Emerging Challenges for the International System of Radiation Protection Quantities and Units

Abel Julio González[1]*

[1]*Autoridad Regulatoria Nuclear, Av. del Libertador 8250, Ciudad de Buenos Aire (C1429 BNP), Argentina*
*Corresponding author's e-mail: abel_j_gonzalez@yahoo.com

Abstract: This paper submitts a diagnosis of potential difficulties with the international system of radiation protection quantities and units and describe potential successes and challenges for addressing possible difficulties with the system. It summarizes critiques to the system, including lessons compiled in the aftermath of the Fukushima accident and reflections from professionals in metrology. It also addresses the reaction of ICRP and ICRU for addressing those challenges. It suggests that the proposed revisions, while welcomed, could be insufficient. The system seems to present some epistemological challenges that need to be addressed. They include that a common quantity and unit are used for: distinct outcomes, such as clinically observable, or statistically observable or biologically plausible radiation effects; different concepts, such as that at high doses, effects are attributed and at low doses risk are inferred; diverse outputs, such as diagnosis of individual effect, estimates of collective incidences, or judgment of risk; attesting on health outcomes trough formal evidence by radiopathologists, or radioepidemiologists or radioprotectionists; and, for imputing individual harm or collective harm (class actions) or presumptions of risk. Moreover, the same family of dosimetric quantities (without any provisos) are used as: intensive quantities, and extensive quantities. This does not happen in other areas of science requiring measurability. Finally, an important shortcoming of the current system is addressed: the current quantities and units seems to be unhelpful for public information and communication; they should fail to convey, in a fully and easily understandable and credible manner, radiation effects and risks therefore facilitating psychological associated to the misunderstanding of radiation. It is concluded that the relevant international and intergovernmental organizations should consider improving the current international system of quantities and units not only in its obvious shortcomings but also in its epistemological deficiencies and its communicational weaknesses.

KEYWORDS: radiation quantities; radiation units; radiation safety standards; ICRP ; ICRU ; UNSCEAR; IAEA.

1. INTRODUCTION

The international system of quantities units for radiation protection is one of the most significant international and intergovernmental successes. It is: universal and consensual; founded in internationally accepted science; based on a universal paradigm recommended by: the International Commission for Radiological Protection (ICRP) and the International Commission for Radiation Units and Measures (ICRU); adopted: Bureau International des Poids et Mesures (BIPM); and established in the international safety standards of all relevant intergovernmental organizations, developed under the aegis of the International Atomic Energy Agency (IAEA). Notwithstanding its success, after almost a century of good service, the system may need some review and eventually some revision.

The objectives of this paper are submitting a diagnosis of potential difficulties with the system and describing potential successes and challenges for addressing remaining problems.

2. CRITIQUE

2.1. Lessons from Fukushima

Following the nuclear reactor accident at the Fukushima Daiichi nuclear power plant in Japan, the ICRP convened a Task Group to compile lessons learned from, with respect to the ICRP system of radiological protection. These included issues with the international system of quantities and units being used by ICRP. In a memorandum the members of the task group express their personal views on issues arising during and after the accident. While the affected people were largely protected against radiation exposure and no one incurred a lethal dose of radiation (or a dose sufficiently large to cause radiation sickness), many radiological protection questions were raised. One issue identified was that the system of radiation protection quantities and units caused considerable confusion and communication problems.[1]

The differences between the quantities were not well understood even by high educational level audiences; for example, differences among absorbed dose, equivalent dose and effective dose. The distinction between the radiation protection quantities and the operational quantities was even more difficult to understand; for example, the equivalent dose *vis-à-vis* the dose equivalent, which in addition presented a grammatical problem for translatability. The practice of using a unique unit for different quantities, without specifying the quantity, increased confusion and misunderstanding; for instance, the use of a common unit (sievert or rem) for equivalent dose incurred by an organ, for the effective dose incurred by the body, and for dose equivalent of a radiation field..

It was not clear for member of the public, and for their representatives, why so many different quantities and units were needed to protect people against radiation.

The Task Group concluded that the radiation protection community has an ethical duty to learn from Fukushima's lessons and to resolve the identified challenges, one of which related with the international system of radiation protection quantities and units. The Task Group advised that, before another major accident occurs, confusions on the international system of radiation protection quantities and units must be resolved.

