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ICRP PUBLICATION 39

Principles for Limiting
Exposure of the Public
to Natural Sources
of Radiation

STATEMENT FROM THE 1983 MEETING OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

The International Commission on Radiological Protection met in Washington, USA, in October, 1983. During the meeting the Commission identified the following points requiring clarification.

Annual Limits on Intakes (ALI) and Derived Air Concentrations (DAC) for Members of the Public

Introduction

Exposure to radioactive materials must be constrained by the relevant dose-equivalent limits recommended in *ICRP Publication 26* (1977) to reduce stochastic effects to an acceptable level and to prevent non-stochastic effects from occurring in the organs and tissues of the body. An ALI of a radionuclide or a DAC for submersion in an atmosphere contaminated with a radioactive chemically inert gas is then determined by the dose equivalent to which the organs and tissues of the body are committed as the result of such exposures. The values of ALI and DAC recommended in *ICRP Publication 30* are for workers based on a Reference Man; the factors by which they would differ from those that would be appropriate for members of the public are many and various, as discussed below.

Dose-equivalent Limits

For stochastic effects in members of the public the Commission recommends that the committed effective dose equivalent from exposure to radioactive materials in any year be limited to 5 mSv, and, for repeated exposures over prolonged periods, that it would be prudent further to restrict this to 1 mSv from each year of lifelong exposure.

For an individual exposed over the whole lifetime, the committed effective dose equivalent will depend partly on the age-specific relationship between annual intakes and committed dose equivalent and partly on age-specific factors influencing the annual intake. In practice, the exposure of the public will be limited by applying environmental constraints aimed at ensuring an adequate limitation on dose for the age group in which the committed effective dose equivalent will be the greatest. For most nuclides, a limit on the annual committed effective dose equivalent of 5 mSv applied to this group will result in a lifetime average exposure below the limit of 5 mSv but not necessarily below the value of 1 mSv. The ratio of the lifetime average to the limit of 5 mSv in a year will depend on the nuclide and also on factors that are determined by environmental considerations and by the lifestyle of the individuals concerned.

The resulting variations are too large for it to be appropriate for the Commission to recommend average or typical values of the various parameters as it has been able to do for workers, and each situation must therefore be dealt with on its own. The Commission can, however, give guidance on the metabolic and dosimetric models that provide an age-specific relationship between intake in a year and the resulting committed effective dose equivalent.

The use of the committed effective dose equivalent calls for two remarks. In *ICRP Publication 30*, the Commission uses an integrating time of 50 years in computing the committed dose equivalent in an organ of a worker. The Commission believes that this period is also adequate for a member of the public since the correction factor would be no more than

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70/50. Exceptionally, the more complicated, but more rigorous, approach of integrating from the age of intake up to the age of, say, 70 years could be applied.

The second remark concerns non-stochastic effects. Many of the ALIs for workers are limited by the need to restrict the accumulated dose in single organs to a value small enough to avoid significant non-stochastic effects. In these cases, an intake limit based on committed effective dose equivalent alone would not be adequate. For members of the public, the lifelong average annual effective dose equivalent will not exceed 1 mSv, giving a maximum lifetime effective dose equivalent of less than about 70 mSv. The smallest organ weighting factor used in deriving the effective dose equivalent is 0.03, so that the greatest possible organ dose equivalent will only just exceed 2 Sv in a lifetime. The Commission's dose limit for single organs of members of the public, which is chosen to avoid the occurrence of non-stochastic effects, corresponds to a lifelong total dose equivalent of about 3.5 Sv. The limitation of the committed effective dose equivalent is therefore sufficient to provide compliance over a lifetime with the limit for single organs, thus avoiding non-stochastic effects.

Body Size

Even if there were no differences with age in the uptake and retention of a radionuclide, the committed dose equivalent in a particular tissue per unit intake of the radionuclide would be greater in children than in adults (and the ALI correspondingly less) because of the smaller masses of their organs and tissues. For the extreme case of a child in the first year of life, whose body mass at age 6 months is about 7 kg (ICRP, 1975), the committed dose equivalent in an organ or tissue per unit intake of a short-lived radionuclide emitting poorly penetrating radiations would be about 10 times greater than for a 70 kg adult. As described by Adams (1981) this factor would be about 2 for intakes of long-lived radionuclides that are long retained in body tissues (e.g. plutonium-239) because the child grows during the prolonged irradiation. For radionuclides emitting penetrating photons the modifying factors for body size are smaller, the committed dose per unit intake of a radionuclide being approximately inversely proportional to body mass$^{2/3}$ rather than body mass (Adams, 1981). Although organ mass is not a constant proportion of body mass, and the shapes and relative positions of organs change with age, these differences will usually have only a small effect on the factors discussed above. Therefore, to allow for body size alone, committed dose equivalents per unit intake for young members of the public will be greater (and ALIs correspondingly less) than those for workers by factors ranging from less than 2 up to 10, the actual value for any age depending not only on the mass of the individual but also on the types of radiation emitted by the radionuclide and its retention in body tissues.

