Management of Waste from Mining and Minerals Processing
(Keynote paper)

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1. Introduction

Radioactive waste is extremely difficult to specify. Everything is radioactive, in particular wastes from mining and minerals processing (MMP waste) may have high contents of naturally occurring radioactive materials (NORM). Approximately 7000 mines are operated worldwide, not included 15,000 coal mines [1]. In MMP waste, or more generally in NORM waste, the relevant radionuclides belong to the U-238 (and U-235) or to the Th-232 series. In the natural matrix the mothers and daughters in the decay series of the primordial radionuclides are usually in the secular equilibrium. In general, processing of NORM may cause a disturbance of the secular equilibrium, e.g. mobile Ra isotopes may be leached off their geochemically immobile uranium and thorium parents, the noble gas Rn may escape and Pb and Po isotopes may be evaporated. In this paper the term NORM is preferred to the other terms used in the literature (TENORM, TENR).

NORM emit alpha radiation, and are long-lived except Pb-210 and its radioactive decay products. NORM wastes have low specific activities (LSA waste). This term is preferred to the expression "Low Level (radioactive) Waste" (LLW). It should be mentioned that NORM wastes are often mixed with hazardous chemical wastes and are themselves often treated like non-radiological hazardous wastes.

2. MMP waste management within the framework of radiation protection

From a radiation protection point of view the wastes should not be assessed in isolation but as part of the activities generating them. That is why their management is one of the many human activities causing enhanced exposure of workers and the public to natural radiation. The following problems have come into the focus of radiation protection in the past decade: cosmic radiation during airflights, radon in dwellings, workplaces with high radon progeny concentrations, work activities with enhanced levels of NORM and residues from mining and other industrial activities. Even if differences in the approaches to these new problems are inevitable a certain consistency should be striven for [2]. Although important for waste management, occupational exposures are not discussed in this paper.

It is even to be questioned whether consistency with the current system of protection against exposure to artificial radiation sources (including natural radionuclides that already have to be controlled in practices such as the use of sources in purified form, e.g. Ra, or the nuclear fuel cycle) can be achieved. It is true that the risk of a mSv is independent of its origin, or an atom of uranium poses the same hazard at a licensed nuclear site as at a rare earth production site. However, several million tons of MMP waste are created each year, and the waste to be handled in restoration programmes may even exceed this quantity. The cost of disposal as ”radioactive waste" may be tremendous (probably 1000-3000 ECU/m³ for LLW taken to a near surface disposal or twice this amount for deep disposal [3]). Industries are often highly competitive. Practicable but expensive measures to reduce doses may lead to plant closure, the consequential detriment to the workforce and the surrounding community may then exceed the benefits from the dose reduction.

For the management of MMP waste other solutions than at present considered for radioactive waste with artificial radionuclides may be reasonable and in agreement with the ICRP statement in Publication 60: ”The primary aim of radiation protection is to provide an appropriate standard of protection to man without unduly limiting the beneficial practices giving rise to radiation exposure”. On the other hand, at least for the time being, MMP waste disposal practices should not be used as an argument to reduce disposal standards for artificial radionuclides as sometimes -not illogically- required [5a]. It may correspond with the concept of ”controllable doses” as discussed in detail at this Congress when flexible and practicable approaches to manage MMP waste are based rather on the existing risk perception than consistently on an apparent equality of the "objective" risks, all the more as the values of the risk coefficients for the low dose range are only precautionary assumptions. Of course, the principles for management of radioactive waste apply also to NORM waste, but the procedures to comply with them may differ from solutions considered at present for artificial radionuclides.

