Comments on the System of Radiological Protection

Michael Moores[1]; Sören Mattsson[2]

[1]IRS Ltd, Liverpool, UK (mikemoores@irs-limited.com); [2] Lund University, Malmö, Sweden

Abstract

Comments and discussion on the following areas are considered:

- The system of radiological protection itself
- Dose and risk assessments in CT
- The development and implementation of effective dose concepts

One of the greatest problems faced by radiological protection results from its "social sensitivity". Why are risks from ionising radiation still perceived differently by society, even though an enormous effort has been expended over many years to establish and promote a legal framework for radiation protection? Perhaps, radiation protection is perceived differently because of its desire to employ the so-called fundamental principles of justification and optimisation.

Average risks from non-natural causes may be compared quantitatively in terms of a micromort unit, where1 micromort represents a risk of 1 in 1 million of dying from an activity. This unit can be used to compare risks, whether arising from an exposure to ionising radiation or any other potentially dangerous activity. It will be shown that other common activities, for example travel by road, can carry greater risks, but society does not yet feel the need for journeys to be justified nor has it established the minimisation of accidents as an international goal. Indeed, justification of any activity is automatically given by society when it operates within the appropriate legal framework.

The scope for forefront IT applications to CT dosimetry as well as patient dosimetry in general, is enormous. Utilising imaging information in conjunction with anthropomorphic phantom based modelling employing Monte Carlo calculations, could provide accurate risk- based information as part of routine practice. Organ dosimetry associated with all types of examinations and age groups can provide a unique and relevant framework for population risk studies leading to improvements in the setting of target optimised doses. The use of Dose Reference Levels (DRLs), a first and collective public health initiative is of little or no value to optimisation when applied to individual patients. This is in contradistinction to the ongoing development of the concept of personalized medicine.

Whole body doses arising from broad beam irradiations may provide suitable risk estimates for occupationally exposed individuals. However, this is not the case for most medical exposures, which involve partial body irradiation and individuals of all ages. To undertake detailed comparative population risk studies arising from medical

exposures, which is the largest source of man-made exposure, accurate means of assessing effective doses are required. However, ideally effective dose needs to take cognisance of the differing radiation sensitivities that might occur in any population due to age, gender and health status. Detailed knowledge of genetic or other predispositions to radiation induced mutations is also a necessary scientific component.

1. Fundamental Principles

One of the greatest problems faced by radiological protection results from its "social sensitivity". Psychological studies have shown this to be the case[(1)] (Slovic ,1987). Thus, an important aspect of the present review of the future of radiation protection pursued by ICRP, a welcome exercise, could usefully address this issue. Are risks from ionising radiation still perceived differently by members of the general public, even though an enormous effort has been made internationally over many years to establish and promote a legal framework for radiation protection.

Activity or Technology	League of Women Voters	College Students	Active Club Members	Experts
Nuclear Power	1	1	8	20
Motor vehicles	2	5	3	1
Alcohol	6	7	5	3
Surgery	10	11	9	5
Mountain climbing	15	22	12	29
Swimming	19	30	17	10
X-rays	22	17	24	7
Prescription antibiotics	28	21	26	24
Vaccinations	30	29	29	25

Table 1: Ordering of perceived risk for various activities amongst different groups where Rank 1 represents the perceived most risky activity.[(1)]

Table 1 indicates that perceived risks from a variety of activities, assessed by means of the psychometric paradigm, were shown to vary amongst different social groups with experts often perceiving risks differently.[(1)] This is noticeable in the case of nuclear power and X-rays where experts had noticeably different perception of risks compared to other social groups. Also, experts considered nuclear power to be significantly less risky compared to the use of X-rays. Thus, if the general public consider an activity to be acceptable from a risk perspective but experts disagree, which viewpoint should governments/society accept?

Factors that might help or hinder the more general acceptance of the use of ionising radiation in society need to be considered. Indeed, what helps to set radiological protection aside as something different in society in terms of risk management may well arise from an implied desire to be perceived as being different through its employment of so-called fundamental principles of justification and optimisation. Many activities pursued by society carry higher risks of death or injury, when compared to the use of ionising radiations but society does not yet feel the need to apply such principles.

