent, female radiation scientists, Marie Curie and Lise Meitner, for their obvious contributions but also for a comparison of their experiences. For example, beyond their scientific endeavors both faced marginalization in their careers and personal life for their gender and Jewish ancestry, both were immigrants, and both became heads of internationally recognized research laboratories [7].

Marie Curie (nee Sklodowska) (1867-1923), by far the most famous female radiation scientist and arguably the most famous historical female scientist in general, was awarded the Nobel Prize in Physics (1903), shared with her husband Pierre, for their combined research on radiation and radioactivity (discovered by Henri Becquerel, who was awarded one-half of the same prize). Curie was also independently awarded the 1911 Nobel Prize in Chemistry for her discovery and associated work with radium, the only person to be a Nobel laureate in two scientific fields. Dr. Curie even coined the term "radioactivity" [8-10]. Lise Meitner (1878-1968) is known for her pioneering work in nuclear physics, particularly in the theoretical realm, with her most famous contributions likely being in the collaborative discovery of nuclear fission along with its theoretical explanation. Dr. Meitner coined the phrase "nuclear fission" [7, 11].

Many women worked on the Manhattan project in the United States, but one of the most prominent health physicists during that time was Elda "Andy" Anderson (1899-1961). A charter member and the fourth president of the Health Physics Society (HPS), she was instrumental in the formation of the HPS as well as the establishment of professional certification for health physicists in the United States. She was a particularly dedicated mentor and spent a good portion of her career focused on the education and training of new health physicists. The HPS established the Elda E. Anderson Memorial Fund in her honor, from which the Elda E. Anderson Award was formed in 1962. This award has evolved to annually recognize a young member of the society for distinguished contribution to the profession of health physics [12, 13].

Many of the early women scientists, particularly ones who gained prominence, came from supportive, encouraging families and also had male allies. There were several notable collaborations between husband and wife, such as between the Curies, although the political situation at the time often precluded the hiring of a spouse or even resulted in the request for a newly married woman's resignation [14]. As an aside, France granted women suffrage in 1944, meaning that in her lifetime Marie Curie was never able to vote [15]. Other women, as Dr. Meitner and Dr. Anderson, never married, but found supportive colleagues. Dr. Meitner eventually moved to nuclear physics from radiochemistry in an effort to establish herself as an independent scientist; at the time, many women who worked in collaboration with men were seen as subordinates and not equally contributing partners. Interestingly, Dr. Meitner never graduated a female doctoral student or even published with another woman. Although she was regarded as a kind and friendly person, she seems to have made no efforts to recruit or mentor other women [11]. Marie Curie, on the other hand, actively encouraged female scientists, including her daughter Irene who would also receive a Nobel Prize [7].

More recent female figures[1] in the nuclear arena include Eileen Gail de Planque (1944-2010), who was the first woman to become a Commissioner (1991) of the United States Nuclear Regulatory Commission (USNRC). She was a nuclear physicist who specialized in environmental radiation measurements. Shirley Ann Jackson, the current president of Rensselaer Polytechnic Institute, was the first woman to serve as chairperson of the USNRC (1995-1999) and the first African American Commissioner. She was also the first African American woman to earn a doctorate (1973) from the Massachusetts Institute of Technology. Clair Cousins, an interventional radiologist from the United Kingdom, is the current

[1] Accessed: December 2015. http://www.nrc.gov, http://www.icrp.org, http://www.irpa.net, http://hps.org

(2009-present) ICRP chairperson, the first woman to hold the position since the ICRP's inception in 1928. Renate Czarwinski is the current (outgoing) president of IRPA, only the second woman to serve in this role (following almost 30 years after the first female president)

There are obviously numerous other women who have made significant contributions to the field, including those women serving as support staff; for a more detailed account of the contributions of women to the radiation sciences, the reader is directed to the companion paper [16].

3 METRICS

3.1 Professional bodies

The number of women in professional bodies was investigated to include both US and international based organizations. This data was collected through information provided by the organizations and by manual inspection of the organization's publically available websites[2] and is presented in Table 1.

Table 1: Leadership of Professional Bodies

Leadership Position	Category		
	Members	Female	Percentage
ICRP Chair[(a)]	12	1	8.3
ICRP Main Commission	14	1	7.1
ICRP Committees	79	17	21.5
NCRP Council	100	28	28
NCRP Officer/Board Member	16	5	31.3
NRC Commissioner[(b)]	35	5	14.3
NRC Commission	33	12	36.4
IRPA President[(c)]	13	2	15.4
IRPA Executive Council[(c)]	156	12	7.7
HPS President[(d)]	60	6	10.0
HPS Officer/ Director[(d)]	621	128	20.6
ANS President[(c)]	49	3	6.1
ANS Officer/Director[(c)]	1,440	182	12.6

[(a)] 1928-2015, [(b)] 1975-2015, [(c)] 1966-2015, [(d)] 1955-2015

The percentage of women in all investigated organizations does not achieve gender parity, defined here as 45 to 55 percent representation per gender, in any leadership position.

3.1.1 Professional Awards

Awards presented by professional organizations are another way in which professional achievement and leadership can be recognized. Investigation of HPS awardees indicates that women receive awards significantly less often than men. The first woman presented with the Elda E. Anderson Award, Dr. Kim Kearfott, became the 31st recipient in 1992, despite this award being named in honor of a female radiation scientist [17]. Of the 53 total Elda E. Anderson awardees to date, only 6 have been women. Other examples of HPS awards include the Distinguished Scientific Achievement award (established in 1968), which only names one woman of the 51 recipients since its induction, and the Founders award (established in 1974), which includes five women of its total 37 recipients [18].

[2] Accessed: January 2016. http://www.nrc.gov, http://www.icrp.org, http://ncrponline.org, http://www.nrc.gov, http://www.irpa.net, http://hps.org, ANS from personal communications

Other awards granted by professional organizations in the United States that were named in honor of a woman include the American Nuclear Society's Mary Jane Oestmann Professional Women's Achievement Award (established in 1990), which recognizes early to mid-career women who have already made substantial contributions to nuclear science and engineering. The ANS also offers the E. Gail de Planque award (established in 2013) for outstanding lifetime or singular achievements by women [19]. In 2011 the American Association of Physicists in Medicine (AAPM) lifetime achievement award was renamed as the Edith H. Quimby Lifetime Achievement Award in the namesake's honor [20]. The American Physical Society created the Maria Goeppert Mayer Award in 1986 as an annual recognition of an outstanding early career female physicist [7].

3.2 STEM degrees awarded

Data on bachelor's, master's, and doctoral degrees conferred from 2002 to 2012 in the aggregate United States (US) made available as detailed statistical tables by the National Science Foundation (NSF) was investigated [21]. Table 2 provides a synopsis of this compiled data focusing on degrees awarded in physics, mathematics, and engineering – other, which includes nuclear engineering among other engineering subspecialties. These specialties were chosen as graduates of these programs are the most likely to be employed in the radiation protection arena.

Table 2: U.S. Science and Engineering (SE) Degrees (2002-2012)

Degree	Category					
	Total SE Degrees Awarded	Percentage White	Percentage Female	Total Specialty Degrees Awarded	Percentage White Specialty	Percentage Female Specialty
Bachelor	5,422,912	49.6	50.4	410,360	66.6	31.2
Master	1,402,319	46.4	44.9	186,269	41.0	30.5
Doctoral	335,565	44.4	39.2	51,903	35.7	24.2

The percentage of women earning degrees in all science and engineering categories as a whole indicates gender parity in both the bachelor and master levels. However the leaky pipeline can be seen as the percentage of women earning higher degrees decreases with degree level with parity not being achieved at the doctoral degree level. The percentage of women earning degrees in the specialty groups is well below gender parity and the leaky pipeline is again evident as the percentage of women earning degrees decreases as the degree level increases [23]. When the female specialty subset is compared against the total science and engineering degrees awarded at the bachelor, master and doctoral level, the numbers are grim; only 2.4 percent, 4.1 percent, and 3.7 percent, respectively, of the total degrees awarded in each degree level are to women in mathematically intensive fields.

3.2.1 Degrees in Radiation Protection

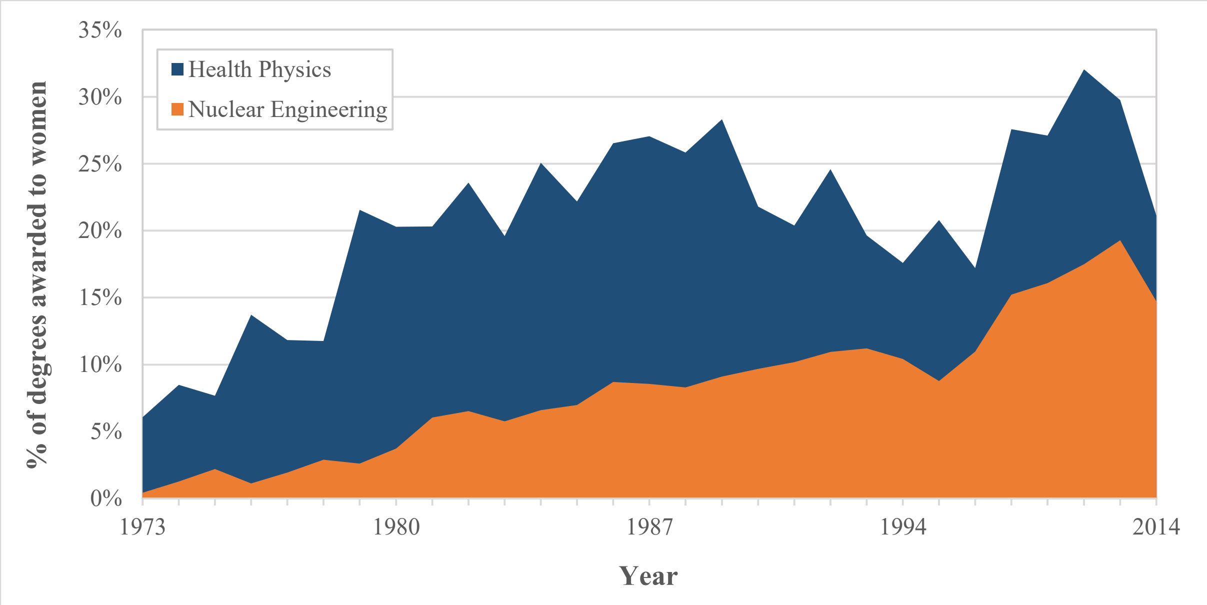
Oak Ridge Institute for Science and Education has conducted enrollment and degree surveys specific to health physics and nuclear engineering programs in the US consecutively since 1973 [22]. This data was compiled to provide an in depth look at the demographics of the US radiation protection degree programs and is presented in Table 3.

Table 3: U.S. Health Physics (HP) and Nuclear Engineering (NE) Degrees (1973-2014)

Degree	Category			
	HP	% Female	NE	% Female
Bachelor	3,635	18.5	20,437	6.1
Master	5,690	17.1	11,930	5.8
Doctoral	1,429	11.4	4,704	4.5

The percentage of women earning degrees in health physics and nuclear engineering both fall well below gender parity. As with the trends from Table 2, the leaky pipeline is demonstrated as the number of women graduates again drops as degree level increases [23]. With that being said, Figure 1 illustrates the increasing trend in degrees obtained by women.

Figure 1: Trends in US HP and NE Degrees[a]

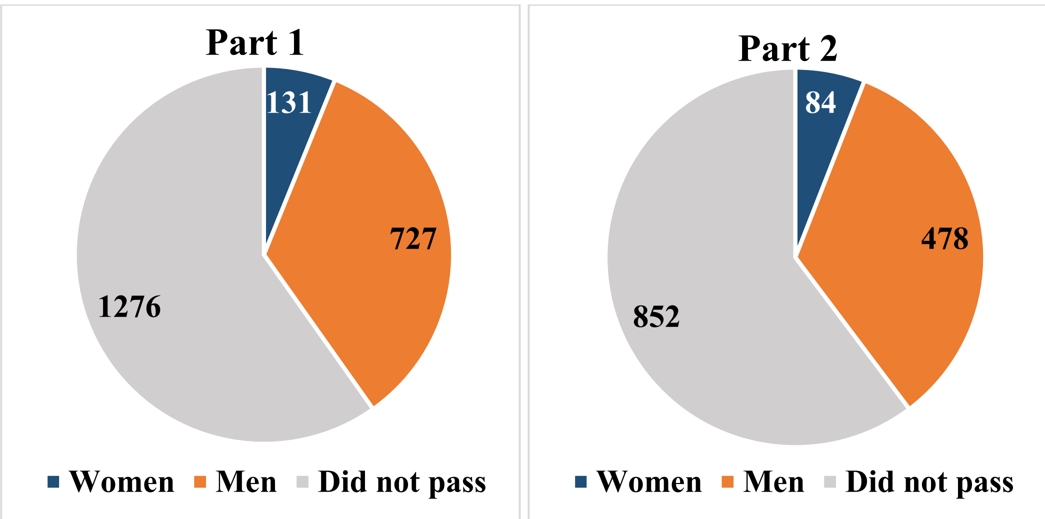


[a] Percentages represent total degrees (bachelor, master and doctoral)

3.3 Professional Certification

Professional certification in the field of Health Physics is granted by the American Board of Health Physics (ABHP), which was formally established in 1959. Examination results[3] for the past 15 years were compiled and are presented in Figure 2. Demographics on applicants for this examination are not available. Analysis of demographics for candidates achieving certification indicates that only 6 percent are female.

Figure 2: ABHP Examination results (2000-2015)

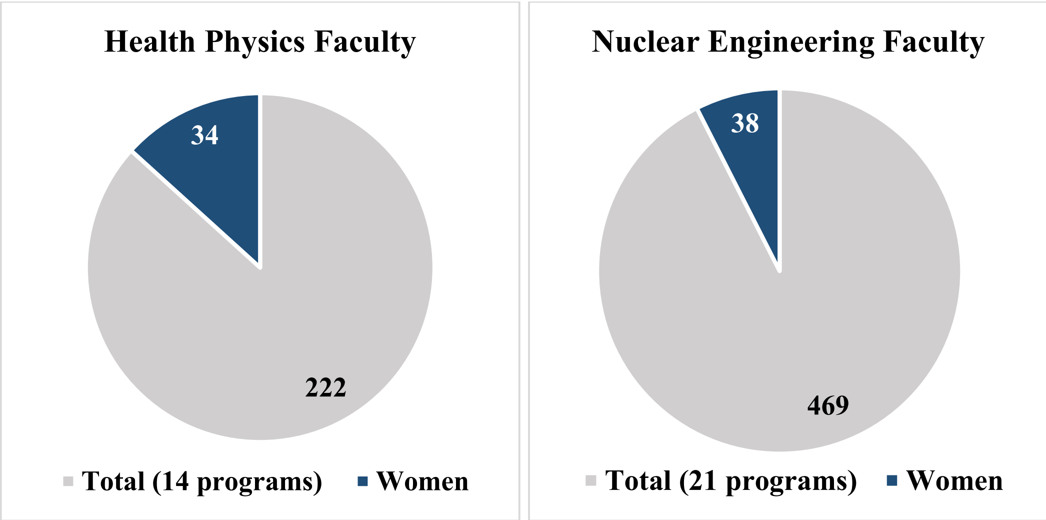


[3] http://www.hps1.org/aahp/certlists.htm

3.4 Faculty

Known US HP and NE degree programs were investigated for faculty demographics. This information is not typically published, therefore gender diversity investigation was performed by visiting the publically available faculty webpages[4] for each degree program. Race/ethnicity demographics for this investigation were not attempted. Raw data is available from the authors on request. Analysis of the data indicates that women represent only 15.3 percent of HP faculty and 8.1 percent of NE faculty, as illustrated in Figure 3.

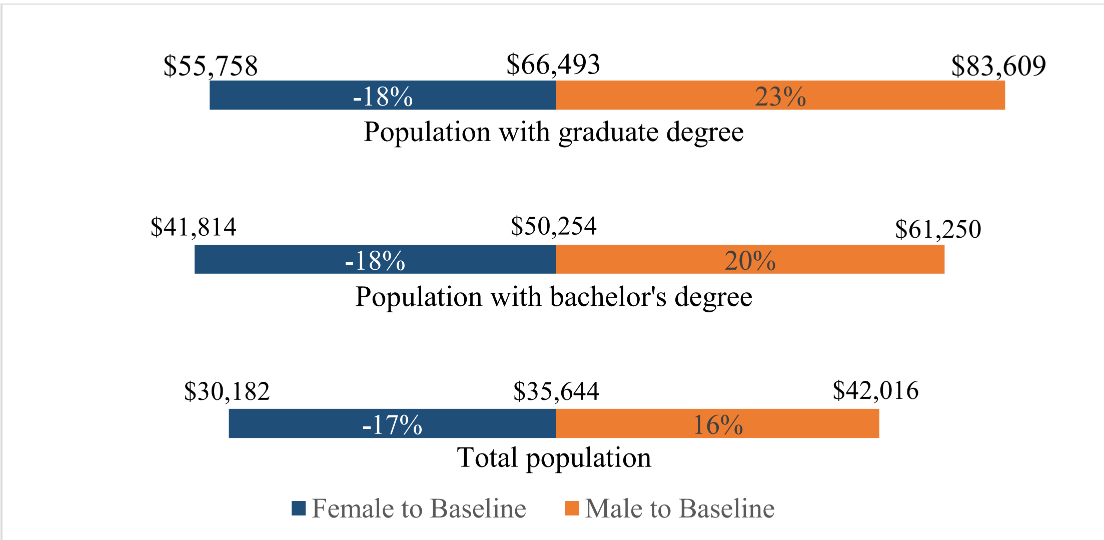
Figure 3: Health Physics (HP) and Nuclear Engineering (NE) Faculty



3.5 Salary

Median earnings data by gender and education was available from the U.S. Census Bureau [24]. A summary of this data is presented in Figure 4. The dataset includes the U.S. population over age 25 with earnings during the investigation period. The baseline salary is the average salary for the population without regard to gender.

Figure 4: Difference in Median Earnings from Baseline by Gender and Education (2009-2013)



[4] Accessed January 2016

Analysis of the total population indicates on average men earn as much as 33 percent more than women. When adjusted for bachelor and graduate level degrees, the wage gap increases to 38 percent and 40 percent, respectively.

4 DISCUSSION

4.1 Personal experiences

Many female friends in the field have communicated to the authors that they have experienced some form of discrimination or even harassment, from commentary on clothing to suggestive remarks to trivializing professional opinions or ability. Others have experienced increased competitiveness from other women, seemingly being perceived as a threat to a hard-fought, established position. These types of experiences are difficult to quantify, plus individual experiences do not necessarily reflect the overall experience of the group. As mentioned earlier, though, true equality cannot be solely determined by quantitative metrics, but although challenging, must also take into account personal experiences [3]. We would like to believe that gender-based attitudes and behaviors no longer exist, but ignoring that gender plays a role in our field will only exacerbate the problem. With that being said, there are a tremendous number of supportive colleagues at both the junior and senior level and of both genders, which has undoubtedly influenced the increasing number of females in our field, as well as enabling these up-and-coming scientists to be successful.

4.2 Moving forward

It is important to express at an early age that women are equally suited for traditionally male-dominated careers in science and mathematics, just as men are equally suited for traditionally female-dominated careers such as teaching, nursing, or home-making [1]. This latter point deserves emphasis: gender bias negatively impacts men as well as women. Discrimination limits the pool of talent, regardless of the field. Additionally, individual choice and ability should be the deciding factors in selecting a career path as well as in finding work-life balance, as opposed to societal perceptions or expectations based on gender, race, creed, etc. Exposing young people to a variety of professions or career options, as well as providing appropriate resources for learning about or pursuing their field of choice, is essential for establishing gender equality [4].

5 CONCLUSION

Gender disparity in the field of radiation protection has been persistent since the origins of the field, the effects of which are still clear 60 years later. Women are underrepresented at all levels of education, leadership, and representation both in the US and internationally, particularly in mathematically intensive fields. Trends in US radiation protection degree programs indicates that the number of women earning these degrees has fairly consistently increased over the past four decades, but gender parity has still not been reached. The number of women available for leadership, faculty, and research is directly affected by the educational pipeline, which still struggles to retain consistent numbers of qualified women. Engaging girls at a young age in science and math, continuing and even expanding the existing support system, as well as giving additional consideration to individual experiences may help retain women and work towards gender parity.

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The FORO Project on Safety Culture in Organizations, Facilities and Activities with Sources of Ionizing Radiation

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Abstract. The aim of the paper is to present the Foro of Iberoamerican Radiological and Nuclear Regulatory Authorities (FORO) Project on Safety Culture in organizations, facilities and activities with sources of ionizing radiation. To achieve and maintain a strong safety culture is a priority, in order to ensure the optimization of protection and prevention of radiological accidents. This means continuous improvement in the attitudes and behaviors about safety of the organizations, their management and workers. The FORO document on Safety Culture, in its various chapters, develops from the theoretical bases of safety culture to the practical tools to assess the level of safety culture. Ten Basic Elements of Safety Culture were established, which are interrelated and all must be present to achieve a strong safety culture. The 10 Basic Elements provide a conceptual framework to orient the actions and efforts for promotion and development of safety culture. The document also describes indicators for the evaluation and the monitoring of the progress of safety culture, proposes ways to promote and develop a strong safety culture and provides a conceptual framework for internal safety culture in the Regulatory Authorities. Various topics such as the analysis of the impact of safety culture in the occurrence of radiological accidents and best practices to foster and develop safety culture are addressed in the appendices and annexes. The document can be a valuable tool to reach and maintain a strong safety culture for organizations and institutions in the Iberoamerican region and all over the world.