The values of DAC for submersion in radioactive chemically inert gases that are given in *ICRP Publication 30* for workers would also need to be modified to provide corresponding values for members of the public who have different dimensions and mass. In most cases this effect on a DAC for submersion would be small, but the annual duration of exposure may be longer than the 2 000 hours assumed for workers.

Metabolism

Children can have a very different metabolism from that of adults, taking up different fractions (often more) of a chemical substance from the blood into their organs and tissues and eliminating it at different rates (often more rapidly). For a radioisotope of a chemical element in the substance, uptake and retention into the organs and tissues of the body will additionally depend on its radioactive half-life. It would be misleading to generalize about the effect this might have on the relative values of ALI for people of different ages, bearing in mind the

complex interplay of rates of biological uptake and loss, together with radioactive decay in the many organs and tissues that might determine an ALI, and it would be prudent to consider carefully each separate case. In fact, relevant data are scarce but the following examples will serve to illustrate the nature of the problem.

From considerations of water balance, the mean life of water in the body is about 14 days for adults and 6 days for infants aged 6 months (ICRP, 1975) and that of the long-lived radionuclide tritium in the form of tritiated water will have similar values. In consequence, the committed dose equivalent to body tissues from unit intake of tritium as tritiated water will be only about four times greater for such infants than for adults, rather than the ten times greater factor derived above that would be expected on the basis of their differences in mass alone. Similarly, as a consequence of the more rapid turnover of the long-lived caesium-137 in people of smaller mass (Cryer and Baverstock, 1972), the committed dose equivalent in body tissues from unit intake of the radionuclide is only about 1.5 times greater for the 6-month infant than it is for adults (Medical Research Council, 1975).

The mean life of iodine in the thyroid also increases with age, but this may be accompanied by a small decrease in the uptake into the gland from the blood, (Medical Research Council, 1975; UNSCEAR, 1977; Dunning and Schwarz, 1981; Stather and Greenhalgh, 1983). For the relatively short-lived radionuclide iodine-131, differences in biological turnover are of little consequence because its rate of loss from the thyroid is dominated by radioactive decay and its mean life in that organ is therefore about the same at all ages. In consequence, the committed dose equivalent to the thyroid per unit intake of iodine-131 is about ten times greater for the infant aged 6 months than it is for adults (Medical Research Council, 1975), reflecting their approximately 10-fold difference in thyroid mass. However, for the very long-lived iodine-129, the more rapid biological turnover in young people tends to offset their smaller mass, and the committed dose equivalent to the thyroid per unit intake of iodine-129 for the 6-month child is only about twice that for adults (UNSCEAR, 1977).

Papworth and Vennart (1973) and Leggett et al. (1982) have described how the uptake of strontium into bone and its retention therein varies with age. The former authors have given values for the committed dose equivalent in red bone marrow and on bone surfaces from unit intake of dietary strontium-90 and strontium-89. For the long-lived strontium-90, the value for a 6-month infant is about five times the adult value, but for the much shorter-lived strontium-89 the corresponding ratio lies in the range 20–40, the actual value depending on the model used for the dosimetry of the radionuclide in bone. There may be additional contributions to the committed effective dose equivalent from other organs and tissues for which the factors might be different.

Chemical Form

Values of ALI given in *ICRP Publication 30* are usually appropriate to those chemical compounds of a radionuclide that are most likely to be encountered at a place of work. Compounds of the same radionuclide found in the environment or in food may be metabolized differently. The consequent changes in values of committed effective dose equivalent have to be considered very carefully. For example, increased absorption of a radionuclide from the gastrointestinal tract into the blood will decrease the committed dose equivalent to the lower part of the tract, but increase the doses in other tissues of the body; such increases are most marked when radioactive decay is small during the time taken for transfer from the gastrointestinal system to the other organs and tissues.

It is known that absorption of some elements from the gastrointestinal system is increased in new-born animals of several species by factors up to 100 for compounds that are very poorly

absorbed by adults, e.g., the actinide elements, as described by Sullivan (1980a and b). This enhanced absorption occurs only early in life and decreases to the adult value at about the time of weaning. It is often accompanied by increased retention in the walls of the gastrointestinal tract. If it occurs in children, this increased absorption and retention could markedly increase the committed dose equivalent in the tissues of the body from intakes of some radionuclides very early in life, with a consequent need for more stringent controls by responsible authorities.