This personalised approach may well have arisen from the sensitivities generated following Roentgen's discovery of X-rays and the resulting deleterious effects received by many early pioneers. However, following the industrial revolution many individuals suffered injury and death from numerous activities and associated hazardous agents encountered in industrialised society that would not be tolerated today (coal mining, chimney sweeping using children, asbestos etc). Such sensitivities may well have been exacerbated following the development and subsequent deployment of nuclear weapons in the 1940's, which demonstrated the unique power associated with nuclear processes culminating in the development of the nuclear power industry. However, these fundamental principles were not applied until 40 years ago when the role of ionising radiations in society was well-established.[2]

Should radiological protection be treated in the same way in respect of safety management as the many other activities pursued by society, which are deemed to provide benefits but also carry risks? One of the main aims of the present ICRP review should be to ensure that the resulting framework for radiation protection is placed on an equal footing perceptually to the many other areas of safety management. This could help the public to perceive the risks from ionising radiation as being merely an example of a well-organized framework of risk management. For example, any safety management system driven by the aim of eliminating risks via a principle of optimisation would seem quite illogical and the promotion of acceptable risks desirable. Radiation protection needs to align itself more clearly, both philosophically and psychologically, with safety management in general, which should always attempt to apply a pragmatic approach to managing risks.

It is possible to assess average risks from non-natural causes (accidents and violence) in terms of a micromort unit, where1 micromort represents a risk of 1 in 1 million of dying from an activity. [3,4] This unit can be used to compare risks, whether arising from an exposure to ionising radiation or any other potentially dangerous activity. Thus, in the case of road transport in the UK, 1 micromort corresponds to the risk from driving 555 km.[4] Since in the UK the average annual mileage is roughly14,000 km, this corresponds to 24 micromort. In the case of an exposure to ionising radiation the lifetime excess fatal cancer risk is taken to be 5×10^{-2} per Sv.[5] Thus, a risk of fatal cancer induction of 1 in a million would equate to an exposure of 20 µSv. Consequently, an exposure corresponding to an equivalent risk of death from driving 14,000 km would be approximately 0.5 mSv. However, it is worth pointing out that in the case of cancer deaths, this may be affected by improvements in treatment. Thus, mortality rates could change during, say a 5 year survival period. Radiation risks expressed in terms of cancer deaths would then be overestimated whilst fatalities from traffic accidents are always the same (yesterday, today and tomorrow).

The annual risk of death in the UK from working in any occupation, including the self-employed is indicated to be 6 micromort,[(4)] which would correspond to the same risk from an annual exposure to ionising radiation of roughly 0.125 mSv. This may be compared with the actual average annual exposures for occupationally exposed persons in the UK who work in industrial sectors of 0.27 mSv, diagnostic radiology 0.066 mSv and veterinary radiography 0.023 mSv.[(6)] For comparison the commercial fishing sector corresponds to a risk of 1,020 micromort equivalent to the risk from an annual exposure of 40 mSv or climbing Mount Everest (12,000 micromorts), which would equate to 480 mSv.[(4)] Equally exposure to 2.4 mSv of background radiation would correspond to a risk of 115 micromorts and the UK per caput dose from medical exposures of 0.4 mSv[(7)] would correspond to 19 micromorts.

The average occupational radiation exposure in the UK in 2015 was also 0.4 mSv,[(8)] which implies that on average a radiation worker may have a greater annual risk of death whilst travelling to and from work (50 km daily equivalent to 24 micromort) than from working with ionising radiation. Worldwide 23-24 million people are injured annually in road accidents and approximately 1.24 million are killed. [(8)]. Consequently, although road travel carries sizeable risks, society does not yet feel the need for people to justify the reasons for making journeys nor attempt to minimise travel risks by setting annual mileage limits. Indeed, justification of any activity is automatically given by society when it operates within the appropriate legal framework.

The fundamental operational principles of radiation protection are in fact:

- Shielding
- Distance
- Time
- Dose assessment and limits (targets) linked to risk quantification and their application

These are the factors that underpin the scientific and quantitative basis of radiological protection. What is the scientific or psychological reasons for having more fundamental principles?

2. CT dosimetry

One of the key objectives of the framework for radiological protection should be to help clarify those fundamental components that can form the basis or road map for scientific developments and applications in safety management. Justification and optimisation do neither, particularly as in the case of medical applications, optimisation is usually applied solely to doses. The most important part of the clinical equation; namely benefits, is then merely an implied facet.

