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RADIATION PROTECTION

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## A. INTRODUCTION

(1) The International Commission on Radiological Protection has been functioning since 1928, when it was established by the Second International Congress of Radiology. It assumed its present organizational form in 1950 in order to cover more effectively the rapidly expanding field of radiation protection. As one of the commissions established by the International Congress of Radiology, ICRP has continued its close relationship with succeeding Congresses, and it has also been looked to as the appropriate body to give general guidance on the more widespread use of radiation sources caused by the rapid developments in the field of nuclear energy. ~~The Commission continues to maintain its~~ traditional contact with medical radiology and the medical profession generally, and it also recognizes its responsibility to other professional groups and its obligation to provide guidance within the field of radiation protection as a whole. Details of the Commission's rules, membership and relationships with other bodies are to be found in the appendix to this report.

(2) The first recommendations of the ICRP were published in 1928, and further reports were issued in 1931, 1934 and 1937. Following the Commission's reorganization in 1950, basic recommendations were issued in 1951, 1955 and 1959. A list of these and other recommendations of ICRP is given in the appendix to this report.

(3) In 1966 the Commission published its recommendations (*ICRP Publication 9*) which had been adopted in 1965; they were amended in 1969 and 1971. During the last decade new information has emerged which has necessitated a review of the Commission's

basic recommendations; the present report results from the examination of such new information by the Commission and its committees and task groups. The recommendations made in this report supersede the former basic recommendations published by the Commission, but not necessarily those of its committees.\* Although this publication comprises a comprehensive review of its recommendations, references are made in it to other reports of ICRP committees and task groups, in which more detailed discussion of various points may be found.

(4) As in its previous recommendations, the Commission deals in this report with ionizing radiations only. Although the Commission recognizes that adequate control should be established over a number of sources of non-ionizing radiations, it continues to consider that this is a subject that lies outside its field of work.

(5) The Commission wishes to reiterate that its policy is to consider the fundamental principles upon which appropriate radiation protection measures can be based. Because of the differing conditions that apply in various countries, detailed guidance on the application of its recommendations, either in regulations or in codes of practice, should be elaborated by the various international and national bodies that are familiar with what is best for their needs. The Commission recognizes that the individual experts responsible for putting radiation protection into practice need guidance that is sufficiently flexible to allow for national, regional or other variation. For this reason the Commission's recommendations are intended to provide an appropriate degree of flexibility. Because of this,

\*The status of the various committee publications is shown in the appendix to this report.

the form in which the recommendations are worded will not necessarily be suitable, and may often be inappropriate, for direct assimilation into regulations or codes of practice.

General guidance on the application of the Commission's recommendations is given in sections F and G.

## B. OBJECTIVES OF RADIATION PROTECTION

(6) Radiation protection is concerned with the protection of individuals, their progeny and mankind as a whole, while still allowing necessary activities from which radiation exposure might result. The detrimental effects against which protection is required are known as somatic and hereditary; radiation effects are called "somatic" if they become manifest in the exposed individual himself, and "hereditary" if they affect his descendants.

(7) "Stochastic" effects are those for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose, without threshold. "Non-stochastic" effects are those for which the severity of the effect varies with the dose, and for which a threshold may therefore occur. At the dose range involved in radiation protection, hereditary effects are regarded as being stochastic. Some somatic effects are stochastic; of these, carcinogenesis is considered to be the chief somatic risk of irradiation at low doses and therefore the main problem in radiation protection.

(8) Some non-stochastic somatic effects are specific to particular tissues, as in the case of cataract of the lens, non-malignant damage to the skin, cell depletion in the bone-marrow causing haematological deficiencies, and gonadal cell damage leading to impairment of fertility. Other non-stochastic effects may arise in the blood-vessels or connective tissue elements which are common to most organs of the body, and therefore require that, as a precautionary measure, a dose-equivalent limit should apply for all body tissues, to en-

sure that non-stochastic effects do not occur in any such tissue. For all these changes, the severity of the effect depends on the magnitude of the dose received, and there is likely to be a clear threshold of dose below which no detrimental effects are seen.

(9) The aim of radiation protection should be to prevent detrimental non-stochastic effects and to limit the probability of stochastic effects to levels deemed to be acceptable. An additional aim is to ensure that practices involving radiation exposure are justified (see paragraph 12 and sections E and F).

(10) The prevention of non-stochastic effects would be achieved by setting dose-equivalent limits at sufficiently low values so that no threshold dose would be reached, even following exposure for the whole of a lifetime or for the total period of working life. The limitation of stochastic effects is achieved by keeping all justifiable exposures as low as is reasonably achievable, economic and social factors being taken into account, subject always to the boundary condition that the appropriate dose-equivalent limits shall not be exceeded (see paragraphs 103-128).

(11) Most decisions about human activities are based on an implicit form of balancing of costs and benefits leading to the conclusion that the conduct of a chosen practice is "worthwhile". Less generally, it is also recognized that the conduct of the chosen practice should be adjusted to maximize the benefit to the individual or to society. In radiation protection, it is becoming possible to formalize these broad decision-making procedures, though not always to quantify

them. The procedure is detailed in section E of these procedures. It is therefore necessary to establish dose-equivalents where the benefits received by the population.

(12) For the above reasons, the Commission recommends a system with the following main features of which

- (a) no practice shall be introduced unless the benefits outweigh the risks;
- (b) all exposures shall be justified in terms of the reasonably achievable social factors being taken into account;
- (c) the dose equivalent limits shall not exceed the limits recommended by the Commission.

### *Detriment*

(15) The deleterious effects of radiation may be of many kinds, including non-stochastic effects on health and individual and stochastic effects. In addition, the effects not associated with radiation need to restrict the use of products.

(16) The Commission's concept of detriment is defined as the sum of the possible to quantify, the effects. In general, the definition is defined as the magnitude of the harm incurred to radiation, taking into account the probability of each type

\*International Commission on Radiological Protection Report 19, International Commission on Radiological Protection

them. The procedures are discussed in more detail in section E. However, the application of these procedures does not always provide sufficient protection for the individual. It is therefore necessary, for this reason also, to establish dose-equivalent limits in situations where the benefits and detriments are not received by the same members of the population.

(12) For the above reasons, the Commission 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.

(13) In applying these recommendations, it must be recognized that many present practices give rise to dose equivalents that will be received in the future. These dose-equivalent commitments (see paragraph 25) should be taken into account so that necessary developments of present or future practice would not be liable to result in undue exposure of any members of the public.

(14) Although the principal objective of radiation protection is the achievement and maintenance of appropriately safe conditions for activities involving human exposure, the level of safety required for the protection of all human individuals is thought likely to be adequate to protect other species, although not necessarily individual members of those species. The Commission therefore believes that if man is adequately protected then other living things are also likely to be sufficiently protected.

### C. BASIC CONCEPTS

#### *Detriment*

(15) The deleterious effects of exposure to radiation may be of many kinds. Among the effects on health there may be both stochastic and non-stochastic effects in the exposed individual and stochastic effects in later generations. In addition, there may be deleterious effects not associated with health, such as the need to restrict the use of some areas or products.