Information on the absorption of some actinides from the gastrointestinal system has been reviewed by Harrison (1982). He suggests that the fractional absorption f_1 of dietary plutonium might be 1% in the first 3 months of life, decreasing during weaning to the value of 0.05% at about 9 months, after which it does not vary with age. Alternatively, Harrison suggests a constant value of 0.5% during the first year of life and 0.05% thereafter. These values are respectively 50 and 5 times greater than the value used in *ICRP Publication 30* to determine the ALI for ingestion by workers of all plutonium compounds other than the very insoluble oxides and hydroxides. An ALI for ingested plutonium-239 will be inversely proportional to the value of f_1 and proportional to the mass of tissues at different ages. In the absence of any evidence to the contrary, it is assumed that there is no change with age in the prolonged retention of the radionuclide in body tissues. Therefore, using the values of f_1 suggested by Harrison, together with the mass factor of 2 discussed above for radionuclides that are long retained in body tissues, the committed dose equivalent per unit intake of dietary plutonium-239 for the 6-month old infant is 20 times greater than for adult members of the public and 100 times greater than the value used in *ICRP Publication 30* to calculate the smallest value of the ALI for the ingestion of plutonium-239 compounds at work. Variations in the value of f_1 of the magnitude suggested here will have little effect on estimates of the ALI for inhaled plutonium-239 because these are determined mainly by the larger fraction of the radionuclide that transfers directly to the blood from the lung.

Other Factors

There are a number of other factors that might be worthy of further research: for example, the dosimetric models developed in *ICRP Publication 30* for the respiratory and gastrointestinal systems and the skeleton are for adults. Until more information is available, they may of necessity have to be used for children, making appropriate allowances for breathing rates and food intake.

There is a need to consider pregnant women and the chronically sick. More needs to be known about the metabolism of radionuclides by the embryo and foetus and about their radiosensitivities. The Commission will keep under review possible differences in radiation sensitivity between tissues at various ages; meanwhile it does not believe that these differences are significant enough to recommend for members of the public a set of weighting factors that are different from those for workers (Para. 125, ICRP Publication 26, 1977).

Conclusion

The limitation of the committed effective dose equivalent for members of the public is sufficient to provide compliance over a lifetime with the limit for single organs, thus avoiding non-stochastic effects. Relative values for infants and adults of the committed dose equivalent in a number of tissues per unit intake for each of a few radionuclides have been given above: the values for infants are just more than 1 up to 100 times greater than those for adult workers. In each of these cases the appropriate annual dose-equivalent limits recommended by the Commission for members of the public are 10 times less than the corresponding values for workers: the resulting ALI for infants aged 6 months will be smaller than the values given in

ICRP Publication 30 for limiting stochastic effects in workers by factors that range from just more than 10 (for caesium-137) to 1 000 (for ingested plutonium-239). Intermediate factors would apply for older members of the public. The magnitude of the range emphasizes the need to consider each situation carefully.

Clearly, to choose a single factor for all circumstances would be unnecessarily restrictive in many cases, and none is recommended. On the other hand, to give an exhaustive list of factors for every case would be a daunting and possibly unrewarding task. The Commission plans to extend the list of examples as information increases and as other nuclides are identified as being of particular interest. Information of this kind, together with information about environmental features and about the behaviour patterns of members of the public, will enable national authorities to limit releases to the environment and to assess the doses likely to result from such releases.

References

Adams, N. (1981). Dependence on age at intake of committed dose equivalents from radionuclides. *Phys. Med. Biol.* **26**, No. 6, 1019–1034.

Cryer, M. A. and Baverstock, K. F. (1972). Biological half-life of caesium-137 in Man. *Health Phys.* **23**, 394–395.

Dunning, D. E. and Schwarz, G. (1981). Variability of human thyroid characteristics and estimates of dose from ingested ^{131}I. *Health Phys.* **40**, 661–675.

Harrison, J. D. (1982). Gut uptake factors for plutonium, americium and curium. National Radiological Protection Board, *NRPB R-129*. HMSO, London.

International Commission on Radiological Protection (1975). Report of the Task Group on Reference Man. *ICRP Publication 23*, Pergamon Press, Oxford.

International Commission on Radiological Protection (1977). Recommendations of the International Commission on Radiological Protection. *ICRP Publication 26, Annals of the ICRP*, **2**, No. 3.

International Commission on Radiological Protection. *ICRP Publication 30*, Limits for Intakes of Radionuclides by Workers: Part 1 (1979) *Annals of the ICRP*, **2**, No. 3/4. Supplement to Part 1 (1979) *Annals of the ICRP*, **3**, Part 2 (1980) *Annals of the ICRP*, **4**, No. 3/4. Supplement to Part 2 (1981) *Annals of the ICRP*, **5**, Part 3 (1981) *Annals of the ICRP*, **6**, No. 2/3. Supplement A to Part 3 (1982) *Annals of the ICRP*, **7**, Supplement B to Part 3 (1982) *Annals of the ICRP*, **8**.

Leggett, R. W., Eckerman, K. F. and Williams, L. R. (1982). A case study in age-dependent dosimetric modelling. *Health Phys.* **43**, 307–322.