KEYWORDS: safety culture; FORO project; basic elements of safety culture; indicators of safety culture.

1 INTRODUCTION

Taking into account that safety culture problems have been widely recognized as one of the major contributors to many radiological events, several international and regional initiatives are being carried out to foster and develop a strong safety culture. One of these initiatives is the project sponsored by the Foro of Iberoamerican Radiological and Nuclear Regulatory Authorities (FORO) with the purpose to

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prepare a document to allow its member states understanding, promoting and achieving a higher level of safety culture.

In the framework of the FORO programs related to human and organizational factors, it was developed the FORO Project on Safety Culture. A group of experts from Argentina, Brazil, Chile, Cuba, Mexico, Peru, Spain and Uruguay, with the leadership of the Cuban expert and the scientific coordination of the International Atomic Energy Agency (IAEA) has been working on it. After two years of work, the project outcome is a document: ¨Safety Culture in organizations, facilities and activities with sources of ionizing radiation¨.

In the framework of the document, the safety culture in organizations, facilities and activities with sources of ionizing radiation has been defined, following the IAEA approach, as "the assembly of characteristics and attitudes in the organizations, its managers and workers which assures that, as an overriding priority, safety issues receive the attention warranted by their significance", and safety is understood "as the protection of people and environment against the associated risks of ionizing radiation and also the radiological safety and the security of radiation sources".

2 DESCRIPTION OF THE FORO PROJECT ON SAFETY CULTURE

The FORO Project on Safety Culture develops from the theoretical bases of safety culture to the practical tools to assess the level of safety culture in medical, industrial and research activities, radioactive waste management and transport of radioactive material. The document also describes indicators of safety culture and proposes ways to promote and develop a strong safety culture. Various topics such as the analysis of the impact of safety culture in the occurrence of radiological accidents and best practices to foster and develop a safety culture are addressed in the appendices and annexes.

The FORO document on Safety Culture has been written in Spanish and is available free of charge at the FORO website (www.foroiberam.org). The document covers theoretical approaches and practical guidance on safety culture, adapted to the environment in which radiological activities are carried out. Some innovative elements are introduced in this document like a safety culture concept which considers that the radiological protection culture and the security culture are inextricable linked.

Safety approaches have had similar developments in almost all sectors of the industry and services with associated risks. Usually the occurrence of accidents or disasters has marked the beginning and the transition to higher stages, because they revealed expiration, failure or vulnerability of the philosophies, concepts and methods to address safety, existing at that time, leading to its renewal and to qualitatively better approaches.

In general, it can be considered that approaches to safety have gone through three phases. There is a first phase, characterized by a focus on technology to guarantee safety. Later, it was more relevant the contribution of individual human error during operation, leading to the human factors phase. Finally and after the analysis of some accidents occurred during the 80´s decade, a new vision leads to the next and most recent phase of safety approaches, the organizational phase. It is in the latter where the safety culture is framed.

In the FORO document on Safety Culture there is as introduction with a description of the historical evolution of safety approaches through the three phases: Technological, Human Factors and Organizational, being the last one associated with the so called Soft Safety. The Human and Organizational factors pose the greatest impact on the occurrence of accidents, with an estimate contribution closer to 80-90% in some sectors, Fig. 1.

Several international documents and events have recognized the contribution of problems of Safety Culture in the occurrence of radiation events. In an Annex of the FORO document on Safety Culture is shown, from the perspective of safety culture, how attitudes and behaviors of managers, workers and organizations as a whole, created the conditions for the occurrence of certain radiological events. The fundamental interest is to know, learn and convey why the events occurred, from the point of view of safety culture. Examples of radiation events confirm that to achieve safety is not enough to have the technology or the most modern equipment, qualified personnel or certificate and all processes or tasks in written procedures.

Figure 1: Historical evolution of safety approaches.

Inappropriate attitudes and behaviors of personnel and organizations, with respect to safety, can make fail barriers and existing controls leading to radiological consequences for the workers themselves, public and the environment, with economic or social impact.

Widespread and intense efforts have been undertaken to develop the theme of safety culture in nuclear and other sectors such as oil, aerospace, civil aviation and the health sector. The assimilation and the practical incorporation of the concept of safety culture in organizations carrying out activities with radiation sources have expanded considerably.

The importance, urgency and the need to promote and develop the safety culture are discussed in the FORO document. Also, there are summarized the most important theoretical aspects of the concept of culture whose understanding is essential to comprehend, address and act on safety culture.

3 BASIC ELEMENTS OF SAFETY CULTURE

The FORO document lists and describes 10 Basic Elements of Safety Culture in organizations, facilities and activities with sources of ionizing radiation. Several existing approaches and criteria in other risky sectors or activities were reviewed and analyzed. As result of this work the minimum elements to be considered in the scope of the document were established.

The 10 Basic Elements of Safety Culture, in the framework of the Project, are: (1) Priority of safety.
(2) Visible leadership and commitment of top management with safety.
(3) Timely identification and proper solution of safety problems. (4) Permanent focus on safety.
(5) Responsibility, involvement and individual behavior in respect to safety. (6) Effective communication on safety.
(7) Free reports on safety concerns.
(8) Fair treatment for individual behaviors in respect to safety. (9) Continuous organizational learning about safety.

(10) Environment of trust and partnership on safety.
These 10 Basic Elements are interrelated and they all must be present to achieve a strong safety culture in organizations working with sources of ionizing radiation, Fig. 2. The 10 Basic Elements provide a conceptual framework to orient the actions and efforts for promotion and development of safety culture.

Figure 2: The 10 Basic Elements of Safety Culture in organizations, facilities and activities with sources of ionizing radiation.

4 INDICATORS OF SAFETY CULTURE

A scheme of four-levels of safety culture has been developed for organizations working with radiation sources. These levels are: Low level, Incipient Progress Level, Advanced Progress Level and Level of Excellence. This classification in levels of safety culture has several benefits. First, it lets, after evaluation, to know where is the organization in terms of its safety culture. Secondly, it is easier to visualize the goals or desired states, define how distant is to achieve them and take relevant measures and actions. Finally, it serves to compare, through successive evaluations, the progress experienced on safety culture by the organization.

In the field of safety culture, any intent of assessment or measurement is complex for many reasons. However, it is necessary to have some kind of indicators to monitor the state of safety culture to recognize if there is progress or decline, and also because it is not possible to improve what is not measured or evaluated. Monitoring the safety culture through indicators identifies trends that are very beneficial for an early alert on potential or imminent deterioration of safety in the organization, acting like an "anticipatory effect", Fig. 3.

In the context of the document, a set of Safety Culture Indicators is proposed, to evaluate each of the 10 Basic Elements and these indicators can be used by the organizations for systematically monitor their behaviors towards safety culture. In an appendix of the document, a total of 62 Indicators, related to the 10 Basic Elements, are described, as well as the possible qualitative or quantitative measures to be used to evaluate each indicator. Also, the recommended measures verification methods and the criteria to evaluate the extent are proposed.

As the indicators are the result of indirect measurements, the information they provide requires an interpretation of what is reflected in terms of culture, the possible beliefs, values and behaviors with regard to safety in the organization.

Figure 3: Indicators of Safety Culture for systematically monitoring.

It should be emphasized that the list of indicators is a guide for the organizations working with radiation sources to start using them in their daily work, in the appropriate form and on their distinctive features. This will enable the organization to become familiar with each type of indicator and simultaneously will validate its effectiveness.

5 EVALUATION OF SAFETY CULTURE

The document also describes how to perform an evaluation of safety culture in an organization working with radiation sources, providing information, criteria and techniques to complete the evaluation. This process may also be applied to the Regulatory Authorities, when they evaluate their own safety culture. The evaluation of safety culture is necessary for the diagnosis of the starting level and to decide the actions for process improvement.

Five techniques are recognized to assess the safety culture. These techniques are: Document Review, Process Observation, Surveys, Interviews and Focus Groups. Each of the techniques has its particular advantages and disadvantages, emphasizing that the application of a single technique is not enough to reach conclusions on the safety culture of an organization. It is therefore necessary to apply a combination of all these techniques, because each has its own effectiveness to reveal or decode the different aspects of safety culture.

6 PROMOTION AND DEVELOPMENT OF SAFETY CULTURE

Achieving a strong safety culture implies a cultural change by modifying the existing values, beliefs and behaviors with new ones that respond to the desired state. A cultural change can occur spontaneously as a result of experiences and processes over a period of time or by the effect of abrupt events or other factors that require change. However, the process of cultural change can be accelerated by the planned actions. In the field of safety, you cannot expect events or accidents occur to produce a cultural change, it is necessary to act proactively to achieve the required level of safety culture, to avoid such events. This process is called: Promotion and Development of Safety Culture.

The promotion and development of safety culture is always a process "top-down", because the way people act is highly conditioned by the requirements set forth in the top levels of the Organization. This process should be complemented by the necessary involvement of all staff in terms of cultural change.

The promotion and development of safety culture in an organization working with radiation sources should be undertaken by the organization, in the first instance. However, there are external factors that may contribute positively promoting cultural changes. These external factors are, for example, the Government, Regulatory Authorities, Professional Societies, Education and Training Organizations and relevant Stakeholders. Therefore, it can be considered that there are two ways to promote safety culture in an organization working with radiation sources: internal action by the organization itself and the action of external agents.

7 SAFETY CULTURE IN THE REGULATORY AUTHORITY

The Regulatory Authority is one of the external factors who may have greater effect on the development and strengthening of safety culture in organizations working with radiation sources. Safety culture in the Regulatory Authority and its staff individually, their values, attitudes and behavior with respect to safety, will influence the methods of its regulatory action.

It is important that the Regulatory Authority has and reflects a strong internal safety culture to ensure the necessary impact of regulatory action and be an example to the organizations that regulate and in promoting a strong safety culture.

A chapter of the document is oriented to provide a guidance for the Regulatory Authority about its internal safety culture and 10 Basic Element of Safety Culture in Regulatory Authority are described, Fig. 4. These Basic Elements are:
(1) Supreme commitment with safety.
(2) Visible leadership and commitment of top management with safety. (3) Timely identification of safety problems and proper decision making. (4) Permanent focus on safety.
(5) Regulatory actions that clearly favour safety.
(6) Professional recognized relationship with regulated organizations. (7) Effective internal and external communication on safety.
(8) Free reports and fair treatment for behaviors in respect to safety. (9) Continuous organizational learning about safety.
(10) Proper individual behavior of Regulatory Authority staff.

Figure 4: The 10 Basic Elements of Safety Culture in Regulatory Authorities.

A Regulatory Authority with a strong safety culture achieves better methods and regulatory strategies, greater rigor, credibility and respect, and better communication and common understanding with regulated organizations, among other features that should distinguish a regulatory body.

The document also provides information on how to develop a Program for the Promotion and Development of Safety Culture and examples of good practices to foster safety culture by the Regulatory Authorities are presented, taken from the experience of FORO member countries.

8 CONCLUSIONS

The FORO Project on Safety Culture in organizations, facilities and activities with sources of ionizing radiation, which has been developed in Spanish language, was accomplished within the framework of the Foro of Iberoamerican Radiological and Nuclear Regulatory Authorities (FORO) and with the scientific coordination of IAEA.

To achieve and maintain a strong safety culture is a priority, in order to ensure the optimization of protection and prevention of radiological accidents. This means continuous improvement in the attitudes and behaviors about safety of the organizations, their management and workers.

Cultural change requires, from organizations working with sources of ionizing radiation, regulators and stakeholders, to have a clear comprehension of the meaning of safety culture and the basic elements that characterize it, as well as the forms and methods to foster, evaluate, monitor and continually improve safety culture.

The FORO project integrates, under the same safety culture, the radiation protection and safety aspects as well as the security of radiation sources, assuming that they are inextricably linked. It also provides a conceptual framework for internal safety culture in the Regulatory Authorities.

The FORO project on Safety Culture is the first stage of the process to achieve a strong safety culture in organizations working with radiation sources and should be completed later with other stages focused on the diffusion and implementation of the project in the different FORO member countries.

The diffusion actions to facilitate the technical understanding of the document and to prepare organizations and their management and workers for project implementation was initiated by placing the document in the FORO website (www.foroiberam.org), will be continued through discussions, seminars and courses organized locally in member countries and in regional events and it will be completed by the possible edition of the FORO project on Safety Culture in other languages.

All the diffusion actions will contribute to the practical, gradual and extensive implementation of the Safety Culture Project in the FORO member countries. The FORO Project on Safety Culture will be a useful reference for the Iberoamerican region and a valuable tool to reach and maintain a strong safety culture for organizations and institutions in other parts of the world.

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The Intersection of Public Health and Radiation Protection in Radiation Emergencies

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Abstract. Effective response to a nuclear or radiological emergency requires a multidisciplinary approach by a multitude of organizations and groups, many of whom may not ordinarily interact with each other under normal non-emergency conditions. Public health professionals perform vital functions during the response and recovery phases of any large-scale emergency that affects populations or the environment. These functions include conducting surveillance for illness and injury, assessing health and medical needs, ensuring public sheltering and mass care safety, addressing safety of food and water, vector control, waste management, rumor control and risk communication. In a radiation emergency, all these functions need to be performed in an environment where radiation levels may be elevated and people may be contaminated with radioactive materials. Consequently, the challenges of performing these vital emergency functions are exacerbated, and collaboration with radiation protection professionals becomes a necessity. Lack of such collaboration and communication before a radiation emergency occurs presents a gap in preparedness that would adversely affect the local and national response activities. During the last decade, the United States Centers for Disease Control and Prevention (CDC) has taken a multipronged approach toward closing this gap. This approach includes assessing training and educational needs of public health professionals through direct engagement, joint development of practical and operational guides, creation of planning tools, delivery of in-person and on-line training, facilitating increased use of volunteer radiation professionals in local communities, and development of innovative approaches to communicating hazards of radiation exposure. This presentation provides an overview of CDC activities and products in radiation emergency preparedness and gives examples of successful collaborations between public health and radiation protection professionals.

Assessment of the Safety Culture at Facilities Involved in Management of the Spent Nuclear Fuel and Radioactive Waste

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Abstract. This paper deals with practical assessment of safety culture at the spent nuclear fuel and radioactive waste storage facilities. The safety culture was being assessed by interviewing the personnel using the method based on the IAEA documents (ASCOT and SCART) and taking into account the special features of the facilities. There were 3 groups of experts: senior management level; middle control managers; ordinary workers. Safety culture was assessed in two companies: the Northwest Center for Radioactive Waste Management "SevRAO" (NWC "SevRAO") and the Far Eastern Center for Radioactive Waste Management (FEC "DalRAO") -subsidiaries of the Federal State Unitary Enterprise "RosRAO" - Radioactive Waste Managing Company. Integral assessment of the safety culture of workers was based on the method of "internal" safety culture assessment being developed by SRC-FMBC. This method helps to find "points for improvement" (weaknesses in work organization, which need the urgent attention) to improve safety culture. Findings of our study have helped to identify barriers to improve safety at the inspected enterprises and justify measures for its regulation, to prevent man-made threats of radiation accidents.

The Decision Threshold and Other Characteristic Limits: An Approach to Re- evaluating the Current Computational Paradigm

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Abstract. Measurements of ionizing radiation in different environments and matrices provide the basis for operational health physics and radiation protection, dosimetry, and the detection and identification of orphan or shielded sources. In low-level measurements, the scientific and technical challenge often involved the decision whether a source of ionizing radiation is present in a sample. Traditionally, a source is detected when a signal is statistically different from the signal obtained from natural background radiation during the measurement procedure; it is the decision threshold (y*) at which a source is recognized as being present. The decision threshold is calculated according to ISO 11929, often by taking a long background count and limiting the false positive error (α error). Recently, several challenges have been identified with this method, including the changing background due to natural environmental fluctuations or due to the movement of a mobile detector, and the large amounts of background data obtain concurrently with any measurement performed by the detector, but not necessarily utilized in the computation of the decision threshold. Novel approaches to addressing these challenges have resulted in a new understanding of the general properties of the decision threshold, and frequentist and Bayesian computations utilizing a rigorous statistical interpretation of accumulated large background data sets may, in some instances, decrease the decision threshold calculated by standard methods. In any case, these approaches provide a more general and complete interpretation of the decision threshold and other characteristic limits for measurements of ionizing radiation. This paper will develop the statistical and mathematical basis for novel computational algorithms to compute characteristic limits, and will provide examples for several possible background distributions. Implementation of these algorithms may improve detection and identification capabilities of currently deployed and future instrumentation, and might allow for enhanced (e.g., internal) dosimetry and for an extension of current search and detection ranges due to the ability to identify signals at lower signal-to-noise ratios.

Lessons learned from 4th African Regional Congress of the International Radiation Protection Association (AFRIRPA04) held in Morocco

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Abstract. The Moroccan Association of Radiation Protection (AMR), organized in conjunction with IRPA and the support of Nine International, fifteen African, and twelve Moroccan associations and organizations, the 4th African Regional Congress of the International Radiation Protection Association (AFRIRPA04) in Rabat, Morocco on September 13 –17, 2014, under the Main Theme: 'Strengthening Radiation Protection Infrastructures for Health and Sustainable Development in Africa'. The main objectives of the Congress were to understand and to promote radiation protection culture in all applications: to enable scientists and professionals from Africa and worldwide to discuss and exchange their expertise in all fields involved with Radiation Protection, to harmonize and coordinate the activities of societies evolving in the field of radiation protection by inspiring from international experience, and to strengthen the cooperation between professional societies. There were seven main topics of AFRIRPA04: Fundamental Radiation Protection including Biological Effects, Healthcare and Medicine, Standards and Metrics, Laws and Regulations, NORM Industries, Strengthening Security of Medical and Industrial Radioactive Sources, and Radiation Protection culture, education, and training. In all, two hundred thirty five effective presentations were delivered as: twelve plenary conferences, four refresher courses sixty three oral presentations in the thematic sessions, twelve communications as part of the Young Scientist Award, twenty five papers in seven workshops, and one hundred seventeen poster communications. Each session featured an open forum for ample debate and, as a result, topical contributions were widely discussed. An overview of radiation protection in Africa was given. Africa is emerging as a leader in the safe use of radiation and radioactive materials in the health care industries, NORM industries, in regulation, and in education and training. Improvements have been made, especially in the area of education and training.

Safety Culture Issues in Nuclear Fusion Activities

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Abstract. Since nuclear fusion scientific and technological research results are pushing the scientists and engineers further to conceive devices as ITER, DEMO, and possibly a real commercial reactor, it is time to start considering, in a global manner, the issue of safety culture in short and long term nuclear fusion labor activities. Even if, the impact and risks of accidents with nuclear fusion reactors seems to be much less severe than considering the ones that might occur in nuclear fission power plants. And this less severe release is due to the lower level radiation field created, for instance, by tritium release, which is not very far from 1/2Sv, per around 1kg released. However, this low amount of radiation is not so low after all, if we consider the year limit exposure established by IAEA for workers and members of the public, dealing with ionizing radiation. Some other types of exposure in nuclear fusion activities are far from being well understood, such as the stochastic effect of non-ionizing radiation in human body due to, for instance, electromagnetic fields. In this paper, we discuss afresh some important issues in this new energy generation area, such as: To which extend is non ionizing radiation relevant to nuclear fusion devices? What is the stochastic effect on people exposed to different intensity of fusion electric and magnetic fields – to where we have to extend ourselves to change rather than keep on using the same guides we have available now? What are the real safe electromagnetic field intensity limits? How and when is the correct time to prepare safety guides and requirements to permit people to be protected from electromagnetic radiation used and/or generated in machines that confine plasmas magnetically? Can the same safety fundamentals issued by IAEA be used to anchor the fusion safety documents or it should be used an appropriated graded hybrid (considering both NIR and IR) approach, or something else? Are those issues relevant to people´s safety after all? Those are questions to be addressed in a deeper way, soon or later, considering nuclear fusion commercial activities and we want to discuss some of them in this paper.

Communication in an Organization within a Framework of Social Responsibility

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Abstract. Communication plays a fundamental role in the achievement of IRPA's goals for the coming years. The development and enhancement of radiation protection culture within organizations –industrial, medical or regulatory, among others- as well as stakeholder's involvement in radiation protection, require a combination of knowledge, expertise, behaviour, values and ethics imparted through an effective 360º communication, both verbal and attitudinal. Personal and organizational accountability, integrity, transparency, openness and exemplary behaviour generate trust and contribute to consolidation of stakeholders' engagement. An important step in this direction is to act within a framework of social responsibility, understanding that one's actions generate impact on the environment, in the organization, employees, the community and other stakeholders. It was in this context and with the purpose of assessing the feasibility of integrating a socially responsible behaviour in a Class I multipurpose irradiation facility with existing strategies and specific requirements, that in 2007 social responsibility started being implemented at the Planta de Irradiación Semi-Industrial- PISI (COMISION NACIONAL DE ENERGIA ATOMICA). There were two primary objectives: reinforcement of safety and security culture by increasing PISI´s human capital and strengthening of our relationship and engagement with different stakeholders. For the selection of the reference document, several aspects were evaluated and although ISO 26000- Guidance on Social Responsibility, was still in a draft version until 2010, it stood out because it was based on international consensus between representatives of a wide range of stakeholders and applicable to all type of organizations, in developed and developing countries. It has seven fundamental core subjects which gather under the term social responsibility: organizational governance, human rights, labour practices, the environment, fair operating practices, consumer issues and community involvement and development. This standard completes the integration of safety, health, environment, security, quality, good irradiation practices and economic elements in one single management system, thus ensuring all these aspects are taken into account and contributing to sustainable development, health and welfare of society.