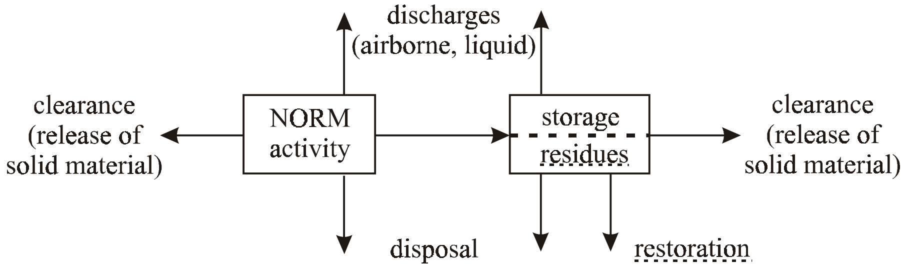


Fig.1 gives an overview of different kinds of NORM waste. Airborne and liquid releases are no subject of this paper. If controlled the emissions from the plants usually comply with even stringent criteria and requirements (e.g. 10 µSv/a and a small collective dose), but in these cases more waste is collected and stored in the plant. Since NORM waste except Pb-210 is long-lived, storage cannot reduce the radioactivity. Often NORM wastes are deliberately stored because no decision has been made on how to dispose of or to release them and the ultimate disposal decision is postponed. Apart from this waste kept in an interim storage there are huge amounts of wastes released into the environment or disposed of in a manner that is not acceptable from the current point of view in radiation protection. These radiological residues often require the remediation of a facility or the restoration of a site, i.e. an intervention. By the way, during a restoration programme like this new types of waste may be generated.

The ICRP distinction between practices and intervention situations is well established and useful. Nevertheless, it can be difficult to apply in cases of natural radiation exposure. Most practices resulting in high natural exposures are already existing, and the initial protection measures are often introduced, de facto, as counter-measures. MMP wastes are affected in particular. This waste was often not disposed of deliberately and under control, resulting in some situations in a source of exposure that was not intended. Unacceptable exposures may be reduced by further restrictions on the current disposal, i.e. by modifying the practice. Often, however, they can be reduced only by remedial measures in the environment, i.e. by an intervention.

Obviously it is difficult to apply different reference levels for existing situations and new practices of the same type, even if it is justified in the radiation protection system to distinguish between intervention or action levels and limits. Title VII of the European BSS [6] covers "work activities" within which "the presence of natural radiation sources leads to a significant increase in the exposure of workers or members of the public which cannot be disregarded from a radiation protection view". Regulatory flexibility is warranted by the recommendation of a four step procedure in which each member state

1. identifies by means of surveys work activities that may be of concern,
2. declares those work activities that must be subject to control,
3. implements corrective intervention measures to reduce exposures,
4. applies radiation protection measures as for practices if still necessary.

This approach should also apply to the management of MMP waste.

3. Overview of MMP and similar NORM waste

At present a complete global overview of the amounts of NORM wastes, their activity concentrations and their characteristics is not available. In the literature a growing number of information is delivered, but many data are still missing or, if delivered, incomplete. The features of waste depend on the characteristics of the raw material, the specific methods of processing (including any protective measures) and how the residual material is stored or disposed of. Altogether a huge variety of activity concentrations and masses of waste, already existing and continuously being generated, with extremely different physical and chemical characteristics, has to be taken into consideration. For the purpose of this paper a complete overview of the literature is not necessary and a very rough indication of the order of magnitude of the problems faced may be sufficient. Table 1 gives an overview of the main mining and minerals processing and similar activities creating wastes in the USA and the EU. The data are taken from [7a,8] and roughly rounded. The quantity of waste may range from few kg in storage at a plant to some ten million t in an uranium mill tailing.

Industry and Wastes	Annual production or waste generation rate (tons) USA	EU	Range of activity concentrations (Bq/g)	Dominating radioisotope
Minerals processing				
- Rare earths	$2 \cdot 10^4$		10 – 1000	Th (U, Ra)
- Zr, Hf, Ti, Sn	$5 \cdot 10^5$	10^6	< 0.3 – 1000	Th (Ra)
- Alumina	$3 \cdot 10^6$	$2 \cdot 10^6$	0.3 – 1	Th (U, Ra)
- Cu, Fe (dust, sludge)	10^9	10^8	< 0.4 (0.1 – 100)	Th (U, Ra) Pb
Oil/gas production	$3 \cdot 10^5$ (?)	10^8		
Scale	$3 \cdot 10^4$	10^2 - 10^3	< 0.1 – 4000	Ra
Sludge	$2 \cdot 10^5$	10^5	< 0.1 – 4	Ra (Pb)
Oil processing			< 4	Ra
Phosphate industry	$5 \cdot 10^7$	$2 \cdot 10^6$		
Phosphogypsum	$5 \cdot 10^7$	$3 \cdot 10^6$	< 0.1 – 2	Ra
Slag	$2 \cdot 10^6$	$2 \cdot 10^6$	< 1 – 3	U, Ra
Scale	$5 \cdot 10^3$		1 – 4000	Ra
Dust		$2 \cdot 10^4$	1	Pb
Coal fly ash	$5 \cdot 10^7$	$3 \cdot 10^6$	0.5	Ra
Uranium mining and milling	world 10^3 t/a, cumulative ~ $2 \cdot 10^{6\,t}$			
Waste rock piles	~ $10^9 – 10^{10}$		< 0.5 – 30	U, Ra
Tailings	~ $10^8 – 10^9$		2 – 500	Ra