Medical Research Council (1975). Criteria for controlling radiation doses to the public after accidental escape of radioactive material. HMSO, London.

Papworth, D. G. and Vennart, J. (1973). Retention of Sr-90 in human bone at different ages and the resulting radiation doses. *Phys. Med. Biol.* **18**, No. 2, 169–186.

Stather, J. W. and Greenhalgh, J. R. (1983). The metabolism of iodine in children and adults. National Radiological Protection Board. *NRPB-R140*, HMSO, London.

Sullivan, M. F. (1980a). Absorption of actinide elements from the gastrointestinal tract of rats, guinea pigs and dogs. *Health Phys.* **38**, 173–185.

Sullivan, M. F. (1980b). Absorption of actinide elements from the gastro-intestinal tract of neonatal animals. *Health Phys.* **38**, 159–171.

UNSCEAR (1977). United Nations Scientific Committee on the Effects of Atomic Radiation: Sources and Effects of Ionizing Radiation. United Nations, New York.

The Derived Air Concentration (DAC)

In *ICRP Publication 30* the values of DAC for occupational exposure to short-lived nuclides (other than isotopes of noble gases) are based on the dose equivalents to organs and tissues as the result of inhalation. The Commission wishes to draw attention to the fact that there is an additional contribution to these dose equivalents from external irradiation. In situations where short-lived materials are widely distributed in the workplace, this additional contribution may be greater than that due to inhalation by a factor that increases from about 1 to 100 as the half-life of the radionuclide decreases from 1 day to 10 min. Such contributions should be assessed as part of the external irradiation.

Average Annual Doses in a Work Force

In discussing dose-equivalent limits for workers in *ICRP Publication 26* the Commission compared their average risks with those in various industries. The Commission did not imply that there should be a specific limit for the average dose equivalent. Rather, the collective dose equivalent, and thus the average dose equivalent, should be limited by the process of optimization of protection, i.e., it should be kept as low as reasonably achievable, economic and social factors being taken into account.

Exposure of Women to Ionizing Radiation

In a recent publication[1] M. Otake and W. J. Schull have drawn attention to the risk of causing severe mental retardation in children exposed to ionizing radiation *in utero*. The risk has been identified as arising from irradiation in the limited period from 8 weeks to about 15 weeks after conception, i.e., after two menstrual periods would have been missed. In the interval leading up to the above-mentioned publication, the Commission examined the implications of this information for its recommendations concerning the employment of pregnant women in work involving exposure to ionizing radiation and concerning radiological examination of pregnant women.

Occupational Exposure of Pregnant Women

Paragraph 116 of *ICRP Publication 26* recommends that the conditions of occupational exposure of women diagnosed as being pregnant should be limited to those in which it is most unlikely that annual exposures would exceed 3/10 of the dose-equivalent limits (Working Condition B).

The Commission has concluded that the new information does not increase substantially the total risk previously judged by the Commission to result from occupational exposure of a pregnant woman (including her foetus) under these conditions. However, the new information, which shows that the risk of inducing mental retardation is confined to a limited period of time, makes some additional recommendations appropriate.

The methods of protecting pregnant women at work should provide a standard of protection for the foetus broadly comparable with that provided by protection of members of the general public. If, under Working Condition B, as would be expected, substantial irregularities in the dose rate do not occur, the dose received by the foetus over the critical period of 2 months would not be expected to exceed about 1 mSv. The Commission recommends that specific operational arrangements should be made to avoid irregularities in the rate at which the dose could be received and to keep the dose to the foetus as low as reasonably achievable.

Occupational Exposure of Women of Reproductive Capacity

No risk comparable with that described by Otake and Schull is incurred from irradiation in the period prior to the first missed menstruation. The Commission's recommendations for occupational exposure of women of reproductive capacity relate to women who may be, but are not known to be, pregnant. These recommendations impose no special dose limits, in addition to that of an effective dose equivalent of 50 mSv in any year, provided that the exposure occurs at an approximately regular rate. The recommendations remain valid.

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[1] M. Otake and W. J. Schull, *Br. J. Radiol.* In press.

Diagnostic Exposure of Women

The information published by Otake and Schull has a bearing also on the diagnostic examination of women in the third and fourth months after the onset of the preceding menstruation. The Commission took this information into account when it prepared *ICRP Publication 34* (Protection of the Patient in Diagnostic Radiology), which includes practical guidance on the protection of pregnant patients. *ICRP Publication 34* also deals with examinations in the first 2 months of pregnancy, whether or not a pregnancy has been recognized.

During the first 10 days following the onset of a menstrual period, there can be no risk to any conceptus, since no conception will have occurred. The risk to a child who had previously been irradiated *in utero* during the remainder of a 4-week period following the onset of menstruation is likely to be so small that there need be no special limitation on exposures required within these 4 weeks.