Interdisciplinary Approach to Radiation and Nuclear Safety Education

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Abstract. Specific characteristics of nuclear energy and its management modes forces to develop advanced education – professional as well as public – nuclear education approaches, with the aim to solve two basic constituents of nuclear sustainability – 1) to maintain and develop reliable professional human resources, 2) to gain positive public attitude to existing as well as forthcoming novel nuclear facilities. There is proposed to develop a common interdisciplinary approach to nuclear education , taking into account that i) the public awareness and knowledge level about nuclear energy problems is different, ii) public perception of nuclear risks markedly differs from scientific assessment of these risks, iii) the inherent incompleteness in data on nuclear safety. The key methodology of our interdisciplinary approach - the use of principles which could manage with the knowledge and information qualities: 1) a self-organization concept, 2) the principle of the requisite variety. As a primary source of growth of internal variety is proposed information and knowledge. Following actual issues are considered related to nuclear education a) nuclear risks and their perception, b) human resource development: c) advanced research and nuclear awareness improvement, d) multi-level confidence building to the nuclear power use. We have shown: public education, social learning and the use of mass media and internet are efficient self-organization mechanisms, thereby forming a knowledge-creating community. Such a created knowledge could facilitate solution of key socio-technical nuclear issues as a) public acceptance of novel nuclear objects, b) promotion of adequate risk perception, and c) fostering of interest to nuclear energy being a key common factor of nuclear sustainability both in the personnel as well as in the public area. Comprehensive knowledge management and informational support firstly is needed in such issues as: a) general nuclear awareness, b) personnel education and training, c) reliable staff renascence, d) public education and involvement of all stakeholder categories in decision making, e) risk management.

Education and Training in Radiopharmacy: The INSTN Approach

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Abstract. Radiopharmacy combine advanced engineering in pharmacy, chemistry and nuclear science together with state-of-the-art technology for non-invasive in vivo imaging and therapy. This field contributes immensely to biomedicine because it is the major technology that can explore and measure the chemistry of life in a non-invasive manner. It is thus a key for the development of new diagnostics and therapeutics. Considering the rapid development of technologies and because the quality of radiopharmaceuticals is an essential requirement for delivering effective diagnostic and therapeutic results in nuclear medicine service, there is an urgent need of specific educational programs in this field. Pharmacists and chemists must be well qualified and appropriately trained to adapt themselves to these new technologies. This must be achieved through suitable and updated trainings. Since 1974, the National Institute for Nuclear Science and Technology (INSTN) within the French Atomic Energy Commission has been responsible for organising the education of pharmacists in radiopharmacy. This Institute is recognised by the European Association of Nuclear Medicine as a training centre in radiopharmacy. The INSTN provides solutions to satisfy needs in nuclear medicine, radiopharmacy and molecular imaging training in the requirements from professionals. To do so, the institute is in charge of organising short trainings for professionals (Life-Long Learners). It also brings training solutions to special needs for national and/or international trainings. Pedagogy is an art and a science of teaching. There is no single, universal approach that suits all situations. However, some strategies are better suited to teaching certain skills than are others. They are better suited to certain student backgrounds and levels. In order to develop effective methods of teaching at the highest level in the field of radiopharmacy, the use of a wide variety of teaching strategies in different combinations are essential. As you probably know, students are not empty vessels to be filled with our expert knowledge. They must construct their own understandings through our professional experiences. Today, the INSTN approach for education and training in radiopharmacy gives students practical skills that will enable them to continue learning after they graduate.

Experience of Belarus to the Introduction of International Radiation Safety Standards to the National System

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Abstract. The radiation safety system of Belarus is now processed according to the last radiation safety standards and recommendations of IAEA and ICRP. Improving and strengthening the system of radiation safety, the establishment of radiation monitoring system and dose assessment of the population living around the NPP are important issues in the Belarus taking into consideration implementing the first nuclear power programme and construction the first NPP. The radiation safety of the Belorussian NPP is require solving complex of problems process and should be under consideration in accordance with that after Chernobyl accident about 20% territory of Belarus was contaminated of ceasium-137. In Belarus in radiation safety distinguish two categories of exposed individuals: workers and population. The new radiation safety standards, guidelines and recommendations of IAEA and ICRP are implemented in radiation safety requirements and criteria have been included in radiation safety regulations and approved by the Ministry of Health of the Republic of Belarus from 2012: Sanitary regulation "The Radiation safety requirements", Hygienic standard "Criteria for assessing radiation exposure", Sanitary regulation "Ensure the radiation safety of workers and the population in applying of atomic energy and radiation sources", Sanitary regulation “"Requirements for ensuring radiation safety of workers and the population in the management of radioactive waste" (SPORO-2015). The radiation safety standards of Belarus are establishing requirements for planed, emergency and existing exposure situations and dose constraints, reference levels for representative person accordance with the International Radiation Safety Standards of IAEA (GSR Part 3). General standards, intervention levels and criteria for use in preparedness and response for a nuclear or radiological emergency for preparedness and response system were introduce in national system accordance the IAEA guideline (GSG-2). A new approach to national radioactive waste classification was set out with due account to recommendations of the IAEA GSG-1 “Radioactive Waste Classification”. The new defined classification scheme has six classes of radioactive waste: exempt waste, very short lived waste (VSLW), very low level waste, low level waste, intermediate level waste and high level waste. SPORO-2015 establishes boundary levels for these classes of waste in terms of range of specific activity for alpha and beta emitting radionuclides (except for VSLW class). The introduction of new approaches to radiation protection will allow more effectively to put into practice the basic principles of radiation safety – ALARA principle. In justifying the need to introduce protective measures in the radiation facility is necessary to rely on the radiation dose to the representative person in Belarus are strengthening the national system.

The Evaluation of the Real Alpha Value in Brazil and Its Projection until the Year 2050

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Abstract. The real evolution of the alpha value in Brazil has been performed three times in 1993 and 2000 making use of the procedure advised by ICRP and in 2004 making use of the procedure recommended by the IAEA. In both, the first two papers were made various projections for the coming years until 2025. Because of the great social and economic crisis in which the country (Brazil) is going, we decided to reassess the alpha value of our country and compare it with the projections of the two previous papers. Therefore, we decided to make a dollar correction from that time to the current dollar, comparing the purchasing power from that time to the current. This procedure has shown us the great gap of value in use and that the actual value should be two to three times higher. By GDP per capita, we could calculate the alpha value updated to various countries including the European Union and compare them with the official value currently in use. In conclusion, we believe that all countries that adopt an alpha value should upgrade it to the present day.

KEYWORDS: Brazilian alpha value evolution; new alpha values for some countries; average dollar value in the future.

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Radiation Protection in Medical Field in Cameroon

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Abstract. Radiation Protection in Cameroon is governed by Law No. 95/08, and the regulatory body in charge of the monitoring of radiation protection in Cameroon is National Radiation Protection Agency (NRPA). Since its creation in 2002 by Presidential Decree No. 2002/250, NRPA main mission is to protect people and environment against the harmful effects of ionizing radiation. This radiation may be hazardous to humans, and it covers all technical and regulatory aspects implemented to ensure their safety. NRPA as other regulatory bodies is very committed to the principles of radiation protection. To ensure that the international standards and national regulations on medical radiation protection are regularly respected, constant routine inspections are programmed and performed by NRPA from 187 medical institutions, 412 X-Ray Generators, 160 Radioactive Sources and 530 Radiation Workers are inventoried. Since 2011, NRPA put in place a Dosimetry Service, responsible for monitoring all workers exposed to ionizing radiation. About 105 workers in medical field are frequently monitored with results delivered accordingly. Inspection carried out by NRPA, showed that about 24,5% workers in the medical field are monitored, 64,6% have protective equipment for workers, 15% assure quality control, 83% have regular maintenance of equipment, 91,7% radiation facilities comply with the standards, 56,25% have protective equipment for patients, and 10% have good delimitation of areas and signage. The extension of our responsibilities to the field of radiation protection has led us to expand our international cooperation with International Atomic Energy Agency, Department of Energy of United State of America.

EURADOS IDEAS Guidelines Spanish Translation: A New Tool for Training Activities from the Collaboration between SEPR-SAR Radiation Protection Societies

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Abstract. The Spanish and Argentine Radiation Protection Societies (SEPR and SAR), in line with IRPA objectives, assume that education and training are a key factor in establishing effective national radiation protection programmes. Based on the common Spanish language, these Societies have decided to undertake a common activitiy in order to facilitate the Committed Effrective Dose assessment in case of internal exposures. As it has already been done with previous publications considered of high interest for the Spanish-speaking scientific community, on this occasion the Spanish and Argentine Radiation Protection societies, have joined forces for the translation of "General Guidelines for the Estimation of Committed Effective Dose from Incorporation Monitoring Data (IDEAS Guidelines)" into Spanish. In March 2013, these IDEAS Guidelines were published by EURADOS Working Group 7 "Internal Dosimetry" whose main purpose was to standardize procedures for the estimation of committed effective dose. The IDEAS Guidelines are based on a general philosophy of: Harmonisation: by following the guidelines, any two assessors should obtain the same estimate of dose from a given data set; Accuracy: the "best" estimate of dose should be obtained from the available data; Proportionality: the effort applied to the evaluation should be proportionate to the dose - the lower the dose, the simpler the process should be. With the certainty of its usefulness, the new publication will contribute to a wider dissemination of the original Guidelines published by EURADOS, will facilitate its use in Spanish-speaking countries, and it will be able for the organization of training in advance methods for estimation of committed effective dose for Spanish-speaking internal dosimetry experts in the future.

Engaging Communities to Discuss Nuclear Power Options for the Future

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Abstract. Around the world, it has been demonstrated that lives improve as access to power and clean water improve. In addition, whether we face catastrophic global warming in the future, or enter into the next glacial period, it will be diverse sources of plentiful energy that keep our civilization intact. Small modular reactors are one potential source of clean, plentiful energy to not only run our factories, medical centers, and universities, but to power desalination plants to prevent drought, and to power small, isolated communities whether in the deserts, jungles or tundra. This can only be accomplished with the support of the people that will benefit, many of whom have grown up with a fear of nuclear technologies, in part due to the destructive capacity of nuclear weapons, and in part to the accidents at Three Mile Island, Chernobyl and Fukushima. In order to embrace technology, it must be clear that the benefits far exceed the risks. We, in the radiation protection community, have focused on the discussion of risk, but rarely expend the energy to elucidate the full spectrum of benefits that nuclear energy brings to the table. Engaging those communities or organizations that would benefit the most from the inclusion of nuclear power in their energy mix will provide the base for expanded use. It is our community that can lead the way to change the world, one city, state or nation at a time.

An IRPA, WHO, IOMP Initiative on Radiation Protection Culture in Medicine

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Abstract. As a follow-up of the publication of the Guiding Principles for Establishing a Radiation Protection Culture in 2014, IRPA in cooperation with IOMP and WHO launched a new initiative for capturing the opinion of all stakeholders to develop a framework document providing guidance for the establishment and maintenance of a radiation protection culture, as part of a sustainable safety culture program in health care settings. The first step of this new project was the organization of two Regional Workshops, the first one for Latin American countries in Buenos Aires, Argentina, in April 2015 and the second one for European countries in Geneva in December 2015, with representatives from health professionals (radiologists, radiographers, medical physicists, nuclear medicine physicians, radiation oncologists, interventional cardiologists, dentists, paediatricians), regulatory bodies, health authorities, manufacturers, and patients associations. The aim of these first workshops was to collect feedback on the following topics: key elements of a radiation protection culture in medicine, priorities for establishing and maintaining a strong culture on all continents, how to engage patients to improve radiation protection culture, how to develop tools and indicators for assessing the level of radiation protection culture in quality assurance programs in medicine. The ultimate purpose of this project has been appropriately summarized during the first workshop through this motto "In our hospital we work as a team to ensure effective use of radiation and protect the patient and our staff". IRPA 14 provides an opportunity to present the results of these meetings and further discuss the way forward with the participants of the congress.

Regulating the Security of Radioactive Sources in South Africa and Institutionalising Nuclear Security Culture and Effective Physical Protection

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Abstract. In South Africa radioactive sources are classified as Group IV hazardous substances in terms of the Hazardous Substances Act No. 15 of 1973. Therefore the legislative requirements for the safety and licensing of actions or processes associated with radioactive sources or sealed sources is in accordance to regulations for Group IV hazardous substances. However, given the worldwide concern for nuclear security in as far as it relates to required security or physical protection measures for radioactive sources, the regulatory framework in South Africa has the option to adopt international nuclear security instruments and best practise. Radioactive sources including radiopharmaceuticals have to be provided a regulatory framework based on a synergistic relationship between nuclear safety culture and security culture. While the latter culture has in recent years been considered as a cornerstone for effective physical protection and information security as pertains such sources, there have been important parallels and aspects of safety culture that support need for institutionalising nuclear security culture. South Africa has the responsibility as IAEA Member State to establish an effective and adequately resourced regulatory framework to provide licensing conditions and oversight on how to protect individuals, society, and the environment from the harmful effects of possible accidents and malicious acts involving radioactive sources. In the wrong hands, radioactive sources can be used as weapons of mass disruption and when they have been misplaced or stolen due to inadequate physical protection measures and lack of information security at facilities or under authorised activity including transportation can result in serious ill-health, injury or death to humans and wide scale contamination in the natural environment and on property. It is for the appointed regulatory authority in the administration of the Hazardous Substances Act No. 15 of 1973 as prescribed by ministerial and legislative powers that security of radioactive sources be a statutory requirement and duly provided with respective adequate resources as can be regarded from non-binding but essential IAEA instruments such as the Code of Conduct on the Safety and Security of Radioactive Sources (2004), International Basic Safety Standards (General safety Requirements Part3) and Security of Radioactive Sources (Implementing Guide No.11) among other.

Fraudulent Exams in the Training of Reactor Supervisors at the Laguna Verde Nuclear Power

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Abstract. In both the nuclear and aeronautical industries, operator training is necessarily rigorous and permanent due to the risks of an accident and its consequences. However, at the Laguna Verde Nuclear Power Plant (LVNPP), this statement was questioned after a group of five candidates presented an exam for Reactor Supervisor, and it was discovered that one candidate left on a computer where the exam would be applied, an electronic storage device (USB) containing the same test. The details are described in the document entitled "Special Inspection IE-01/15-LV1", which was obtained through the National Institute of Access to Public Information and was prepared by the institutions involved: the National Commission of Nuclear Safety and Safeguards (NCNSS)- the regulatory body in nuclear matters in Mexico and the Federal Commission of Electricity (FCE), which operates the LVNPP. In this paper we discuss the contents of the "Special Inspection IE-01/15-LV1", which also revealed the vulnerabilities of the LVNPP, because the same document mentioned that anyone with computer knowledge could remotely access information relating to the safety of LVNPP. This paper aims to draw attention and bring up for discussion the need of international monitoring over this workplace in order to eliminate possible unsafe conditions in LVNPP that could have consequences for the integrity of the population, its workers and the environment. This work was done in the Department of Physics at the Faculty of Sciences of the National Autonomous University of Mexico (UNAM).

Plenary Panel International Standards – RP in Medicine

Claire Cousins

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Abstract. Standards in relation to radiological protection in medicine are well-documented, particularly with the recent update of the Basic Safety Standards (BSS). The principles of justification and optimisation remain key, as dose limitation is not applicable in medical practice. However, using standards in daily practice is not always easy and some issues remain difficult. Appropriate justification relies on the knowledge, experience and discretion of the relevant medical practitioners and this may be overlooked in the race for diagnosis and treatment. One argument would be further regulation of medical exposures, although it is difficult to see how this could be imposed without denying patients essential investigations and treatments. Another contentious issue is individual patient dose management with the possible creation of a 'radiation passport. Although in theory this may sound an attractive concept, the practicalities of monitoring such a scheme, with regard to when and by whom any action would be taken concerning doses received, would be fraught with difficulty. Other challenges in radiological protection in medicine require serious consideration. Individual radiation susceptibility is a hot topic that has attracted much attention, but how to manage such persons, if identified, raises further questions. Communicating radiation risks and benefits to patients appropriately needs to be addressed, including who should be responsible for this, given accurate knowledge is a pre-requisite. Ethics in radiological protection is a topic also being widely discussed and this in relation to medical practice, which already involves numerous ethical issues, is likely to be open to debate in the near future. Whether it would be appropriate to even try and adopt standards relative to these issues in medicine, is another point for deliberation.

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Radiation Safety Culture in the UK Medical Sector: A top to bottom strategy

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Abstract. In response to the International Radiation Protection Association's recently published 'Guiding Principles for Establishing a Radiation Protection Culture', the UK professional bodies (Society for Radiological Protection, Association of University Radiation Protection Officers, British Institute of Radiology, British Nuclear Medicine Society, Institute of Physics & Engineering in Medicine, Royal College of Radiologists, Society & College of Radiographers) have established a number of sectorial working parties to provide guidance on the improvement of radiation safety (RS) culture in the workplace. The medical sector provides unique challenges in this regard, and the remit of the medical sector working group was both to review the current state of RS culture and to develop a framework for improving RS culture in this sphere. The review of current RS culture is based on measurable indicators, including data from regulatory inspections, personal monitoring data and incident data. An online survey to capture the RS-related views and experience of hospital staff at all levels has also been developed, and provides a wealth of information on the current state of RS awareness and implementation across the country. It will enable the impact of culture improvement initiatives to be assessed. The results of this survey will be presented. The framework for improving RS culture has two distinct strands; both 'top-down' initiatives to engage management and regulators, and 'bottom-up' initiatives relating to engagement and training of different staff groups. Initiatives are considered relating to both staff and patient radiation protection and, in the context of the latter, links to the Bonn Call for Action are highlighted. A 'Ten-point Assessment' on what constitutes a good approach to radiation safety culture in the medical sector is proposed and will be discussed, including its potential use in regulatory inspections.

KEYWORDS: radiation safety culture; medical applications; Bonn Call for action.

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Implementation in the Republic of Moldova the Requirements of Directive 2013/59 / Euratom on Indoor Radon Concentrations

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Abstract. In the radiation protection of the population exposure to natural sources an important role is to establish reference levels for indoor exposure to gamma radiation emitted by building materials, including Radon concentrations. Recently residential epidemiological studies demonstrate a significantly increased risk of lung cancer due to prolonged exposure to indoor Radon at levels of the order of 100 Bq/m-3. The new concept of Directive 2013/59 / Euratom, based on the provisions of Recommendation 90/143 /Euratom, reviews the inside exposure situations as the mandatory requirements of the basic safety rules with sufficient flexibility regarding their implementation. When Radon enters from the soil inside, the employment situation must be considered as one of the existing exposure. These exposures can be significant in certain areas, so they must be identified and appropriate action taken on reducing exposure to Radon if levels exceed national benchmarks. In this regard the Radiation Hygiene &Radiation Biology Laboratory specialists of the National Center for Public Health in Moldova developed a guide entitled "Methodology for monitoring natural sources of Radon and evaluation of the radiological risk to humans exposed". Guide covers radiometric investigations and sets out the methodology for monitoring the concentrations of indoor Radon and its progeny, and also in soil and water. They describe methods for calculating the radiation doses of internal and external range of radiological risk for the exposed population. The main objectives of measurements were: to identify areas with potential for Radon, in particular, its exhalations from the ground, defining the percentage of habitat with a concentration above the norm and identifying the factors that influence Radon concentrations. Measurements were made using both active measurement methods through Radonometer RTM 1688-2 and passive ─ passed RAMARN detectors in bedroom and kitchen. A separate study consisted the monitoring of Radon in the schools and kindergartens of the main geographical areas. The Fundamental Norms on Radiological Protection of the Republic of Moldova stated that the annual Radon average concentration in the air spaces of designed, constructed or rebuilt building with finding permanent people should not exceed 100 Bq/m-3, and in the already constructed buildings ─ 150 Bq/m-3. At detection of higher values, radiation protection measures are taken, aimed at avoiding penetration of gas into the air spaces (ventilation of the space above the floor, efficient use of wall coverings impermeable materials) and enhancing the ventilation of premises.

Workshop on Radiopathology and Radiation Protection at the Annual Rotating Internship, School of Medicine at the University of Buenos Aires

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Abstract. Due to the worldwide increase in medical procedures using ionizing radiation, and considering the limited training about the risks associated with these practices, an intensive workshop was held during 2015 as an obligatory activity included in the curricular of the Annual Rotating Internship (IAR), as part of the School of Medicine at the University of Buenos Aires (UBA). The project involved 929 students attending 8 workshops and was conducted by medical specialists in the fields of radiopathology, nuclear medicine and radiotherapy. The methodology was based on the analysis of clinical cases of radiation-induced injury, in order to elaborate on the basics of radiopathology and radiation protection. Also from the exchange between students and teachers and their concerns and doubts about the peculiarities of presentation of lesions and diversity of response of patients, some classes were conducted focusing on knowledge and understanding on basic topics such as radiation hazards, radiation quantities and units, principles of radiation protection, tissue reactions and stochastic effects and on the cellular and molecular aspects of the interaction of radiation with biological material. Questionnaires were administered at the beginning and the end of each workshop in order to assess the training process as well as opinion surveys which were completed voluntarily and anonymously. Both assessment tools allow to recapture a substantial change in the understanding and evaluation of future physicians about the importance of the subject and their responsibility in the increase of radiation-induced risk. Through this workshop we expected to train more than 1200 students yearly.