(16) The Commission has introduced the concept of detriment to identify, and where possible to quantify, all these deleterious effects. In general, the detriment in a population is defined as the mathematical "expectation" of the harm incurred from an exposure to radiation, taking into account not only the probability of each type of deleterious effect,

but also the severity of the effect. These deleterious effects include both the effects on health and other effects. On some occasions it is convenient to deal separately with the effects, or the potential effects, on health. These are then characterized by the concept of detriment to health. For effects on health, if  $p_i$ , the probability of suffering the effect  $i$ , is small and the severity of the effect is expressed by a weighting factor  $g_i$ , then the detriment to health,  $G$ , in a group of  $P$  persons is given by

$$G = P \sum_i p_i g_i$$

#### *Dose equivalent*

(17) The absorbed dose,\*  $D$ , is insufficient by itself to predict either the severity or the

\*International Commission on Radiation Units and Measurements, Radiation Quantities and Units, *ICRU Report 19*, International Commission on Radiation Units and Measurements, Washington, 1971.

probability of the deleterious effects on health resulting from irradiation under unspecified conditions. In radiation protection it has been found convenient to introduce a further quantity that correlates better with the more important deleterious effects of exposure to radiation, more particularly with the delayed stochastic effects. This quantity, called dose equivalent, is the absorbed dose weighted by the modifying factors  $Q$  and  $N$  given in paragraphs 18-20.

(18) The dose equivalent,  $H$ , at a point in tissue, is given by the equation

$$H = DQN$$

where  $D$  is the absorbed dose,  $Q$  is the quality factor and  $N$  is the product of all other modifying factors specified by the Commission. Such factors might take account, for example, of absorbed dose rate and fractionation. At present, the Commission has assigned the value 1 to  $N$ . The special name for the unit of dose equivalent is the sievert (Sv)

$$1 \text{ Sv} = 1 \text{ Jkg}^{-1} (= 100 \text{ rem}).$$

(19) The quality factor,  $Q$ , is intended to allow for the effect on the detriment of the microscopic distribution of absorbed energy. It is defined as a function of the collision stopping power ( $L_{\infty}$ ) in water at the point of interest. Interpolated values of  $Q$  as a function of  $L_{\infty}$  can be obtained from the figure, which is based on the values shown in the table.

$L_{\infty}$ - $Q$ RELATIONSHIP	
$L_{\infty}$ in water (keV/ $\mu\text{m}$ )	$Q$
3.5 (and less)	1
7	2
23	5
53	10
175 (and above)	20

For a spectrum of radiation, an effective value,  $\bar{Q}$ , of  $Q$  at the point of interest can be calculated.\*

(20) When the distribution of radiation in  $L_{\infty}$  is not known at all points in the volume of interest, it is permissible to use approximate

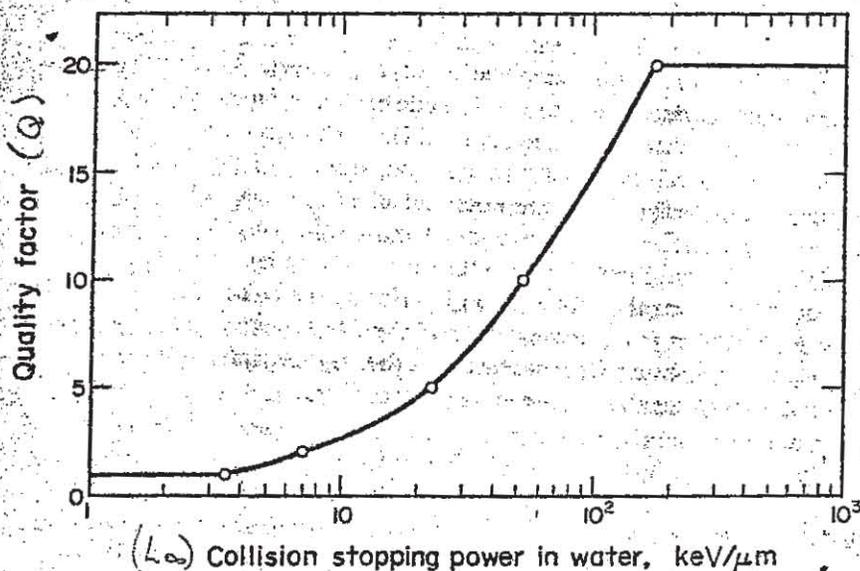


FIG. 1. Quality factor as a function of collision stopping power in water.

\*International Commission on Radiation Units and Measurements, Dose Equivalent, *Supplement to ICRU Report 19*, International Commission on Radiation Units and Measurements, Washington, 1973.

values for  $\bar{Q}$  related primary radiation. F mission recommend:  $\bar{Q}$  to be used for bo radiation:

X rays,  $\gamma$  rays and e  
Neutrons, protons  
singly-charged parti  
greater than one at  
unknown energy  
 $\alpha$  particles and multi  
particles (and parti  
charge), of unknown

In the case of ther  
uniquely defined, an  
the tables and diagra  
function of neutro  
Publication 21, fig.  
thermal neutrons).

(21) The recomme  
are intended for use  
tion, and then for co  
exposure with the lim  
for assessing those ca  
that are taken into a  
such limits. The value  
selected on the basis o  
relative biological effe  
account of the fact t  
limits (see paragraph  
extrapolations from l  
which deleterious effe  
ly assessed. These va  
not necessarily repre  
relative biological e  
observed effects, such  
animals at low levels c  
stochastic effects in  
doses. It is particular  
equivalent should no  
likely early consequer  
exposures in man.

Collective dose equiv

(22) The relations  
and the distribution c  
exposed population  
single quantity can a

values for  $\bar{Q}$  related to the various types of primary radiation. For this purpose the Commission recommends the following values of  $\bar{Q}$  to be used for both external and internal radiation:

X rays, $\gamma$ rays and electrons	1
Neutrons, protons and singly-charged particles of rest mass greater than one atomic mass unit of unknown energy	10
$\alpha$ particles and multiply-charged particles (and particles of unknown charge), of unknown energy	20

In the case of thermal neutrons the  $L_{\infty}$  is uniquely defined, and  $\bar{Q}$  may be taken from the tables and diagrams which present  $\bar{Q}$  as a function of neutron energy (*viz.* ICRP Publication 21, fig. 15, giving  $\bar{Q} = 2.3$  for thermal neutrons).

(21) The recommended values of  $Q$  and  $\bar{Q}$  are intended for use only in radiation protection, and then for comparing actual levels of exposure with the limits of dose equivalent, or for assessing those components of detriment that are taken into account in the setting of such limits. The values of  $Q$  and  $\bar{Q}$  have been selected on the basis of relevant values of relative biological effectiveness but they also take account of the fact that the dose-equivalent limits (see paragraphs 103-104) are based on extrapolations from higher absorbed doses at which deleterious effects in man can be directly assessed. These values of  $Q$  are therefore not necessarily representative of values of relative biological effectiveness for other observed effects, such as stochastic effects in animals at low levels of absorbed dose or non-stochastic effects in man at high absorbed doses. It is particularly important that dose equivalent should not be used to assess the likely early consequences of severe accidental exposures in man.

#### Collective dose equivalent

(22) The relationship between detriment and the distribution of dose equivalent in an exposed population is not simple, and no single quantity can adequately represent the

distribution for the purpose of assessing detriment. Nevertheless, there are many situations in which valuable use can be made of the quantity called collective dose equivalent. The collective dose equivalent ( $S$ ) in a population is defined by the expression

$$S = \sum_i H_i P_i$$

where  $H_i$  is the *per caput* dose equivalent in the whole body or any specified organ or tissue of the  $P_i$  members of sub group ( $i$ ) of the exposed population. The application of this concept is discussed in paragraphs 219, 221 and 232.