RADIATION PROTECTION

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Principles for Limiting Exposure of the Public to Natural Sources of Radiation

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INTRODUCTION

Exposure to Natural Sources of Radiation

(1) Man, like any organism, has always been exposed to ionizing radiation from natural sources of radiation. A century ago natural sources were the only sources of radiation exposure, and their existence was unknown. Even today, they contribute larger collective doses to the world's population than do all artificial sources.

(2) Natural sources of radiation may be grouped in three types according to origin:

Cosmic radiation, from the sun and from outer space, varies with altitude and latitude;
Cosmogenic radionuclides (mainly carbon-14), produced through interaction of the cosmic rays with atoms in the atmosphere: and
Primordial radionuclides, which have existed in the earth's crust throughout its history (e.g., potassium-40 and nuclides in the uranium and thorium decay series).

From these sources, man is exposed both *externally* (e.g., by cosmic radiation and by radionuclides in the environment) and *internally* (by radionuclides brought into the body with air, water and food.)

(3) Extensive reviews of the natural sources of radiation and of the radiation doses they cause have been published by UNSCEAR (1982). Table 1 summarizes the estimated annual effective dose equivalents from natural sources of radiation in areas of "normal" background.

(4) Until recently, the annual "whole body" dose equivalent from natural sources of radiation was estimated to be about 1 mSv (100 mrem). In the 1982 UNSCEAR report, however, the annual effective dose equivalent is estimated at 2 mSv. The higher estimate is caused mainly by the addition of the effective dose equivalent resulting from the dose to the lung from the decay products of radon and thoron, principally in indoor air, to that from the more uniform exposure of the whole body by the other components of background radiation.

Table 1. Estimated annual effective dose equivalents from natural sources of radiation in areas of "normal" background

Source	Annual effective dose equivalent (millisievert)		
	External irradiation	Internal irradiation	Total
Cosmic rays			
Ionizing component	0.28		0.28
Neutron component	0.02		0.02
Cosmogenic nuclides		0.015	0.015
Primordial nuclides			
Potassium-40	0.12	0.18	0.30
Rubidium-87		0.006	0.006
Uranium-238 series	0.09	0.95	1.04
Thorium-232 series	0.14	0.19	0.33
Total (rounded)	0.65	1.34	2.0

(UNSCEAR, 1982)

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(5) Over the last few years, increasing information from extensive measurements in many countries has shown that the doses caused by natural radiation are in many ways influenced by man's activities. Surprisingly high doses have sometimes been found and, in some countries, trends towards higher doses have been indicated. The main contributors to this trend have been radon decay products in dwellings, where the combination of new building techniques, enhanced concentrations of radium in the building material or in the ground, and reduced ventilation rates have caused high radon concentrations (see Table 2).

Table 2. Estimates of human exposure to natural sources of radiation

	Average annual effective dose equivalent (mSv)	Fraction of total (%)	Range of doses*	Readily controllable
Extraterrestrial				
External exposure	0.3	15	medium	no**
Internal exposure	0.01	0.5	narrow	no
Terrestrial				
External exposure				
Outdoor	0.06	3	medium	no**
Indoor	0.29	14	large	yes
Internal exposure				
^{40}K and ^{87}Rb	0.19	9	narrow	no
^{238}U series:				
Outdoor inhal.	0.06	3	medium	no
Indoor inhal.	0.77	38	very large	yes
Ingestion	0.14	7	medium	yes
^{232}Th series:				
Outdoor inhal.	0.03	1.5	unknown	no
Indoor inhal.	0.17	9	large	no
Ingestion	0.02	1	medium	yes

* "Very large" means a variation by a factor of the order of 1000 between extremes, "large" a factor of up to 100, "medium" a factor of about 10, and "narrow" a variation by less than a factor of 5.
** Reducing this type of exposure usually means moving geographically. This may be possible but is often impracticable. Avoiding new situations will usually be less difficult.

(6) Partly because of the new information on unexpectedly high doses to some individuals from natural sources of radiation (mainly due to wide variations in the indoor concentrations of radon and its decay products) and partly because of the stringent requirements applied to the limitation of exposure to artificial sources of radiation, it is now being suggested that increased emphasis should be given to the extent to which it would be possible to control and limit exposures to natural sources. It is the aim of this report to give guidance on the principles to be applied to the control of exposures to natural sources.

Current ICRP Recommendations

(7) For controllable artificial sources of radiation, ICRP (1977) recommends a system of dose limitation, the main features of which are as follows:

(a) no practice shall be adopted unless its introduction produces a positive net benefit;

(b) all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account; and

(c) the dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.

(8) It is explicitly stated that the dose limits recommended for this purpose by the Commission shall not apply to contributions from "normal" natural radiation (para. 83 of *ICRP Publication 26*). However, the Commission recognized that there may be levels of natural radiation which might have to be controlled, to the extent practicable, in much the same way as for artificial sources.

