Lower Bound of Optimization for the Public Considering Dose Distribution of Radiation due to Natural Background Radiation

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Abstract. The International Commission on Radiological Protection (ICRP) released drafts of new recommendations in June 2004, June 2006 and January 2007 and finally approved a new set of fundamental recommendations on the protection of humans and the environment from ionizing radiation at its meeting in Essen, Germany, 19-21 March 2007. In the process of the completion of the draft recommendations, the numerical value for the minimum dose constraint ensuring public protection was deleted or redescribed using other expressions. This issue remains undetermined even in the recently released Publication 103. On the other hand, ICRP also recently published a new concept of a representative person in Publication 101. This representative person is a hypothetical person exposed to a dose that is representative of the most highly exposed persons in the population. On the basis of this new concept, it is theoretically reasonable that the 95th percentile of the dose received by such representative persons is always lower than the dose constraint, which indicates that the main part of the dose distribution is considerably lower than the dose constraint. In this study, by using the relationship between the dose constraint and the dose distribution of the representative persons and a probabilistic approach using Monte Carlo calculation techniques, the effects of the dose distribution of radiation due to manmade radioactive nuclides when added to those of natural background radiation have been carefully investigated. The results show that additional exposure to manmade radiation of up to 0.5 mSv/y (as a dose constraint) would not significantly change the distribution of the public dose. Taking into consideration such probabilistic analysis and the rationale behind the derivations of exemption and clearance levels, it can be concluded that the minimum dose constraint that requires optimization in radiation protection should be set to 0.1 mSv/y, which is one order of magnitude higher than 0.01 mSv/y, the current dose criterion for exemption and clearance.

KEYWORDS: Optimization, Public, Exemption, Clearance, Natural background radiation, Dose constraint.

1. Introduction

The International Commission on Radiological Protection (ICRP) published new recommendations, namely, Publication 103 [1] on Dec. 2007, as a result of open discussions in a transparent way using a web-consultation system. In these recommendations, the ICRP emphasized a source-related approach and the key role of the principle of optimization. Optimization is one of the three principles of radiological protection, which is defined as a source-related process for keeping the likelihood of incurring exposures, the number of people exposed, and the magnitude of individual doses as low as reasonably achievable, taking economic and societal factors into account. The ICRP has not stated in Pub. 103 the lower bound where radiation dose does not have to be reduced, since the use of a linear nonthreshold (LNT) model is considered to be the best practical approach to managing risk from radiation exposure and a prudent basis for radiological protection at low doses and low dose rates. In addition, guidance on the scope of the radiological protection was recently issued in Publication 104 [2], but there is no description about the lower bound of optimization.

On the other hand, the International Atomic Energy Agency (IAEA) published the Basic Safety Standard (BSS) [3] in 1996 involving exemption levels for relatively small amounts of radioactive solid materials less than a few tons. The IAEA also published a safety guide, RS-G-1.7 [4], in 2004 and gave specific activity concentrations, i.e., clearance level for radionuclides that may be used for bulk amounts of radioactive material for the purpose of applying exemptions. The primary radiological basis of establishing the specific activity concentration is that the effective doses to individuals should be on the order of 0.01 mSv or less in a year. To take into account the occurrence of low-probability events leading to higher-radiation exposures, an additional criterion was used; namely, the effective doses due
to such low-probability events should not exceed 1 mSv in a year. This approach is consistent with that used in establishing the exemption levels for small amounts of solid materials. These backgrounds show that there are a variety of dose criteria in the stage of deriving levels of exemption and clearance. In this context, any numerical values of the lower bound of optimization cannot be found in the safety standards of the IAEA.

In this paper, the lower bound of optimization for the public has been newly proposed in the current radiological protection system, reconsidering the relationship between optimization and dose constraint, the effects of the dose distribution of radiation due to manmade radioactive nuclides when added to those of natural background radiation, and comparisons with the dose criteria for exemption and clearance.

