ENVIRONMENTAL RADIATION STANDARDS AND RISK LIMITATION*

D. C. Kocher
Health and Safety Research Division
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6383

ABSTRACT

The Environmental Protection Agency and Nuclear Regulatory Commission have established environmental radiation standards for specific practices which correspond to limits on risk to the public that vary by several orders of magnitude and often are much less than radiation risks that are essentially unregulated, e.g., risks from radon in homes. This paper discusses a proposed framework for environmental radiation standards that would improve the correspondence with limitation of risk. This framework includes (1) the use of limits on annual effective dose equivalent averaged over a lifetime, rather than limits on dose equivalent to whole body or any organ for each year of exposure, and consideration of exposures of younger age groups as well as adults, (2) limits on annual effective dose equivalent averaged over a lifetime no lower than 0.25 mSv (25 mrem) per practice, (3) maintanence of all exposures as low as reasonably achievable (ALARA), and (4) establishment of a generally applicable *de minimis* dose for public exposures. Implications of the proposed regulatory framework for the current system of standards for limiting public exposures are discussed.

KEY WORDS: Radiation standards; public exposures; radiation risks

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INTRODUCTION

This paper presents a proposed regulatory framework for limiting radiation exposures of the public that would provide a reasonable correspondence with limitation of risk. The impetus for this proposal is the observation that current environmental radiation standards for specific practices, as promulgated by the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC), provide limits on risk that (1) may vary by several orders of magnitude, (2) often are much less than radiation risks that are essentially unregulated, and (3) in some cases are less than risks that are generally regarded as negligible. Thus, the effectiveness of the current system of radiation standards in relation to limitation of risk to the public is called into question.

CURRENT REGULATORY FRAMEWORK FOR LIMITING PUBLIC EXPOSURES

The current regulatory framework for limiting radiation exposures of the public in the U.S. involves (1) generally applicable radiation protection standards and (2) environmental radiation standards for specific practices.

Radiation Protection Standards

Radiation protection standards for the public are applicable to all sources of exposure, exclusive of natural background and deliberate medical practices. Such standards are regarded as necessary for protection of public health and are based on an assumed limit on acceptable risk from radiation exposure.

Current radiation protection standards for the public include (1) a limit on annual dose equivalent from uniform whole-body irradiation of 0.5 rem and (2) maximum permissible concentrations of radionuclides in air and water which correspond to annual committed dose equivalents to whole body or any organ from inhalation or ingestion.[1] In addition, all exposures should be maintained as low as reasonably achievable (ALARA).

Current recommendations of the International Commission on Radiological Protection (ICRP)[2] and the National Council on Radiation Protection and Measurements (NCRP)[3] replace limits on annual dose equivalent to whole body or any organ by limits on annual effective dose equivalent.[4] These recommendations include (1) a principal limit on annual effective dose equivalent of 1 mSv (0.1 rem) for continuous exposure and (2) a subsidiary limit on annual effective dose equivalent of 5 mSv (0.5 rem) for occasional exposure, provided the annual effective dose equivalent averaged over a lifetime does not exceed 1 mSv (0.1 rem).

Environmental Radiation Standards

Environmental radiation standards apply to specific practices and are based primarily on (1) levels of public exposure that are judged to be reasonably achievable using best-available effluent control technologies or (2) reduction of environmental radioactivity to levels near ambient background. Thus, environmental radiation standards are not based on the need for limitation of risk *per se*, but they result essentially from application of the ALARA principle to standard setting itself. The importance of these standards is that they provide a practical set of requirements for limiting public exposures which assure that generally

applicable radiation protection standards will be met.[5]

Environmental radiation standards for several practices have been established by the EPA and the NRC.[6-12] Many of these standards include a limit on annual dose equivalent to whole body of 25 mrem.[6,8,10-12] Thus, a *de facto* environmental radiation standard for many practices is a limit on annual effective dose equivalent of 25 mrem (0.25 mSv). Federal agencies have also issued guidance that concentrations of radon in homes should not exceed 4 pCi/L, in order to limit risks to the public to acceptable levels.[13]

LIMITS ON RISK ASSOCIATED WITH CURRENT RADIATION STANDARDS

This section discusses the correspondence between current radiation standards for the public and limitation of risk. We first consider a particular example.

Several environmental radiation standards contain limits on annual dose equivalent of 25 mrem to whole body, 75 mrem to thyroid, or 25 mrem to any other organ.[6,8,10,11] If we assume a risk factor for uniform whole-body irradiation of 2×10^{-4} rem^{-1} and weighting factors for specific organs recommended by the ICRP,[14] then the annual risk corresponding to these dose limits ranges from 5×10^{-6} for whole body to 2×10^{-7} for bone surfaces. Thus, the limits on risk associated with the standards for several practices may vary by as much as a factor of 30.

A general comparison of lifetime risks associated with radiation protection and environmental radiation standards, including the Federal guidance on radon in homes, is given in Table 1. The estimated risks assume exposure over 70 years, and the risk factor and organ-specific

weighting factors again are those recommended by the ICRP.[14] The assumptions used in some cases are described below.