(9) The Commission did not give any practical guidance on the principles for such control but indicated the problem in the following paragraphs in *ICRP Publication 26*:

(87) Man has always been exposed to radiation from his natural environment, the basic sources of natural radiation exposure being cosmic rays, radioactivity in rocks and soil, and radioactive nuclides incorporated into his tissues. The dose of natural radiation that a person receives depends on a number of factors such as the height above sea-level at which he lives, the amount and type of radioactive nuclides in the soil in his neighbourhood, and the amount that he takes into his body in air, water and food. The total absorbed dose rate in most human tissues from natural radiation is about one-thousandth of a gray per year, but absorbed dose rates up to one-hundredth of a gray per year, or more, have been reported from certain limited areas of the world.

(88) Man-made modifications of the environment and man's activities can increase the "normal" exposure to natural radiation. Examples of this include mining, flight at high altitudes, and the use of building materials containing naturally-occurring radioactive nuclides. Even living within a house is often sufficient to increase radiation exposure because restricted ventilation tends to lead to an accumulation of radioactive gases and their decay products.

(89) In radiation protection the Commission's recommended dose-equivalent limits have not been regarded as applying to, or including, the "normal" levels of natural radiation, but only as being concerned with those components of natural radiation that result from man-made activities or in special environments. This convention, valid on the assumption of linearity, is justified in the sense that the Commission's recommended limits are intended as guides for planning purposes, and thus primarily apply to man-made practices. Clearly, however, there is no sharp dividing line between levels of natural radiation that can be regarded as "normal" and those that are more elevated owing to human activities or choice of environment. There will therefore be instances in which judgment will have to be exercised as to whether the component of increased natural radiation should or should not be subject to the Commission's recommended system of dose limitation.

(90) It should be emphasized moreover that, on the premise that the frequency of radiation effects is linearly proportional to the dose received, such harm as may be caused by natural radiation could be regarded as independent of, and simply additive to, the amount of harm that may be caused by any of the man-made practices involving radiation exposure to which the Commission's limits apply. In this sense, regional variations in natural radiation are regarded as involving a corresponding variation in detriment in just the same way as, for example, regional variations in meteorological conditions or volcanic activity involve differences in the risk of harm in different areas. On this basis there is no reason why differences in natural radiation should affect acceptable levels of man-made exposure, any more than differences in other natural risks should do.

This advice is now expanded and significantly modified. The Commission had already drawn attention to the difficulty of distinguishing between normal and enhanced levels of exposure. It has now concluded that this distinction is unhelpful and bases its new advice on a different approach in which the emphasis is on the extent to which the exposure to the source is controllable.

PROPOSED NEW PRINCIPLES FOR LIMITING EXPOSURES FROM NATURAL SOURCES OF RADIATION

Existing and New Exposure Situations

(10) Almost all exposures to natural sources of radiation are controllable to some extent but the degree of controllability varies very widely, as does the complexity, cost and inconvenience

of the possible control measures. Controllability must therefore be a major factor in any system of dose limitation. From this point of view, there is a clear difference between *existing* exposure situations, where any action would have to be remedial, and *future* situations, which can be subject to limitation and control at the stages of decision and planning. Remedial measures are more likely to be objectionable than are future controls because they withdraw existing facilities or freedoms, or require changes in life-style, or cause an observable increase in personal expenditure. Future controls may do all these things but only by comparison with a situation which has not been allowed to develop. There is no appreciable sense of loss. This distinction, which is exemplified in Table 3, is so marked that the Commission recommends different procedures for existing and future situations.

Table 3. Examples of existing and future exposure situations

Examples of *existing* exposure situations, which can only be influenced by remedial action:	Examples of *future* exposure situations which can be subject to administrative control:
Living in existing houses	Building new houses
	Reducing ventilation in existing houses (e.g., to conserve energy)
Maintaining present production of building materials	Producing building materials from new production facilities
Supplying water from existing facilities	Supplying water from new facilities
Flying in the present manner	
Burning natural gas from old wells	Burning natural gas from new wells
Using fertilisers from operating mills and factories	Using fertiliser from new mills and factories
Consuming food produced in the present manner	

(11) There are cases when the borderline between the two situations will be ill-defined and the choice may seem arbitrary. For example, an existing production of highly radioactive building material may be discontinued, if such *remedial* action is judged necessary, but it may, alternatively, be possible to treat it as a new operation and to require it to conform with conditions intended for new production and *future* situations. However, if such changes are applied to existing practices, they are retrospective in nature, and they will be inherently at variance with earlier judgments of the acceptability of the situation.

(12) Although Table 3 shows a wide range of situations, by far the most important are those concerned with the presence of radon in houses. This report is therefore written with this problem in mind, but is also intended to be general in its application.