Table 1: Rough overview of mining and minerals processing and similar activities

Other similar activities with the generation of NORM waste are water treatment, geothermal energy use, paper mills or manufacture and the use of thorium compounds such as welding rods or gas mantles.

4. Typical examples of MMP waste management problems

In addition to the overview a few typical examples of mining and minerals processing and related waste management problems will be briefly discussed. They are more or less arbitrarily selected and should not be understood as a representative description of the present situation. At recent conferences many papers on other cases describing similar problems were presented [5,7,9,10,11].

- In the UK in a plant processing mineral sands a furnace dust collector was installed to meet release requirements. The furnace dust with 200 Bq/g Pb-210 and 600 Bq/g Po-210 could go to a landfill site for hazardous waste but was rejected by the operators of the disposal site because it was classified as radioactive waste. 200 t of waste have been accumulated and a disposal route has not yet been identified [12].

- Zircaloy sands with ~4 Bq/g Ra were used in a research facility in New Mexico/USA and placed in a field behind the plant. Although no significant hazards were identified, migration to waterways could not be excluded and several 1000 kg were taken to a hazardous waste disposal [7b].

- In Brazil ~1000 t of waste resulting from monazite processing with Th-232 and Ra-228 concentrations up to 3000 Bq/g are stored in buildings, trenches or silos in two large and some other installations. There are not any proposals for a final disposal yet [5b].

- Steel production in the UK is connected with an annual generation of filtered off-gas dust in the order of 10.000 t. This waste with Pb/Po concentrations in the order of few Bq/g is not classified as radioactive and can go to an ordinary refuse disposal [7c].- In Germany and in the Netherlands an economic option is the recycling of steel scrap arising from the decommissioning and dismantling of gas and oil exploration and production facilities, phosphate processing plants and last but not least from uranium mining and milling facilities. After melting, the steel is usable without restrictions, but in the slag and filter dust activity concentrations in the range of 2-100 Bq/g may occur. They can be reduced on-site by chemical or mechanical (e.g. hydroblasting) decontamination of the equipment as exercised in the oil and gas industry, which creates liquid wastes with concentrations of few Bq/g though. Their disposal may be difficult as well, and a volume reduction is up to now economically unattractive [7d]. Based on an exposure analysis,slag is permitted to be used as road building material up to 65 Bq/g Ra until new regulations come into force [5c].

- In the British coal-fired electricity industry huge amounts of fly-ash with total activity concentrations of ~1 Bq/g are generated. Public exposures due to stack releases, ash piles and landfill disposal are negligible (< some 10 μSv/a) and acceptable if used in building materials (< 0.25mSv/a to the critical group) [7e]. However, there are single coal deposits with much higher activity concentrations. For example, in Germany the Freital hard coal with up to 25 Bq/g U-238, 33 Bq/gRa-226 and 11Bq/gTh-232 had been mined for some hundred years until 1989. Ashes and coal deposits were used for uranium extraction after the war. The deposits of ashes and slags from this coal with up to ~300 Bq/g U and Ra and ~100 Bq/g Th have to be radiologically evaluated and, if the exposure to the critical group exceeds 1mSv/a., remediated.

- Another unusual German example is copper shale mining and processing in the Mansfeld region since the middle ages until 1990. About 200.000 t sludge with 3-20 Bq/g Pb-210/Po-210 and high concentrations of heavy metals are provisionally deposited, sometimes disposed of as hazardous waste. About 50 Mio t slag with 0.3-1 Bq/g Ra-226 are deposited as dumps and may be used for road building if covered by a >10cm layer under controlled conditions. In the past it had been used in large amounts as building material without control.- In the USA ~100.000 t tailings material of a copper mine are to be transported to a lined impoundment. The cost of some million $ is compensated by the sale of copper recovered from the material [5e].