2. Optimization and Dose Constraint in ICRP Publication 103

ICRP assumes that the increase in the incidence of stochastic effects occurs with a small probability and in proportion to the increase in radiation dose over the background dose at radiation doses below approximately 100 mSv in a year. This so-called linear nonthreshold (LNT) model is considered by the ICRP to be the best practical approach to managing risk from radiation exposure and a prudent basis for radiological protection at low doses and low dose rates. On this basis, the radiological protection system has been constructed with three principles, that is, justification and optimization as source-related principles, and dose limitation as an individual-related principle. The ICRP emphasizes the primary importance of the source-related approach and significant role of the principle of optimization in the new recommendations, Publication 103, because any actions can be taken on a source to assure the protection of a group of individuals from that source.

The principle of optimization is defined in paragraph 203 in Pub. 103 as follows: “the likelihood of incurring exposures, 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. This means that the level of protection should be the best under the prevailing circumstances, maximising the margin of benefit over harm. In order to avoid severely inequitable outcomes of this optimisation procedure, there should be restrictions on the doses or risks to individuals from a particular source (dose or risk constraints and reference levels).” It is a fundamental concept in the optimization principle, that individual doses should be kept as low as reasonably achievable (ALARA) taking into account economic and societal factors.

As given in the above definition, the dose constraint for the public is a concept that was introduced as a means of ensuring that the optimization process did not create inequity in the previous recommendations in Publication 60 [5], which still remains valid in Pub. 103.

In addition, the ICRP states about optimization and dose constraint in paragraph 231: “Treating a dose constraint as a target value is not sufficient, and optimisation of protection will be necessary to establish an acceptable level of dose below the constraint.” This implies that additional dose reduction is always necessary even if the individual dose being below the relevant dose constraint is satisfied. Since the primary basis of the radiological protection is the LNT model in Pub. 103, none can find any solutions to the issues on whether endless endeavour should be required even in an extremely low dose region and how the minimum dose constraint should be determined in the current radiological protection system.

3. Natural Background Radiation Approach

The author proposed a new approach in a paper to be published in a scientific journal [6], which gives us a conceptual suggestion for solving the above-mentioned issues using a probabilistic analysis. The outline of this approach is given as follows.

3.1 Dose Distribution due to Natural Background Radiation
The UNSCEAR 2000 report [7] provides the annual dose distribution due to natural background radiation averaged over fifteen countries. The arithmetic mean of the dose distribution is approximately 2.0 mSv/y. [7] The distribution has a peak at a dose lower than the median value and can be redrawn as a lognormal distribution. On the other hand, the UNSCEAR 2000 report [7] also states that the annual worldwide mean dose is 2.4 mSv/y determined using an approach other than those used to obtain the 15 countries’ data, which is frequently used when addressing natural background radiation level.

Taking these investigation results into consideration, in this approach, the dose distribution of natural background radiation was assumed to be lognormal with 2.0 mSv/y for the geometric mean (GM) and 2.0 for the geometric standard deviation (GSD). 2.5 mSv/y can be theoretically obtained as the arithmetic mean of the supposed distribution, which is almost consistent with the 2.4 mSv/y worldwide mean dose provided by the UNSCEAR 2000 report. This indicates that the assumption of the dose distribution for natural background radiation is sufficiently valid.

### 3.2 Dose Distribution due to Manmade Nuclides

The first step in this study is to determine the additional effect on the public of a dose due to a manmade source added. In this approach, it is not important for us to exactly determine the dose of radiation due to a manmade source; however, a probability distribution is required. It is therefore necessary to determine the standard deviation of the dose distribution of radiation due to a manmade source.

There are few, if any, studies that have actually investigated the distributions of external and internal doses that affect the public. Thus, no rationale can be found to consider a case study result as a representative dose distribution. However, there are some cases in which the dose distributions of radiation that workers in nuclear facilities were exposed to, where individual doses were not limited and controlled, were similar to the lognormal distribution [8], which is the same as that in the case of natural background radiation. For this reason, the dose distribution of radiation due to a manmade source that members of the public may be exposed to was assumed to be lognormal.