- The value for radon in homes is the mean of the range of estimates in the Federal guidance, assuming a radon concentration of 4 pCi/L and an indoor residence time of 75%.[13]

- The value for uranium and thorium mill tailings is based on the limits on (1) concentration of outdoor ^{222}Rn, (2) concentrations of ^{226}Ra in soil, (3) concentration of indoor ^{222}Rn daughter products, and (4) indoor gamma radiation level.[8,9] The risks from ^{222}Rn and daughter products are based on the mean annual effective dose equivalents per unit concentration or exposure for outdoor and indoor residence estimated by the ICRP.[15] The risk from ^{226}Ra in soil assumes external photon exposure above ground for daughter products in secular equilibrium with the parent, absorbed dose rates in air above ground per unit concentration of radionuclides in soil,* indoor and outdoor residence times of 85% and 15%,[15] respectively, a shielding factor during indoor residence of 0.7,[17] and a ratio of effective dose equivalent to absorbed dose in air of 0.7. The risk from indoor gamma radiation assumes an indoor residence time of 85%[15] and a ratio of effective dose equivalent to air exposure of 0.6.

- The values for drinking water are based on (1) the limits on concentration of ^{226}Ra plus ^{228}Ra and on annual dose equivalent to whole body or any organ from man-made, beta/gamma-emitting radionuclides,[7] (2) a daily water intake of 2 liters, and

* The results in Appendix H of ref. 16 should be increased by a factor of 94 to correct an error in the calculations.

(3) effective dose equivalents and dose equivalents to specific organs per unit activity ingested.[18]

- The value for high-level waste disposal is the average risk to an individual in the current U.S. population, based on a limit of 1,000 health effects per repository over 10,000 years.[10]

In comparing the results in Table 1, it should be borne in mind that (1) radiation protection standards apply to all sources, excluding natural background, whereas other standards apply to specific practices, (2) standards for drinking water and high-level waste disposal limit risks to average individuals in the population, whereas other standards apply to maximally exposed individuals, (3) the guidance on radon in homes and standards for drinking water and uranium and thorium mill tailings include contributions from natural background, and (4) the guidance on radon in homes is not a standard for limiting public exposures. Nonetheless, the following conclusions may be drawn from Table 1.

- The risks associated with different environmental radiation standards for specific practices, excluding the standard for high-level waste disposal, vary by nearly four orders of magnitude.

- The risks associated with all environmental radiation standards for specific practices are less than the risk associated with the guidance on radon in homes, which is a radiation risk that is essentially unregulated.

- The risks associated with the guidance on radon in homes and the uranium and thorium mill tailings standard are higher than the risks

associated with the NRC's radiation protection standard and the standard recommended by the ICRP and the NCRP.

- The risks associated with several environmental radiation standards for specific practices are comparable to or less than the negligible risk level of about 10^{-5} recommended by the NCRP.[3]

Thus, the results in Table 1 demonstrate that current environmental radiation standards generally provide a poor correspondence with any desired limit on risk to members of the public.

PROPOSED REGULATORY FRAMEWORK FOR LIMITING PUBLIC EXPOSURES

This section presents a proposed regulatory framework for limiting radiation exposures of the public that would (1) provide a reasonable correspondence with limitation of risk, (2) establish limits on risk for specific practices that are well above levels regarded as negligible, and (3) minimize impacts on the current system of standards.

Limitation of Lifetime Risk to the Public

An essential aspect of the proposed regulatory framework for limiting public exposures is the assumption that limitation of lifetime risk, rather than risk for each year of exposure, is the fundamental goal of standards for limiting exposures of individuals,[14] and that exposures of younger age groups as well as adults should be taken into account. Furthermore, for regulatory purposes, the effective dose equivalent[4] is assumed to be a reasonable surrogate for risk from radiation exposure.

The importance of exposures of younger age groups in obtaining a reasonable correspondence between standards expressed as limits on effective dose equivalent and limitation of lifetime risk is discussed elsewhere.[19] Age-dependent calculations of dose from ingestion of radionuclides have shown that the dose from intakes by infants may be one-to-two orders of magnitude greater than the annual dose from intakes by adults. Thus, the usual practice of limiting dose to the public for each year of exposure (1) could lead to annual doses to infants that exceed limits in radiation protection standards if the dose is calculated only for adults, as is often the case, even when the limit on annual dose equivalent for a specific practice is as low as 25 mrem, and (2) could overestimate lifetime risk from chronic exposures, which are likely for many practices, by more than an order of magnitude if the dose limit is applied to infants. A much closer correspondence with lifetime risk is obtained if standards are expressed as limits on annual effective dose equivalent averaged over a lifetime.

Proposed Regulatory Framework

Based on the foregoing discussions, the following regulatory framework for limiting radiation exposures of the public is proposed.