Implications of ICRP 103, the International and the European Basic Safety Standards on the use of Dose Constraints in the Management and Disposal of Radioactive Waste, Including Waste Containing Elevated Levels of Naturally Occurring Radionuclides in France

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Abstract. The most recent recommendations of ICRP, Publication 103, and the latest international and European Basic Safety Standards provide clarification on exposure situation by grouping them into planned, existing and emergency situations. In addition the need for consistent and coherent consideration of radiation exposure from all sources of radiation of both artificial and natural origin is given particular emphasis. France has a very large nuclear industry covering all nuclear fuel cycle activities and generating substantial amounts of radioactive waste. Uranium mining was carried out in the past and considerable effort has been expended in remediating the former mining and processing sites, and work continues on a number of legacy sites contaminated from these past mining and processing activities. In addition, various industrial activities have and continue to use materials containing elevated levels of naturally occurring radionuclides, which need consideration from a radiation safety perspective. These different activities are controlled and regulated by a number of legal instruments in France, but it is nevertheless important that a coherent and consistent application of radiation protection standards is applied. The use of dose constraints is one aspect of these standards considered to be of high importance and approaches are being explored and developed to ensure a correct, consistent and coherent application across these various industries and activities. This paper presents and elaborates on the approaches under consideration.

Dose Limits in Radioactive Waste Management: Interdisciplinary Perspectives from the German ENTRIA Project

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Abstract. ENTRIA ("Disposal Options for Radioactive Residues: Interdisciplinary Analyses and Development of Evaluation Principles") is a joint research project funded by the German Federal Ministry of Education and Research (BMBF) and carried out by 12 departments from German universities and major research institutions and one partner from Switzerland. The scientists participating in ENTRIA represent natural sciences, civil engineering, philosophy, law, social and political sciences, and technology assessment. Recognising that all these disciplines need to interact when radioactive waste management is concerned, the project aims at investigating and developing evaluation principles for three options to manage especially high-level radioactive waste: Deep geological disposal without retrievability provisions, emplacement in deep formations with monitoring and retrievability, and prolonged surface storage. Dose and other regulatory limits, constraints, threshold and reference values (for the sake of simplicity hereinafter referred to as "dose limits") are an issue of utmost importance and concern for the operational and post-operational phases of management facilities when addressing both technical and governance aspects of disposal options. ENTRIA scientists synthesize technical, sociology of knowledge, legal, societal, and political views on current definition and perception of dose limits. 14 propositions identify perceptions of radiation effects and dose limits by different players, such as stakeholders, politics, NGOs and citizens. Controversies about the meaning and role of such limits are identified as well as technical and non-technical drivers in definitions of dose limits. While such limits are indispensable for technological development and legal security they often have a contraproductive effect in communication, political, and governance contexts. In order to better understand the interaction and interdependencies of these various contexts, future interdisciplinary research needs to address the relationship between dose limits and risk perception as well as the role of confidence and trust. It should aim at a discourse based communication about underlying values, objectives, actors and procedures when defining limits, and potential alternatives and complements to established limits.

The ICRP System of Protection for Existing Exposure Situations: The Work of Committee 4 to Elaborate the Framework for Protection

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Abstract. The International Commission on Radiological Protection (ICRP) system of protection was developed principally in the context of what were called practices, where a source is deliberately introduced, and for which protection measures could be planned and implemented in advance. With Publication 103, ICRP moved to a set of exposure situations, and ICRP Committee 4 on Practical Application is now in the process of developing a set of reports that elaborate on how the system of protection is applied to Existing Exposure Situations. The first such report, ICRP Publication 126, updated recommendations on radon. The second, Radiological Protection from Cosmic Radiation in Aviation, was available for public consultation in the summer of 2015. Committee 4 Task Groups are currently working on reports related to Application of the Commission's Recommendations to NORM (Naturally Occurring Radioactive Material) and Application of the Commission's Recommendations to Exposures Resulting from Contaminated Sites. In parallel, work is also underway to provide updates to Publications 109 and 111 on Emergency Exposure Situations and Living in Long- term Contaminated Areas following a Radiological Emergency. Through this series of reports, the ICRP is using a coherent, graded approach based on: 1. Assessment of the exposure and prevailing circumstances; 2. Justification for action; and 3. Optimisation of protection using individual dose criteria to reduce inequities in exposure, focus actions on exposures that are the most significant, and move the dose distribution towards lower levels of exposure. This approach recognizes the uniqueness of each circumstance, and recognizes that some of the tools, such as designation of occupational exposure, may be appropriate to create a pragmatic, practical, and protective system. This presentation will describe the ongoing work of ICRP Committee 4, and the unifying approach to applying the system of protection to the widely varying circumstances that comprise Existing Exposure Situations.

Policy Standards and Culture

David Crawford

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Abstract. The integrated management systems approach of combining the management standards ISO 9001, ISO 14001, ISO 45001 and ASME NQA-1 has its own inherent challenges in that it makes the assumption that the employee's are integrated in their knowledge of implementing the systems. All of these systems are based on a common approach of plan, do, check, act. In addition to the above systems it would be critical to also consider ISO 31000 risk management which address risk from a total holistic approach. ISO standards focus on the process approach, which mainly addresses the continual improvement and improving the effectiveness of the various processes in the organisation. Continuous improvement is a smooth curve whereas continual improvement may be a series of unrelated, individual incremental activities. Continuous improvement therefore can be regarded as a summation of a multitude of these individual achievements, which includes the strategic issues also driving efficiency that ISO does not address. This presentation will offer an inclusive management break through solution that addresses a strategic approach towards continuous improvement driving project-by-project improvement at a rate of revolution throughout the organisation.

The UK Ministry of Defence Radon Safety Programme

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Abstract. The Radon Safety Programme (RSP) on the UK Ministry of Defence (MoD) estate has been in place since 2005. The UK has statutory legislation in place to protect employees from radon exposure and the MoD has established a robust policy to ensure the health and safety of its personnel. The RSP covers thousands of workplace areas including caves, underground bunkers, aircraft hangers and office buildings, with the aim of protecting the health of military and non- military personnel now and in the future. MoD also implements a duty of care policy that extends beyond the workplace to include barrack accommodation and military family accommodation. Communication of the radon risk in a non-technical way is essential to these populations. The presentation will provide an overview of the radon monitoring strategy, the monitoring results and the remediation techniques employed. In addition, the methods of communication of radon issues to stakeholders will be described.

Certified Training for Nuclear and Radioactive Source Security

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Abstract. The international community has spent considerable time, money, and effort attempting to establish a series of national and regional Centers of Excellence (COEs), also known as Nuclear Security Support Centers (NSSCs). These centers tend to have a wide variety of objectives, structures, and methods of delivery. Unsurprisingly, no internationally accepted standard exists on how they should operate. Against this backdrop, WINS launched the WINS Academy, an initiative to provide practitioners with opportunities to earn certification in nuclear and radioactive source security management. The training program can be completed entirely online, and candidates can sit for their certification exams at more than 5,100 accredited test centers in 180 countries. The program already has over 550 participants from over 70 countries. While launching the Academy, we applied for and achieved the ISO certification 29990:2010. The purpose of ISO 29990 is to improve and standardize the quality of education and training in non-university settings, including industry training programs. Achieving ISO 29990 certification has given WINS an internationally recognized external benchmark of quality; demonstrates our credibility, competence and professionalism; and gives potential employers and others in the industry an objective measurement of our participants' security knowledge. Such knowledge is also transferrable across international boundaries. We recommend that all COEs follow a similar model, in which their programs are evaluated against professional standards developed by a recognized, respected certifying body rather than developing their own ad hoc arrangements, which are ultimately unsustainable. Having an independent assessment of a COE's services is a highly effective way to demonstrate their quality and competence and gives confidence to stakeholders, legislators and learners alike. This approach is probably the most effective, most efficient way to demonstrate that the title of Center of Excellence is justified.

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Radiation Safety Culture at United States Nuclear Power Plants

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Abstract. Nuclear safety culture has been thoroughly examined and adopted by international organizations and regulatory bodies throughout the world. The United States Nuclear Regulatory Commission (U.S. NRC) and the Institute of Nuclear Power Operations (INPO) have facilitated nuclear power operators in the execution of an overall safety culture at their facilities. In addition to the regulatory requirement for safety culture and in coordination with external industry organizations, U.S. radiation protection management has adopted a philosophy for implementing industry's best radiation protection practices, whereby enhancing the nuclear safety culture at U.S. nuclear power plants. This paper examines the various regulatory and radiation protection industry initiatives that comprise the radiation safety culture at U.S nuclear power plants.

43 Years of Experience in Training in Radiation Proctetion

Eduardo Medina-Gironzini

Peruvian Institute of Nuclear Energy, Lima, Peru

Abstract. Since 1972, the Superior Center of Nuclear Studies - CSEN of Peruvian Institute of Nuclear Energy - IPEN has conducted various training courses to enable people to work safely with ionizing radiation in medicine; industry and research, so much so that until 2014 has organized 2.417 courses which enabled the training of 29 106 people. The courses are organized according to the specific work being done with radiation (medical radiology, dental radiology, nuclear medicine, radiotherapy, industrial radiography, nuclear gauges, etc...). Most of the courses are aimed at people who use first the radiation but there are also refresher courses on the subject. The CSEN also conducts graduate programs highlighting the Second Professional Specialization in Radiation Protection is carried out since 2004 with the support of the National University of Engineering. So far there are three programs that have been made.

Experience in the Use of Social Networks in Radiation Protection

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Abstract. Social networks have become a useful tool for exchanging experience and resolve technical consultations on various issues in very short times average. It has the experience of the interest list called "radiation protection" which has existed since 15 March 2002 and currently has more than 2700 subscribers in 32 countries. This list created in the yahoo groups, is the distribution of emails on technical issues, event announcements, news and technical consultations are duly answered by professionals in the field of radiation protection. Today Facebook, Twitter, LinkedIn and other options are used to view and share videos, presentations and photos that help the specialist to upgrade, improve their work and deepen their knowledge. In addition, social networks also allow personal and professional relationships increase. Social networks are part of our reality, are forms of social interaction with dynamic exchange between people and institutions that allow the participation of groups that are identified with the same needs and problems and that are organized to leverage their resources. A good example is the use of interest groups in Facebook as in the case of the "Radiation Protection" (www.facebook.com/groups/proteccion.radiologica.oficial/) in about 24 months has 15,000 members from various countries , mostly Spanish speaking. Here, almost every day of the year information on topics of the specialty and related spreads, announcements of technical events is made, rules and technical documents are distributed, the activities of various national and international organizations are broadcast, it mentions links Interest on videos, presentations, photos and publications. Special attention is paid to the news that routinely appear on the Internet and deserve to be disseminated for information and comments from stakeholders. Subscribers working in regulatory agencies, universities, radioactive and nuclear facilities, and in general, both national and international public and private entities in different countries. In this paper the advantages of social networks and experience in radiation protection group shows, highlighting its contribution to keep up and improve radiation protection, and improve human relations and exchange of experiences.

Nuclear regulators need to adopt international standards applicable to radiation measuring instruments into their national legislation

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Abstract. Accurate dosimetry forms the backbone of radiation safety. Dosimetric measurements require traceability to secondary standards of measurement. Confidence in measurement accuracy and using appropriate measuring equipment have an impact on dose records of radiation workers, the accuracy of national dose registers and international reporting of radiation doses. Traceability is also required for research publications and legal proceedings. Legal metrology is the application of legal requirements to measurements and measuring instruments. The International Organization for Legal Metrology (OIML) creates global standards in legal metrology. This presentation uses a case study from industrial radiography to highlight the need for nuclear regulators to adopt international standards applicable to radiation measuring instruments into their national legislation. National legislation, national standards on radiation measurements and measuring instruments are necessary to ensure accuracy of measurements and radiation dose reporting. Recommendations for task specific ionizing radiation measuring equipment should be developed. IAEA Safety Specific Guidelines should incorporate adequate information to assist operators with the selection of appropriate radiation measuring equipment.

ICNIRP: Preliminary Thoughts on Protection Principles for Non-ionizing Radiation

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Abstract. The International Commission for Non-ionizing Radiation Protection (ICNIRP) is currently engaged in a process of revising its general approach for protection against adverse effects of exposure to non-ionizing radiation (NIR). Under the charter of ICNIRP, NIR contains electric, magnetic and electromagnetic fields, optical radiation, infra- and ultrasound. The goal of the project is to harmonize as much as possible with the principles for ionizing radiation protection as laid down in Publication 103 of ICRP, in order to come to a comprehensive system of radiation protection over the entire electromagnetic spectrum and for infra- and ultrasound, that is as consistent as possible. With ionizing radiation protection, social, economic, and political issues may be taken into account. Since ICNIRP bases its guidelines only on scientific information and expert judgement, and does not involve any stakeholders in this process, it does not address these issues, but leaves them to governments and authorities. The core principles of ionizing radiation protection, Justification, Optimisation, and Limitation, cannot be applied as such throughout the NIR spectrum, but need to be adapted depending on the effects considered. The draft philosophy statement to be discussed also contains considerations on population groups (workers, general public, patients), biological and health effects, when an effects is considered to be substantiated, health effect levels, reduction factors, basic restrictions and reference levels, indirect effects, and effects on the environment.

Ethical Considerations on the Empowerment of People Living in Contaminated Areas after a Nuclear Accident

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Abstract. After a nuclear accident, the main dilemma for affected people is to leave or to stay in the contaminated area where it is allowed to live, or for those who have been evacuated to return or not in these areas. Such decisions are complex and involve many factors where the radiation protection dimension is only one aspect. Experience of Chernobyl and Fukushima have demonstrated that the direct involvement and empowerment of affected people is a way to help them to regain freedom, to make informed decision and to act accordingly (i.e. to regain dignity), and is also an effective way to reduce exposure as low as reasonably achievable by contributing to the development of prudent attitude and vigilance towards exposure and favouring adoption of efficient and sustainable protection strategies (optimisation principle). However, involving stakeholders in the post-accident management raises ethical questions related to the position of the experts and public authorities with regard to their support to the inhabitants who have to take decision about their future. In this context, authorities and experts have the duty to accompany and support all affected people in their local projects to restore decent spiritual, moral and material living conditions. However, authorities and experts have to avoid some pitfalls regarding people empowerment: trivialising the radiological risk, abandoning people facing the risk alone, manipulating people to make them staying in contaminated area or trying to protecting people without them. At the opposite, ethical principles have to be adopted such as: refusal to take decision for the people about their future (respect of their autonomy and freedom); commitment to be at the service of improving the protection and living conditions for the population (well-being); adoption of a prudent attitude toward the radiological risk. Based on the experience of post-accident management, this paper will discuss the position of experts and public authorities in the stakeholder involvement process and address the associated ethical dimensions.

The Inter-Agency Committee on Radiation Safety – 25 years of Cooperation Efforts to Harmonize International Radiation Protection and Safety

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Abstract. In 1990, the Inter-Agency Committee on Radiation Safety (IACRS) was constituted as a forum for consultation on and collaboration in radiation safety matters between international organizations and played a key role in the development and revision of the International Basic Safety Standards (BSS). It consists today of representatives of eight intergovernmental (EC, FAO, IAEA, ILO NEA, PAHO, UNSCEAR and WHO) and five non-governmental (ICRP, ICRU, IEC; IRPA and ISO) entities. Its objective is to promote consistency and co-ordination of policies with respect to areas of common interest in radiation protection and safety, such as applying principles, criteria and standards of radiation protection and safety and translating them into regulatory terms; identifying needs and priorities for research and development; advancing education and training; promoting widespread information exchange; facilitating the transfer of technology and know-how; and providing services in radiation protection and safety. The IACRS operates based on agreed terms of reference, last updated in June 2015, which established for the first time a standing secretariat to ensure continuity, while the Chair rotates around the members for each regular meeting, which are held about every 18 months. Online meetings are used to progress business between the regular meetings. The IACRS has also established a Task Group to foster implementation of the International BSS. This paper presents briefly the functions of the IACRS, its main achievements in recent years, and provides an outlook on key challenges for the future.

Lessons Learned from the Fukushima Event: The Radiation Protection Emergency Preparedness

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Abstract. As it is well known, the Fukushima event in 2011, with four reactors severely damaged at the Dai-chi NPP, has activated a long sequence of analysis and a not yet finished verification process. A quite complete analysis of the survival capabilities of nuclear power plants to very adverse condition (first of all a complete station black out like the one in Fukushima) has been carefully performed all around the world with as a consequence the implementation of various new safety protocols and the multiplication of emergency support systems and plans that should be able to guarantee an adequate response. The radiation protection emergency aspect, is however a little different, because it could become a serious constraint even for Countries like Italy that do not have NPP on their territory, but are instead in proximity of a whole heterogeneous fleet of installations. From this point of view, the setup at local and national level of an early warning system and the capillary diffusion of a radiation protection culture and network has to be a mandatory mission at various levels. One of the Fukushima lessons learned is in fact that, due the extremely short grace-time of several old style reactors, still operational, any emergency response must be prepared and put into operation quickly and in a really short time.

Interplay of Nuclear Power on Earth and in Space: Nuclear Energy as Sustainable Energy

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Abstract. This paper examined the important challenges such as CO2 emission, safety, waste, management, decommissioning cost and proliferation risk caused by nuclear power. In addition, the paper examined new emerging technologies empowered by emerging the new materials and offered recommendations for research, development, and demonstration. A brief comparison to solar energy is presented too. Importance of nuclear energy in space research is explored too. In general paper deals with question: Is nuclear energy the sustainable energy?

Scientific Issues, Emerging Challenges and Emerging Digital Social Innovations for Radiation and Radiological Protection

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Abstract. This paper presents comprehensive research on possible scientific issues and their implications on radiation protection, including radiological protection and emerging new areas of collaborative research. The emerging digital social innovations are in particular explored and a new insight is given.

Workers' Knowledge on Radiation Protection. A Survey at Mongi Slim Hospital

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Abstract. Introduction: In Tunisia, the knowledge of hospital staff in radiation protection is still undervalued. The purpose of this study was to evaluate the knowledge in radiation protection of hospital staff exposed to ionizing radiations (IR). Methods: We conducted a cross-sectional descriptive study, exhaustive with the staff of operating rooms of Orthopedics, Interventional Cardiology and Diagnostic and Interventional Radiology Department of the Mongi Slim hospital. A self based questionnaire established on data from the literature was distributed. Results: Fifty four participants attended the survey, 58% participated to our study, 13% of them graduated in medical field, 50% of them were technicians and 13% nurses. 59% of participants were working in the radiology department and the others in operating room of orthopedic (26%) and interventional cardiology room. The mean score of knowledge was 11.8/20 and 41% had an average score less than 12/20. The Kruskal-Wallis test showed that the level of knowledge was significantly depending on the professional category. The knowledge's score was higher in the medical group compared to paramedical one. The score of knowledge was better in graduated doctors than in junior ones (0,0479). In radiology department, the score were significantly higher (12.66/20) than the other two services (10.5/20) (p=0,023). Conclusion: This study highlights the insufficiencies in radiation protection knowledge. We recommend to organize training sessions and awareness on radiation protection especially for technicians and nurses.

Importance to Engage in Dialogue with the Affected Population after the Acute Phase of an Accident

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Abstract. It is well known that our risk judgments have an influence on our behaviour and this is particularly important in the aftermath of a nuclear accident. One of the main lessons we can draw from the Chernobyl and Fukushima accidents is that once the acute phase of the accident is over, it is important to engage in dialogue with the affected population. Science- based government measures imposed from above and expressed in µSv/h, mSv/year, Bq/kg or kBq/m² give rise to much opposition, to fruitless discussion and to conflicts in principle. Some examples from the Chernobyl and Fukushima accidents to illustrate my point of view. The first example relates to the aversion to live in a contaminated environment. The local population has the feeling of being abandoned; of having to live as second-class citizens in an area contaminated by radioactivity even if the increase in exposure is only a fraction of the natural background exposure and within the typical range. The second example looks at the reluctance of consumers to buy slightly contaminated food. This behaviour has led to frequent changes of the maximum food contamination levels in the aftermath of the Fukushima accident and despite this, the consumers in Japan tend to be very reluctant to buy food from the affected areas. The last example I wish to mention is that after a few years most of the evacuated people do not want to return in spite of all the efforts to clean up the contamination. In order to avoid these pitfalls it is important to empower the affected population in a way that they feel they have some kind of control over the situation. This requires, after the acute phase, the establishment of a formal consultation structure. A kind of partnership funded by the authorities but operated by the local community. The partnership should be given sufficient financial means to consult experts on their own and to put a variety of dosimeters and radiation monitors at the disposal of the affected population. Such a participatory approach is very demanding from the part of the authorities, but is likely to change the minds of the affected people from victims to survivors.