- The Dutch authorities detected NORM wastes in the order of 1 to some 100 kg, all with activity concentrations in the order of some 10 to 1000 Bq/g: drums with bags of sludge from the gas-producing industry at a disposal site, tubings and valves from the fertilizer or gas-producing industry, metal smelts from a smelting plant and old fire-doors with slagwool at scrap yards, and mineral ore concentrates stored by warehouse companies. With the exception of the first case the companies or the originators were requested to introduce appropriate control measures. Reference levels of 100 or 500 Bq/g were applied [7f].

- As a consequence of the phosphate fertilizer production in many countries piles with millions of tons of phosphogypsum with concentrations of up to 3 Bq/g Ra-226 were created. The piles are often unprotected against rainfall and are hydraulically connected to surface water and to shallow aquifers. The Ra is rather insoluble but can become soluble due to the high concentration of Ca. The dominating exposure pathway is the release of Rn. The piles belong to the hazardous waste sites and do not pose a significant radiation protection problem [9a]. Special requirements apply if the phosphogypsum is used as building material.

- Storage of minerals in museums and research institutes may cause high radon levels and gamma doses of the order of 10mSv in a year [7g].

The waste from uranium mining and milling constitutes a particular problem because of the huge waste quantities as shown in Tab.1 even if appreciable exposures are limited to within 0.5 km of the tailings impoundment. In principle, as part of the nuclear fuel cycle uranium ore mining and the processing of the ores belong to the practices within the system of radiation protection. However, under the conditions of the Cold War radiation protection rules had not always been adequately observed, and usually the tailings as the most problematic waste deposits have been only provisionally secured. Some large restoration programmes are carried out in the USA, Canada and Germany. For example, in Germany this programme covers ~300 million m^3 waste rocks and ore dumps (up to 30 Bq/g), ~150 million m^3 tailings ponds (up to 300 Bq/g) and an open pit mine [4a]. In addition to the radioactivity chemical pollutants such as arsenic, molybdenum, heavy metals or organic substances and mechanical risks such as insufficient stability of tailings dams or waste rock piles have to be taken into account. Apart from filling up the open pit mine, the relocation of waste is minimised. The preferred option is on-site restoration based on a site specific exposure analysis. The established reference level is 1mSv/a in addition to the natural background. Besides, in Germany other mining residues, including conventional ore mining executed since the middle ages, are radiologically evaluated. Up to now almost 9000 residues have been identified, most of them do not need restoration [4b].

5. Waste management options

In principle an optimisation procedure should decide on which part of the generated wastes is to be im-mediately diluted and dispersed, i.e. discharged as airborne or liquid effluents, and which part is to be collected, stored and disposed of or ultimately released (Fig.1). Such an optimisation requires a detailed exposure analysis including normal and potential exposures to future generations. At the moment the MMP waste management is still under discussion and no comprehensive regulations have been established yet. If a MMP waste problem has been identified in a plant, there is a tendency to reduce the effluents complying with stringent requirements (e.g. an exposure of <10 µSv/a to the critical group and a collective dose of <1manSv/a) and to keep solid or sludgy wastes in an interim storage or to dispose them more or less provisionally awaiting future regulations.

A typical example of dilution is phosphogypsum discharge into the sea. Individual doses become trivial and the collective dose remains low. However, if the waste is discharged into coastal waters there may be an accumulation in marshlands, harbour sludge or seafood resulting in enhanced radiation exposures to man [5e]. Whether this dispersion is acceptable will now be discussed in the framework of the OSPAR Convention with emphasis on political rather than radiological viewpoints.

In the following disposal options for solid or sludgy waste will be discussed only qualitatively.

Interim storage as a systematic approach is useful if only the nuclides Pb-210/Po-210 occur, e.g. in dust filtered from stack emissions in the case of high temperature processes. In 100 years the radioactivity decays to ~5%. Interim storage of few centuries may suffice to release this waste, and this time period is not in contradiction to the required surveillance of the storage site.

The simplest and cheapest disposal option is unrestricted release which should be based on clearance levels. Spreading of waste with relatively low concentrations over the land (in a thin layer on soil or by mixing with a top layer of soil) may not, or only to a low degree, increase the original radiation exposure. This may be demonstrated by the use of phosphate fertilizer on farmland [5e]. Calculations show that the extended use of phosphate fertilizer (even if recently proposed clearance levels will slightly be exceeded) increases the dose rate above ground by 1-3%. Even if, at a later stage, the land is used for permanent residence purposes, the annual dose will increase only by 7µSv/a. The ingestion dose caused by consumption of crops cultivated on such farmland is negligible. Normally unrestricted release will take place as landfill, and the answer to the question whether such an option is reasonable depends on the activity concentration of the relevant radionuclides and the physical and chemical characteristics of the NORM determining leachability and volatility.

