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RADIATION PROTECTION OF THE PUBLIC - PAST, PRESENT, AND FUTURE*

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ABSTRACT

This paper discusses (1) the historical development of radiation protection standards for the public, (2) the present system in the United States for limiting radiation exposures of the public primarily by means of environmental radiation standards for specific practices or sources, and (3) recent developments that may affect future standards and policies for radiation protection of the public. The radiobiological and epidemiological basis for radiation protection standards and policies is emphasized. Difficulties associated with the current regulatory framework are discussed, and proposals for addressing these difficulties are presented.

INTRODUCTION

This paper discusses three topics related to radiation protection of the public for routine exposure situations:

[1] the historical development of radiation protection standards,

[2] the present system in the United States for limiting radiation exposures of the public primarily by means of environmental

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radiation standards for specific practices or sources, and

[3] recent developments that may affect future standards and policies for radiation protection of the public.

This paper also discusses (1) inconsistencies in the relationship between current standards for limiting radiation exposures of the public and limits on lifetime risk, (2) the use of quantitative radiation risk factors to estimate risks at low levels of exposure, and (3) the use of prescribed and largely generic models to demonstrate compliance with standards at specific sites. The radiobiological and epidemiological basis for standards and policies for limiting radiation exposures of the public is emphasized.

In discussing the current regulatory framework for limiting radiation exposures of the public, a clear distinction must be made between a radiation protection standard and an environmental radiation standard. The former is generally applicable to all sources of exposure, exclusive of natural background and medical practices. Compliance with radiation protection standards is regarded as necessary for protection of public health; i.e., the standards must be met, except in the case of accidents or emergencies, regardless of cost. In contrast, environmental radiation standards are applicable only to a specific practice or source of exposure. Furthermore, these standards usually are based primarily on judgments regarding levels of public exposure that are reasonably achievable, rather than on a need for limitation of health risk *per se*.

HISTORICAL DEVELOPMENT OF RADIATION PROTECTION STANDARDS

Recommendations on radiation protection standards for the public were first developed by the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) beginning in the mid-1950s,[1,2] primarily in response to atmospheric testing of nuclear weapons. However, the standards applied only to routine releases to the environment, e.g., from nuclear facilities.

In 1954 the ICRP recommended that limits on exposures of the public be set at one-tenth of the limits for radiation workers. This reduction, while somewhat arbitrary, was based on risk-benefit considerations; i.e., exposure limits for the public should be lower than those for workers because the public receives no direct benefit in association with exposures. The maximum permissible dose to the whole body for workers, which had been recommended in 1949, was 3 mSv (0.3 rem) per week, or 150 mSv (15 rem) per year. Thus, the first radiation protection standard for the public was a dose limit of 15 mSv (1.5 rem) per year. In 1949 the NCRP also had introduced the risk-benefit philosophy into radiation protection, which led to the principle that doses should be As Low As Reasonably Achievable (ALARA).

In 1956 the NCRP recommended a dose limit of 5 mSv (0.5 rem) per year for individual members of the public, in conjunction with a recommendation that the maximum permissible dose to workers be reduced to 50 mSv (5 rem) per year. This recommendation was also adopted by the ICRP, which in 1959 further recommended that the average dose to gonads for individuals in large population groups - the so-called genetically significant dose to the population - be limited to 50 mSv (5 rem) in 30 years.

During the period 1954-1959 when radiation protection standards for the public were first developed, there were no quantitative data on risks from radiation exposure (i.e., risk factors) that could be used to develop standards. Rather, the dose limits were based primarily on direct evidence of deleterious effects of radiation exposure in humans and animals - e.g., (1) the observed excess of leukemias among early radiologists and (2) concern for the genetic hazard as evidenced by observed effects in fruit flies. Concern for the genetic hazard also was the primary reason for the reduction in the dose limits for workers and members of the public by a factor of three in 1956 and for the 1959 recommendation on limitation of the genetically significant dose to the population.