(23) The collective dose equivalent ( $S_k$ ) from a practice or source ( $k$ ), is defined by the expression

$$S_k = \int_0^{\infty} \overbrace{HP(H)}^? dH$$

where  $P(H) dH$  is the number of individuals receiving a dose equivalent in the whole body or any specified organ or tissue in the range  $H$  to  $H + dH$ . It is often not necessary to assess the contributions from small values of  $H$  accurately, provided that an upper estimate shows that they would not add significantly to the total integral. Ordinarily, the upper range of the integration is limited by the relevant dose-equivalent limits. A collective dose equivalent including contributions from high doses is not suitable for assessments of the type described in paragraph 24.

(24) In the definition of the detriment to health (paragraph 16), if there is a proportional relationship between  $H$  and  $p_i$  (see paragraphs 27-30) and if  $g_i$  is independent of  $H$ , then the detriment to health,  $G$ , is proportional to the collective dose equivalent,  $S_k$ . The validity of this relationship between detriment and collective dose equivalent depends on the validity of the assumed linearity, with no threshold, between risk and dose equivalent. The Commission has stressed that this is a cautious assumption, the reliability of which has not yet been established, and it is conceivable that the proportionality factors

or risk factors (risk per unit dose equivalent) could vary with the previously accumulated dose equivalent. However, for practices resulting in small increments of dose equivalent above that corresponding to the natural background, the additional detriment to health,  $\Delta G$ , from a practice ( $k$ ) must be closely proportional to  $S_k$ , even though the proportionality constant may be unknown. Furthermore, approximate proportionality would hold in cases where all the individual dose equivalents fell within a roughly linear region of the dose-response relationship.

#### Dose-equivalent commitment

(25) Further quantities are needed when the exposure is extended in time. The dose-equivalent commitment,  $H_c$ , from a given decision or practice, is the infinite time integral of the *per caput* dose-equivalent rate,  $\bar{H}(t)$ , in a given organ or tissue for a specified population:

$$H_c = \int_0^{\infty} \bar{H}(t) dt$$

## D. RADIOBIOLOGICAL CONSIDERATIONS

### DOSE-RESPONSE RELATIONSHIPS

(27) The relationship between the dose received by an individual and any particular biological effect induced by irradiation is a complex matter on which much further work is needed. For radiation protection purposes it is necessary to make certain simplifying assumptions. One such basic assumption underlying the Commission's recommendations is that, regarding stochastic effects, there is, within the range of exposure conditions usually encountered in radiation work, a linear relationship without threshold between dose and the probability of an effect. The simple summation of doses received by a

The exposed population is not necessarily constant in number. It is also possible to define a collective dose-equivalent commitment, which is obtained by integration of the collective dose-equivalent rate.

#### Committed dose equivalent

(26) Another quantity used in these recommendations is the "committed dose equivalent",  $H_{50}$ , to a given organ or tissue from a single intake of radioactive material into the body. This quantity, which may be considered to be a special case of dose-equivalent commitment, is the dose equivalent that will be accumulated over 50 years, representing a working life, following the intake:

$$H_{50} = \int_{t_0}^{t_0+50y} \bar{H}(t) dt$$

where  $\bar{H}(t)$  is the relevant dose-equivalent rate and  $t_0$  is the time of intake.

tissue or organ as a measure of the total risk, and the calculation of the collective dose equivalent (see paragraphs 22 and 23), as an index of the total detriment to a population, are valid only on the basis of this assumption and that the severity of each type of effect is independent of dose.

(28) The added risk from a given dose increment will depend on the slope of the dose-response relationship. If the dose-response relationship for stochastic processes is in fact highly sigmoid, the risk from low doses could be overestimated by making a linear extrapolation from data obtained at high doses.

There are radiobiological indications that the dose-response relationship for stochastic effects will generally increase with increasing dose and absorbed dose range. Many effects studied in this range show a linear response in this range. An expression of the form

$$E = a + bD^2$$

where  $E$  denotes the effect,  $a$  and  $b$  are constants, and  $D$  is the dose (in gray) and high absorbed doses (of the order of one gray per year) will come to predominate. Although the form has been documented for many effects, the relative values of  $a$  and  $b$  vary from one effect to another. The extent to which the linear term may differ for other situations is not determined. For human populations, knowledge of the shape of the curves at low doses and the relative values of  $a$  and  $b$  is limited. Nevertheless, in a few instances based on results of experiments with populations involving doses of the order of 0.5 Gy or less, repeated at intervals of 1 year, such cases it can be seen that the frequency per unit dose of individual harmful effects from repeated exposures is not likely to

\*1 gray (Gy) = 1 J kg<sup>-1</sup> (= 100 rad)  
†At high doses this expression is not valid for cell sterilization. This effect is discussed in paragraph 33.)

There are radiobiological grounds for assuming that the dose-response curve for low-LET radiation will generally increase in slope with increasing dose and dose rate, over the absorbed dose range up to a few gray.\* For many effects studied experimentally, the response in this range can be represented by an expression of the form:

$$E = aD + bD^2$$

where  $E$  denotes the effect,  $D$  the dose and " $a$ " and " $b$ " are constants. The quadratic term ( $bD^2$ ) in this expression predominates at high absorbed doses (generally above one gray) and high absorbed-dose rates (of the order of one gray per min); however, the linear term ( $aD$ ) and the slope that it represents come to predominate as the dose and dose rate are reduced. Although a relationship of this form has been documented for a variety of effects, the relative values of the parameters " $a$ " and " $b$ " vary from one observation to another. The extent to which the relationship may differ for other situations remains to be determined. For human populations in particular, knowledge of dose-response relationships is too limited to enable confident prediction of the shapes and slopes of the curves at low doses and low dose rates. Nevertheless, in a few instances risk estimates can be based on results of irradiation of human populations involving single absorbed doses, of the order of 0.5 Gy or less, or to such doses repeated at intervals of a few days or more. In such cases it can be reasonably assumed that the frequency per unit absorbed dose of particular harmful effects resulting from such exposures is not likely to overestimate greatly

the frequency of such effects in the dose range of concern in radiation protection, even though the latter may be received at much lower dose rates.

(29) In many instances, however, risk estimates depend on data derived from irradiation involving higher doses delivered at high dose rates. In these cases, it is likely that the frequency of effects per unit dose will be lower following exposure to low doses or to doses delivered at low dose rates, and it may be appropriate, therefore, to reduce these estimates by a factor to allow for the probable difference in risk. The risk factors discussed later have therefore been chosen as far as possible to apply in practice for the purposes of radiation protection.

(30) The use of linear extrapolations, from the frequency of effects observed at high doses, may suffice to assess an upper limit of risk, with which the benefit of a practice, or the hazard of an alternative practice—not involving radiation exposure—may be compared. However, the more cautious such an assumption of linearity is, the more important it becomes to recognize that it may lead to an overestimate of the radiation risks, which in turn could result in the choice of alternatives that are more hazardous than practices involving radiation exposures. Thus, in the choice of alternative practices, radiation risk estimates should be used only with great caution and with explicit recognition of the possibility that the actual risk at low doses may be lower than that implied by a deliberately cautious assumption of proportionality.

\*1 gray (Gy) = 1 J kg<sup>-1</sup> (= 100 rad).

†At high doses this expression would have to be modified to take account of the decreased tumour risk caused by cell sterilization. This effect is not significant at the doses encountered in normal exposure conditions. (However, see paragraph 33.)

disadvantage of overestimating risks

No over

but estimated

## IMPLICATIONS OF ASSUMPTIONS ABOUT DOSE-RESPONSE RELATIONS

(31) A practical radiation protection system needs to be based on certain simplifying assumptions if it is to be applied effectively. The assumptions already made about the proportionality between dose and effect over the range of doses of concern in radiation protection imply certain principles that can be applied to important practical problems such as those relating to significant volumes and areas and the rate at which doses may be accumulated. These are discussed in the paragraphs that follow.