Lognormal distributions are determined by two parameters, GM (median) and GSD, which represent the degree of scattering. As described in the previous section, the GSD of the dose distribution of radiation due to natural background radiation was assumed to be 2.0. From the point of view of external and internal exposures through various pathways, because both natural and manmade nuclides are distributed in the environment in the same way, the dose distributions of radiations due to natural and manmade nuclides would be similar to each other. For this reason, the GSD of a dose distribution of radiation due to manmade nuclides was assumed to be 2.0, which is the same as that due to natural background radiation.

On the other hand, the assumption of an appropriate GM is closely related to the requirement for compliance with dose constraint using the concept of a representative person [9], which was published as Publication 101 by the ICRP. The representative person is a hypothetical person who receives a dose that is representative of the more highly exposed people in the population. In a probabilistic dose assessment, the ICRP recommends that the representative person should be defined such that the probability is less than about 5% that a person drawn at random from the population will receive a greater dose. This concept of the ICRP defines how the dose constraint should be complied with using a probabilistic approach, in addition to the previous approach of compliance with the dose constraint, namely, the deterministic approach, which is based on conservative and simple dose assessments. In other words, the magnitude of the conservativeness of the dose assessment is mathematically and more accurately given by the concept of the representative person.

When using the concept of the ICRP, it can be proven theoretically using the following equation that the 95th percentile of the dose distribution for the representative person is always lower than the dose constraint.
DC > 95th percentile, \hspace{1cm} (1)

where DC is the dose constraint (mSv/y) and 95th percentile is that of the dose distribution for the representative person (mSv/y). In the case of a log normal distribution, the 95th percentile can be obtained from the GM and GSD as

\[
95\text{th percentile} = \text{GM} \times \text{GSD}^{1.645}.
\] \hspace{1cm} (2)

If a value of 2.0 is given to the GSD, then equation (2) can be expressed as

\[
\text{DC} > \text{GM} \times 3.13.
\] \hspace{1cm} (3)

From the above results, the maximum dose distribution of radiation that the public can be exposed to due to manmade nuclides can be determined from equation (3), on the basis of the ICRP concept of the representative person. As an example, the dose distributions of natural background radiations and that due to manmade nuclides are shown in Figure 1 in the case of 0.5 mSv/y for the dose constraint. It can be seen from the figure that the dose distribution of radiation due to manmade nuclides range in the dose region lower than the dose constraint.

**Figure 1**: Relationship between 0.5 mSv/y as dose constraint and 95th percentile of dose distribution for manmade radiation (thin line). The assumed dose distribution for natural background radiation is shown by the bold line as reference.

### 3.3 Effects of Summation of Two Distributions

The probabilistic distribution of the public dose obtained by adding a dose distribution of radiation due to manmade nuclides to that due to natural background radiation was calculated using the Monte Carlo technique. The dose distribution of radiation due to natural background radiation was lognormal with 2.0 mSv/y for the GM and 2.0 for the GSD. The dose constraints to be complied with were selected as 0.1, 0.3, 0.5 and 1.0 mSv/y. Using these values and equation (3), the dose distributions for manmade nuclides were chosen as lognormal with 2.0 for the GSD and 0.032, 0.096, 0.16 and 0.32 mSv/y for the GM.

Figure 2 shows plots of the dose distribution for natural background radiation and its summation with that for manmade nuclides. In Figure 2, the bold and thin solid lines are the dose distribution for natural background radiation and the distribution of the total dose, respectively. It can be seen that at dose constraints of up to 0.5 mSv/y, there is no significant difference between the two distributions. On the other hand, at a dose constraint of 1.0 mSv/y, which is both the maximum dose constraint and...
the dose limit, there is a slight difference between the two distributions. However, the difference is only significant in the lower-dose region, and there is no difference in the higher-dose region. This indicates that the effect of an additional dose is relatively higher for people who receive a lower-dose of radiation due to natural background radiation, but it should be noted that in such a case, the absolute dose level is remarkably low. Moreover, a more important point is the fact that the public is unaware of the dose they are actually exposed to and where they are located in the dose distribution for natural background radiation. From the above results, an additional dose resulting from setting the dose constraint to the order of 0.1 mSv/y, can be regarded as trivial in the framework of the discussion of the radiation protection system.