Existing Exposure Situations

(13) In existing situations, the exposures can be altered only be taking remedial action. As an aid to deciding whether such action should be initiated, the Commission recommends the use of an action level specific to the initiation of the remedial action being considered. An action level is not determined by the choice of any limits intended for future situations, nor by the primary dose limits recommended by the Commission for members of the public (or for workers) in the control of artificial sources of radiation. In deciding whether to take action, the hazard or social costs involved in any remedial measure must be justified by the reduction of risk that will result. Because of the great variability of the circumstances in which remedial action might be considered, it is not possible for the Commission to recommend action levels that would be

appropriate for all occasions. However, it may sometimes be possible to gauge, by an analysis of the effectiveness and costs of the remedial action, levels below which it would not be appropriate to take action.

(14) The action level determines the initiation of a particular type of remedial action and it is implicit in its selection that the exposed individual should be put in a "better" position by the remedial action. In this sense "better" means at lower risk achieved at a reasonable cost in financial and social terms. Many remedial actions are progressive in their effect—they can be applied with greater or lesser rigour and, thus, with greater or lesser effect. There may also be further remedial action options to be considered once the idea of intervention has been accepted.

(15) The process of deciding how far to go with remedial actions, either singly or in combinations, should involve a process rather similar to that of the optimization of protection. The cost of the radiation detriment to the exposed individuals and the detrimental costs of the remedial actions should be added and a minimum sought for the sum. This optimization process is possible only if the expected dose reduction, as well as the costs, of the remedial action can be forecast. For dealing with radon in houses, there is a rapidly increasing body of experience, but care is still needed to achieve reliable forecasts. The optimization process should be constrained by the requirement that the total cost of all the detriment to the individual should never exceed that corresponding to his exposure in the absence of remedial measures. This constraint might have to be reconsidered if the level of individual risk in the absence of remedial measures was so high that society was not prepared to allow it, even if it were acceptable to the individual. A constraint at a lower level of radiation detriment would then have to be applied, even though the net effect on some individuals would then be disadvantageous.

(16) A well chosen action level will take account of the likely effectiveness of the action to which it will lead and of the total detrimental consequences of the action, which may not be limited, to financial costs. The choice may also be influenced by the social cost and impact of the action and by the distribution of responsibility such as the attribution of the financial liability. Another factor of practical importance is the degree of voluntariness. For example, it may influence the decision on remedial action in a house with high radon concentration if the person at risk is the owner of the house, a tenant, or a child that cannot understand the nature of the risk.

(17) For all these reasons, it would not be helpful to suggest a generally applicable value of an action level, even one limited to the specific case of radon in houses. However, if the remedial action considered is fairly simple, an action level for equilibrium equivalent radon concentration in the region of 200 Bq/m^3 (annual effective dose equivalent of about 20 mSv) might be considered. For severe and disrupting remedial action, a value several times larger might be more appropriate.

(18) Although action levels are, in principle, related to defined remedial actions, they should in practice be thought of as related to the intention to take action. This intention may be thwarted by the personal views of individuals or by their failure to continue a course of action for a prolonged period. For example, it may not be realistic to expect the long continued use of enhanced ventilation in homes, where the householder will become increasingly conscious of the expense but is less likely to retain a corresponding concern about the radiation risks. Features such as this must be taken into account in assessing the feasibility of intervention action.

(19) When action levels are used, it is implicit that there is knowledge of radiation doses and therefore some measure, albeit uncertain, of the individual risks. For practical reasons, some screening mechanism has usually to be developed to avoid undue monitoring and assessment. It is recommended that competent national authorities establish *investigation levels* to separate exposures that require investigation from those that do not.

(20) To a large extent, the need for investigation levels and the feasibility of establishing them depend on the existence of simple monitoring or assessment methods for the preliminary studies. Thus the establishment of an investigation level should not imply that all individual sources and exposure situations must be monitored in order to identify those cases where further investigation is appropriate. In practice, limited studies may indicate which sources (e.g., building materials) might need monitoring, and these sources may often be identified by other means than radiation measurements. For buildings, for example, the type of building material, ground, ventilation, construction, and so on, may suffice for a crude first classification. Water in deep wells is usually markedly more radioactive than surface water and a consideration of the type and cost of action may lead to the decision to assess well water supplies but not surface waters.

(21) The degree of controllability will often indicate whether an action level and an investigation level are useful; for example, the concentration of potassium-40 in food will not influence the radiation exposure significantly since the potassium concentration in human tissues is under homeostatic control and the isotopic composition of potassium is essentially constant. Since this exposure cannot be administratively controlled, neither an investigation level nor an action level is needed. In other cases, easy control may imply that the action level should be low, because remedial action might be worthwhile even at low exposures.

(22) In short, investigation levels will be applied to sample measurements and will be related to the likely action levels. Set too low, they will result in over-burdened resources by yielding an unmanageable number of cases for further investigation. Set too high, such levels may involve inappropriate risks to individuals, because situations calling for action will not be detected.