### *Significant volumes and areas*

(32) From the assumption about the proportionality between dose and response (see paragraphs 27-30) it would follow that for stochastic effects it would be justifiable to consider the mean dose\* over all cells of uniform sensitivity in a particular tissue or organ. This use of the mean dose has practical advantages in that the significant volume can usually be taken as that of the organ or tissue under consideration.

(33) When the irradiation of a tissue is non-homogeneous, the use of the mean dose over the tissue ceases to be strictly valid if doses to individual cells differ more widely than the range of doses over which the dose-response relationship for the tissue can be regarded as linear. An example of this may be the irradiation of the lung by radioactive particulates. However, on the basis of theoretical considerations, and of available epidemiological evidence, the Commission believes that, for late stochastic effects, the absorption of a given quantity of radiation energy is ordinarily likely to be less effective when due to a series of "hot spots" than when uniformly distributed, because of the

effect of high doses in causing the loss of reproductive capacity or the death of cells. Thus, with particulate radioactive sources within a tissue, to assess the risk by assuming a homogeneous dose distribution would probably overestimate the actual risk. Moreover, for non-stochastic effects, the limited amount of cell loss that might result at moderate dose levels would be most unlikely to cause any impairment of organ function.

(34) For exposure of the skin, either to external sources or as a result of skin contamination, it is not generally appropriate to average the dose equivalent over the entire skin. The averaging procedure will depend on the circumstances and is discussed in more detail in paragraphs 182 and 183.

### *Rate of dose accumulation*

(35) The Commission previously recommended that, for occupational exposure, the magnitude of a single dose equivalent should be limited to one-half of the former annual dose-equivalent limit. This practice, which was intended to prevent the accumulation of more than the annual dose-equivalent limit within a short period of time, now seems to be unnecessary. The Commission therefore believes that it is sufficient to set annual dose-equivalent limits and does not recommend any further restrictions either on the instantaneous rate or on the rate at which the dose equivalent may be accumulated, except in the case of occupational exposure of women of reproductive capacity and pregnant women (see paragraphs 115 and 116). In consequence, the Commission no longer recommends the use of the former age-related formula.

*Supplement for the 1977 ICRP*

\*Unless specifically qualified, the term dose equivalent refers to the mean dose equivalent over the entire organ or tissue.

(36) In its former Commission stated one organ of the irradiation of one pa is likely to be of great of the dose it rece radiation or the impo damage that results. I referred to as the c circumstances, and d individual was dete equivalent limit for th concept of the critical did not permit the su according to the relati the irradiated tissues. recommends a pro account of the total r exposure of all tis paragraphs 104, 105 ar (37) For the pu protection it is necessa of organs and tissues considered because of t radiation damage, the damage and the extent treatable. In this sect presents an outline of t about these features radiation protection.

(38) Some of the qu discussed in the follo clearly age- or sex-depe those for the developr or for the induction of addition, the risk facto of malignancies are red because of the long later the development of the reasons the total risk exposure will vary som with sex, although in from the average value sexes are not considere purposes therefore, su obtained by using a sin

## TISSUES AT RISK

(36) In its former recommendations the Commission stated that, when more than one organ of the body is exposed, the irradiation of one particular organ or tissue is likely to be of greatest importance because of the dose it receives, its sensitivity to radiation or the importance to health of any damage that results. This tissue or organ was referred to as the critical one under the circumstances, and dose limitation for the individual was determined by the dose-equivalent limit for that tissue or organ. The concept of the critical organ used in this way did not permit the summation of detriment according to the relative radiosensitivities of the irradiated tissues. The Commission now recommends a procedure which takes account of the total risk attributable to the exposure of all tissues irradiated (see paragraphs 104, 105 and 125).

(37) For the purposes of radiation protection it is necessary to specify a number of organs and tissues that have to be considered because of their susceptibility to radiation damage, the seriousness of such damage and the extent to which this could be treatable. In this section the Commission presents an outline of the assumptions made about these features for the purposes of radiation protection.

(38) Some of the quantitative risk factors discussed in the following paragraphs are clearly age- or sex-dependent, as for example those for the development of breast cancer or for the induction of hereditary defects. In addition, the risk factors for the occurrence of malignancies are reduced in older persons because of the long latent periods involved in the development of these effects. For these reasons the total risk from an individual exposure will vary somewhat with age and with sex, although in fact the variations from the average value for all ages and both sexes are not considerable. For protection purposes therefore, sufficient accuracy is obtained by using a single dose-equivalent

limit for each organ or tissue for all workers regardless of age or sex. These limits are based upon the average risk levels described below for the various organs or tissues. The same principle applies also for different members of the general public.

(39) The risk factors for different tissues are based upon the estimated likelihood of inducing fatal malignant disease, non-stochastic changes, or substantial genetic defects expressed in liveborn descendants. It is recognized that the appropriate basis for quantifying detriment should include the evaluation of all other forms of hurt and suffering that may result from exposure. This problem is the subject of a task group report being prepared for the Commission. It appears likely that the forms of detriment mentioned above would be regarded as the dominant components of the harm that may be caused by radiation, and those on which risk factors should most appropriately be based.

*Gonads*

(40) Deleterious effects caused by irradiation of the gonads may be of three different types: tumour induction, impairment of fertility in the irradiated individual, and hereditary effects in descendants.

(41) Human gonads appear to have a relatively low sensitivity to the induction of cancer by irradiation, since no carcinogenic effects in these organs have yet been documented conclusively.

(42) In the female, impairment of fertility varies with age. Induction of menopause, with permanent cessation of fertility, could result from an absorbed dose of 3 Gy (low-LET radiation) in a woman aged 40, whereas the same absorbed dose might cause only temporary amenorrhoea in a woman aged 20. The difference is related to the fact that production of new oocytes normally ceases in childhood, the number of such cells decreasing progressively with age after

menarche, as oocytes lost from the ovary through ovulation or for other causes are not replaced. In the testis, by contrast, the supply of spermatozoa is replenished continually throughout adult life by proliferation of spermatogonia and other sperm precursor cells. Depletion of such cells by irradiation can be repaired if enough spermatogonia remain intact to repopulate the damaged testis. Although the sperm count may be depressed temporarily by an absorbed dose of 0.25 Gy (low-LET radiation) delivered at a high dose rate, the absorbed dose required to cause permanent sterility is larger by at least an order of magnitude.

(43) The gonads are the tissues involved in the production of radiation-induced gene mutations and chromosomal changes leading to hereditary defects. Observations, mainly on small mammals and lower organisms, have provided data on the frequencies of hereditary changes resulting from irradiation; observations on man have indicated the frequencies of the various naturally-occurring hereditary and partially hereditary diseases that might be affected. The extents to which these diseases would increase with a given increase in the mutation rate have for the most part not been demonstrated directly in any organism. It is believed that the frequency of dominant, sex-linked and certain chromosomal diseases would increase in direct proportion to dose. The increase in the more common "irregularly inherited" diseases would be less, especially in the first two generations. Where the whole of the body is exposed uniformly, it has been estimated for present purposes that the hereditary detriment is likely to be less than the detriment due to somatic injury in the irradiated individuals. The risk of serious hereditary ill health within the first two generations following the irradiation of either parent is taken to be about  $10^{-2}$  Sv<sup>-1</sup>, and the additional damage to later generations to be of the same magnitude. The risk factor for radiation protection purposes is given in paragraph 60.