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Establishing Radiation Protection Culture for Local Residents Left in the outside Boundary of Fukushima and Challenges facing Mothers and Children

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Abstract. The southern part of Miyagi, located along the boundary between Fukushima and Miyagi Prefecture, was strongly affected by the radioactive plumes. Immediately after the accident, Some families with children and expecting mothers voluntarily evacuated and residents who stayed lived very insecure daily life since they did not have much knowledge on the effect of radiation to human body. However, the support for solving the radiological problems has been rather poor for the regions outside of the prefecture since the Fukushima Daiichi accident has been regarded by the Japanese government as the issue of Fukushima Prefecture. Health surveillance, monitoring of exposure dose, and thyroid ultrasound examination have not been conducted by the government. Proposed decontamination methods by the government for this area is not entirely satisfactory for residents' requests as well. In this paper, we'll present how they measure radiation dose in and around the district and radioactivity contained in products and how local residents accept and establish RP culture. We'll also describe how RP professionals communicate with them in many aspects and support them to establish RP culture. These local residents left in the outside boundary of Fukushima raised an attention of ICRP delegates. Delegates visited this area and had dialogues with residents. After four and a half years have passed, they seem gradually return their daily life. However, our recent questionnaire investigation for mothers and young children revealed that the level of stress and insecurity against radiation in the southern part of Miyagi was much higher than that in unaffected areas and the same level with that in Fukushima city. The challenges facing mothers and children should be considered carefully in the aspects combined RPC with sociological and social psychological approach.

Scientific, Societal, Implementation and Regulatory Challenges of Radiological Protection

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Abstract. In 1998 and 2007 the Committee on Radiation Protection and Public Health (CRPPH) of the OECD Nuclear Energy Agency (NEA) produced reports summarising the state-of-the-art in radiological protection science, and the potential implications that ongoing research could have on radiological protection policy, regulation and application. In 2013 the CRPPH again decided that it would be worthwhile to produce such a report, which was completed in 2015. The report covers the areas of: Cancer risk of low dose rates; Non-cancer effects; Individual sensitivity; Societal aspects of RP; Existing exposure situations; Planned exposure situations; Emergency exposure situations; Environmental radiological protection; and International standards. The NEA report is a comprehensive summary of the latest discussions and directions for the radiological protection system, and an overview of the state-of-the-art research that underpins the system. This paper will provide an overview of the report's findings, and of its identified challenges for ongoing research and for policy, regulation and practice.

Radiation Protection in a Mixed Contaminant Context, Risk Assessment Methodologies

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Abstract. Increasing industrialisation and population density have led to situations where humans and the environment are exposed to a multitude of potential stressors. Often little is known about the mid- and long-term health and ecological consequences of these especially when they occur in synergy, as mixtures. The consideration of chronic low-level mixed exposures presents considerable challenges for methodology and data interpretation. To fully understand the effects of multiple stressors on life-history responses such as growth, reproduction and survival requires challenging experimentation and a multidisciplinary approach. X- rays is a specific stressor present in our lives for more than a century. It´s use, except for medical purposes, spreads very fast in civil use, airport security, state office security etc. The special agencies dealing with homeland security are being established after the furious terroristic attacks all over the world. The people employed in such agencies use a sophisticated imaging equipment. They need to be well educated, although their overall education is sufficient to be secondary grade. Radiation protection education is needed. These new working places are loaded with totally new psychological and technological stressors which are certainly a new research challenge in occupational health. Population as a whole will be exposed to these new stressors. The need to develop and use improved assessment tools and novel models, to reduce uncertainty in current risk assessment and screening methodologies, for example by improving the scientific basis for setting safety factors exists. This will facilitate human and ecosystem health monitoring by providing the link with information concerning the health condition of the population and environment while using the new technology in an unselective manner.

OPERRA-HARMONE: Harmonising Modelling Strategies of European Decision Support Systems for Nuclear Emergencies

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Abstract. The decision support systems (DSS) SYMBIOSE and RODOS are used to estimate doses to a population after nuclear emergencies and to provide information and guidance on the contamination and countermeasures. This allows the development emergency management strategies for reducing doses to the affected population. The HARMONE project aims to address scientific, methodological and operational gaps in these DSS and to harmonise and expand the models used in these systems. In work package (WP) 1 of the project, distinct release scenarios will be defined and the corresponding contamination of the environment will be quantified. This will be done for a range of potential releases into the atmosphere including core melt, unfiltered and filtered venting scenarios. In addition to this, direct discharges into aquatic ecosystems will be assessed. Since the current model parameter sets valid for just one averaged climatic region in Europe, WP2 will identify region or climate dependant model parameters for up to six different regions. So far, temperate, subtropical, continental boreal, tundra and a freely customizable set are candidates for potential radioecological regions. Values for these parameters will be collected from literature, national and international databases. In a second task, a conceptual snowfall and snowmelt model with shielding and washout parameters will be developed. These radioecological regions and snow models will be implemented into the DSS in WP3. In addition to this, current terrestrial, aquatic and watershed models will be improved and adapted. Simulations with the updated models will be performed and the results for the different scenarios and radioecological regions will be compared and assessed. The model results will be used to develop recommendations and minimal sets of parameters necessary for human dose assessment in WP4. Current post accident monitoring strategies will be refined and recommendations for improvements made. In order make the project results accessible for interested parties, the HARMONE consortium intents to develop a guidance handbook and knowledge data base in WP 5.

How to Develop and Maintain an Effective Training Program in Radiation Protection

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Abstract. Radiation protection training can be a challenge in any environment. A training program that is informative, engaging and relevant can ensure compliance with current regulations and a program on par with industry best practice. Clear understanding of regulations, policies, job functions, goals and expectations lead to increased motivation, protection and safety for employees, members of the public and the environment. It requires a commitment to stay current with international recommendations and implement local changes. Training programs provide multiple benefits for employees and the employer, but only if they are sensibly planned and properly implemented. In this presentation it will be shown how to: incorporate practical scenarios in the place of citing regulations to keep the course interesting and maintain participation, use story telling techniques to illustrate past successes and failures, effectively use a power point presentation, and establish a safe environment where sharing ideas and experiences in encouraged. Overcoming the challenges of radiation safety training can be positive for a student who may actually enjoy and learn from a course, but it can also be positive for the instructor who can watch a safety program evolve as a result.

Delineation of Radon Prone Areas for Mandatory Radon Measurement in Workplaces in the Czech Republic

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Abstract. The new European directive No. 13/59/EURATOM laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation introduces the new obligations in the fields of protection from radon exposure. Radon measurements should be mandatory in workplaces within the radon prone areas identified and located on the ground floor or basement level. This presentation shows the approach and criteria used for the delineation of radon prone areas in the Czech Republic. The base for identification of the radon prone areas was previous measurements in buildings within the country, geological data and information from radiometric survey. By using statistic method of "neuron network" the probability of the percentage of the building exceeding reference level in selected territorial unit was predicted. Different results (for 10%, 20%, 30%, 50% of exceeding buildings in municipalities or in districts) presents different numbers of potentially affected workplaces varying approximately from 5000 to 50 000. Then the results had been compared with the objective to find the most effective way for regulation, which would be manageable for the workplaces and also for the regulatory body.

Nuclear Security Consideration for Radiation Protection Professionals

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Abstract. Radiation Protection is an essential function in most nuclear and radiological facilities and the primary responsibility is a safety function. Nuclear security is, however, extremely important in the post-9/11 environment for all these facilities. The role of the radiation protection professional in nuclear security matters is not clearly defined despite the fact that a fundamental understanding of radiological hazards of adversary target material is required for understanding the total risk to the facility and/or material. Radiation Protection can be integrated into nuclear security culture during design basis threat definition, through risk management exercises, participation in response force activities, developing dose guidance criteria, radiological training and in communicating hazard and risk to security personnel, facility operators and regulatory bodies. When integrating Radiation Protection into nuclear security culture, it is important that Radiation Protection management or the responsible/senior health physicist establish dialogue early with nuclear security personnel in generating the design basis threat. The dialogue must include the advantages of considering radiological hazard as part of the comprehensive response plan. Health physicists and other radiation protection professionals are multi-capable scientists, engineers and systems integrators that can contribute greatly at multiple levels for effective and efficient nuclear security. To be an effective partner in the nuclear security objective, health physicists must embrace the nuclear security culture

Communicating Risk to the Public: An Important Element in Mitigating the Impact of a Radiological Terrorist Attack

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Abstract. Any radiation or nuclear accident usually results in the spread of radioactive material, not only in close proximity of the affected site but also in larger surrounding areas. This is even more sensitive in the case of a radiological terrorist attack, which may trigger unprecedented confusion, panic and anxiety among the insufficiently knowledgeable members of the general public. This can only be defused by providing appropriate information so that lay persons can understand what happened as well as perceive and assess the emergency situation realistically. The public commonly exaggerates any danger associated with nuclear related areas mainly because they usually rely on unreliable sources of information, including rumours and tabloids. This is why there is a substantial difference in understanding the magnitude of hazard between the public and specialists who are trained and experienced in the field and can evaluate the situation more accurately taking into account relevant sound scientific findings. It is therefore important to work towards narrowing of the gap between professionals and laymen in assessing the factual impact of the potential use of a radiological dispersive device which may be used by terrorists. The preparation of the public for such an event requires appropriate communication of specialists and assigned public information officers which cannot be limited to only the case of a particular emergency but it should be rather a continuous process involving schools and mass media. This is the only way to gain the trust and confidence of the population at large and its cooperation in mitigating the consequences of a radiological attack or sabotage involving radiation and nuclear installations. The paper discusses the means of effective communication of the radiation and nuclear related risks to various groups of the public. The results of a review conducted among students before and after attending lectures on basic radiation and nuclear safety are used to illustrate the difference in perceiving radiological hazards among persons who were not aware of basic principles of the safe use of radiation and nuclear technologies and people who received some basic clarification regarding nuclear risks. The most relevant argument was the comparison between the risk we encounter in our everyday life, including that associated with other industries, and the effects of radiation exposure in normal and emergency situations.

Improvement in Radioactive Waste Management over the Past 40 Years in the U.S

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Abstract. Waste Control Specialists LLC (WCS) operates the first licensed radioactive waste disposal facility since the U.S. Congress enacted the Low-Low Radioactive Waste Policy Act of 1980. This facility is located in the far western reaches of the State of Texas. The site's physical features and engineering design have demonstrated to be the most robust facility for disposing of Class A, B, and C Low-Level Radioactive Waste (LLW) in the U.S. It also includes a facility licensed that disposed of highly concentrated uranium-bearing ores that originated from the former African Belgium Congo that were generated during the Manhattan Era. The WCS facilities also included a separate landfill authorized for disposal of waste with low-levels of radioactivity that provide a safe and cost effective disposal alternative. Most recently, WCS received authorization to dispose of 500,000 m^3 of Depleted Uranium generated over the past several decades using state-of-the-art methodologies. Current deliberations by the State of Texas and Federal authorities are exploring the possibility that waste exceeding the class C limits, but that do not require the same level of isolation as a geologic repository, could be disposed of at these disposal facilities. By April 2016, a license application is planned to be filed with the U.S. Nuclear Regulatory Commission to store Used Nuclear Fuel from twelve of the shutdown decommissioned commercial nuclear reactors located across the U.S. Once approved, the WCS facilities will be capable to supporting the complete decommissioning of commercial reactors and allowing their return to green field status. In short, the WCS disposal facilities have clearly demonstrated the maturation of radioactive waste management practices that have occurred over the past 40 years in the U.S.

Current Discussions in Japan Health Physics Society regarding Radiation Protection of the Lens of the Eye

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Abstract. The international commission on radiological protection issued the statement on tissue reactions in 2011. In the statement, the threshold of the cataract was reviewed, and the new dose limits were recommended as 100 mSv/5y and 50 mSv/y. After that, the new dose limits were introduced into the International Basic Safety Standards of the International Atomic Energy Agency (IAEA BSS) and the European Directive. In Japan, the importance of the new dose limits has been recognized among the members of Japan Health Physics Society (JHPS), and a special committee "JHPS Expert Committee on Radiation Protection of the Lens of the Eye" was established in 2013. The period of the committee was two years. The purposes of the committee are to share the information on the exposures of the lens of the eye, and to discuss on the radiation protection for the eye considering both Japanese and international current situation of the exposures. We have had several meetings every year, and tentatively summarized the information on the current situation of the eye exposures. Since 2015, the committee has been reorganized as "JHPS Expert Committee on the Dose Limit for the Lens of the Eye" and started new activities for next two years. The outline of our activities will be reported.

The Ethical Foundations of the Radiological Protection System

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Abstract. The International Commission on Radiological Protection (ICRP) has established Task Group 94 (TG 94) of Committee 4 to develop a publication on the ethical foundations of the system of radiological protection, aiming to consolidate the basis of ICRP's recommendations, to improve the understanding of the system and to provide a basis for communication on radiation risk and its perception. TG 94 has reviewed the Publications of the Commission to identify the ethical values associated with the system of radiological protection for occupational, public and medical exposures and for the protection of environment. And through the conduct of a larger series of workshops organized by the Commission in cooperation with IRPA and IRPA Associated Societies involving radiation protection professionals and specialists of ethics in the different regions of the world, TG 94 has identified the key components of the ethical theories and principles prevailing in the fields of safety, health, labour, the environment and sustainable development relevant to the system of radiological protection. The purpose of eliciting the ethical principles and values underpinning the system of radiological protection is not only to clarify the rationale for recommendations made by the Commission, but also assist in discussions related to its practical implementation. A clear understanding of the ethical principles will help to resolve dilemmas caused by potential conflicts in actions that might be considered, or decisions that must be made. TG 94 is working for the development of its report, which elicits the core ethical values underlying the existing ICRP principles of justification, optimization, and dose limitation, which are guiding the tools and procedures for the practical implementation of the system of radiological protection and provides some ethical analysis of actual issues and makes suggestions for possible evolution of the system as far as the ethical dimension is concerned. TG 94 report will present the key steps concerning the scientific, ethical and practical evolutions of the system of radiological protection since the first ICRP Publication in 1929 and describe the core ethical values underpinning the present radiological protection system, and address the key procedural ethical values for the implementation of the system.

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Assessing and Promoting Radiation Safety Culture in the UK Nuclear Sector

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Abstract. Over many years the UK nuclear industry has put significant resources into adopting an ALARA culture and the more general Radiation Safety Culture, that in turn is a subset of Safety Culture. In this respect, the publications by the Institute of Nuclear Power Operations (INPO), the US Nuclear Regulatory Commission (NRC) and in the IAEA International Nuclear Safety Advisory Group (INSAG-4 and 15 reports) were of great value. More recently the development and publication of IRPA's Guiding Principles for Establishing a Radiation Protection Culture, has attracted attention. The UK Society for Radiological Protection (SRP) included in its Strategic Plan an objective to "promote a strong Radiation Protection Culture in the UK", across all sectors of use. As an early part of this programme of work a paper was published in the Journal of Radiological Protection, vol 34 (2014) 469–484, which included sector specific possible action plans. In parallel sector Working Groups (WGs) were established and this paper covers the work of the Nuclear WG. In recent years the nuclear sector has undergone some significant changes that bring with it challenges. The profile of the industry has changed with more decommissioning operations, often of very old facilities; and effort being put into new build, where there may have been some loss of skills. Add to this the significant financial and programme pressures on nuclear industry management and employees; and whilst good safety performance is a significant strategic requirement, one can see challenges for safety culture. The programme of the WG is focusing on an assessment of the current position of Radiation Safety Culture in the Industry and in the light of this revisiting the action plan.

Managing Suitably Qualified and Experienced Persons (SQEP) Requirements to Meet Business Need

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Abstract. The Defence Science and Technology Laboratory (Dstl) Radiation Sciences Group provides Radiation Protection Advice and Services to the UK Ministry of Defence and other customers. To enable the provision of advice and services of the appropriate scope and quality the Group must invest in the Continuing Professional Development (CPD) of staff as well as its facilities to meet business need. This poster will show that by bringing together management and technical personnel within the Group current and future customer technical requirements are assessed in a reasonably light touch way. Decisions are then made for capability planning and in particular the investments that may be required in having the right number of Suitably Qualified and Experienced Persons (SQEP) in particular technical specialist areas. One of the technical specialism areas in use will be described and the process of demonstrating that individuals are SQEP and able to lead on the provision of such work or review others work will be explained. The specialism descriptions allow staff to follow a development path and be able to demonstrate their competency in the specialism in due course. A Specialisms Approval Board sits to assess the evidence provided by an individual and agree or disagree that person is suitably SQEP. In conclusion the benefits of using this management approach will be stated.

The Selected Issues Related to the Development of National Legislation Based on ICRP103, IAEA BSS and EU BSS

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Abstract. The new Czech legislation is currently in the process of the adoption in the Parliament. New Atomic Act is already reflecting and implementing ICRP 103, IAEA BSS and new EU directive no.59/2013 called EU Basic Safety Standards. The relevant regulations are also in preparation. The authors are personally responsible for the development of national legislation in the field of radiation protection. The description of the issues and challenges when trying to be in compliance with all mentioned documents will be given in the paper. The Czech Republic as an European country shall be in compliance first with European legislation but another international standards shall be inevitably taken into account. The selected issues for discussion are for example the approach to regulation of radon in dwellings and radon in workplaces, regulation in NORM industries, the choice of reference levels for emergency and existing exposure situations, some aspects of personal dose control and the problem of establishment of dose constraints in planned exposure situations. The Czech legislation is now almost ready – the problems were addressed and the solutions were taken.

Updating the Radiation Protection Guidance for the United States

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Abstract. The National Council on Radiation Protection and Measurements (NCRP) published its last complete set of basic recommendations specifying dose limits for exposure to ionizing radiation in 1993 (NCRP Report No. 116). The International Commission on Radiological Protection (ICRP) published its most recent recommendations for a system of radiological protection in 2007 (ICRP Publication 103). There is a pressing need to update NCRP guidance with regard to radiation protection as applicable to the current needs in the United States while, to the extent possible, furthering an international harmonization of radiation protection recommendations and standards. This update will incorporate new information and recent epidemiological studies that have added to and advanced our understanding of the relationship between radiation dose and risk of harm and will provide further explanation and additional clarity to previous recommendations. Furthermore, this update is expected to add to the previous U.S. recommendations by including sources and exposures that have not been specifically addressed. These exposures include patients undergoing diagnostic or interventional medical procedures, caregivers for patients treated with radioactive materials, voluntary participants who may be exposed to ionizing radiation in medical research, workers and the general public exposed to naturally occurring radiation sources including those enhanced by technology (such as during hydraulic fracturing), and exposures to non-human biota in the environment. NCRP aims to solicit input during development of this updated guidance for the United States, and welcomes advice and recommendations from the international radiation protection community, particularly as we move forward with international harmonization of radiation protection and standards.

Unification of Legal and Procedural Documentation for Emergency Response in the FMBA of Russia

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Abstract. Emergency response system FMBA of Russia is based on their territorial organizations and divisions. All of them are potential participants in the mitigation the effects of possible radiation accidents and incidents and need of a unified regulatory and procedural framework on emergency planning and response (EPR). A wide variety of documents that must be available at each level of emergency response system (Health centers, Medical sanitary units, Regional managements, etc.) needs to unify and standardize as much as possible. Lack of standard methodical documents (master plans, regulations, forms, etc.) required centralized development and was unresolved issue at the moment of creating a system. In Emergency Medical Radiation Dosimetry Center FMBA of Russia as a result of several years of research was formed a Consolidated List (CL) of documents. A CL of health-care provision in the event of a radiological accident is a single (uniform) set of emergency documents meets the modern requirements of domestic and international practice. In summary CL includes standard documents, which are necessary for the effective work at the initial stage of the accident: the provisions on the exchange of information, protocols (standards) of work, the Regulation on the notification instructions on radiation safety for the various types of work, programs of measurements, training and education, tables of equipment, medicines, personal protective equipment, etc. It is shown, that certain documents that are included in the CL and give recommendations of investigation of the environment and population allow to narrow conducted radiation control and optimize the strength and resources. Most of the documents currently developed, approved and put into practice. With the view to test the effectiveness of the developed documents and to identify shortcomings in the organization and management of the emergency response the documents are working out in practice in the ongoing exercises and trainings. The report examines the practical examples of working out standard measures of emergency medical and radiation hygienic response. Documents of EPR aimed at the uniform implementation of the operational protective actions can reduce the time spent on emergency response; contribute to rapid processing and exchange of information.

Development of Nuclear Security infrastructure in Nigeria: Achievements Challenges and prospects

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Abstract. The Nigerian Nuclear Regulatory Authority (NNRA) is charged with the responsibility for nuclear safety and radiological protection regulation, and to amongst others advise the Federal Government on nuclear safety and security matters. Nuclear and other radioactive material are used in several sectors of Nigeria's economy including, the Petroleum Industry, Health Sector, Manufacturing Sector, Education and Research, Agriculture and Water Resources and Research Reactor Operations. With the changing paradigm in global nuclear security, Nigeria is developing the necessary infrastructure for nuclear security and physical protection management. This paper discusses the achievements, challenges, prospects for nuclear security infrastructure development in Nigeria. The national legal framework for nuclear security is evolving with the development of new nuclear security and physical protection regulations while existing ones are being reviewed in line with current global trends. Physical security upgrade of high-risk nuclear and radiological facilities is being implemented and quarterly inspection exercises are conducted by the NNRA to ensure sustainability of the upgrades. Nigeria is proactively developing the capacity of Scientists, Technicians and Engineers within the nuclear security industry. Three Officers are currently undergoing training at Masters level in nuclear security; Several Officers have undergone different Professional Development Courses (PDC) in Nuclear Security; Many others have completed their online World Institute for Nuclear Security (WINS) Academy programme. Border monitoring and prevention of Illicit Trafficking is being achieved through the installation of radiation portal monitors and training of frontline Officers. As a means of securing legacy/disused radioactive sources, a programme for search and recovery of orphan sources is on-going. Nigeria is at the threshold of establishing of a Nuclear Security Centre and this poses a daunting challenge; One of the goals of this Centre is to ensure the introduction of nuclear security training to the curriculum of security agencies and other stakeholder organizations.