Given that in the developed world CT is increasingly the most desirable from a clinical information perspective, the scope for forefront IT applications to CT dosimetry as well as patient dosimetry in general, is enormous and desirable. Utilising imaging information in conjunction with anthropomorphic phantom based modelling (Monte Carlo calculations etc) could provide accurate risk- based information as part of routine practice. Organ dosimetry associated with all types of examinations and age groups could provide a unique and relevant framework for population risk studies leading to improvements in the setting of target doses beyond the existing Dose Reference Level (DRL) framework. The latter is a collective public health initiative, which is of limited value in respect of optimisation, particularly when applied to individual patient examinations. Given the present movement towards personalised medicine, such a concept may also become outmoded within the not too distant future. Indeed, genomic mapping may well lead to the application of healthcare risk factors for individuals. Surely, radiation risk factors such as age, gender and health status should aspire to the same goal of scientific clarity.

ICRP could be more proactive in defining an operational framework for radiological protection that can stimulate scientific developments, particularly in medicine. This should include those quantities and information that could ensure demonstrably safer practices to individuals and thereby the patient population at large. Focussing more on the individual patient from a radiation protection perspective could also have an enormous impact on improving overall clinical efficacy. For example, exposure factors are largely selected on a representative basis rather than matched to individual patients. This is exacerbated by the fact that modern digital detectors have such a wide exposure latitude. However, AI/Machine Learning techniques can provide the basis for more personalized optimised practices, both in terms of image production as well as clinical outcome, through the utilisation of specific patient characteristics in decision-making processes.

These techniques are already being applied to CT reconstruction methods with the aim of creating significant dose reductions. Radiological protection will need to reflect the fact that many processes that determine outcomes that are presently undertaken by humans may eventually be performed by self-learning machine-based systems. CT with its ability to generate large volumes of clinical data quickly are tailor made for such applications. Therefore, given the length of time since the last ICRP review, an important question concerns the level of development that might be expected if a similar length of time passes before the next review of radiological protection. Society will probably be very different in 40 – 50 years’ time so that future-proofing outcomes from the present review is an important consideration.

3. Effective dose

Whole body doses arising from broad beam irradiations may provide suitable risk estimates for individuals who are exposed to this type of radiation field. However, this is not the case where partial body irradiations occur, which applies largely to medical exposures, both diagnostic and therapeutic. These involve both male and female patients across all age groups and various disease states, each having their own risk factors.

To undertake detailed population risk studies arising from medical exposures; the largest single source of man-made exposure, accurate means of assessing effective doses are required. However, ideally effective dose should also take cognisance of differing radiation sensitivities that might occur in a population. Hence such measurements would need to be combined with knowledge of genetic predispositions to mutations that may be caused by exposure to ionising radiations.

The exposure of all age groups is a unique and important aspect of the medical use of ionising radiations so that age dependent risk assessments are of equal importance. This is one reason why optimisation only in terms of dose received is inadequate. Risk -benefits can vary significantly with the age and not least with health status and expected survival time of a patient. Consequently, the assessment and comparison of risk related doses in specific patient populations that have involved the irradiation of different anatomical regions with different frequencies will be required. By combining imaging data with well researched and documented anatomically localised dosimetry, the effective dose arising from each and every examination should be feasible. However, patient dosimetry centred around Dose Reference Levels (DRL's) and driven by public health considerations, where the dose to an individual patient is a hidden variable is in fact counterproductive to the achievement of these desirable aims.

The present framework for radiological protection attempts to combine the safety management of a working age population of occupationally exposed individuals with one that is medically exposed. When benefits from the use of ionising radiations are collective eg nuclear power, then there are arguments for treating risks on a collective (average) basis. However, where benefits apply to individuals, which is the case for medical applications, then risks and risk-benefits apply to an individual. The scientific development of the concept of effective dose, can underpin meaningful comparisons of risk-benefits to a diverse patient population, from the perspective of individual patients, groups of patients and whole populations. Surely this is a worthy aim.

Modern society to a large extent has evolved from the application of scientific principles and associated technological developments and it must be considered one of mankind's greatest (intellectual) strengths. It has led, amongst other things, to humans setting foot on the moon, exploring beyond our own solar system and back towards the early dawn of the universe, detecting cosmological ripples in space-time, exploring the inner workings of the fundamental forces of nature, developing new ways of imaging the body as well as analysing and manipulating the genetic building blocks of our very being. Perhaps the development of a framework for radiological protection that places the individual patient at its heart should not be beyond the realms of modern science.

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