- In generally applicable radiation protection standards, establish a principal limit on annual effective dose equivalent averaged over a lifetime of 0.1 rem (1 mSv) and a subsidiary limit on effective dose equivalent for any year of 0.5 rem (5 mSv), in accordance with current recommendations of the ICRP[2] and the NCRP.[3] Exposures of younger age groups as well as adults should be taken into account in

evaluating annual effective dose equivalents and their average over a lifetime.

- Express environmental radiation standards for practices that do not primarily involve naturally occurring radionuclides in terms of limits on annual effective dose equivalent averaged over a lifetime.

- In environmental radiation standards that primarily involve naturally occurring radionuclides, specify limits on annual dose equivalent averaged over a lifetime to the extent practicable. Secondary limits on concentrations of radionuclides in the environment could also be specified, as in some current standards,[7-9] but these limits should be clearly related to dose.

- Specify that all exposures should be maintained ALARA.[1-3]

- Establish limits on annual effective dose equivalent averaged over a lifetime in environmental radiation standards at levels no lower than 25 mrem (0.25 mSv) per practice, in order to avoid setting limits at levels that correspond to negligible risks to the public. However, maximum doses lower than the limit could be achieved by use of the ALARA principle.

- Establish a generally applicable *de minimis* dose for public exposures, i.e., a limit below which reductions in dose using the ALARA principle would be deliberately and specifically curtailed.[3] In accordance with current NCRP recommendations,[3] an annual effective dose equivalent averaged over a lifetime in the range 1-5 mrem (0.01-0.05 mSv) is suggested as *de minimis*.[20] In conjunction with

the proposed dose limit for specific practices described above, this *de minimis* dose would provide a substantial range over which the ALARA principle could be applied.

Implications of Proposed Framework for Current Standards

The proposed regulatory framework would require some changes in the current system of radiation protection and environmental radiation standards. The most important changes are described below.

- All standards and dose-assessment methods would need to take into account the age-dependence of the effective dose equivalent.

- Environmental radiation standards which contain limits on annual dose equivalent of 25 mrem to whole body, 75 mrem to thyroid, and 25 or 75 mrem to any other organ[6,8,10-12] could be changed, with minimal disruption, to specify a limit on annual effective dose equivalent averaged over a lifetime of 25 mrem (0.25 mSv).

- In standards for uranium and thorium mill tailings,[8,9] limits on environmental concentrations of radionuclides could be retained as secondary standards. However, they would need to be related to specified limits on annual effective dose equivalent averaged over a lifetime to the extent practicable.

- Current drinking water standards[7] would require significant modification. First, the standards would need to specify a single limit on annual effective dose equivalent averaged over a lifetime for all radionuclides. Second, if the dose limit were set at the

proposed lower limit of 25 mrem (0.25 mSv) per practice, then the corresponding limit on risk would be considerably higher than the risks associated with current drinking water standards (see Table 1) which, in many cases, correspond to risks that are regarded as negligible.[3] Again, however, doses from drinking water could be reduced below the proposed limit by use of the ALARA principle.

Recent Developments in Radiation Protection Standards

A recent development in radiation protection standards for the public is to provide assurance that the dose limit from all sources will be met by specifying that the dose from individual sources should not exceed one-fourth of the limit.[3,5] This approach takes into account that an individual is not likely to receive significant exposures from more than four sources.

For a limit on annual effective dose equivalent averaged over a lifetime of 0.1 rem (1 mSv) from all sources, this approach would result in a limit on annual effective dose equivalent averaged over a lifetime of 25 mrem (0.25 mSv) per source. Thus, the suggested source-related limit in radiation protection standards would correspond to the lower limit for practice-specific standards proposed in this paper.

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Table 1. Lifetime risks associated with various radiation protection and environmental radiation standards for the public

Risk	Standard
3×10^{-2}	Radon in homes[a,b]
1×10^{-2}	Uranium and thorium mill tailings[a,c]
7×10^{-3}	Annual dose equivalent to whole body of 0.5 rem[d]
1×10^{-3}	Annual effective dose equivalent of 0.1 rem[e]
4×10^{-4}	Annual dose equivalent to whole body of 25 mrem[f]
6×10^{-5}	Ra-226 plus Ra-228 in drinking water[a,g]
6×10^{-5}	Annual dose equivalent to whole body of 4 mrem[g]
3×10^{-5}	Annual dose equivalent to thyroid of 75 mrem[f]
1×10^{-5}	Annual dose equivalent to bone of 25 mrem[h]
5×10^{-6}	Sr-90 in drinking water[a,g]
2×10^{-6}	I-129 in drinking water[a,g]
5×10^{-8}	Disposal of high-level wastes[a,i]

[a] See text for discussion of assumptions used in estimating risk.

[b] Federal guidance.[13]

[c] EPA and NRC standards.[8,9]

[d] NRC's radiation protection standard.[1]

[e] Radiation protection standard recommended by ICRP and NCRP.[2,3]

[f] Limit contained in several EPA and NRC standards.[6,8,10-12]

[g] EPA standards for drinking water.[7]

[h] Limit contained in several EPA and NRC standards.[6,8,10,11]

[i] EPA standard.[10]

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