2.2. Appraisal from metrology

On 23-25 November 2014, took place in Rio de Janeiro, Brazil, the First Brazilian Congress on Ionizing Radiation Metrology (Primeiro Congresso Brasileiro de Metrologia da Radiação Ionizante, CBMRI).[2] The main purpose was to review various concepts, fundamental topics and methods related to the primary or secondary measurements of ionizing radiation. Following the approach proposed by the BIPM Comité Consultatif pour les Etalons de Mesures des Rayonnements Ionisants, the CBMRI was devoted to three different aspects of metrology, namely: radionuclides and radioactivity; X-rays, gamma, electron and charged particles; and, neutron metrology. It also addressed approaches to traceability, primary standard (absolute) and secondary (relative), assessment of uncertainties, nuclear instrumentation, and laboratory infrastructure. But one major topic was a critical review of the international system of quantities and units.

There an extensive discussion took place on the desirability of improvements in the system of radiation protection quantities and units [3]. The global system of quantities and units was critically reviewed. It was recognized that the system has proved successful in helping radiation protection to become a globally uniform, consistent and coherent professional discipline. However, as it happen with any other successful development, it was found, the experience gained over time is showing that the system my benefit from some improvements. It was suggested that the time seems to be ripe for undertaking a deep review of the current system of quantities and units and suggest the necessary revisions to update it, by taking into account a number of lessons learned, particularly in the aftermath of nuclear accidents and in the protection of patients in the practices of radio-diagnosis, interventional radiology and radiotherapy.

Difficulties with the system were analysed and some feasible solutions were suggested. The system was found to be used successfully for more than 30 years in controlling occupational exposure and public exposure in normal situations, prospectively in the design of facilities and planning of operations and retrospectively for demonstrating compliance with regulations. However, it was found, the use has also demonstrated great difficulties in communicating radiological information to non-specialized experts and to the public. These difficulties in understanding the units and quantities appeared to be a consequence of the complexity of the system which uses more than one quantity and combines physical exposure data with scientific data on radiation risk for organs and tissues.

Moreover, it was considered that, although the system and the quantities have shown to be well suited for occupational radiological protection, there is less suited for use in the public domain where communication with non-experts is required, particularly in emergency situations.

The number of difficulties found included: the differences between the quantities (e.g. effective dose and equivalent dose and absorbed dose) are not well explained and are not well understood even by educated audiences; the distinction between the quantities used in the radiological protection system (e.g. equivalent dose and effective dose) and the operational quantities used for radiation measurement (the dose equivalent quantities, e.g. personal dose equivalent) is even more difficult to understand; the use of the same unit (i.e. Sievert) for the quantities equivalent dose of an organ and the effective dose over the body, without specifying the quantity, and for the operational quantity dose equivalent, enhances confusion and misunderstanding; and, in sum, it was confirmed that many people not understand why there are so many different quantities.

It was moreover found particularly confusing that the different radiation protection quantities have a common unit, the Sievert. The problem becomes particularly evident when reporting thyroid doses to workers and the public from intakes of radioactive iodine. The equivalent dose is the relevant quantity for reporting organ doses but, if the dose is reported indicating only the unit, it can easily be confused with effective doses. The effective dose is a risk-related quantity for the whole body and can differ appreciably from the equivalent dose to an organ for the same person.

The discussion concluded that there were are a number of possibilities for improving the situation in the short term. For instance: avoiding the use of equivalent dose without specification of the organ or tissue concerned, e.g. a thyroid equivalent dose; and using the shorter and simpler term ‘organ dose’ for organ equivalent dose in communications, e.g. thyroid dose, which is already usual in many radiological protection practices. Another solution to minimize confusion is to always add the quantity when the unit Sievert is being used. Another solution would be to consider renaming the units, but this would require careful deliberation.

On important shortcoming confirmed was that the current system does not include simplifying quantities for the sole purpose of public information. Purists working in quantities and units would probably reject the idea. Simplification will always imply a loss in the scientific rigor that is essential in quantification. But, is not rigor already violated in the current system of protection quantities? In fact, it was concluded, the protection quantities do not comply with the essential requirements for quantities. A further simplification could be welcomed if this will make easier the serious problem of public communication.