#### Red bone marrow

(44) The red bone marrow is taken to be the tissue mainly involved in the causation of radiation-induced leukaemia; other blood-forming tissues are thought to play a minor role in leukaemogenesis. Observations on humans irradiated for therapeutic purposes or on Japanese survivors of nuclear explosions indicate that the incidence of radiation-induced leukaemia reaches its peak within a few years after irradiation, and returns to pre-irradiation levels after about 25 years. For radiation protection purposes the risk factor for leukaemia is taken to be  $2 \cdot 10^{-3}$  Sv<sup>-1</sup>.

(45) The haematopoietic cells in adults are assumed to be randomly distributed throughout the haematopoietic marrow within trabecular bone (see *ICRP Publication 11*). Therefore, dose equivalent to those cells is calculated as the average over the tissue which entirely fills the cavities within trabecular bone.

(46) Animal experiments have indicated that a protracted absorbed dose of 20 Gy (gamma radiation) over a lifetime would not impair the haematopoietic function of the red bone marrow. In man the impairment of function of the red bone marrow is not considered likely to be a limiting effect, provided that occupational non-stochastic dose limits are set at the levels recommended in paragraph 103.

#### Bone

(47) The radiosensitive cells in bone have been identified as the endosteal cells and epithelial cells on bone surfaces (see *ICRP Publication 11*). The Commission recommends that, where possible, dose equivalent in bone should apply to the endosteal cells and cells on bone surfaces, and should be calculated as an average over tissue up to a distance of 10  $\mu$ m from the relevant bone surfaces.

(48) A review by the Commission of the radiosensitivity of bone in relation to the development of radiation-induced cancer indicates that, per unit dose equivalent, it is

much less sensitive than red bone marrow, lung and thymus. For radiation protection purposes the risk factor for cancer is taken to be  $5 \cdot 10^{-3}$  Sv<sup>-1</sup>.

#### Lung

(49) Cancer of the lung in miners exposed to high concentrations of radon and its decay products is difficult to derive a quantitative risk in terms of dose, because of the wide range in the estimates of the risk per unit concentration of radon. However, the epidemiological evidence makes it possible to set a concentration of radon in air and the length of time of exposure as to ensure an adequate level of protection. A more detailed discussion can be found in the forthcoming report of the Committee 2's task group on radon and its daughter products.

(50) Cancer of the lung is caused by radiation exposure to people who have worked in uranium mines, even though some of the radon concentration is above current limits. In paragraph 33, the Commission has considered the hazard of particulate matter distributed in the air, which is likely to be less than that of radon in the lung.

(51) There is evidence that radiation exposure can also induce lung cancer. The present indication is that the risk of lung cancer is about the same as that of leukaemia; this risk should be modified when the dose is available on the time-course of lung cancer after irradiation. For radiation protection purposes the risk factor for cancer is taken to be  $2 \cdot 10^{-3}$  Sv<sup>-1</sup>.

*Pulmonary lymphoid tissue* is a particularly important case of importance concerning the risk of inhaled particles containing radon daughter products.

much less sensitive than breast, red bone marrow, lung and thyroid. For purposes of radiation protection the risk factor for bone cancer is taken to be  $5 \cdot 10^{-4} \text{ Sv}^{-1}$ .

### Lung

(49) Cancer of the lung has been observed in miners exposed to high concentrations of radon and its decay products. In miners it is difficult to derive a quantitative estimate of risk in terms of dose, because of the great range in the estimates that have been made of dose per unit concentration of activity in air. However, the epidemiological evidence makes it possible to set limits combining the concentration of radon daughter products in air and the length of time spent in that air, so as to ensure an adequate degree of protection. A more detailed discussion of this subject is to be found in the forthcoming report of Committee 2's task group on radon, thoron and their daughter products.

(50) Cancer of the lung clearly attributable to radiation exposure has not been reported in people who have worked with radioactive materials in particulate form, such as plutonium, even though some of them were exposed above current limits. As already noted in paragraph 33, the Commission believes that the hazard of particulate material in the lung is likely to be less than that of the same material distributed uniformly throughout the lung.

(51) There is evidence that external irradiation can also induce lung cancer in man. The present indication is that the risk of lung cancer is about the same as that for the development of leukaemia; this estimate may need to be modified when further data become available on the time-course of development of lung cancer after irradiation. For radiation protection purposes the risk factor for lung cancer is taken to be  $2 \cdot 10^{-3} \text{ Sv}^{-1}$ .

*Pulmonary lymphoid tissue* (52) A particular case of importance concerns the retention of inhaled particles containing insoluble com-

pounds in bronchopulmonary lymph nodes, which comprise about 1% of all lymphoid tissue in the body. Their selective irradiation can be regarded as corresponding to extremely non-uniform irradiation of the lymphoid tissue as a whole and so probably involving a lower hazard than if the contained activity were uniformly distributed through the total mass of lymphoid tissue. For irradiation of lymphocytes, however, the non-uniformity is less extreme, owing to the normal circulation of lymphocytes through the lymph nodes of the body.

(53) Autopsy data from men who had previously inhaled plutonium particulates indicate that the mean concentration of plutonium as averaged over the total mass of all lymphoid tissue is likely to be substantially less than the mean concentration in lung tissues. Since the lung is regarded as of higher sensitivity than the lymphoid tissue, it is to be assumed that the irradiation of lung is likely to be more limiting than that of lymphoid tissue in determining the dose limitation for such inhaled insoluble radioactive particulates.

(54) For the purposes of radiation protection therefore the Commission considers that, in adults, it will be satisfactory to consider the trachea, bronchi, pulmonary region and pulmonary lymph nodes as one composite organ of mass 1 kg, to which dose limitation for the lung should apply.

### Thyroid

(55) The cells at risk in the thyroid gland appear to be the epithelial cells of the thyroid follicles for which the dose calculation should be made. In most cases the mean dose to the whole gland will be substantially the same as the dose to these cells.

(56) The sensitivity of the thyroid to the induction of cancer by radiation appears to be higher than that of the red bone marrow to the development of leukaemia. However, the mortality from these thyroid cancers is much lower than for leukaemia, primarily because

of the success in the treatment of thyroid cancer and the slow progress of this type of tumour. The overall mortality risk factor is considered to be about one quarter of that for the red bone marrow; for radiation protection purposes the risk factor is taken as  $5 \cdot 10^{-3} \text{ Sv}^{-1}$ .

#### Breast

(57) Data on the development of breast cancer, following irradiation of women, suggest that, during reproductive life, the female breast may be one of the more radio-sensitive tissues of the human body. There are indications that, under these circumstances, the risk factor for breast cancer may be a few times higher than that for leukaemia. For radiation protection purposes the risk factor is taken to be  $2.5 \cdot 10^{-3} \text{ Sv}^{-1}$  (see also paragraph 38).

#### Risk of cancer in all other tissues

(58) In addition to those tissues discussed above, for which an approximate estimate has been made of the frequency with which malignancies are induced by moderate doses of radiation, there are other tissues (e.g. stomach, lower large intestine, salivary glands and probably liver) for which there is evidence that radiation is also carcinogenic at moderate doses. However, for these tissues no estimate can yet be made of the risk factor, although it is likely that this is low. There are other tissues, such as muscle and adipose tissue, for which little evidence has been obtained of any tumour induction at moderate doses.

