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

	Annual effective dose equivalent (millisievert)		
Source	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)

(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

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