Practical Aspects of Applying Ethics to Occupational Exposures within the Nuclear Sector

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Abstract. The paper provides an overview of the ethical values of the ICRP system which ultimately aim to respect individual rights (deontological ethics), promote the collective interest (utilitarian ethics) and favour vigilance and equity (virtue ethics) and their practical application to occupational exposures within the nuclear sector. Behavioural elements such as leadership, expertise, effective communication etc. are discussed and linked to the IRPA Code of Ethics with an emphasis placed upon the importance of developing an ethical radiation protection culture within the nuclear sector. Practical examples of applying ethics to occupational exposures during submarine operational life (maintenance and refit support) and submarine end of life (decommissioning) are discussed, looking at the principles of justification, optimization, limitation (and prudence) and the importance of applying such principles to the practice which causes the exposure within the working environment. The importance of embedding radiation protection ethics at a cultural level is also discussed whereby the nuclear sector should continually strive to ensure that an ethical radiation protection culture continually evolves in line with the demands of the nuclear industry.

Stakeholder Dialogue Webinar: Experience and Lessons for Young and Old Experts and Researchers

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Abstract. The Committee on Radiation Protection and Public Health (CRPPH) of the OECD Nuclear Energy Agency organised on a Webinar to bring together experienced and young professionals to exchange information on dealing with stakeholder concerns through public communications. Three 2-hour sessions were held on three consecutive Wednesday afternoons (from 13:00 to 15:00 GMT+1) in February and March, gathering remote participants from North America, Europe and Asia. Radiological protection professionals with significant experience working with concerned stakeholders presented their opinions on how to most effectively establish effective dialogues with stakeholders in order to address their concerns. Young radiological protection professionals presented their views on how to best take advantage of modern social media to effectively reach broad groups of stakeholders in order to bring radiological protection science to their service. This paper will present the results of the Webinar, and the lessons it holds for future exchange meeting organisation.

Goals and Intermediate Results of the 7FP ENETRAP III Project

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Abstract. For a vast amount of applications in the medical, industrial, research and other sectors, a good understanding of radiation protection (RP) is fundamental in order to protect workers, the public and the environment from the potential risks of ionising radiation. Within this perspective, building and maintaining an advanced level of competence in RP, assuring sufficient well-trained personnel and organising an adequate knowledge management, is crucial. Effective education and training (E&T) is a critical element in these matters, helping to prevent the decline in expertise and to meet future demands. ENETRAP III adds new and innovative topics to existing E&T approaches in RP. It will further develop the European reference training scheme with additional specialized modules for Radiation Protection Experts working in medical, waste management and NPP. It will implement the ECVET principles and will establish targeted assistance from regulators that will play a crucial role in the endorsement of the proposed courses and learning objectives. ENETRAP III will also introduce a train-the-trainer strategy. All organised pilot sessions will be open to young and more experienced students and professionals. In this way, ENETRAP III aims to contribute to increasing the attractiveness of nuclear careers and to lifelong learning activities. ENETRAP III will also propose guidance for implementing E&T for Radiation Protection Experts (RPEs) and Officers (RPOs), hereby providing assistance to all Member States who are expected to transpose the Euratom BSS requirements into their national legislations. Moreover, ENETRAP III will demonstrate the practical feasibility of earlier developed concepts for mutual recognition and thus provide leading examples in Europe demonstrating effective borderless mobility. This poster will give a general presentation of the overall aim of ENETRAP III, and will go into detail on the results achieved: three pilot sessions of new courses to be organised in 2016, a text providing guidance for the implementation of the new E&T requirements as stated in the BSS for RPEs and RPOS, and a new database presenting RP courses.

Problems Associated with Radiation Protection Training Programs

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Abstract. Radiation protection training programs are conducted in several countries in Africa. In Egypt, and for years eight training centers were recognized. Following the new Egyptian ionizing radiation protection legislations, Atomic energy Authority training center is currently the recognized training center. Problems associated training programs include the followings: ionizing radiation users to be certified are numerous; hence other Egyptian training centers should be recognized. EAEA Training program are conducted in house and at other premises upon the request. Lack of practical sessions and replaced by visits to working sites Lack of radiation measuring instruments and personnel dosimeters Different radiation protection program for different specialization. The syllabus of the training course should follow latest ICRP and IAEA recommendations

The INEX 5 Exercise: Notification, Communication and Interfaces for Catastrophic Radiological Events

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Abstract. The INEX series of international nuclear emergency exercises, organized under the OECD Nuclear Energy Agency's Committee on Radiation Protection and Public Health (CRPPH), has proven successful in testing, investigating and improving national and international response arrangements for nuclear accidents and radiological emergencies. Building on the INEX 3 and 4 outcomes, the new exercise, INEX 5, is planned as a table-top exercise addressing emergency management aspects of notification, communication and interfaces between and among countries and international organizations related to catastrophic events involving radiation or radiological materials. The INEX 5 scenario involves a release from a nuclear power plant (NPP), however exercise material is developed to enable countries with or without nuclear power plants to participate via regional table-top exercises or through their own independent exercise. Twenty countries will participate in the INEX 5 exercise, holding regional and independent table-top exercises from September 2015 to June 2016 to test and demonstrate the value of relevant changes put in place as a result of the Fukushima Daiichi NPP accident. An important outcome of the exercise will be the identification of good practices as well as key needs for future work that would benefit from international co-operation. This paper will report on the preliminary results from the exercise. *Austria, Chinese Taipei, France, Germany, Greece, Hungary, Ireland, Italy, Japan, the Netherlands, Norway, Poland, Portugal, Russian Federation, Slovak Republic, Slovenia, Spain, Sweden, Turkey, United Kingdom

Mini UAS based Gamma Spectrometry Measurements in case of Emergency

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Abstract. The unmanned UAS platform allows make gamma spectrometry in severe nuclear release situation where manned radiation measurements are not acceptable. The system is based on Kromek GR1 gamma-ray spectrometer, Intel 32/64 architecture computer and small unmanned helicopter. The detector is solid state Cadmium Zink Telluride (CZT) detector. We have used for manned aerial radiation measurements twenty years Unisampo measurements program with online extension to control measurements, combine GPS coordinates with radiation data to produce radiation map layer to be presented on geographical map. The measurement and analysis programs run on Linux (Ubuntu 14.04 LTS) platform. Kromek spectrometer and computer weight approximately 100 grams. The UAS radiation measurement platform will be used to: measure heavily contaminated areas, identify nuclear power plant release, and it is possible that the system can be implemented meteorological sounding balloon and then we can get information from radiation levels in upper air.

Radon occupancy factor for the public areas, needs for revision

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Abstract. The radon gas inhalation is known to be the second cause of lung cancer after smoking. Reducing the annual exposure of the people from alpha particles of radon gas is a basic step to improve the health status of the community. It is obvious that the public sites such as universities, hospitals, schools and etc are different in the number residents and presence duration. For example, only one classroom of school has been used by more than 100 students in the morning. The occupancy factor of public sites have been considered same but it seems that this factor for all or part of the population should not be considered same since the number and presence duration are different in the public sites. We suggest different occupancy factors to be considered for different places dependent on the number and presence duration of the people. This means that, the sites which occupied by more populations also theirs with more presence time of the people should have a greater occupancy factor. Due to this subject, a suitable occupancy factor could provide a better environmental radiation protection against radon gas exposures of population.

An Insight into the Nuclear Security Science and Policy Institute at Texas A&M University

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Abstract. The Nuclear Security Science and Policy Institute (NSSPI) at Texas A&M University is an interdisciplinary organization formed in March 2006. Through the poster presentation, the author will be sharing his personal experience and thoughts on this research team. The author has been a part of NSSPI for more than three and half years. NSSPI is a joint center between Texas A&M and the Texas A&M Engineering Experiment Station – the engineering research agency of the Texas A&M University System. NSSPI works in collaboration with various U. S. national laboratories, the International Atomic Energy Agency, and numerous academic universities worldwide. What is unique about the NSSPI is the amount of exposure its students get while pursuing either an undergraduate, masters or doctoral program. NSSPI provides several opportunities to students that help them to comprehend the complexity of nuclear security and safeguards and proliferation challenges by not only academic knowledge but also through numerous exercises, or workshops. Moreover, NSSPI students are exposed to the policy world as they prepare to become the next generation of nuclear leaders. The author has been able to attend all classes conducted under the NSSPI umbrella at Texas A&M to get a fundamental knowledge of nuclear security and safeguards. NSSPI organizes various exercises for their students such as at the International Safeguards Laboratory at Oak Ridge National Laboratory to get hands-on laboratory based radiation detectors by performing some measurements. These activities help a student in applying his knowledge, gaining practical experience, and appreciating the distinct viewpoints and enthusiasm of his peers. Also, an NSSPI student gets an opportunity to learn and lead by organizing and conducting exercises/workshops under the guidance of the NSSPI faculty and staff.

KEYWORDS: NSSPI; Texas A&M; radiation detection; nuclear security; safeguards and policy.

Education Standards and Standards Education (ESSE) Process in Radiation Protection in a National Education Cycle

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Abstract. Education Standards and Standards Education (ESSE) is a process through which a country may establish a standardized education and training system in a National Education Cycle (NEC) by developing a standard document on “National Basic Education Standards” (NBES). The NBES sets the general ESSE philosophy, concept, and requirements for setting relevant standards and procedures for preparation, approval and implementation of the ESSE standards in the NEC. The National Education Cycle includes education and training stages from mother care, nursery school, kindergarten, pre-school, primary school, secondary school, university, vocational programs and public education at large which continues to start the NEC again. The “ESSE Process in a NEC” was initiated at the Engineering Science Group of the Academy of Sciences of IR Iran to establish the culture and to found necessary grounds for developing NBES in cooperation with other relevant national ministries and organizations. In fact, the ESSE process best fit to implementation of radiation protection education and training at different stages of the structure of the NEC since the public, regardless of age and gender, and the workers in different applications benefit from the ESSE process. In this context, a “Basic Radiation Protection Education Standards” should be developed based on which the requirements at different education and training stages of the NEC are formulated. While the ESSE Process should be applied through the NEC in all educational and training disciplines in a country, it is equally of most important to be applied in the area of radiation protection where the workers, patients, and public are exposed to natural and man-made radiation. In fact all individuals should have an adequate education and training with careful consideration of not developing radiophobia. In this paper, the ESSE Process in the National Education Cycle in general and in RP in particular will be presented and discussed.

The URPS Hypothesis for Universal Radiation Protection Standardization

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Abstract. A "Universal Radiation Protection System" (URPS) hypothesis with a novel philosophy, concept and methodology has been recently proposed by this author and further developed in this paper. The URPS considers that an individual either a member of public or a worker receives "unfractionated" national natural background (NBG) doses with a mean value different from country to country. A worker is also exposed to "fractionated" occupational doses. The present RP system only considers occupational doses in dose limitation. The URPS applies a "Standardized Integrated Individual Dose System" for workers and public; assigns equal health risk per unit dose of NBG or of man-made exposures; integrates doses from existing, planned and emergency exposure situations as relevant to an individual; integrates for public, doses from planned exposure within a dose limit (e.g. 1 $mSv.y^{-1}$) on top of a mean national NBG dose of a country to also prevent radiophobia; integrates for workers, all dose a member of public receives daily (such as NBG radiation, planned exposures and possibly medical exposures) and occupational exposure; sets risk-limit-based dose limits by taking into account all stated doses; applies for epidemiology study of workers the integrated doses of a worker as stated above for the period under study; and considers the effects of "fractionation" of occupational exposure and "unfractionation" of NBG exposure in dose integration which might increase the present dose limit. This dose extension might bridge the linear-no-threshold model and hormesis model. The Author strongly believes that URPS has a simple philosophy, concept and mechanism with a universal consistency and advantages over the present RP system. It standardizes the "dose limit" based on equal "risk limit" in particular for a worker in any country in the world. A panorama overview of the URPS is presented and discussed with a hope to ignite thoughts with constructive feedback of the world's leading experts in establishing the URPS universally.

Lessons from Fukushima Daiichi Nuclear Accident and Efforts of Nuclear Regulation Authority

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Abstract. Since its establishment in 2012, the Nuclear Regulation Authority (NRA) has been implementing enhanced nuclear regulations incorporating lessons learnt from the Fukushima Daiichi nuclear accident. They include strengthening design basis particularly for external hazards, requirements for severe accident measures and backfitting of the regulatory requirements. The framework of emergency preparedness and response has also been changed and the new NRA EPR guide introduced operational criteria based on measurable quantities and observables. As to the post-accident response to the Fukushima Daiichi nuclear power station (NPS), the NRA designated the NPS as Specified Nuclear Power Facilities and required the operator to submit an implementation plan of safety measures. The NRA examined the plan and set priorities for the mid-term risk reduction. It continues to monitor the progress and reviews the prioritization regularly. The NRA is also responsible for coordinating and conducting a comprehensive radiation monitoring in the affected areas. After five years from the accident, dose rates are becoming lower and stable due to the decay of radionuclides, weathering and decontamination. More resources for the monitoring will be shifted to the heavily contaminated areas to provide information that would contribute to the returning of evacuees.

Balancing Theory and Practicality: Engaging Non-Philosophers in Ethical Decision Making

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Abstract. This paper discusses an approach to engage practicing radiation protection professionals in the ethical aspects of decision-making, with discussion on how this approach fits in with the existing system of radiological protection. It explores finding common ground between ethical and scientific theory, how to present relevant moral theory in accessible language, and provides a practical framework for dealing with real-world problems. Although establishing the ethical theory behind the system of radiological protection is an important, ongoing endeavour within the community, it is equally important to communicate this information in a way that is useful to non-philosophers. Discussion of both ethical theory and a useful strategy for applying the theory makes ethics more accessible to those working in the field by providing them the knowledge and confidence to apply ethical principles in decisions and practice.

The 4th Workshop on Science and Values in Radiological Protection Decision Making

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Abstract. The 2008 (Finland), 2009 (France) and 2012 (Japan) Science and Values workshops, organised by the Committee on Radiation Protection and Public Health (CRPPH) of the OECD Nuclear Energy Agency, contributed to the integration of new scientific and technological developments and socio-political considerations into radiological protection. To continue this progress, the CRPPH organised, in June 2015, the 4th Science and Values workshop in Moscow. Alongside novel scientific and academic phenomena, issues like consent, equity, control and responsibility are also very important for defining and imposing appropriate radiological protection measures and criteria. Taking account of the Fukushima accident experience, these dimensions of *science* and *values* were addressed by Russian and international delegates through the following three key topics: Medical Surveillance of workers and the post-accident affected public; the use of effective dose; and the concept of safety in standards, regulations and public communications. This paper will present the results of this workshop.

Cs-137 Contamination Incident at Scrap Yard in South Africa

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Abstract. Purpose: The purpose of this presentation is to provide an overview of a sealed radioactive source recovery operation that was performed at a Scrap Yard in South Africa, following a request from the Department of Health: Directorate Radiation Control (DoH). The purpose of the presentation is to highlight the presence of lost and orphan sources in SA and to demonstrate how to safely perform source recovery operations. Discussion: NESCA was requested by the DoH to perform an evaluation, followed by a source recovery at a Scrap Yard in South Africa. The presentation aims to give details regarding the findings and challenges encountered during the source recovery. Conclusion: The presentation demonstrates why proper control over radioactive sources are needed, not only by users, but also by the regulators.

KEYWORDS: radioactive; control; lost; orphan; source.

Evaluation of the National Legislative & the Regulatory Framework of Security of Sealed Radioactive Sources in interim Storage

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Abstract. In Morocco, sealed radioactive sources are widely used in medicine, agriculture, industry, and other domains benefiting from ionizing radiations. In spite of all its advantages sealed radioactive sources while becoming unused can threat health and security of human kind if not secured appropriately, where security of sealed radioactive sources in interim storage is crucial. This paper highlights security of sealed radioactive sources in interim storage seeing that they were the origin of many radiological accidents with several consequences. The storage of radioactive sources is placed under a national legislative and regulatory framework, but its touch on implicitly the security of sealed radioactive sources especially in storage. This paper evaluates the Moroccan legislative and regulatory framework by identifying regulatory gaps within it and shows how the regulatory body which is the National Centre of Radiation protection (CNRP) deals with security of radioactive sources in the light of international recommendations, conventions and treaties ratified by Morocco. As a result, regulatory gaps will be identified and based on international recommendations adopted by the country, recommendations and propositions will be proposed as proposal of the essential elements of a regulatory model for security of SRS in interim storage sites in order to fill in the regulatory absence to ensure security of sealed radioactive sources in storage.

South African Perspective for Radon in Dwellings and the Anticipated Regulatory Control Measures

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Abstract. International epidemiological studies conducted confirmed that radon exposure increases the risk of lung cancer. Radon is the second most important cause of lung cancer after smoking in many countries and is the primary cause of lung cancer among people who have never smoked. The studies also revealed that there is no known threshold concentration below which radon exposure presents no risk. Even low concentrations of radon can result in a small increase in the risk of developing lung cancer. According to the studies conducted thus far in South Africa, there are areas with elevated indoor radon exposure and therefore there is a need for some form of regulatory control to protect the potentially affected inhabitants from hazards associated with indoor radon. Internationally, there are recommended action levels and/or reference levels for controlling radon exposure. The IAEA Basic Safety Standards has very detail requirements for indoor radon that emphasises the need for a comprehensive regulatory control system for indoor radon. The regulatory framework in South Africa at this stage does not include the control of indoor radon and no reference levels have been formalized and set for the country. However, considering all the developments internationally and some of the prevailing radon exposures in the country, South Africa is in the process to include indoor radon in its regulatory framework. However, from the perspective of the National Nuclear Regulator indoor radon exposure is regarded as not amenable to regulatory control due to the number of dwellings across the country with potential for elevated radon concentrations above acceptable levels considering the capacity of the regulatory body. Hence, the proposed regulatory framework involves different government authorities for effective implementation of regulatory control. The proposed structure of regulatory control, reference levels and the relevant control measures will be presented.

Contribution of a Master Program in Radiation Protection to Building Competencies in Morocco and Regionally

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Abstract. Today, radiation technologies and radioactive sources are widely used around the world, mostly in medicine (diagnostic radiology, radiotherapy, nuclear medicine) as well as in industry, agriculture, and research. There are indications that exposures of populations from the diagnostic and therapeutic uses of ionising radiation are increasing worldwide. Education and training are indispensable to the development of human resources in radiation protection around the world. In this sense, Morocco has experienced in recent years a great development of the use of ionizing radiation in different applications and therefore there is a need for competent radiation protection professionals. Moreover, Moroccan legislation and regulations requires training in radiation protection appropriate to the kind of work performed. University of Ibn Tofail has established the first master program in radiation protection in Morocco in 2010. This master aims to educate and train national students as well as students from sub-Saharan Africa in radiation protection. So far around 55 students graduate from this master program and serve at national and regional institutions. This paper aims to describe this master program and how it has contributed to meet the needs in radiation protection professionals of our country. It has also contributed to the formation of some sub-Saharan graduates who serve actually in their home countries.

Promoting Nuclear Security Culture through the International Nuclear Security Education Network (INSEN)

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Abstract. In recent years, the international community noted a growing demand in nuclear power as well as an increase in the use of nuclear techniques in non-power applications. Consequently, the need for nuclear security experts has become of great importance to develop and implement nuclear security measures nationally. This goal can be reached through appropriate education and training at all levels and in all organizations and facilities involved in nuclear security issues. A well-educated and trained professionals is needed to serve in national authorities and nuclear/radiological facilities to lead and contribute to the establishment and maintenance of an effective and sustainable nuclear security regime. The International Atomic Energy Agency (IAEA) with partnership with academia, research institutions and international organizations established the International Nuclear Security Education Network (INSEN) in March 2010. The network's mission is to enhance global nuclear security by developing, sharing and promoting excellence in nuclear security education. INSEN now includes 142 member institutions from 51 countries. INSEN members work together with experts from the IAEA's Division of Nuclear Security to develop teaching materials and textbooks based on the IAEA nuclear security guidance, and run academic courses, modules and degree programmes that serve over 2600 students around the World. This paper will provide an overview of the activities and achievements of INSEN so far and how it contributes to the promotion of nuclear security culture worldwide.

Nuclear New Build – Integrating Cultural Differences in Radiation Protection

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Abstract. Across the world we are seeing a resurgence in Nuclear New Build with a current estimated 160 new reactors planned for construction and an additional 300 proposed. In the UK alone plans are under way for the construction of 10 new reactors, using 4 different reactor designs (EPR, ABWR, AP1000 and HL1000) all of which are to be provided by foreign vendors. These reactors are to be operated by 3 newly formed licensees within the UK, majority of which are owned by joint ventures, and funded by foreign investors. As these new licensees and future operators embark on the task of establishing themselves and progressing the design and build of these new reactors there are challenges faced in integrating the Radiation Protection Requirements, Culture and Ethos from the various Foreign Investors and Vendors (including France, China, Japan and America) into the UK "Context". Due credit needs to be taken not only for the regulatory regime of the foreign countries where these reactors originate, but also for the stage in the design development of the reactors, noting they are not being designed from a blank piece of paper, but are rather an existing design which are to be assessed for suitability for licensing, build and operability under the UK Regulatory Regime. Where shortfalls are identified, a proportionate solution needs to be introduced and agreed to resolve any regulatory issues and allow continuation in the design and build process in a cost effective manner, whilst ensuring the risks are adequately controlled and reduced to As Low As Reasonably Practicable (ALARP).