(23) Sometimes, a small group of monitoring results will be far enough above the investigation level to trigger remedial action. Usually, however, more elaborate measurements will be needed before action can be justified. This is of particular importance in situations where the exposure may vary from day to day, as in the case of radon in buildings, because action has to be decided on the long term average exposure, not on the basis of a single measurement.

Future Exposure Situations

(24) For future situations involving exposure to natural sources of radiation, the position is closer to that recommended by the Commission for artificial sources of exposure. Future exposure situations should be justified in the sense that the source of such exposures should do more good than harm and the protection arrangements should be selected so that the total detriment is minimized, i.e., the radiation doses should be kept as low as reasonably achievable. However, the Commission's recommended dose limits should *not* be applied to these situations; these dose limits were set with full recognition of doses from natural radiation sources, which were not to be included under the limts. If this recommendation were changed, the limits for members of the public would have to be changed (increased). This is not the solution that the Commission recommends.

(25) Instead, it is recommended that the exposure of the most highly exposed individuals should be limited by the application of an *upper bound* of individual dose in the optimization assessment. The upper bound should be established by the competent national authority on the basis of the highest risk that might be considered acceptable to individuals under the various exposure conditions. It will thus be derived in a way which is analogous to the choice of an action level for existing situations but will take into account the fact that future restrictions are less traumatic than retroactive restrictions. It is, therefore, to be expected that an upper bound for a new situation will be lower than the action level for a similar existing situation. The idea of

an upper bound has been used by the Commission in the limitation of exposure to artificial sources (ICRP, 1983). Its function is to constrain the optimization of protection associated with a single source in such a way that the exposure of any individual will remain below the relevant dose limit even if he is exposed to several sources. The upper bound for a single artificial source is therefore set at some fraction of the dose limit which applies to the total exposure to all the relevant sources. For natural sources, the Commission does not recommend a dose limit applying to the total exposure from all such sources, so the upper bound for each class of source or exposure must stand on its own.

(26) It could be argued that an upper bound (as with the action level for existing situations) would only be meaningful if the exposure were controllable. However, *future* exposure situations are usually controllable in the sense that they can be totally avoided (e.g., avoiding living in a high-background area which is not already inhabited). Exposure situations which are not readily controllable (e.g., exposure to potassium-40 or to cosmic radiation) usually imply continuation of an existing practice.

(27) As in existing situations, there will often be merit in using investigation levels applied to simple monitoring or assessment techniques in order to select those situations which most need studying in detail and, if necessary, controlling. Since the doses from radon daughter products in indoor air dominate the exposure pattern from natural sources, the exposure situation in dwellings is the one of immediate interest and the one for which an upper bound is most urgently needed. The need can be illustrated by the fact that indoor equilibrium equivalent radon concentrations of more than $10\,000$ Bq/m^3 have been measured in dwellings in some countries. This implies annual effective dose equivalents of more than ten times the Commission's dose limits for workers and a lung cancer risk which is not likely to be considered acceptable for the future.

(28) In order to establish an appropriate upper bound for exposures from radon indoors, some indication of reference levels of risk would be helpful; for example, the overall risk from other risk sources at home (falling down stairs, electricity, fires, etc.). However, these risks are highly age-dependent and a reference risk is not easily derived. The Commission believes that a reasonable upper bound for the equilibrium equivalent radon concentration is of the order of 100 Bq/m^3 and that, in many countries, a value of this magnitude would prevent radon from becoming a dominating source of risk in dwellings. The upper bound for the individual dose in the optimization assessment of radiation protection in new houses may influence building standards for construction, manufacture, ventilation, etc.

(29) The Commission has issued detailed advice on the application of cost–benefit analysis in the optimization of radiation protection (ICRP, 1983). This advice, modified in relation to the use of action levels and upper bounds rather than dose limits as constraints on the process of optimization, is also applicable to the protection against exposure from natural sources of radiation. Further guidance may be obtained from the examples included in that report. The experience of practical application of protective measures in existing buildings and of suitable precautions in new buildings is rapidly accumulating. The available information indicates that the policy now recommended is both realistic and appropriate.

(30) Administrative intervention in order to limit doses to the public from natural sources of radiation has already occurred in a number of countries. However, the intervention has often occurred in cases where the problem has been local and where some organization or corporation has been identified as responsible for enhanced radiation levels (e.g., the owners of buildings or mill tailings). Consequently, the action levels implied by these previous decisions stem from these local situations and were not necessarily consistent with the present recommendations of the Commission.

References

UNSCEAR, 1982. Ionizing radiation: sources and biological effects. 1982 report to the General Assembly. United Nations, New York, 1982.

ICRP, 1977. Recommendations of the International Commission on Radiological Protection, *ICRP Publication 26, Annals of the ICRP*, **1,** No. 3, 1977.

ICRP, 1983. Cost–benefit analysis in the optimization of radiation protection, *ICRP Publication 37, Annals of the ICRP*, **10,** No. 2/3, 1983.

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