It was also concluded that a system of public information quantities should be tailored to convey, in a fully and easily understandable and credible manner, radiation effects and risks. This would at least avoid the serious psychological effects that are associated to the misunderstanding of radiation and its quantification. In fact, public distrust is generated when the authorities transmit information in a quantitative manner that is not understandable not only by the public at large but also to many experts.

Perhaps a system like this, it was suggested, could include simplified quantities to convey, for instance, the presence of radioactive substances in the environment including its temporal variation. The ideal would be to have few, or even an unique, quantity, summarizing in a simplified manner all the elements currently covered by activity, absorbed doses, weighting factors, temporal variation, etc.
It was concluded that it was difficult to answer if this possibility is really feasible. However, it is clear that it is feasible and desirable to study the possibility to develop a system of quantities for public communication.

In sum the discussion at CBMRI concluded that the quantities used for radiation protection purposes and for measurement purposes are somewhat sophisticated and their application requires professional knowledge. However, radiation protection practitioners are not alone in using these quantities, as emergency decision-makers—who do not necessarily know the details—rely on them for their choices of intervention and in the receiving end the public claim for simplicity in understanding. Misunderstandings about the quantities in the aftermath of an accident may lead to untoward difficulties, incorrect interpretations of potential consequences and incorrect decisions and after all serious psychological and social detriment for member of the public. Ways to improve and foster information exchange and education and to develop ‘easy-to-read’ material on the system of radiological protection quantities and units are sorely needed.

Recently, on november, 2020, the CBMRI 2020 took place virtually. The same problems were discussed again [4]. But this time the critique expanded to include the epistemological problems with the current system, an issue that will be discussed hereinafter.

3. ONGOING REVISIONS

Following the various critique on the system, the ICRP. Crated a task group (ICRP-Task Group 79), under ICRP Committee 2, on the use of effective dose as a risk related radiological protection quantity. The Task Group on Effective Dose is providing guidance on when the quantity ‘effective dose’ can be used and when it should not. ICRP indicated that experience has shown that ‘effective dose’, which has been defined and introduced by ICRP for risk management purposes, i.e. for risk limitation and optimization, is widely used in radiological protection and related fields beyond its original purpose, incorrectly in some cases. Useful guidance on restrictions on the use of the quantity has provided in the main ICRP recommendations. ICRP consider that this guidance needs to be further expanded, and proposals made for the control of exposures and risk management in situations where ‘effective dose’ should not be used. The ICRP recommendations on the use of effective dose as a radiological protection quantity are being presented [5]

Meanwhile, ICRU-Committee 26 is also addressing a revision of operational radiation protection quantities for external radiation. Concept and practical implications of the new definitions of ICRU and ICRP operational quantities for external radiation are being presented [6]. The changes proposed by the ICRP-TG79 include inter alia discontinuing the use of the *organ equivalent dose* (H_T in Sievert) and instead use the *organ absorbed dose* (D_T in Gray). The changes proposed by ICRU-Committee 26 includes: discontinuing the use of *ambient dose equivalent* (H*(d)), *directional dose equivalent* (H’(d, Ω)) and *personal dose equivalent* (Hp(d)), and replacing them with *ambient dose* (H* in Sievert), *personal dose* (Hp in Sievert), *personal* *absorbed dose* (Dp in Gray) and *directional absorbed dose* (D'(Ω) in Gray). These changes are welcomed but will might not resolve some fundamental epistemological and communicational challenges with radiation protection quantities and units, as it will be discussed hereinafter. The industry is reacting with some scepticism: the World Nuclear Association is presenting some views from radiation protection practitioners in the nuclear industry [7]

4. REMAINING EPISTEMOLOGICAL ISSUES

There are at least two epistemological anomalies in the current system. The first refer to the use of the same quantity and unit for addressing health effects attributable to radiation and inference of radiation risks. The second relate to the current confusion between intensive ad extensive quantities.