Restricted release as landfill or in burial sites with control of the further use of the site is a further disposal option that may become popular because similar arrangements and provisions are used at ordinary refuse disposals for conventional industrial waste. As long as these sites are operated access control is necessary. After the closure and covering of the burial site the land can be used e.g. for forestry, for recreation such as sports fields or for industrial purposes. Housing development should be avoided. - Restricted use is very often the condition underlying restoration programmes with in situ stabilisation of insufficiently preserved former waste sites, especially from uranium milling. Another very illustrative example is the restoration of the environmental contamination in a former radium facility [4c].

Disposal by shallow land burial such as in trenches or engineered facilities may be used for large volumes in analogy to other radioactive wastes (LLW) when the activity concentrations become higher. Since in trenches the waste is immediately accessible to leaching and dispersion a physical barrier to water is necessary in the construction. Engineered facilities rely on multiple engineered and natural barriers to isolate the wastes effectively. Deep geological disposal as the proposed strategy for high level wastes and spent fuel may be used only in exceptional cases for smaller volumes of NORM waste with extreme activity concentrations because of the very high costs and the relatively low potential exposures in case of human intrusion. Another option is disposal at a repository for hazardous waste, occasionally located in underground dumps. In all these cases immobilising NORM waste by cement and chemical based solidification supports the isolation from the environment. - If tailings from uranium milling with their huge volumes have not yet been restored or secured it may be reasonable to transfer other NORM wastes to them.

Tailings from uranium milling are normally stabilised in situ. However, in the UMTRA Project of the US DOE the tailings material is mostly transferred to especially constructed disposal cells (engineered facilities) located preferably in remote areas [5f].

In the oil and gas production special waste disposal options in addition to land disposal with or without encapsulation and scrap metal recycling are available and assessed as radiologically justified: re-injection of waste by hydraulic fracturing or in the well during plugging and abandonment of operation, or sea disposal of waste or equipment with or without encapsulation [7h]. The latter option may be in contradiction to the OSPAR Convention.

It may be useful to reduce volumes of waste considerably through separation of radionuclides from the bulk of the waste. The small volumes of concentrated waste may justify selecting an expensive disposal option. Decontamination of equipment may reduce the radiation risk connected with wastes from decommissioning and dismantling. Smelting of contaminated steel is a good example of recycling. Table 2 shows the activity distribution after melting [24]. The steel may be used without restrictions, and only slag and dust are left as waste. These materials again may be recycled under certain controlled conditions by using them e.g. for specified building purposes such as road construction or may be disposed of in landfills. Another example of recycling is the addition of coal fly-ash to cement or its use to fill in closed underground galleries, or the use of slag from the phosphorus production for road construction or probably in dike building [7].

	melt	slag	dust
U	1 %	98 %	1 %
Th	< 1 %	> 98 %	1 %
Ra	-	98 %	2 %
Pb	-	7 %	93 %

Table 2: Activity distribution after melting

6. Institutional control

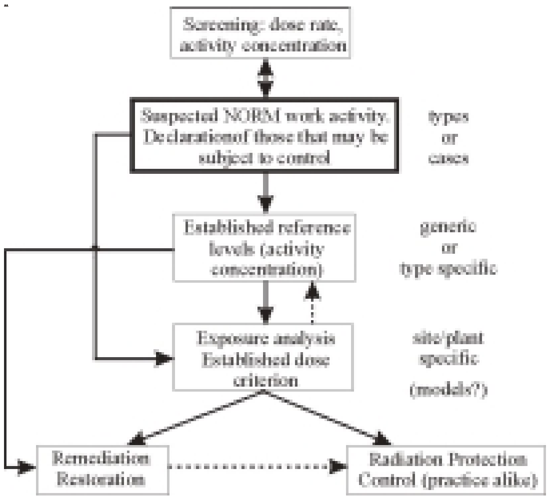
According to recent discussions in ICRP [14] institutional controls (monitoring of the site, surveillance and maintenance, observation of use restrictions, prevention of misuse) maintained over a disposal facility after closure or over a site after restoration, respectively, may enhance confidence in the safety of the disposal facility or site particularly by reducing the likelihood of intrusion and detecting natural degradation resulting in a loss of containment. There is no reason why these controls may not continue for extended periods of time and may make a significant contribution to the overall radiological safety of shallow disposal facilities in particular. Furthermore, for surface or near surface disposals of uranium mill tailings, these controls may be relied on for long periods of time in situations where, if the controls fail, consequences will be generally lower than those associated with other long-lived wastes.