KEYWORDS: cultural differences; radiation protection; nuclear new build; regulatory framework.

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What to Say to the General Public: CT Doses are Safe or Causing Cancer?

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Abstract. Being a very important diagnostic modality for delivering better treatment to the patients, computed tomography (CT) usages in continuously increasing worldwide. Consequently people are concerned and sometimes alarmed about the risk of cancer associated with the radiation exposure from CT scans. Prior to the results of large scale epidemiologic studies the cancer risks were estimated using the involved organ dose and organ specific cancer incidence data from the studies of atomic bomb survivors. Although almost everyone in the radiological community is convinced that CT scans increase cancer risk, the usages of CT scans are increasing rapidly. In many countries, especially in developing countries, there is no existence of regulations regarding CT usages. In many cases CT scans are done without proper referral. Recently results from large-scale epidemiologic studies are being published and there are visible contradictions among the results and their interpretations about the cancer risks from CT doses. So far results from UK studies (178,604 patients, published in 2012), Australian studies (680,000 patients, published in 2013), Taiwanese studies (24,418 patients, published in 2014), and French studies (67,274 patients, published in 2015) show indecisive risk estimations and some results are contradictory to each other regarding cancer risk. Results from UK studies show that radiation exposure from CT scans in children triple the cancer risk at cumulative CT dose of 50 mGy. Although there was an excess of 608 cancers in people exposed to CT scans in Australian study, the life-time cancer risk from CT scans could not be determined. Radiologic community become more confused when results from French study find no significant excess risk of cancer in relation to CT exposure. These results take us to a point of confusion. Now we are not sure about what to say to the public about radiation doses from CT scans. Should we still support the predicted cancer risks, or relax? The aim of this paper is to explain some of these points and the cultural differences of views towards the doses from medical radiations among the developed and developing nations.

The IAEA Safety Standards – Current and Future Perspectives

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Abstract. Currently the IAEA has an extensive suite of safety standards covering safety fundamentals, safety requirements and safety guides. Radiation protection of workers, patients, the public and the environment is specifically covered in General Safety Requirements Part 3: Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, more generally referred to simply as "the BSS". The BSS applies to all facilities and all facilities giving rise to radiation risks and addresses radiation protection and safety from both natural and man-made radiation sources. In March 1960, the Board of Governors of the IAEA agreed that "the Agency's basic safety standards …will be based, to the extent possible, on the recommendations of the International Commission on Radiological Protection". The fifth edition of the BSS, which is cosponsored by eight international organizations, was published in July 2014. Compared with previous editions, the 2014 revision places additional emphasis on protection of patients, occupational exposure in NORM industries and public exposure due to radon in homes. The BSS forms the basis for current international programmes dealing with radiation protection. The "Bonn Call for Action" is a joint position statement issued by the IAEA and the WHO, identifying the main actions considered to be essential for the strengthening of radiation protection in medicine over the next decade. Following the 2014 International Conference on Occupational Radiation Protection, the implementation of the Call for Action in the statement of the President of the Conference will be important for occupational radiation protection in future. While both the System of Radiological Protection and the IAEA safety standards stood up well to the "examination" of the Fukushima Daiichi accident, many challenges remain. Lessons learned and identified from this accident, as well as from other events worldwide underline the importance of having a consistent and coherent approach among national and international organisations and authorities. The System itself has become more complex with time, adapting to new concerns but not always dealing with them in a holistic manner. Communication with the public on issues such as exposure, health effects and future risks continues to be challenging, complicated by the ready access to what is often contradictory information on social media. International trade in food and contaminated non-food commodities is a matter of continuing concern for many States. The IAEA will address all of these issues in upcoming safety standards and supporting documents.

1,200 High School Students Involved in Radiation Protection Actions: Eight Years of Experience Feedback in Dissemination of Radiation Protection Culture.

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Abstract. For the eighth consecutive year, IRSN, CEPN, CCSTI, INSTN and ASN offer to French and foreign high school students (approx. 16 to 18 years old) to participate in international workshops named "Radiation Protection Workshop". More than 1,200 students have participated and contributed to the spread of radiation protection culture. These workshops, led by professors in partnership with radiation protection experts, academics and researchers in scientific disciplines are intended to engage students, on a voluntary basis, in multidisciplinary activities related to radiation protection practice. International meetings are organised at the end of the second quarter of the school year to allow students who participated in the workshops to present their work and interact with other students and with radiation protection professionals. During the 2014-2015 school year, more than 120 students were involved in this action coming from 16 high schools: France, Germany, Belarus, Ukraine, Morocco, Moldavia and recently involved, a high school from Fukushima (Japan) in close partnership with about thirty radiation protection experts. This international meeting was held in March 2015 at CEA / INSTN Cadarache. Throughout the academic year, students under the guidance of their teachers and with the assistance of radiation protection experts carry out work on various topics concerning the practical implementation of radiation protection. These annual international meetings are organized to enable everyone - student, teacher and expert to present their work and exchange information and opinions with other students and professionals in radiation protection. This type of action can contribute to inform young people about key issues related to radiation protection. In addition to oral presentations in French during plenary sessions, one afternoon is devoted to presenting the work carried out throughout the year, by means of workshops and posters. Another afternoon is reserved for visiting scientific installations related to RP. The growing success of this action to spread the RP culture, forces the organizers to consider all arrangements to ensure the sustainability of the 9th RP Workshop.

Prudence in Radiation Protection - How Much? A Case Study

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Abstract. Prudence, including the precautionary principle, is a cornerstone of radiation protection philosophy. The current ICRP work on Ethics in Radiation Protection seems likely to re- emphasise its central role in the system of protection. However, whilst the concept is clearly valid at the level of principle, it is nonetheless necessary to ask 'How much prudence is really appropriate' in the context of various practical situations. This is perhaps particularly important where exposures are low – within the range of natural background, where changes in the level of protection will have no meaningful impact whatsoever on the overall exposure level of any individual. The concept of prudence/precaution is applied at a 'top tier' level through the application of the Linear No Threshold (LNT) hypothesis. Additionally, in the form of 'conservatisms', it is applied in impact assessments and day to day protection considerations. The combined effect of multiple layers of prudence has rarely been assessed and is worthy of further attention. This paper considers the combined impact of accumulated layers of prudence and conservatism, using the example of clearance and exemption as a case study. It concludes that doses actually resulting from the clearance process are typically around a few tenths of a μSv/y, i.e. two orders of magnitude below the internationally-agreed objective of 'some tens of μSv/y', which was itself established on the basis of considerable prudence. The implications of this outcome are discussed, both for clearance and exemption processes and for potential conflicts with other ethical considerations such as beneficence – i.e. that the resources used to achieve the very low dose levels derived from a dogmatic application of prudence could be used more effectively to do good in other aspects. It is recommended that it would be helpful to derive a clearer framework for the application of prudence.

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Ethical Basis of Radiation Protection

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Abstract. ICRP task group 94, supported by IRPA, is preparing a publication on the ethical basis of radiation protection. Workshops to gather input from radiation protection professionals have been held in Europe (Milan and Madrid), America (Baltimore and Boston), and Asia (Deajeon and Fukushima). The results of these workshops are that the basic principles of radiation protection, namely justification, limitation, and optimization, are broadly consistent with both western and eastern ethical traditions. Of the many ethical goals that have been developed, four in particular have emerged as being most relevant to radiation protection: beneficence (or at least non-maleficence), autonomy (dignity), prudence, and justice. However, conflicts may arise among these goals in practice. For example, after a release of radioactive material, prudence may call for evacuation of a population, but autonomy argues against mandatory evacuation, and beneficence argues against imposing risks due to evacuation that typically exceed the avoided radiological risks by an order of magnitude. Autonomy and justice come to the forefront in the remediation stage, in which stakeholder involvement is essential for a successful outcome. However, stakeholder involvement is complicated by differing exposure limits proposed for planned, emergency, and existing exposures.

The 1980 Sievert Lecturer: Lauriston S. Taylor

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Abstract. Dr. Lauriston Sale Taylor (1902-2004), a radiological physicist at the National Bureau of Standards, was named as one of two U.S. appointees to the predecessor of the ICRU in 1928 and helped organize what became the ICRP that same year. In 1929 he was named chair of the U.S. Advisory Committee on X-ray and Radium Protection, which later became the NCRP, which he served as President until 1977. His remark at a UNESCO conference in Paris in 1957 that "…the establishment of permissible levels of radiation exposure is not basically a scientific problem. Indeed, it is more a matter of philosophy, of morality, and of sheer wisdom" is frequently quoted to the present day. His 1980 Sievert lecture, entitled "Some Non-Scientific Influences on Radiation Standards and Practice" foreshadowed the current practice of stakeholder involvement by stating "I feel strongly that we must turn to the much larger group of citizens generally, most of whom have to be regarded as well-meaning and sincere, but rarely well-informed about the radiation problems that they have to deal with." Taylor's foresight has been realized in numerous efforts, including the IRPA initiative on public communication, and the joint ICRP/IRPA effort on the ethical basis of radiation protection. What is most interesting however, is that lessons learned from the Chernobyl and Fukushima Dai-Ichi nuclear power plant accidents are moving us not merely to stakeholder engagement, but to stakeholder empowerment, in which the stakeholders themselves become the decision makers, and determine such matters as acceptable exposure levels, remediation priorities, and waste management options for themselves. The new role of the RP professional is to serve as an independent, unbiased source of scientific information to provide input to the stakeholders, rather than to receive input from them and make the decisions for them.

Management of Contaminated Goods in Post Accidental Situation: Synthesis of European Stakeholders' Panels

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Abstract. Recommendations and requirements for the management of foodstuffs including drinking water and feedstuffs as well as other commodities contaminated after a nuclear accident or a radiological event have been developed by international bodies such Codex Alimentarius Commission or Euratom as well as by individual countries. However, the experience from severe nuclear accidents (Chernobyl, Fukushima) and less serious radiological events, shows that the implementation of such systems (based on criteria expressed in activity concentration) seems to be not fully suitable to prevent several difficulties such as, for instance, stigmatisation and even rejection attitudes from consumers or retailers (anticipating the fears of consumers). To further investigate the possible strategies and stakeholders expectations to deal with this sensitive issue, a reflection has been launched within the European research project PREPARE. The overall objective of this work, coordinated by IRSN with the support of CEPN, is to contribute to the development of strategies, guidance and tools for the management of the contaminated products, taking into account the views of producers, processing and retail industries and consumers. For this purpose, 10 stakeholders' panels from different European countries have been set up. In addition, feedback experience from the management of contaminated goods following the Fukushima accident has been provided by Japanese stakeholders. This paper will highlight the key topics tackled by the different European stakeholders' panels. The following issues will be addressed: preparedness modalities, management of consumer goods production on the basis of the justification and optimization principles, use of numerical criteria, dissemination of information to different publics, stakeholder participation process, role of the market and organization of the trade, ethical considerations and development of solidarity.

Establishment of a New Nuclear Regulatory Authority in Ghana

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Abstract. The use of radioisotopes in Ghana started in 1952 when radiostrontrium was used in experiments on monkeys. Subsequently, there have been a lot of developments in the peaceful uses of atomic energy in Ghana. Currently, the country operates nuclear facilities such as Research Reactor, a Multi-Purpose Gamma Irradiation Facility, two Radiotherapy and a Linear Accelerator facilities for medical use, Gamma and a Linear Accelerator for destination inspection facilities for scanning containerised shipping containers among others. In 1993, the Radiation Protection Board (RPB) was established as the National Competent Authority for the control of these practices empowered by the Legislative Instrument, LI 1559. The operational functions of the Board are carried out by the Radiation Protection Institute, which was established under RPB to provide technical support for the enforcement of LI 1559. The RPB was under the Ghana Atomic Energy Commission (GAEC), which compromised the effective independence of the regulator. Also, with Ghana's intention of introducing nuclear power into its energy mix in the future, it became imperative that an independent nuclear regulator be established in the country. This led to the enactment of the new independent Nuclear Regulatory Authority (NRA) law, Act 895 of 2015. The NRA will take the regulatory functions of GAEC to enable GAEC focus on its core functions of research and training. The NRA will seek to establish high calibre safety, security and safeguards standards reflective of best practices in other International Atomic Energy Agency (IAEA) Member States ranging in scope from engineering safety, operational safety and radiation, radioactive and nuclear material transport and waste safety. The Act also addresses Nuclear Liability in accordance with IAEA Conventions on Liability. Members of the Board of the new NRA are yet to be appointed by the Government of Ghana, to be followed by the commencement of official business.

Lessons learned from the Fukushima Dai-ichi accident and safety enhancements for the restart of nuclear power plants in Japan

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Abstract. Almost all the safety functions were simultaneously lost at Fukushima Dai-ichi Nuclear Power Station as common cause failures due to the earthquake and its subsequent tsunami on March 11, 2011. The escalation of events could not be mitigated and, eventually, the situation developed into a severe accident. About 5 years have passed since the accident and the situation has been stabilized. Radiation level on the site premises has been significantly reduced because of the progress of decontamination and use of robots and other remote controlled machines. New regulatory requirements for commercial power reactors were enforced in Japan on July 8, 2013. Under the new regulations, the design bases for and countermeasures against external events, which include natural phenomena, internal flooding and fires, are required to be enhanced significantly with emphasis on the concept of Defense- in-Depth and prevention of common cause failures. Systems, components, procedures and the technical capability to deal with severe accidents became subject to regulatory review. Nuclear operators in Japan are improving the safety of their own nuclear power plants by adding new safety features to physical plant systems and emergency procedures. As an example, Kashiwazaki Kariwa Nuclear Power Station has now added barriers to protect safety systems, diversified water injection systems, mobile heat removal systems, filtered containment venting systems, and so on. The filtered containment venting system has been newly developed with added capability of capturing organic iodine. Applications were submitted by nuclear operators to the Nuclear Regulatory Authority for conformity reviews under the new regulatory requirements. As of February 1, 2016, four units had completed the review and three units had restarted operation.

Accreditation Model of Courses in Radiation Protection in Medicine: One proposal to Latin America countries

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Abstract. Introduction: Medical facilities that use ionizing radiation are responsible for the radiation safety of patients, workers and members of the public. These facilities must comply with regulations and should be authorized by a regulatory authority to use the ionizing radiation for a specific practice. The Radiation Protection Officer (RPO) is responsible to implement the Radiation Protection Program. With a great cultural, educational and financial diversity, the Latin America region comprises 33 countries but only 21 have a regulatory authority in place on the use of radiation in medicine. The adequacy of the regulatory framework with the GSR Part 3 varies significantly between countries. In general, requirements regarding RPO qualification such as minimum educational background, theoretical and practical training, and minimum experience are not included in the legislation. Furthermore, the regulatory authorities are not in charge in the process of courses accreditation and requirements are not established in national standards. Objective: Development of an accreditation model of radiation protection courses in medical practices that could be implemented by each country of the region. Material and Methods: Based on international recommendations, the model structure was designed considering: minimum syllabus, practical and theoretical course load, lectures qualifications, admission and approval criteria, infrastructure, adequacy to national regulations, outcome indicators and an established quality assurance system. Results: An accreditation program to assure the quality of specialization courses for RPO in medical field was developed. A grading system of compliance for each step of the accreditation process was defined. Guidelines with the minimum requirements were developed to assist the applicants. Re-evaluation processes and criteria to maintain the accreditation certificate was also prepared. Conclusions: This accreditation program is important to assure the quality of the educational program provided by the countries in the region. The model can be adopted according to national regulations and cultural, economic and educational status.

Development of Practical Guidance's for Workplace Monitoring in Nuclear and Radiation Facilities - an IAEA TECDOC Project

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Abstract. The outcome of workplace monitoring plays paramount role in control of radiation exposures of occupation workers employed in controlled areas of a nuclear power plant and other radiation facilities. IAEA has recently (2014) revised and published the Basic Safety Standards (BSS) [1] in tune with latest recommendations of ICRP and also integrated the other safety guides to form Occupational Radiation Protection (ORP) [2] safety guide. The BSS defines the requirements of protection and safety for various exposure situations and the ORP guide advocates the guidelines that are required to meet the requirements. Notwithstanding the presence and application of these safety standards, a technical document that describes the practical aspects of workplace monitoring is also essential to establish the effective workplace monitoring programme in every nuclear facility which will contribute exposure control and hence less collective dose. Since the workplace monitoring remains the nucleus of Radiation Protection programme, it is necessary to provide a detailed methodology that facilitates its effective implementation. This manuscript discusses about the ongoing development of a TECDOC focusing on practical aspects of workplace monitoring. This work is sponsored by European Commission under contribution agreement and being executed by Radiation Protection Professional at IAEA with an aim to support the Member state to strengthen the radiation protection infrastructure. The objectives of developing this technical document are a) to provide the practical guidance on implementation of workplace monitoring by incorporating the recent revisions made in BSS and ICRP towards optimisation of protection b) to provide the technical guidance and practical information on workplace monitoring related to selection of instruments, the methods/procedures for type testing, calibration and quality assurance in measurements. This document is primarily designed to support the plant management, radiation protection officers, qualified experts, regulators and other technically competent professionals who have the responsibility of ensuring safety of occupational workers dealing with ionizing radiations. This guide provides the guidelines on implementation of three important elements of workplace monitoring namely, evaluation of 'exposure rates' to control the external doses, determination of 'surface contamination' to minimize the possibility of inhalation hazards and prevention of spread of contamination by estimating both transferable and non-transferable contaminations and quantification of 'airborne contamination' presence of which poses the risk of internal exposures in working environment. A comprehensive discussion on designing of monitoring programme along with need for monitoring with specific attention to Pu and transuranic monitoring, Noble gases, Iodine, Tritium and Carbon-14 sampling and analysis is underlined. The document is structured in such a way that it stresses, the need for workplace monitoring as part of prior radiological evaluation to design a monitoring programme for an upcoming facility.

Management of Malaysian Nuclear Agency's License: Experiences and Challenges

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Abstract. Malaysian Nuclear Agency (Nuclear Malaysia) is a leading agency in introducing and promoting the application of nuclear science technology for Malaysia development. The agency provides several major nuclear facilities purposely for research and commercialisation such as reactor, irradiation plants and radioisotope production laboratory. The agency is the biggest licensee's holder of national regulatory body, Atomic Energy Licensing Board (AELB). In order to ensure the execution of the nuclear law, a secretariate of the Radiation Protection Programme (RPP) was set –up. The secretariate is responsible in managing the compliance of AELB's Act 304 in Nuclear Malaysia. This paper will discuss the experiences and challenges by the secretariate in managing and maintaining AELB's class A,B,C,D,E,F and H licences.

KEYWORDS: Act 304; radiation protection programme; license.

Microdistribution of Plutonium in Human Skeleton. Should we Change the ICRP Model?

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Abstract. Skeleton is one of the major organs of plutonium deposition within the human body. It is well known that plutonium distribution in bone tissue is quite uneven. According to generally accepted model, main fraction of plutonium activity resides on endosteal bone surface and Haversian canal walls. Present study is devoted to analyzing plutonium microdistribution in the thoracic vertebra obtained from a former Mayak PA worker and preserved by SUBI Human Tissue Repository; the analysis was carried out using neutron induced autoradiography. Obtained results are in sharp contrast with the corresponding values for Leggett's biokinetic skeletal model recommended by ICRP, especially in case of cortical bone. According to main results of the study, the authors suggest adjusting the parameters of ICRP biokinetic model and to revise dose coefficients for radiation protection purposes.

A Tool for Implementing the UNSCEAR Methodology for Estimating Human Exposures from Radioactive Discharges

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Abstract. The UNSCEAR methodology for estimating human exposures due to radioactive discharges from the nuclear fuel cycle has been used successfully for many years. The 56th session of UNSCEAR agreed to update the methodology with the scope being extended to include discharges from other sources of electricity generation. The aim of the methodology is to assess the individual and collective doses from routine (continuous) discharges to the environment. The Committee uses this methodology for realistic, worldwide, assessments; it is not intended for other situations or uses (for example, not for accidents, risk assessments or regulatory purposes). Electronic workbooks are being developed, the purpose of which is to implement the methodology in a transparent way and allow the sources of data to be clearly identified. The workbooks are being developed to assess individual and collective doses from the unit discharge of each of the key radionuclides to the atmosphere, lakes, rivers and seas. The workbooks are being expanded to take account of radioactive discharges resulting from not only the nuclear fuel cycle (uranium mining and milling; uranium enrichment and fuel fabrication; nuclear power reactor operation; and reprocessing) but also from other sources of electricity generation such as coal, oil, gas and geothermal. A systematic review of the workbooks will have been carried out for quality assurance purposes, firstly by the workbook developers and then by independent reviewers. It is envisaged that UNSCEAR would approve the methodology and workbooks at its coming session in June 2016, and they would be published thereafter.

International Standards for Managing Radionuclides in Food and Drinking Water

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Food and drinking water contain radionuclides at relatively low levels and the sources of these radionuclides include: (1) naturally occurring radionuclides which are present throughout the environment; (2) authorized discharges from nuclear, medical, research and other licensed facilities; (3) fallout from nuclear weapons tests; and (4) residual amounts of radionuclides present in the environment as a result of accidents, such as the Windscale nuclear reactor fire in 1957, the Chernobyl nuclear power plant in 1986 and, more recently, the Fukushima Daiichi nuclear power plant in 2011. Radionuclides of natural origin will always be present and, depending on the particular circumstances, radionuclides of artificial origin may be present in varying amounts over extended time periods. In such circumstances, consideration will need to be given to whether or not some form of control or restriction is justified. This paper reviews the various current international standards that apply to radionuclides in both food and drinking water and proposes a framework to establish activity concentration levels that can be used as the basis for their long-term management in normal circumstances. Different criteria apply in the immediate response phase following a nuclear or radiological emergency and are outside the scope of this paper.