**Figure 2**: Plots of dose distribution for natural background radiation (bold line) and its summation (thin line) with that for manmade radiation assuming its 95 percentile is equal to a) 0.1, b) 0.3, c) 0.5 and d) 1.0 mSv/y as dose constraints.
In the above approach, the dose distributions for manmade nuclides were only added to those for which the natural radiation levels were already known by the UNSCEAR. However, the contribution to total public exposure due to medical exposure in addition to natural radiation should be considered. It might be possible that the effects of exposure to manmade nuclides can be regarded as trivial even in the case of the setting of a higher dose constraint, if sufficient quantitative knowledge of medical exposure is clarified hereafter. In addition, it should be noted that dose distribution for manmade radiation is a hypothetical one for a representative person who receives a dose that is representative of the more highly exposed persons in the population, and that the dose actually received by the public may be lower.

4. Discussions

In his previous paper [6], the author also proposed 0.1 mSv/y as a minimum dose constraint comparing the dose criteria of exemption and clearance. To discuss how the numerical value for the minimum dose constraint should be set in the radiological protection system, the rationale and theoretical background of exclusion, exemption and clearance are needed; it has been agreed upon to adopt the IAEA safety guide RS-G-1.7, and it might be adopted in the revised BSS. In RS-G-1.7, the exclusion criterion for natural origins is approximately 1 mSv/y. Exemption criteria for manmade origins have been categorized into two types: the order of 0.01 mSv/y for normal situations and that of 1 mSv/y for low-probability events. Also note that RS-G-1.7 permits member states to exceed the relevant activity concentrations for natural and manmade origins by up to ten times (or on the order of 0.1 mSv/y: 10 × 0.01 mSv/y), because regulatory bodies’ decisions will depend on the nature of the national regulatory infrastructure.

From the above discussions, it can be considered that requirements for further optimization toward less than 0.1 mSv/y is equivalent to making the dose criteria for exemption and clearance lower, which leads to inconsistency with the current dose criteria for exemption and clearance. As shown in Figure 3, although the ICRP requires an optimization in the region where the individual dose level is below the relevant dose constraint, no optimizations should be required when the dose constraint is lower than 0.1 mSv/y. It can be concluded that both the minimum dose constraint and the lower bound of optimization for the public should be set to 0.1 mSv/y.

Figure 3: Comparison between dose constraint and dose criteria of exemption and clearance.

Planned exposure situations

Dose limit for public exposure

<table>
<thead>
<tr>
<th>Dose constraint</th>
<th>Minimum dose constraint</th>
</tr>
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<tbody>
<tr>
<td>Optimisation</td>
<td>No need of Optimisation</td>
</tr>
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</table>

1 mSv/y

0.1 mSv/y

0.01 mSv/y

Dose criteria of exemption and clearance
The rationale and numerical value of dose limit for the public in Pub. 60 still remain valid in Pub. 103. In Pub. 60, 1 mSv/y as a dose limit for the public has been determined using risk-based and natural background radiation approaches without quantitative analysis. Also, the present approach have no accurately quantified basis to derive the lower bound of optimization, but this is not a significant issue because there are no clear quantitative rationales even in the cases of dose limit for the public and dose criteria of exemption and clearance. In the region of low doses and low dose rates, there is no clear boundary between safe and danger because the current radiological protection system is based on the LNT model, which takes stochastic effect of radiation exposure into account. These facts imply the validity of the present approach for deriving the lower bound of optimization on the basis of the natural background radiation approach and comparison with the dose criteria of exemption and clearance.

5. Conclusion

Taking into account the probabilistic analysis of the dose distribution of radiation due to manmade radioactive nuclides when added to those of natural background radiation and dose criteria of exemption and clearance, it can be concluded that the minimum dose constraint should be set to 0.1 mSv/y, which implies the lower bound of optimization, i.e., public exposure below 0.1 mSv/y should be outside the range of the ALARA concept. Note that the lower bound of optimization might be higher if additional effects due to medical exposure and nonradiation risks are considered in addition to natural background radiation.

REFERENCES