Normally institutional controls are assumed to last not longer than a few hundred years. This may suffice if the major part of the radionuclides will have been decayed. However deposits of long-lived NORM wastes including mill tailings are unlikely to remain safe in the absence of institutional control for a much longer time. Human intrusion, building on the site and extraction of sand are the immediately dominating and continuing risks, and natural erosion processes with the transport of radionuclides into the neighbouring biosphere are certain to occur within a few centuries or even earlier. It should not be considered as a contradiction to the waste management principles if there is no end of the institutional control in view and some burden is left to future generations. Because of the low activity concentrations a loss of control cannot result in acute radiation detriments. Moreover, alternative solutions without the necessity of continuing institutional controls are too expensive for the huge volumes of these wastes. The experiences with the UMTRA disposal cells for uranium milling tailings material clearly show that an continuing institutional control is inevitable [5g].

One should also recognise the fact that after a time period in the order of 10,000 years risks associated with geological changes such as glaciation or tectonic movements may obscure risks associated with the waste disposal system.

7. Regulatory approaches

As recommended in Title VII of the European BSS (cp. section 1) the authorities should first identify by means of surveys work activities including management of MMP and other NORM wastes (either types or individual cases) that may be of concern and then declare those activities that must be subject to control. Fig.2 elucidates this flexible regulatory approach which allows to concentrate first on the most significant problems and then, using the experiences gained, tackle those problems that were initially assessed as less significant– possibly incorrectly. This first step should be based on screening measurements of dose rates and/or activity concentrations covering not only the wastes themselves but also the raw materials and materials at different processing stages.



The ultimate decision on corrective intervention or control measures should be based on established reference levels. There are two options, see Fig.2. The levels may be given in terms of activity concentrations of the waste and can be either generic or specified for particular waste types. More generic levels are necessarily more restrictive. In the UK specific reference levels for different types of work activities were developed. However, the needed waste disposal capacity is not yet available [10a]. All wastes with concentrations below such a reference level can be eliminated from further considerations (i.e. unrestricted release), the others have to be taken to the appropriate waste disposal. Here again, reference levels may be established for disposal at specified types of waste disposal sites.

As a second option the reference level may be established as a dose criterion. Its direct application requires an exposure analysis specific for a site or a plant. This way offers the advantage of a realistic risk assessment as a prerequisite for reasonable decisions on the management of the relevant waste, provided that the exposure scenarios and models are adequately selected. Different computer-based modelling approaches for radioactive waste sites are available which provide results which in general agree to a satisfactory extent [8]. Reference levels of the first type may be applied in addition as screening levels to eliminate those wastes that are of no concern, before an exposure analysis is carried out. Of course, reference levels in terms of activity concentrations should for their part be derived from a dose criterion based on generic exposure models.

	Exemption levels (Bq/g)		Clearance levels (Bq/g) unrestricted (ordinary waste disposal)			
	1 **)	2	3	4	5	6
U-238	~ 50	1	0.1	500 *)	-	0.01 (0.1)
Ra-226	~ 50-500	10	0.1	0.5 *)	0.03 (0.1)	0.01 (0.1)
Pb-210	~ 500	10	0.1	0.5 *)	0.02 (10)	0.02 (10)
Th-232	~ 50-100	1	0.1	5*	0.02 (1)	0.02 (1)

1. Current German Radiation Protection Ordinance
2. IAEA + Int. Org. BSS, European BSS
3. IAEA proposal (TECDOC – 855) 1996
4. Current German Radiation Protection Ordinance
5. Recommendation of the German Commission on Radiological Protection
6. Possible future German regulations

All radionuclides in equilibrium with their progeny except
*) single radionuclides
**) There is only an established exemption level of 500 Bq/g for the total natural radioactivity

Table 3: Comparison of different exemption and clearance levels

Exposure assessments for long time periods are essential for the management of radioactive waste. The increasing uncertainty of the exposure scenarios and models used with the increasing time frame should not be discussed here. However, in view of the necessity of a continuing institutional control as discussed in section 6 uncertainties in exposure assessments become less significant since the necessity of corrective actions at a distant future may be easier to identify.