(59) Some estimate can be obtained, however, of the total of all malignancies induced, relative to the risk of leukaemia induced under the same conditions of irradiation. From this evidence it appears likely that the majority of all induced malignancies arise in those tissues from which approximate estimates of risk have been obtained. On this basis it is estimated that the combined risk of malignancy in all remaining unspecified

tissues is unlikely to exceed  $5 \cdot 10^{-3} \text{ Sv}^{-1}$ , and it is further assumed that no single tissue is responsible for more than one-fifth of this value.

*Total stochastic risk from uniform whole body irradiation*

(60) For the purposes of radiation protection involving *individuals*, the Commission concludes that the mortality risk factor for radiation-induced cancers is about  $10^{-2} \text{ Sv}^{-1}$ , as an average for both sexes and all ages. The average risk factor for hereditary effects, as expressed in the first two generations, would be substantially lower than this, when account is taken of the proportion of exposures that is likely to be genetically significant, and can be taken as about  $4 \cdot 10^{-3} \text{ Sv}^{-1}$ . Both for the somatic, and for the hereditary risk factor, the estimates will differ somewhat for workers and for members of the general public, because of the difference in age structure of the two populations. These differences in total risk, however, are not sufficiently large to warrant the use of separate values for protection purposes in the two cases. However, the assessment of the *total population detriment* due to radiation from a given exposure should also take account of the total risk of hereditary damage that may be expressed in all subsequent generations. This risk, per unit dose, is considered to be about twice that which is expressed in the first two generations only.

#### Lens

(61) When the lens is subjected to protracted irradiation over the occupational lifetime with high or low-LET radiation it can be concluded that a total dose equivalent of 15 Sv would be below the threshold for the production of any lens opacification that would interfere with vision. The Commission therefore recommends that for radiation workers the annual dose-equivalent limit for the lens should be derived from the above dose

equivalent delivered (see paragraph 103).

(62) In adults the anterior epithelium of the lens is most susceptible to radiation-induced lens opacities. For protection purposes the equivalent dose is considered to lie 3 mm from the eye.

#### Skin

(63) In comparison with the tissues discussed, skin is the most liable to develop fatal effects. However, cosmetically significant changes in the skin may occur after absorbed doses of 20 Sv over weeks or months of exposure. Therefore, the limit for exposure over a lifetime should prevent such non-stochastic effects (see paragraph 103).

(64) The thickness of the skin varies considerably from one part of the body to another. The basal cell layer is taken to be the skin layer most sensitive to radiation. Because of undulation of the skin and because of the finite thickness of the skin, a range of 50–100  $\mu\text{m}$  is considered appropriate for specifying the thickness of the sensitive layer of most of the body. In practice are not protected therefore exposed directly. The Commission therefore recommends the use of a reasonable mean value.

equivalent delivered over the working lifetime (see paragraph 103).

(62) In adults the equatorial portion of the anterior epithelium of the lens is the anatomical region generally considered to be the part of the lens most susceptible to the induction of lens opacities. For the purposes of radiation protection the equator of the lens can be considered to lie 3 mm behind the surface of the eye.

#### *Skin*

(63) In comparison with the tissues already discussed, skin is thought to be much less liable to develop fatal cancer after irradiation. However, cosmetically-unacceptable changes in the skin may occur after irradiation with absorbed doses of 20 Gy or more, delivered over weeks or months to limited portions of skin. Therefore, the use of this value, as a limit for exposure over the whole occupational lifetime, should prevent the occurrence of such non-stochastic changes (see also paragraph 103).

(64) The thickness of the skin varies considerably from one part of the body to another. The basal cell layer of the epidermis is taken to be the skin tissue most at risk. Because of undulations in the basal cell layer and because of the finite thickness of its cells, a range of 50–100  $\mu\text{m}$  (or 5–10  $\text{mg cm}^{-2}$ ) is appropriate for specifying the depth of the sensitive layer of most parts of the skin that in practice are not protected by clothing and are therefore exposed directly to radiation. For practical dose assessment the Commission recommends the use of a depth of 70  $\mu\text{m}$  as a reasonable mean value.

#### *Children and foetuses*

(65) Exposure before birth or during childhood may interfere with subsequent growth and development, depending on factors such as dose and age at irradiation. Susceptibility to the induction of certain malignancies also appears to be higher during the prenatal and childhood periods than during adult life.

#### *Tissues of low sensitivity*

(66) It is now established that there are various tissues in which the development of malignancy following irradiation seems to be very rare, as evidenced by the fact that epidemiological surveys have so far not shown excess rates of malignancy in such tissues. For these tissues dose limitation is based on the possibility of vascular or other deleterious changes. There may also be some tissues, for example those containing non-nucleated cells, the irradiation of which can be ignored for the purposes of radiation protection.

#### *Other effects*

(67) Other than the specific effects already discussed, there is no good evidence of impairment of function of organs and tissues at the levels of dose normally encountered in radiation work. The evidence for life-shortening from effects other than tumour induction is inconclusive and cannot be used quantitatively. Moreover, it seems unlikely that any major hazard from irradiation at recommended levels has been overlooked, as judged by the evidence from heavily irradiated populations, observed for periods up to 30 years.

## E. THE SYSTEM OF DOSE LIMITATION

(68) In order to achieve the objectives listed in paragraph 12, the Commission recommends a system of dose limitation, the main purposes of which are to ensure that no source of exposure is unjustified in relation to its benefits or those of any available alternative, that any necessary exposures are kept as low as is reasonably achievable, and that the dose equivalents received do not exceed certain specified limits and that allowance is made for future development. These points are expanded further in the following paragraphs.

(69) Ideally the acceptability of a proposed operation or practice involving exposure to radiation should be determined by cost-benefit analysis, the purpose of which is to ensure that the total detriment should be appropriately small in relation to the benefit resulting from the introduction of the proposed activity. Comparisons between practices should be made after the application of the procedure of optimization (see paragraphs 72-76). The choice between practices will depend on many factors, only some of which will be associated with radiation protection. For this reason, the comparison of practices is not discussed further in this report. Optimization, on the other hand, should be a major part of practical radiation protection; it is discussed in more detail in the following paragraphs.

(70) In cost-benefit analysis the benefits are taken to include all the benefits accruing to society, and not just those that will be received by particular groups or individuals. In certain circumstances benefits can be quantified, but, when they contribute to the satisfaction of human desires, such quantification may prove difficult. Costs are considered as comprising the sum total of all negative aspects of an operation, including monetary costs and any damage to human health or to the environment. Since the distribution through the population of these benefits and

costs will not be the same, this broad process of balancing would, however, be legitimate only if the detriment to each individual does not exceed an acceptable level. In exercising this process in relation to ionizing radiation, the individual limitation of detriment would be achieved by compliance with the Commission's dose-equivalent limits.

(71) It may thus be necessary to make subjective value judgments in order to compare the relative importance of the costs imposed on human health by radiation exposure with other economic and social factors. In this respect radiation is not unique, and the same statement could be made in respect of a number of other agents to which mankind is exposed.

### *The bases for deciding what is reasonably achievable in dose reduction*

(72) Many of the factors described in the preceding paragraphs will not be necessary for deciding what is reasonably achievable in dose reduction below the recommended limits. For this purpose the question is whether or not the activity is being performed at a sufficiently low level of collective dose equivalent (and usually, therefore, of detriment) so that any further reduction in dose would not justify the incremental cost required to accomplish it. In making this determination, the cost-benefit analysis shifts from a consideration of the *total* benefit of the activity to the *change* in net benefit that might be involved in requiring the activity to be performed at one level of dose rather than another.