During this time the ICRP and NCRP attempted to set dose limits at levels where it could be assumed, on the basis of data in humans and animals, that the incidence of leukemia and genetic effects would not be perceptibly increased. That is, dose limits defined levels of exposure that were regarded as "safe", even though it was recognized that a small, but unquantifiable and presumably imperceptible, risk could be associated with exposures below the limits. The reduction in the dose limit for members of the public by a factor of ten below the limit for workers also provided an extra margin of safety.

Beginning in 1977 the ICRP developed a new set of recommendations on radiation protection of workers and the public[3,4] which were later adopted by the NCRP.[5] Four important new developments were embodied in the ICRP recommendations.

First, the ALARA principle was given primacy over dose limits for individuals. That is, the collective dose should be optimized even if

doses to all individuals are below applicable limits.

Second, quantitative risk factors, based primarily on data on the Japanese atomic-bomb survivors, were used to derive dose limits from an assumed limit on acceptable risk. For purposes of radiation protection, the ICRP assumed a risk factor of 10^{-2} Sv^{-1}. Then, by assuming that a risk from radiation exposure greater than 10^{-5} per year would be unacceptable to members of the public, the ICRP recommended a principal dose limit of 1 mSv per year, except doses as high as 5 mSv in some years were permitted if the annual dose averaged over a lifetime would not exceed 1 mSv.

Third, the ICRP introduced a new dosimetric quantity - the effective dose equivalent - which is a weighted sum of dose equivalents to several organs and tissues. The effective dose equivalent was intended to be proportional to stochastic risk for either uniform or nonuniform irradiations of the whole body. Thus, for purposes of radiation protection, exposures with equal effective dose equivalents were assumed to correspond to equal risks regardless of the distribution of dose in the body.

Fourth, the genetic hazard no longer was the principal concern in setting dose limits in radiation protection standards. For whole-body irradiation, the risk of genetic effects was assumed to be 25% of the total stochastic risk, and a separate recommendation on limitation of the genetically significant dose to the population was no longer included. The reduction in the importance of the genetic hazard was based primarily on experiments in mice and data from the Japanese atomic-bomb survivors.

In summary, radiation protection standards for the public, as they have evolved since the mid-1950s, have been based primarily on

radiobiological and epidemiological evidence of risks from radiation exposure at dose levels considerably higher than those embodied in the standards. In the early standards, a somewhat arbitrary margin of safety was applied in establishing the dose limits, but quantification of risks associated with the dose limits was not possible and the limits were assumed to ensure a "safe" level of exposure. However, with the development of quantitative risk factors, dose limits for the public have been based on an assumed acceptable risk and the assumption that, for purposes of radiation protection, risk factors derived from exposures of human and animal populations at high doses could be applied at the much lower doses embodied in the standards.

ENVIRONMENTAL RADIATION STANDARDS

Environmental radiation standards for specific practices or sources were first developed in the U.S. beginning in the mid-1970s.[6,7] These standards are important because they provide a practical means of ensuring that radiation protection standards, which apply to all sources of exposure except natural background and medical practices, will be met; i.e., they provide the practical basis for limiting radiation exposures of the public. Standards have been developed or proposed for several categories of practices and sources: operations of uranium fuel-cycle facilities, radioactivity in drinking water, uranium or thorium mill tailings and residual radioactivity, radioactive waste disposal, and airborne radioactivity. Guidance also has been developed on acceptable levels of radon in homes.

In addition to applying only to specific practices or sources, environmental radiation standards differ from radiation protection standards for the public in two important respects. First, some standards (e.g., for radioactivity in drinking water and mill tailings and residual radioactivity) apply to naturally occurring as well as man-made radionuclides. For this reason, the dose limit associated with the standards for uranium mill tailings, for example, *exceeds* the dose limit in current radiation protection standards for the public by an order of magnitude.[7]

Second, as mentioned in the introduction, environmental radiation standards usually represent exposure limits judged to be reasonably achievable. An exception is the recent standards for airborne emissions of radionuclides, which were based primarily on (1) a determination of an acceptable level of risk to individuals or populations and (2) an ample margin of safety for protecting public health.[8] Judgments regarding standards that are reasonably achievable take into account the costs of reducing exposures in relation to the health risks averted and consider (1) best-available technologies for control of radioactive effluents and/or (2) background levels of radioactivity in the environment. Given the variety of practices or sources that are regulated, usually without consideration of standards for other practices or sources, and that some standards apply to naturally occurring sources, it is not surprising that the dose limits associated with different standards vary by several orders of magnitude.[7]

RECENT DEVELOPMENTS IN RADIATION PROTECTION

This section discusses three developments that may indicate future trends in standards and policies for radiation protection of the public.