4.1. Common quantity and unit for attributing effects and for inferring risks

A fundamental epistemological problem with the current system is that the same quantity, the effective dose, and te same unit, the sievert, without any proviso, are used for assessing health effects that are attributable to radiation exposure and also for inferring conjectural radiation risks. Relatively recently, an international intergovernmental consensus on the attribution of provable radiation health effects vis-à-vis the inference of conjectured risk has been at achieved by the United Nations Scientific Committee of the United Nations on the Effects of Atomic Radiation (UNSCEAR) [8]. UNSCEAR is the international intergovernmental organization assigned by the United Nations General Assembly to be responsible for estimating the global levels and effects of radiation. In the exercise of his functions UNSCEAR has estimated the attribution of the effects on health and the inference of radiation risks. The UN General Assembly has unanimously welcomed with appreciation the scientific report of UNSCEAR on this issue [9]. The UNSCEAR estimates have been summarized by the United Nations Environment Program (UNEP) [10].The paradigm can be condensed in the dose-response relationship presented in Figure 1.

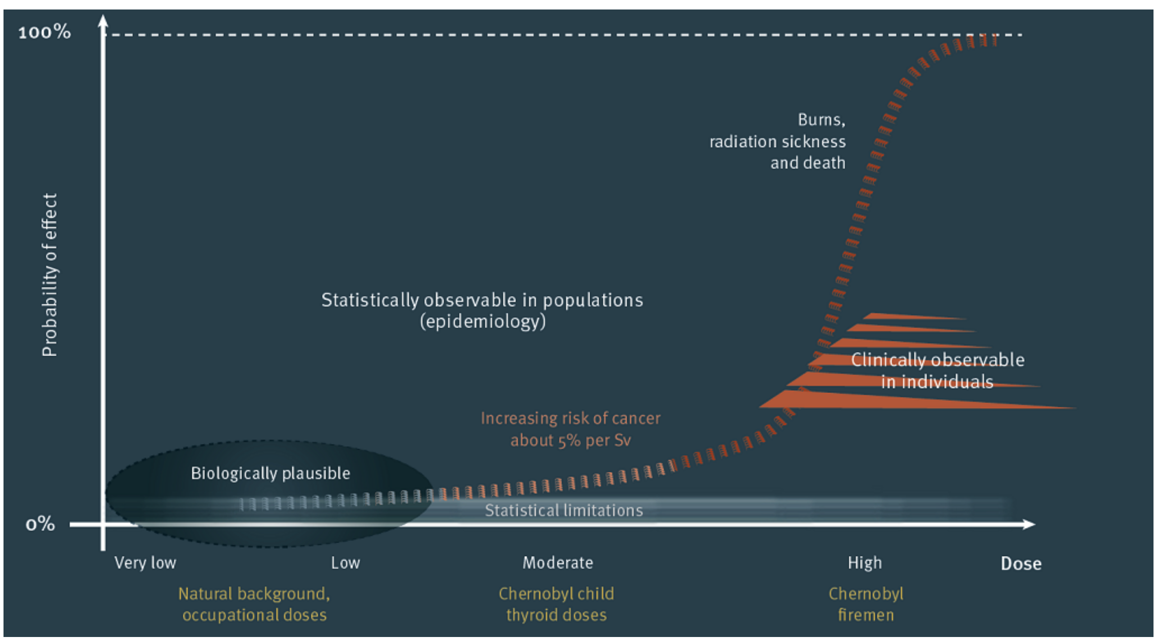

Figure 1: Relationship of radiation dose and probability of effects

The renewed UNSCEAR paradigm is subtly precise than the UNSCEAR's previous estimates [11]. The figure summarizes it by presenting a simplified relationship between effective doses incurred by people and the probability of occurrence of health effects. It clearly differentiates three zones: doses at which effects are clinically observable in individuals; doses at which effects are observable in populations throughout epidemiological studies; and doses where the effects are just biologically plausible. The abscissa indicates effective doses expressed as: 'high doses' (around a thousand of milliSievert'); 'moderate doses' (around hundreds of milliSievert; 'low doses' (about tens of miliSievert); and, 'very low doses' (around the milliSievert). The ordinate expresses probabilities presented in percentages between 0% and 100%, where: 100%, corresponds to the certainty that the effect will occur; and, 0%, corresponds to the certainty that the effect will not occur. In the moderate, low and very low region they represent what ICRP termed detriment-adjusted nominal risk, defined as the probability of the occurrence of a stochastic effect, modified to allow for the different components of the detriment in order to express the severity of the consequence(s).