(73) The net benefit,  $B$ , of a product or an operation involving irradiation can be regarded as equal to the difference between its gross benefit,  $V$ , and the sum of three components: the basic production cost,  $P$ , the cost of achieving a selected level of protection,  $X$ ,

and the cost,  $Y$ , of the operation or disposal of the product.

$$B = V -$$

Cost as used here purely economic cost.

(74) In order to determine the change in exposure is necessary to compare the increase of benefit on the other the increment in the achievement. In the analysis, intended to the independent variable,  $S$ , from the maximum net benefit would

$$\frac{dV}{dS} - \left( \frac{dP}{dS} \right)$$

Since  $V$  and  $P$  can be  $S$  for a given practice optimization condition  $S^*$  such that the increment per unit dose reduction of detriment equivalent, i.e.

$$\left( \frac{dX}{dS} \right)_S$$

However, other costs of detriment, such as respiratory or use of areas, will not be the collective dose equivalent in the exposure.

(75) Assessments of the equation may be helpful in determining a monetary value to the detriment equivalent. Although difficult to quantify the components of the detriment equivalent of the cost equivalent of the published, and, with a possible quantitative decision-making procedure (22).

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and the cost,  $Y$ , of the detriment involved in the operation or in the production, use and disposal of the product, so that

$$B = V - (P + X + Y)$$

Cost as used here includes social as well as purely economic costs.

(74) In order to determine whether a reduction in exposure is "reasonably achievable" it is necessary to consider on the one hand the increase of benefit from such a reduction and on the other the increase of cost involved in its achievement. In the differential cost-benefit analysis, intended to maximize the net benefit, the independent variable is the collective dose equivalent,  $S$ , from the practice. The optimum net benefit would be attained if

$$\frac{dV}{dS} - \left( \frac{dP}{dS} + \frac{dX}{dS} + \frac{dY}{dS} \right) = 0$$

Since  $V$  and  $P$  can be considered constant with  $S$  for a given practice, it follows that the optimization condition is fulfilled at a value  $S^*$  such that the increase in the cost of protection per unit dose equivalent balances the reduction of detriment per unit dose equivalent, i.e.

$$\left( \frac{dX}{dS} \right)_{S^*} = - \left( \frac{dY}{dS} \right)_{S^*}$$

However, other components of radiation detriment, such as restrictions in the access to or use of areas, will not normally be related to the collective dose equivalent and may, in some cases, be influenced by the highest dose equivalent in the exposed group.

(75) Assessments based on the above equation may be helped by the assignment of a monetary value to the unit of collective dose equivalent. Although in practice it is very difficult to quantify even some of the components of the detriment, several estimates of the cost equivalent of a man sievert have been published, and, with all their limitations, they provide possible quantitative inputs to the decision-making process (see *ICRP Publication 22*).

(76) The application of the processes described in preceding paragraphs does not always provide sufficient protection for the individual, particularly when benefits and costs are not identically distributed through the population. For a given practice, regardless of the result of the differential cost-benefit analysis, individual dose-equivalent limits must be respected. If the use of the optimal collective dose equivalent would cause any individual to exceed an appropriate limit, it would be necessary to set the collective dose equivalent at the point where individual dose-equivalent limits would be respected.

*Dose-equivalent limits—general*

(77) The dose equivalent limits formerly recommended by the Commission have been in effect for over 20 years. They have been widely used internationally and have been incorporated into legislation in a number of countries and regions. Furthermore, there is no evidence to indicate that the Commission's recommended system of dose limitation has failed to provide an adequate level of safety. However, the Commission believes that it is appropriate to review its dose-equivalent limits in the light of present knowledge, to determine whether any change in the levels is called for. The Commission's recommended dose-equivalent limits are discussed in paragraphs 103-108.

(78) Almost every exposure of the body involves the irradiation of more than one tissue, and therefore, for reasons referred to in paragraph 36, the Commission believes that, for stochastic effects, it is appropriate to recommend a dose-equivalent limit based on the total risk of all tissues irradiated. This system incorporates the setting of a single dose-equivalent limit for uniform irradiation of the whole body (see paragraphs 104 and 119) and a system designed to ensure that the total risk from irradiation of parts of the body does not exceed that from uniform irradiation of the whole body (see paragraphs 104, 105 and 125). The system is further subject to the

constraint that no single tissue should receive more than a specified dose-equivalent limit to prevent the occurrence of non-stochastic damage (see paragraphs 103 and 126). Ideally, the recommendations of the Commission should be designed to ensure that the detriment from any year's practice should be limited to a value independent of the distribution of dose equivalent within the body.

(79) The Commission's dose limitations are intended to relate to the dose-equivalent commitment resulting from 1 year of a particular practice. With most external irradiation, and with short-lived radionuclides taken into the body, the committed dose equivalent from a year of practice will be received either instantaneously or within a short time, and thus should be subject to the limit for that year. However, the committed dose equivalent from 1 year's intake of a long-lived radionuclide refers to dose equivalents delivered over a long period, even up to many years, after the year in question. In principle, the use of the dose-equivalent commitment concept does permit the dose equivalent received in a single year to exceed the annual limit (e.g. in the case of an intake in 1 year of a material of long effective half life, followed by an intake in the next year equal to an ALI\* of a material of short effective half life). In practice such situations will be rare and the dose equivalent during any year in excess of the annual limit will normally be small.

(80) The Commission considers that, in assessing risks for the purposes of setting the dose-equivalent limit for individuals, the hereditary detriment in the immediate offspring of an individual (i.e. in the first two generations after irradiation) should be added to the total of any radiation-induced somatic detriment. The present indications are that a substantial part of the total hereditary harm appears in these first two generations of an individual's offspring. The harm to be received by all subsequent generations would

need to be considered in any assessment of total hereditary effects. The reproductive life of workers exposed to radiation is considered to last about one third of their working career, and the Commission has therefore taken this factor into account in deriving the weighting factors given in paragraph 105.

(81) The Commission's recommendations deal quite differently with two distinct conditions of exposure:

- (i) in which the occurrence of the exposure is foreseen and can be limited by control of the source and by the application of the Commission's system of dose limitation, including the development of satisfactory operating procedures;
- (ii) in which the source of exposure is not subject to control, so that any subsequent exposure can be limited in amount, if at all, only by remedial actions.

When a source of exposure is subject to control it is feasible to apply the Commission's system of dose limitation (see paragraph 12). Once such a system has been established, the objective should be to plan the use of radiation sources in such a way that, in normal practice, the system will not be infringed. The dose-equivalent limits assume the additional critical function of acting as a check on proper and adequate working practices at the source of exposure. The dose-equivalent limits should not be regarded as a dividing line between safety and danger; when limits have been exceeded by a small amount it is generally more significant that there has been a failure of control than that one or more individuals have slightly exceeded a certain agreed dose.

(82) In many practical situations it will be convenient to make use of a derived limit, calculated with the aid of a model, which provides a quantitative link between a particular

measurement and equivalent limit. paragraph 140 of the intention should be such that adherence to the Commission's recommendations. However, failure to meet the limit will not necessarily achieve compliance with the recommendation. more careful study of the matter is discussed in F.