First, the recent re-evaluation of the doses and risks among the Japanese atomic-bomb survivors has led to an increase in risk factors for low-LET radiations.[9] For purposes of radiation protection, the ICRP intends to assume an increase in the risk factor by about a factor of four.[10] In order to maintain the previously assumed limit on acceptable lifetime risk for members of the public (e.g., 10^{-3}), a corresponding decrease in the present dose limit of 1 mSv per year could be warranted.

However, a reduction in the present dose limit of 1 mSv per year for members of the public apparently will not be recommended by the ICRP.[10] Rather, the ICRP probably will delete the subsidiary dose limit of 5 mSv in any year and recommend that the limit of 1 mSv per year apply to the average dose over any five-year period. The recommendation to maintain the present limit takes into account (1) the widespread use of dose limits for specific practices or sources that are substantially less than 1 mSv per year and (2) the high doses from natural background, in comparison with the dose limit, that are experienced in some geographical areas.

Second, the ICRP is developing recommendations on age-dependent doses to members of the public from intakes of radionuclides.[11] Heretofore, most radiation protection and environmental radiation standards for the public, as well as models used to demonstrate compliance with the standards, have assumed that members of the public were reference adults. The ICRP recommendations indicate that, for some radionuclides, the committed dose equivalents per unit intake are substantially higher for

infants and children than for adults. This result also could warrant a reduction in the dose limit for adults in order to protect younger age groups.

The ICRP apparently will not revise its recommendations on radiation protection of the public in response to the recommendations on age-dependent doses,[10] although the dose limit of 1 mSv per year presumably will apply to any age group in the population. As an alternative approach, the Nuclear Regulatory Commission probably will establish revised limits on radionuclide concentrations in air and water in its radiation protection standards for the public that are based on a limit on annual dose to an adult of 0.5 mSv (0.05 rem), rather than 1 mSv (0.1 rem).[12] The reduction in the implicit dose limit for adults by a factor of two takes into account the higher doses and risks to younger age groups from chronic lifetime exposure.

Third, there is an increasing tendency to regulate radiation exposures of the public in the same manner as exposures to hazardous chemicals in regard to defining an acceptable level of risk. For example, in the recent standards for airborne emissions of radionuclides,[8] a maximum individual lifetime risk as low as 10^{-6} was considered in accordance with a risk level that often has been applied in limiting exposures to hazardous chemicals; and remediation of inactive radioactive waste disposal sites shall be in accordance with requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) for cleanup of hazardous waste sites. Given the low levels of risk at which exposures to hazardous chemicals usually are regulated, regulation of radiation exposures in the same manner could lead to substantial reductions in present dose limits.

It may be reasonable to regulate exposures to different hazardous substances in the environment, including radionuclides, at similar levels of risk. However, it is questionable whether radiation exposures should be regulated at risk levels as low as 10^{-6} when exposures of average individuals in the U.S. population to natural background[13] may correspond to lifetime risks well in excess of 10^{-3} (ref. 7). It should also be emphasized that radiation exposures have been regulated quite differently from exposures to other hazardous materials. For radiation, a dose limit corresponding to an *upper limit* on acceptable risk is established, and doses are *reduced* below the limit using the ALARA principle. For other hazardous materials, however, a *lower limit* on risk is established as a goal, but this limit is *increased* in specific cases to reflect risk levels that are judged to be reasonably achievable. Thus, the limit on lifetime risk of 10^{-6} that often has been applied to hazardous chemicals is a *de minimis* level, rather than a level that is analogous to the risk limit of 10^{-3} which has been used in developing radiation protection standards for the public.