A big confusion about the reference levels to be applied to NORM waste management can be observed in the national and international discussions at present. One reason may be that the system of exclusion, exemption and clearance needs further clarification, and the related discussions are going on. It is not the purpose of this paper to present an exhaustive overview of the levels already being discussed. In the following a rather personal view is given, illustrated by some reference levels established internationally and in Germany, and additionally some values as discussed in connection with the revision of the radiation protection legislation in Germany. In Tab.3 different reference levels are compared.

The IAEA has established exemption levels for single radionuclides that are in the order of 1 to 10 Bq/g for those of relevance for NORM (Tab.3). The same values are given in the European BSS and will certainly be used in many national regulations. These values are based on a dose criterion of 10µSv/a (and an annual collective dose of 1manSv) and are derived from exposure scenarios covering practices where less than about 1m³ of radioactive material is used. Derived from a generic optimisation these practices are exempted from radiation protection control. Obviously these levels should not be applied to decisions on NORM waste management. By the way, in many countries as in Germany the current legislation prescribes exemption levels for the total NORM activity concentration in the order of 100 to 500 Bq/g that should also not be applied.

Type of rock / soil	Concentration range (Bq/g)	
	Ra-226	Ra-228
granite	0.001 – 0.5	< 0.001 – 1
limestone	< 0.001 – 0.3	< 0.001 – 0.5
gneiss	0.001 – 2	< 0.001 – 0.4
sand, silt	0.005 – 0.03	0.004 – 0.03
clay	0.002 – 0.1	0.03 – 0.1

Table 4: Activity conventrations of Ra isotopes in the U-238 and Th-232 decay chains after UNSCEAR 1993

Clearance levels for unrestricted use (or in special cases also for restricted use) seem to be generally applicable to waste management decisions. For the sake of consistency with the exemption levels they are derived from the dose criterion 10/µSv/a and for large volumes. Examples are given in Tab.3 (proposals of the IAEA and German bodies, for comparison also the current German values established pragmatically and not derived from a dose criterion.) Although they are applicable to artificial radionuclides, e.g. for decommissioning nuclear facilities, they are sometimes criticised as being in contradiction to a more appropriate dose criterion such as the proposed constraint of 0.3mSv/a or the limit of 1mSv/a. Anyway, they were derived for materials handled within approved practices and should not be applied to NORM waste. Tab.4 presents some values on the range of radionuclide concentrations in the untouched nature. Obviously the proposed clearance levels may be significantly lower than natural concentrations and are hardly measurable if only those attributable to the practice have to be registered.

There are also clearance levels given for surface contamination, e.g. 0.4 Bq/cm² for alpha emitters [7f]. For unrestricted use of scrap from the uranium mining and milling industry in Germany 0.05 Bq/cm² for alpha emitters are established, and 0.5 Bq/cm² are applied to melting down the scrap without additional radiation protection measures.

In principle, clearance levels for a defined disposal could be higher than the generic exemption levels even if based on the same dose criterion and much higher volumes. Sediments dredged out in coastal waters with activity concentrations in the range of several 10 to few 100 Bq/g could be allowed to put back because this complies with the 10µSv/a level [7i]. It should be clarified whether this option is prohibited by the London Convention as sea dumping of radioactive material. However, it shows clearly that a realistic exposure analysis is to be preferred to the use of generic reference levels in terms of activity concentrations.

Maybe appropriate clearance levels could be established. However, a different approach following the philosophy of the European BSS seems possible. According to TitleVII enhanced natural radiation is separately regulated ("work activities"). It would not make sense if different dose criteria are applied to the management of NORM wastes and the restoration of previous NORM waste sites. In the latter case it seems that internationally the limits or constraints as established for practices are applied, i.e. values between 0.3 and 1mSv/a. This was demonstrated at the recent IAEA Symposium in Arlington,USA [4] (even if according to EPA a value of 0.25 mSv/a may be not sufficiently protective). Such reference levels may not correspond to an ICRP recommendation in connection with residues from previous mining and minerals processing, saying that a restoration should only be performed if the reduction of doses will more than offset the social and financial costs of the intervention and that decisions should be made case by case and aim at doing more good than harm and not be based on a preselected dose [13]. However, the practicability of regulations favours a selected level, and public acceptance of restoration programmes seems more likely to be achieved if the dose criteria are the same as for practices. Following the logic underlying the definition of the "work activities" the same dose criteria should be used for the unrestricted use of NORM wastes.