Transition of Public Awareness and Its Factor Analysis Concerning Nuclear Energy and Radiation Application Based on Japanese Nationwide Fixed-Points Poll

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Abstract. A systematic nationwide fixed-points poll in Japan has been performed in order to monitor a transition of awareness, understandings and acceptance of Japanese public concerning nuclear energy and radiation application. The transition were analyzed mainly based on the results by the polls from 2006 to 2014. Opinion among 15-79 years old has been surveyed by the “door-to-door and placement method”. The main purpose of this continuous poll is to know effective measures to share right and adequate information on nuclear and radiation application with stakeholders. The number of survey participant in almost every-year is 1,200 from all over Japan. The poll results has been analyzed mainly from the two viewpoints on (1) the reasons and parameters for transition of public opinion tendency and (2) the difference of this between before-and-after the disaster of the Fukushima Daiichi nuclear power plant in 2011. As a general tendency, the answer from a member whose knowledge level on the nuclear and radiation application is high tends to be similar with that from a member whose sociality is high. There might be a high correlation between sociality and knowledge. A person whose sociality is high might get more additional knowledge. A person who are interested in nothing more, and a person without sociality would not intend to get additional knowledge. In addition, a person who lacks related knowledge answers in the poll as "I cannot say YES or NO." As knowledge level becomes higher, ratios of "I cannot say YES or NO" decrease and they show more clear opinion. Opinions from high knowledge members were bipolarized in several questions. Continuously fixed questions in this poll will be shown, and main results tendency and preliminary analysis will be presented.

Communicating Radiological Concepts in Plain Language: The Value of International Consistency

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Abstract. The Inter-Agency Committee on Radiation Safety (IACRS) was created in the early 1990s to provide a forum for international organisations dealing with radiological protection to exchange information and discuss emerging issues in order to maintain a consistent and coherent international voice, find synergies, and avoid unnecessary duplication of efforts. The IACRS played a key role in the development of what became both the 1996 and 2014 International Basic Safety Standards. Since this time, the IACRS has continued its coordinational efforts, with contributions from its 8 member organisations (EC, FAO, IAEA, ILO NEA, WHO, PAHO, UNSCEAR) and five non-governmental (ICRP, ICRU, IEC; IRPA and ISO) entities. In particular, experience from the Fukushima Daiichi NPP accident showed the importance of communicating radiological protection concepts (e.g. radiological risk, radiological dose quantities, radiological protection approaches, etc.) to different stakeholders. In response to this challenge the IACRS is working to develop a consistent set of short, plain language explanations of radiological protection concepts for public and non- specialist communications use by IACRS organisations. This paper will describe the plain language work of the IACRS, including draft examples, and the direction that this work is taking.

ICRP Stakeholder Dialogues: Lessons for the International Community

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Abstract. As part of the response to the Fukushima Daiichi NPP accident, the Japanese government sought the views and advice of many experts from foreign governments, from international organisations, and from the International Commission on Radiological Protection (ICRP). In its recommendations for the protection of people living in long term contaminated territories, the ICRP emphasizes the effectiveness of directly involving the affected population and local professionals in the management of the situation, and the responsibility of authorities at both national and local levels to create conditions and provide means favouring the involvement and empowerment of the population. Putting this philosophy into practice, the ICRP initiated a series of stakeholder dialogue meetings, beginning in the fall of 2011. Participants included representatives of Fukushima Prefecture, local professionals, local communities, representatives of Belarusian, Norwegian and French organisations with direct experience in managing long-term consequences of the Chernobyl accident, and the Committee on Radiation Protection and Public Health of NEA/OECD. The objective of these meetings was, broadly, to find ways to respond to the challenges of the long term rehabilitation of living conditions in the areas affected by the Fukushima nuclear power plant accident. Between November 2011 and September 2015 a total of 12 Dialogue Symposia were held. This report is intended to briefly present the processes that were used to organise these stakeholder dialogue meetings, and to highlight and document the lessons learned by the CRPPH through the participation of the CRPPH Scientific Secretariat in all 12 Symposia.

Management of Protection through Prevailing Circumstances: Interpretation of the ICRP System of Radiological Protection

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Abstract. The International System of Radiological Protection, as recommended in ICRP Publication 103, is now, after 5 years, beginning to appear in international documents and national regulations. This transposition is broadly working well, but this is also highlighting a few implementational difficulties. The most important of these are the designation of worker protection in Existing and Emergency Exposure Situations, and the nature and use of dose limits. A key focus of the ICRP system in Publication 103, although not directly expressed, is the need to focus protection decisions clearly through the optic of prevailing circumstances. This is to say that in planning and implementing protective decisions it is essential to begin with as clear an understanding as feasible of the radiological and non-radiological conditions that cause the need for protection decisions. In fact, prevailing circumstances, and the ability to control the source of exposure and to manage exposure pathways given the prevailing circumstances, provide a central rationale for identifying the type of situation, and for the tolerability of exposures, i.e. the selection of the appropriate band for dosimetric criteria. The ICRP RP System provides a framework in which protection decisions should be taken. A way to approach the difficulties that have been encountered, and to give the System more flexibility, is to consider the relationships among the 3 ICRP Principles, the 3 ICRP Exposure Situations, and the 3 ICRP Types of Exposure. The following interpretation, and slight refocusing of Publication 103, provides a somewhat new picture, asserting that the prevailing circumstances drive the choice of management tools.

Plain Language We Can All Understand

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Abstract. The expression of complex radiological protection science and concepts in plain, understandable language is a challenge, yet is central to good decision making. The Committee on Radiological Protection and Public Health (CRPPH) of the OECD Nuclear Energy Agency (NEA) has been studying the role of radiological protection professionals in radiological protection decision-making since the early 1990s, focusing on "stakeholder involvement" aspects. The Committee has broadly concluded that while most radiological protection decisions are informed by radiological protection science, they are in fact driven by social and individual values, e.g. a member of the public's desire to protect children or the environment; a worker's desire to effectively finish a job but to do so as rapidly as is reasonable; the desire of a manager to be cost-effective. Choices are always judgmental, but to help assure that stakeholder decisions are properly scientifically informed, it is central that complex radiological protection concepts and science are appropriately articulated. Such plain-language explanations can be challenging for radiological protection professionals, who are broadly technically trained and oriented. This paper will discuss the need for and the challenges of stakeholder communications in plain language.

Developing Radiation Protection Culture at School: The Experience of the 2015 France-Japan High School Students Radiation Protection Workshop in Fukushima

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Abstract. Since 2013, a partnership has been established between French and Fukushima high schools and jointly coordinated by CEPN, IRSN and Tokyo University, to initiate joint work on radiation protection and promote sharing on issues related to post-accident management. The aims of the work undertaken are to put in perspective radiological exposures between the region of Fukushima and France, and share the concerns and lives of Japanese students on one hand and the questions of French students about the accident and its consequences on the other hand. Several exchange activities were implemented: video-conference, participation of Japanese high school students to the French annual workshop, inter-comparison project on external exposure to radiation. In August 2015, during one week, 21 high school students from France and Fukushima participated to the radiation protection workshop in Japan. During the 5 days of the workshop, students visited locations affected by the Fukushima accident and tsunami and had the occasion to exchange with experts, farmers, tourist organisations, inhabitants, medical doctor… They also monitored their external exposure during the week and the food coming from the farms they visited. A public presentation was organised at the end of the workshop, providing the opportunity for the students to summarize their understanding of the situation and to express their feelings. Their comments at the end of the workshop clearly express the output of the exchange. By their visits and the exchanges they had in the families and the observation of the daily life in Fukushima Prefecture, the students have got information to be able to build their own judgement on the radiological exposures. They have observed the various situations, including areas where the day-to-day life is not always possible due to radioactive contamination. They have discussed and debated on issues of concern for the people related to the human dimensions of the situation, notably related to the rumours, the decontamination programme, the future of agriculture. This paper will highlight the key features of this exchange for the development of the radiation protection culture.

Measurement and Data Analysis Concepts Combined with Data Assimilation Techniques for Source Term Reconstruction and Dose Assessment

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Abstract. The combination of measured data from stationary ambient dose equivalent rate (ADER) monitoring systems and stationary and mobile in situ gamma-spectrometry systems have been the basic elements of the monitoring strategy in Germany over the past years. Recently two types of improvements enabled the refinement of radiation protection strategies. Due to the development of room-temperature detectors, ADER detectors with spectroscopy capability have become available. Secondly, the concept of so called deployable ADER probes has been introduced aiming at enhancing the density of ADER monitoring stations at locations close to where a release is expected to potentially take place. In the early phase of an emergency situation, the ability to combine prognostic data and measured data is important to understand the radiological situation, to identify affected areas and to assess the dose for the public and task forces. Today, on-line monitoring data from stationary and mobile ADER probes together with spectroscopic data can be combined and nuclide specific ground contamination maps can be generated. In addition, data from aero-gamma and car-borne monitoring can be integrated. Currently, different research projects are aiming on source term reconstruction using monitoring data in the vicinity of nuclear power plants. For this task, information from spectrometric ADER monitoring stations is helpful especially in cases where stack monitoring instruments are not able to quantify the accidental release of radioactivity. Furthermore, concepts are under development for reconstructing the exposure of the population by considering all types of monitoring data.

Optimizing a Commercial Radiation Portal Monitor for Spot Traffic Controls

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Abstract. The Swiss Federal Office of Public Health (FOPH) performs spot traffic checks for prevention of inadvertent movement and illicit trafficking of radioactive materials in Switzerland. For this purpose, a commercial Radiation Portal Monitor (RPM) was modified for rapid deployment in temporary field campaigns. In close collaboration with Swiss customs, the FOPH commissioned the testing and operation of the RPM to the Paul Scherrer Institute (PSI). Further to the radiological evaluation tests under laboratory conditions field-testing the RPM at a Swiss custom border point was performed. As a result, technical modifications for increased mobility and better compliance with road traffic were made. At PSI, a stress-test was applied to the RPM with up to 2000 measurement cycles per day over several weeks proving the effectiveness of the modifications. Practical problems and appropriate solutions are shown. Three additional spot traffic controls have been successfully carried out using the modified RPM measuring more than 12.000 heavy load vehicles.

Training as Awareness Factor and Dissemination of the Brazilian Nuclear Area

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Abstract. Knowledge is accessible at all times and know manage strategic data in order to employ them in the most appropriate manner possible, it is essential for the preservation of an institution. The storage of information, essential in generating technical and scientific processes, is only in the minds of people, a richness that needs to be shared efficiently to make the process of knowledge exchange within the nuclear area. Knowledge management arises in this scenario as a proposal for identification, maximization, coding and sharing strategically relevant knowledge in order to create a favorable disposition for constant learning and enhancement of intellectual capital in the institutions of the Brazilian nuclear sector. In this paper we propose the creation of a training program, aimed at the servers of these institutions, both technical and administrative areas, with a view to preparing these to become multipliers in the dissemination of activities developed by the institution so that they can, with strong arguments to defend the industry's work from outside criticism of this form of energy. This program aims to create an important process of change of mentality and attitude among people who belong to the circle of relationship of industry servers, expanding the debate on the subject, so that it can reach the company, clearly and free of prejudices to understand the benefits of using nuclear energy. The efficient management of nuclear knowledge will facilitate the training process servers, aimed at shaping public opinion about nuclear energy, i.e., the main step is to work the workforce to reach the general public.

INSTN: The Most Complete Training Centre for First Time Nuclear Plant Workers.

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Abstract. Introduction: As part of its policy to maintain its power plants fully operational, EDF has scheduled a vast overhaul programme dubbed ‘Grand Carénage’, to which has been added further refits and improvements identified in analysis following the Fukushima accident in March 2011. No programme of this importance has been undertaken since the initial construction of France’s vast network of nuclear power plants, and will see an increase in the numbers of workers entering nuclear sites for the first time. In this context EDF has identified training as a major key to the success of the programme. Therefore, since September 2014, training for subcontractors has been completely reviewed and enhanced with the support of human resources specialists. Among the resources necessary to reach the objectives set, vocational academies and enactment training centres have taken on an important role by making enactment training as realistic as possible and increasing the number of training situations. Aim and approach: In the context of this challenge, INSTN has chosen to work side by side with EDF by creating its own enactment training centre and propose a complete training programme for first-time nuclear plant workers, covering health & safety, quality, risk prevention, fire protection, environment and radioprotection. This investment has been accompanied by the acquisition of new skills for training team management. To build this enactment centre, INSTN has made a considerable investment, integrating at the very beginning of the project, the quality standards equivalent to the reference EDF ‘ARC’ academies. Results: An enactment training centre equivalent to a reduced-scale nuclear power station has been built on the Cherbourg premises of INSTN. This training tool is composed of 2 independent heating & cooling circuits, and a control room and was inaugurated in November 2015. It has enabled, to this date, the training of approximately 80 people in the areas of site safety, and a further 160 people in the area of radioprotection, all in exceptional conditions. This training centre has been commended by EDF as one of the most complete in France. Conclusion: INSTN can apply a very realist training, with very realistic equipment for a best prevention of risk, for the first-time workers.

Comparison between Brazilian Radiation Protection Norm and the Basic Safety Standards Published in 2014

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Abstract. In the year 2014, IAEA published an international basic safety standard (GSR), which changed some important concepts off BSS 115. This work aims to compare the CNEN-NN-3.01 with the new IAEA basic safety standard, by checking the existing differences. The main difference between cnen-nn-3.01 and GSR is the changing of the concept of protection based on process, by using the concepts of practice and intervention, to the protection based in the exposition situation, by using the concepts of planned exposure, emergency and existing situation. Other important difference lies in the values of the radiation and tissue weighting factors, in the quantities equivalent and effective dose, and updating the radiation detriment. At last, the demonstration of the environment radiation protection must be clear, and this concept is not found in Brazilian nuclear legislation. Also some similarities were found. The fundamental principles of the Brazilian norms are the same as that of GSR, which are the justification principle, the optimization principle and the application of dose limits. The individual effective dose limit of Brazilian norm is the same of the GSR, established as 20 mSv per year. In order to adequate, the Brazilian norm it is necessary to change its concept of protection and the values of radiation and tissue weighting, and updating the radiation detriment, besides making clear the concept of protection of the environment. It is important to notice that although the Brazilian norm is not in complete agreement with all international recommendations, it must be completely followed as the norm which is in use in the country.

Licensing of Nuclear Facilities in Brazil: Radiological Aspects

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Abstract. The licensing of nuclear facilities in Brazil requires satisfying two main aspects: the environmental one in charge of the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (Brazilian Institute of Environment and Renewable Natural Resources - IBAMA) and the radiological one, in charge of the Comissão Nacional de Energia Nuclear (National Nuclear Energy Commission - CNEN). This study aims to assess Brazilian standards for radiological licensing. Radiological licensing aims to ensure the preservation of the physical integrity of nuclear installations, the preservation of workers and the protection of the environment. For radiological licensing a series of standards must be followed. The step- by-step process established by CNEN applies to activities related to the location, construction and operation of nuclear facilities, as follows: Local Approval; Construction License (total or partial); Authorization for Use of Nuclear Materials; Authorization for Initial Operation; Authorization for Permanent Operation and Cancellation of Authorization for Operation. In addition to this standard, other standards need to be contemplated to regulate various aspects of plant safety, radiation protection, use and transport of radioactive materials and waste management. In conclusion, it can be stated that the nuclear licensing in Brazil covers all relevant aspects of the life cycle of a nuclear installation, since the location prediction, installation, construction, operation and decommissioning, reaching thus the present international state of the art.

The Principle of Low Risk and Optimization and the Connection with the ALARA concept. Exemption, Exclusion and Clearance

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Abstract. The principle of low risk was introduced in 1996 by the IAEA in a simplified and limited form, where a direct correlation between individual risks and the respective doses that generate these risks was proposed. Optimization is one of the foundations of radiation protection and is based on the need for continued efforts to reduce doses. These two principals have different bases and formulations but intend to achieve the same goal: the safe use of radiation. But how much should one reduce the dose in order to reach the level of acceptable trivial risk? The concept of As Low As Reasonably Achievable (ALARA) answered this question indicating that the doses should be reduced within a subjective perspective of reasonability. But dose reduction should only occur in certain situations. The exemption applies to practices and sources associated with practices that, due to low levels of radiation involved, meet certain criteria, e.g. when the individual risk associated with radiation is irrelevant, or the collective radiological impact is low enough so that it should not require compliance with radiological protection requirements and the exempted practices and sources should be intrinsically safe. The exclusion of the regulatory scope applies to any exposure whose intensity or probability of occurrence cannot be reduced by radiation protection actions, e.g. 40K in the human body and cosmic radiation on the surface of the earth. The clearance that can be considered as a subsequent exemption is actually a withdrawal from the regulatory scope. In conclusion, the principle of low risk establishes a relationship between dose and risk. The optimization predicts dose reduction and therefore reduction of risks, when the ALARA principle establishes subjective criteria to decide how far the dose should be reduced. In some cases the reduction is not justified (exemption) because the risks are too low to include them in the regulatory scope and in other cases the exclusion of the regulatory scope is due to lack of capacity to regulate exposure. Finally, the clearance occurs in practices or sources that can be released from the service of radiological protection requirements when they fit to the exemption criteria, including the use of optimization.

The State of the Art about the Radiation Protection System in the World

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Abstract. The exposure processes form a chain of events and situations. Radiation or radioactive material, through exposure routes, expose individuals, and this exposure generates a dose in the individual. Protection against these effects is carried out through actions at the source, at points on the routes of exposure and, changing the position or other characteristics of exposed individuals. This approach allows to divide the network of events and exposure situations in steps and to evaluate which are important for intervention. This is a complex process called radioprotection. The aim of this study is to assess the state of the art of radioprotection by ICRP. For operational reasons the radiological protection needs to perform simplifications in the relations between sources and biological effects. The first dividing the exposed individuals in three categories: workers, patients and members of the public. For practical reasons, the network of events and situations has been divided into practice and interventions. The second simplification was called "source-related assessment". In this new approach the types of exposure situations are: planned, emergency and existing exposure situations. The categories of exposure are: occupational, public and medical exposure of patients. The Principles of radioprotection were maintained and strengthened, as well as the values of dose limits. The source-related assessment allowed the definitions of the concepts of dose constraint and reference levels. All this, when used with the principle of Optimization and the dose limits demonstrates the confidence of the radioprotection community in the safety of these limits. The Brazilian radiological protection did not reach the state of the art described here, but being the legal norms for Brazil they must be obeyed.

The Importance of Including the Human Error Factor and Decision Making in Training and Education Programs to Avoid Radiological Incidents of Accidents

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Abstract. In the last decades there have been numerous efforts and contributions to improve and integrate various issues related to radiation safety training programs and education of occupational exposed workers. The implementation of education and training activities in radiation safety needs to continue and facilitate the inclusion of new approaches, developing and implementing different mechanisms and strategies to strengthen capacity building. In particular those related to industrial and medical applications or processes, which technologies are modified and updated permanently, and in some cases even more frequently than training and education programs, standards, and regulations. These training programs are extensive and deep, as to the knowledge of radiation safety and security, but do not reinforce or include the problem of human error during the training, in general. The evaluation of international information concerning the occurrence of radiological events, shows that even after this effort, new incidents still occur. During the evaluation of different mistakes that may have caused the event, it was detected that people involved had adequate knowledge of radiation safety, but it was not enough to prevent it from occurring. Cultural aspects, human factor, deviation frequencies, social and personal values, change of attitude and evolution resistance are concepts that must be included in the training programs to facilitate the comprehension of the nature of the occurrence of radiological events. For this reason, it is necessary to implement a strategy to update and change training programs effectively, incorporating models that include deep concepts of perception and communication of the radiological risk, management systems, vulnerability and other educative tools for the assessment of training needs. The development of specific theme including human errors or failures and their consequences, and other specific preventive concepts for decision-making, will be the last step in order to implement barriers capable to stop and prevent a radiological incident. The inclusion of these concepts in training programs will modify educational training strategies and the learning process of the occupationally exposed workers, and more over will help to reduce the occurrence of accidents with consequences for health, environment and future generations.

Individual Monitoring for External Exposure of Users at Synchrotron Radiation Facilitates and New Solutions

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Abstract. In recent decades, many synchrotron radiation facilities have been put into operation in the worldwide. Compared with a traditional nuclear or radiation facility, most of the synchrotron radiation facilities are regarded as large-scale scientific facilities, in which there are a group of special people, the Users, in addition to radiation workers. The Users is a large group who access to the radiation area frequently, but most users are non-radiation workers. As incompatible with international and national existing standards of radiological protection, individual monitoring for external exposure of the Users at these facilitates has become a prominent issue. This paper reviewed the current status firstly, and then described the situation at Shanghai Synchrotron Radiation Facility (SSRF) in details as a typical case. Under the existing system of radiation protection, we proposed a new solution idea that we cancel the mandatory individual monitoring as required for a radiation worker, instead of the User voluntary monitoring and User representative monitoring, with analysis the monitoring data accumulated in the past years. This solution not only brings convenience to the users but also save resources.