Radiation protection standards for the public have not yet incorporated the much lower levels of risk at which exposure to other hazardous substances has been regulated, and only a few environmental radiation standards reflect the tendency to regulate exposures of the public to all hazardous substances at similar levels of risk. However, it should be anticipated that pressures to do so may increase. Perhaps a solution to this potential problem for radiation protection will arise as more information is obtained on public exposures and risks from naturally occurring hazardous chemicals.

PROBLEMS WITH CURRENT POLICIES FOR RADIATION PROTECTION

This section discusses three issues that illustrate potential difficulties with current standards and policies in the U.S. for radiation protection of the public. These issues generally involve the relationship between standards and policies and limits on lifetime risk.

The first issue concerns inconsistencies in the levels of lifetime risk embodied in current standards for limiting exposures of the public. Table 1, which is adapted from ref. 7, gives relative lifetime risks associated with selected radiation protection standards, environmental radiation standards, and the guidance on radon in homes. The values are normalized to the risk to average individuals in the U.S. population from exposure to natural background, including radon, and the average risk from exposure to radon only is also given. The only assumptions required to obtain the estimates of relative risk are that (1) the effective dose equivalent is proportional to risk in a population containing all age groups and (2) the dose-response relation is a linear function of dose, without threshold.

The results in Table 1 indicate that the risks associated with different standards and guidances for limiting radiation exposures of the public vary by nearly six orders of magnitude and are as much as five orders of magnitude less than the average risk from exposure to natural background, including radon. Furthermore, the risks associated with the guidance on radon in homes and the standards for uranium mill tailings, both of which are concerned with exposure to naturally occurring sources, are greater than the average risk from exposure to natural background.

The results in Table 1 notwithstanding, it can be argued that the present system of standards for limiting public exposures is reasonable because (1) some standards are concerned primarily with exposure to natural sources but others are not and (2) most of the environmental radiation standards and guidances result essentially from application of the ALARA principle to standard setting itself. However, there appear to be several problems associated with the present system of standards.

First, as argued previously, it seems unreasonable to regulate a source of exposure at an assumed level of risk that is very much less than the largely unavoidable risk from natural background. This is particularly the case when epidemiological studies have not shown a positive correlation between levels of natural background radiation and incidence of cancer over a range of doses much greater than the dose limits in some standards.[13]

Second, the use of very low dose limits in standards for a specific practice or source may give the public the misguided impression that doses above such limits are harmful to their health. For example, the public may tend to regard as unsafe any doses above 0.04 mSv (4 mrem) per year (i.e., about 1% of the average dose from natural background[13]) because this dose limit is incorporated in drinking water standards.

Third, although the low dose limits incorporated in some standards often can be met at little cost, the same dose limits may be applied to other situations for which the standards were not originally intended and for which the attendant costs in meeting the standards could be considerable. For example, current drinking water standards, which strictly apply only to community water systems, may be applied to (1) protection of groundwater at sites for disposal of radioactive

wastes[14] and (2) cleanup of groundwater near inactive radioactive waste disposal sites in accordance with the requirements of CERCLA. This approach may greatly increase the costs of disposal and remediation activities without commensurate benefits in reducing health risks or protecting the environment.

Finally, the development of environmental radiation standards essentially by applying the ALARA principle to standard setting itself appears to be at odds with the intent of the ICRP and NCRP in incorporating this principle in radiation protection recommendations. Specifically, the ICRP and NCRP intended that the ALARA principle embody a *process* that is applied on a site-specific basis, rather than a predetermined *result* that is applied at any site.

The second issue concerns the common practice of estimating risks to individuals or populations at low levels of exposure (e.g., at levels of natural background or below) using estimates of dose equivalents and quantitative risk factors based on data at much higher levels of exposure. It is reasonable to use the effective dose equivalent and a nominal risk factor, in conjunction with an assumed limit on acceptable risk, for purposes of radiation protection (i.e., to establish dose limits) as in current ICRP recommendations.[3] However, as the ICRP cautions, it is quite another matter to use the same dosimetric quantity and risk factor for purposes of estimating risk at low levels of exposure.