The inherent inflexibility of preselected dose criteria could be partly compensated by a flexible procedure for the inclusion of work activities in the radiation protection system as contained in the European BSS and described above. If those work activities, that are not included, are called "excluded" and regarded as "not amenable to control" (in the sense of not reasonable to be controlled, what should be the result of a generic optimisation) the approach discussed would correspond to recent ideas on a modified system of exclusion, exemption and clearance as now under discussion at the IAEA [15].

The deliberations in revising the German radiation protection legislation on the basis of the European BSS follow this direction. Work activities with enhanced natural radiation exposures and restoration of radioactive residues are regulated in separate parts of the legislation. Restoration is demanded if a source related dose criterion of 1mSv/a is exceeded what has to be demonstrated by a site specific exposure analysis. A screening level for the unrestricted use of 0.2 Bq/g A* (A* means radionuclide with the highest activity concentration in the material) was established. It has been oriented at the highest concentrations found in the unaffected nature in the relevant region) but is not in contradiction to the dose criterion. For specified restricted uses a screening level of 1 Bq/g A* was established [4b].

The same dose criterion of 1mSv/a is to be applied to work activities. Only work activities specified in an official list should be considered. As screening levels will probably be used: 0.2 Bq/g A* for unrestricted use, 0.5 Bq/g A* for disposal at an ordinary refuse disposal site, 5 Bq/g A* for disposal at an underground dump. Higher values (possibly in the order of 50 Bq/g) are accepted for disposal as hazardous waste. The screening levels were derived from generic exposure scenarios and models and are thus rather low. A first analysis of the impact of their application on the relevant industries has supported this approach, but the discussions are not yet finished. These screening levels may be used directly for decisions, but an exposure analysis specific for the material streams within a work activity should be preferred. This is a simplified presentation, reflecting only the basic ideas of a much more sophisticated approach (established reductions or increases of the values above, considering special radionuclide compositions, total quantities of NORM waste in relation to the volumes of ordinary waste at a disposal site, ground water characteristics at the disposal site etc.). This approach is still under discussion.

A basic problem may be the inclusion of exposures to radon in the dose criterion. There may be cases where trivial outdoor concentrations of a few Bq/m^3 are decisive for taking costly actions if a dose criterion of 1mSv/a is applied [4b]. This could be regarded as an unacceptable inconsistency with the action level for radon in dwellings which should be in the order of 200-600 Bq/m^3 (3 to 10 mSv/a). The main exposure to radon occurs indoors, and an equilibrium is assumed between the source related contributions indoors and outdoors. On the other hand, if houses are built on a disposal site, radon may be the most significant exposure pathway. This problem is still controversially discussed in Germany, and a separate reference level may be applied to take radon emissions from the wastes into account. This approach is supported by the fact that the long-term stability of cover layers against radon emissions is particularly uncertain. In many proposals for regulating NORM radon is excluded from the dose criterion[5h].

8. Outlook

This paper has attempted to give a rough overview of the problems faced in the management of wastes from mining and minerals processing and of similar wastes, of selected current practices to solve these problems, as well as of related regulatory approaches. At the end more questions may arise than answers have been given. Because of the large social, economic and political consequences of any decisions in this area and the missing international harmonisation one should be cautious about establishing relevant national regulations. However, the approaches discussed in this paper enable a flexible solution starting with the most significant exposures. A comprehensive, systematic and totally consistent approach seems not to be achievable at the present time. Public acceptance of the criteria laid down in regulations and stakeholder involvement in the decision-making processes are the key issues. At the present time it seems to be prudent not to call MMP and other NORM wastes “radioactive waste” since this could prevent radiologically acceptable solutions other than taking the waste to an extremely expensive disposal site or interim storage for radioactive waste. Terms such as “residual material”, “residues”, “hazardous waste”, “industrial waste” etc. may be preferable.

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