It is to be noted that, the probabilities estimated by UNSCEAR are of two distinguishable types:

- *frequentist probabilities*, which are in the medium and high dose area, based on the truthful and verifiable existence of radiation health effects, and can be described as the limit of the relative frequency of incidence of the effect in a series of certifiable epidemiological studies; and,
- *subjective probabilities* (also called "Bayesian"), which are in the low dose area, are expressed a possible expectation that radiation health effects might occur, and are quantified by a personal belief or expert's judgement, that is not substantiated by the frequency or propensity that the effects actually occur.

Both frequentist and subjective probabilities are mathematically compatible but epistemologically very different: the first is based on facts; the second is based on conjectures. This is a crucially important difference because UNSCEAR has highlighted the importance of distinguishing between: verified observations of health effects in exposed individuals and populations, which allow such effects to be unambiguously attributed to the exposure situations that generated them; and, theoretical projections of health effects, which occurrence is feasible but not verifiable –namely those projections only allowing some inferring of risks.

In simpler terms, the situation can be described as follows: the detriment-adjusted nominal risk for a nominal population is estimated to be around 5% per Sievert of effective dose; this number is mathematically equivalent to 0.005% per milliSievert of effective dose; however, the mathematically equal coefficients of 5% per Sievert and 0.005% per milliSievert are epistemologically very different because they describe different sciences, factual epidemiological evidence versus conjectural estimates.

Notwithstanding these fundamental epistemological differences, a common quantity, the effective dose, and a common unit the Sievert are used for both, the attribution of effects and the inference of risk. This implies using the same quantification approach for very disparate situations such as:

- distinct outcomes, such as what is clinically observable, or statistically observable or biologically plausible;
- different concepts, such as that at high doses, effects are attributed and at low doses risk are inferred;
- diverse outputs, such as diagnosis of individual effect, estimates of collective incidences, or judgment of risk;
- attesting on health outcomes by providing formal evidence by radiopathologists, radioepidemiologists and radioprotectionists; and, last but not least,
- for imputing individual harm or collective harm (class actions) or risk presumptions.

This is an epistemological anomaly of the system that would merit a deep discussion.

This important global agreement reached by UNSCEAR was reported in the literature [12], [13] but it is still far from being implemented in the regulatory practice. It is not currently used in the radiation protection standards of international intergovernmental regulations [14] and, consequently, in the vast corpus of nuclear safety regulations being established under the aegis of the IAEA with the co-sponsorship of all relevant intergovernmental organizations. The IAEA Commission on Safety Standards has been addressing the issue and a report is in preparation.

Thus, the use of the same quantification for the diverse epistemological situations of factual attribution of effects versus the conjectural inference of risk merits a deep discussion among the experts in radiation protection quantities and units.

4.2 Common quantity and unit for intensive and extensive quantities

An additional epistemological problem is that the same same family of dosimetric quantities (without any provisos) are used for expressing intensive quantities, and extensive quantities. This does not happen in other areas of science requiring quantification. The dose is an intensive quantity, namely a physical quantity whose value does not depend on the amount of matter for which it is measured, similarly to the quantity temperature. Conversely, the collective dose is an extensive quantity, namely a physical quantity whose value is proportional to the size of the system it describes or the amount in the system, similarly to the quantity energy. However, the same unit, the Sievert, is used by such diverse quantities, although qualified by the name 'man' or 'person' for the collective dose. This has cause serious problems of interpretation among experts and communication among the amateurs.

5. QUANTITIES, UNITS AND COMMUNICATION.

An important shortcoming of the current system is that the current quantities and units are not helpful for public information and communication. The quantities and units should be tailored to convey, in a fully and easily understandable and credible manner, radiation effects and risks. They should prevent the serious psychological effects that are associated to the misunderstanding of radiation. Public distrust is generated when the authorities transmit quantities that are not understandable not only by the public but also to many experts. A revision should facilitate to solve the problem of communication

6. CONCLUSIONS

The ongoing revision of the current international system of radiation protection quantities and units is needed and welcomed. However, it might not be sufficient. A deeper revision could provide an opportunity for making a distinction between the quantification of attributable radiation effects and the quantification of conjectural inferred risk, and, also for clearly differentiating intensive dosimetric quantities from extensive dosimetric quantities. A substantive revision could also be an opportunity for improving language and enhancing communication. It is suggested that the relevant international and intergovernmental organizations may use this opportunity to improve the current system of not only in its obvious shortcomings but also in its epistemological deficiencies and its communicational weaknesses.

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