Estimation of risk from a given radiation exposure is fraught with uncertainty. The macroscopic average of absorbed dose, which is the basic physical quantity used in estimating risk, may be inappropriate for predicting risk at low doses, particularly for high-LET radiations.[15,16] The quality factor (Q), which converts absorbed dose to dose equivalent

and is chosen to encompass appropriate values of relative biological effectiveness (RBE) for different types of radiation but to be independent of organ or tissue and the particular biological endpoint, clearly is highly judgmental. Estimation of risk factors at low doses from data in human populations involves many important judgmental considerations: uncertainty in doses received, incomplete expression of radiation-induced health effects in study populations, extrapolation from data at much higher doses and dose rates, study populations that may differ from normal populations in their responses to radiation exposure, the choice of dose-response relations for different radiation types and cancer sites, the effect of competing risks, and unexplained differences in risks for external and internal exposure. Therefore, in spite of the considerable body of information on radiation risks in comparison with risks from other hazardous substances, it seems unconscionable to estimate risks at low levels of exposure using estimates of dose equivalent and nominal risk factors without an accompanying expression of the considerable uncertainty in the result, including the possibility that the actual risk could be zero.[9]

The third issue concerns the use of prescribed and largely generic dose-assessment models to demonstrate compliance with standards for limiting exposures of the public at specific sites. For example, the standards for airborne emissions of radionuclides strongly encourage the use of a specified computer code in demonstrations of compliance.[8] The use of largely generic models for site-specific analysis only serves to increase the likelihood of significant errors in estimates of dose and risk.

CONCLUDING REMARKS

Limitation of radiation exposures of the public in the U.S. is based primarily on an extensive system of environmental radiation standards for specific practices or sources. When one considers the very low dose limits embodied in some of the standards and that the dosimetric quantities and risk factors used in establishing standards may be inappropriate for estimating risks to exposed individuals or populations, it seems clear that the practice of radiation protection of the public has become increasingly distanced from any radiobiological or epidemiological basis.

Changes in present standards and policies for radiation protection of the public would, in my opinion, be desirable. In particular, greater consideration should be given to the magnitude and variability of natural background in establishing exposure limits for the public. Thus, for example, dose limits for specific practices or sources should be set at no lower than 0.25 mSv (25 mrem) per year,[5] and reductions in dose below this limit should be based on site-specific application of the ALARA principle. Furthermore, less emphasis should be placed on quantitative estimates of risk from exposures at levels less than natural background.

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TABLE 1. Estimated Relative Lifetime Risks Associated with Selected Radiation Protection Standards for the Public, Environmental Radiation Standards, and Exposures to Natural Background[a]

Relative Risk	Standard or Exposure
7.0	Guidance on radon in homes
3.3	Uranium mill tailings standards
1.7	Annual dose equivalent to whole body of 5 mSv (500 mrem) in radiation protection standards
1.0	Annual effective dose equivalent of 3.0 mSv (300 mrem); average dose from exposure to natural background, including radon
0.67	Annual effective dose equivalent of 2.0 mSv (200 mrem); average dose from exposure to indoor radon
0.33	Annual effective dose equivalent of 1 mSv (100 mrem) in radiation protection standards
0.083	Annual dose equivalent to whole body of 0.25 mSv (25 mrem) in several environmental radiation standards
0.017	Concentration limit for Ra-226 plus Ra-228 in drinking water standards
0.013	Annual dose equivalent to whole body of 0.04 mSv (4 mrem) in drinking water standards
0.0075	Annual dose equivalent to thyroid of 0.75 mSv (75 mrem) in several environmental radiation standards
0.0025	Annual dose equivalent to bone of 0.25 mSv (25 mrem) in several environmental radiation standards
0.0012	Annual dose equivalent to bone of 0.04 mSv (4 mrem) from Sr-90 in drinking water standards
0.00040	Annual dose equivalent to thyroid of 0.04 mSv (4 mrem) from I-129 in drinking water standards
0.000012	Containment requirements for disposal of high-level wastes (average risk in U.S. population)

[a]See Table 1 and text of ref. 7 for further description of entries and additional assumptions used in obtaining risk estimates.