(83) The Commission's recommendations are intended to protect individuals; hereditary effects on the offspring of an individual should be considered as a whole population. The dose limits are intended to protect the population, namely the general exposure of an organ or tissue. The dose equivalent shall be calculated from the dose equivalent of the sources and committed radioactivity taken into account over a year of practice. The limits, the dose equivalent include contributions from the procedure or from (see also paragraph

(84) The dose limits have been established and are regarded as equivalent to the maximum permissible limits and are not equivalent to the theoretical concentration. The design and operation makes it unlikely that the population will receive more than the equivalent. This is checked by ass

\*Annual Limit of Intake.

measurement and the recommended dose-equivalent limit or intake limit (see also paragraph 140 *et seq.*). In deriving such a limit the intention should be to establish a figure such that adherence to it will provide virtual certainty of compliance with the Commission's recommended dose-equivalent limits. However, failure to adhere to the derived limit will not necessarily imply a failure to achieve compliance with the Commission's recommendations and may require only a more careful study of the circumstances. This matter is discussed in greater detail in section F.

(83) The Commission's recommendations are intended to limit somatic effects in individuals, hereditary effects in the immediate offspring of irradiated individuals, and hereditary and somatic effects in the population as a whole. It is therefore necessary to consider the exposure of both individuals and populations. The Commission's recommended dose limits apply to two categories of exposure, namely occupational exposure and general exposure (see paragraph 137). In any organ or tissue the limitation of the dose equivalent shall refer to the sum of the annual dose equivalents contributed by external sources and committed dose equivalents from radioactivity taken into the body during any year of practice. In relation to dose-equivalent limits, the dose equivalent shall not be held to include contributions from any medical procedure or from "normal" natural radiation (see also paragraphs 87-93).

(84) The dose-equivalent limits that have been established for occupational exposure are regarded as upper limits, and the dose equivalents may have to be individually monitored and controlled to ensure that the limits are not exceeded. Limitation of dose equivalent for members of the public is a more theoretical concept, intended to ensure that the design and operation of radiation sources makes it unlikely that individuals in the public will receive more than the specified dose equivalent. The effectiveness of this is checked by assessments through sampling

procedures and statistical calculations, and by control of the sources from which the exposure is expected to arise, and only rarely by spot checks of individual exposures.

(85) The basis for the limitation of individual exposures, either of workers or of members of the public, is the limit for the weighted mean whole body dose equivalent (see paragraph 104) and not the derived limits or levels by which the dose is controlled. The actual doses received by individuals will vary depending on factors such as differences in their age, size, metabolism and customs, as well as variations in their environment. With an occupationally-exposed individual it will often be sufficient to use derived limits and levels to assess his exposure status. With exposure of members of the public it is usually feasible to take account of these sources of variability by the selection of appropriate critical groups within the population provided the critical group is small enough to be relatively homogeneous with respect to age, diet and those aspects of behaviour that affect the doses received. Such a group should be representative of those individuals in the population expected to receive the highest dose equivalent, and the Commission believes that it will be reasonable to apply the appropriate dose-equivalent limit for individual members of the public to the weighted mean dose equivalent of this group. Because of the innate variability within an apparently homogeneous group some members of the critical group will in fact receive dose equivalents somewhat higher than the mean. However, because of the maximizing assumptions used, the dose equivalent actually received will usually be lower than the estimated dose equivalent (see also section G).

(86) Before discussing the limitation of doses in different conditions of exposure, it is first necessary to review the relationship of the Commission's recommended dose-equivalent limits to exposures from natural radiation and of patients from medical procedures.

*Natural radiation and dose-equivalent limits*

(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 (see paragraphs 27-30), 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 there-

fore 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.

*Medical exposures of patients and dose-equivalent limits*

(91) In these recommendations "medical exposure" refers to the intentional exposure of patients for diagnostic and therapeutic purposes, and to the exposures resulting from the artificial replacement of body organs or functions (e.g. by heart pumps and cardiac pace-makers). It applies to exposures administered by medical and paramedical personnel. It does not refer to the irradiation of the staff involved in the administration of medical exposures to patients, nor to the irradiation of one patient by another.

(92) Medical exposure is, in general, subject to most of the Commission's system of dose limitation, that is: unnecessary exposures should be avoided; necessary exposures should be justifiable in terms of benefits that would not otherwise have been received; and the doses actually administered should be

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limited to the minimum amount consistent with the medical benefit to the individual patient. The individual receiving the exposure is himself the direct recipient of the benefit resulting from the procedure. For this reason it is not appropriate to apply the quantitative values of the Commission's recommended dose-equivalent limits to medical exposures. With certain medical exposures a very much higher level of risk may in fact be justified by the benefit derived than by the level judged by the Commission to be appropriate for occupational exposure or for exposure of members of the public.

(93) It has already been indicated in paragraph 89 that the Commission's recommended dose-equivalent limits are intended for planning purposes and refer to that component of risk resulting from a particular practice to which radiation protection applies. Under the assumption of linearity the risk from such a practice is unaffected by the risks from other sources, and it is therefore justifiable to consider separately the doses received from such practices from the doses acquired from medical exposure. In view of the considerations detailed in paragraph 92, the Commission considers that radiation doses resulting from medical exposures should not influence any of the procedures of dose limitation applied to exposures from other sources. However, because of the possibility of non-stochastic effects developing in the exceptional cases of workers who have undergone radiodiagnosis or radiotherapy involving heavy irradiation of part of the body, and whose work would involve substantial exposure of those parts, the working situation should be reviewed by the competent medical authority.

#### *Implications for non-stochastic effects*

(94) As already stated, the Commission's recommended dose-equivalent limits for the limitation of *stochastic* effects do not apply to contributions from natural radiation sources or from medical exposure. However, the

question of *non-stochastic* effects merits consideration.

(95) When exposure is limited by consideration of stochastic effects, it is unlikely that the addition of occupational exposures and normal medical or natural radiation exposures would cause a total dose equivalent that would be near threshold values of any harmful non-stochastic effect. Although, in principle, contributions to the dose equivalent from *all* sources (i.e. also from medical sources and normal natural background) should be added in assessing the likelihood of non-stochastic damage occurring, the Commission considers that in practice it is not necessary that this should be done. High doses from natural radiation sources would only be expected to occur under the special conditions mentioned in paragraph 89 and should in any case then be included under the dose-equivalent limits to the extent that the elevated exposures are subject to human control. In the case of high medical exposures (e.g. in radiotherapy) it would be the doses from these exposures that would dominate, and the consideration of possible risks of non-stochastic effects (e.g. to the lens of the eye) would be part of the medical considerations in the treatment of the patient, rather than the task of those responsible for radiation protection in general.

#### *Dose-equivalent limits for workers*

(96) As stated in paragraph 77, the Commission's recommended dose-equivalent limits for occupational exposure have been in effect for over 20 years. In view of the emphasis that the Commission places on risk estimations, it believes it appropriate to assess the levels of risk that are associated with its dose-equivalent limits. The Commission believes that for the foreseeable future a valid method for judging the acceptability of the level of risk in radiation work is by comparing this risk with that for other occupations recognized as having high standards of safety, which are generally considered to be those in

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$$\text{Total of } 1/4 \text{ death} \quad \frac{10^{-2} \text{ Sv}}{1 \text{ Sv}} = 10^{-2} \text{ Sv} = 10 \text{ mSv}$$

which the average annual mortality due to occupational hazards does not exceed  $10^{-4}$ . In most occupations, fatalities, whether due to accidents or disease, are accompanied by a much larger number of less severe consequences. Radiation exposure, on the other hand, at levels imposed by adherence to recommended dose-equivalent limits, is expected to cause very few injuries or illnesses in exposed workers other than any malignant diseases which may be induced. In assessing the implication of dose-equivalent limits therefore the Commission believes that the calculated rate at which fatal malignancies might be induced by occupational exposure to radiation should in any case not exceed the occupational fatality rate of industries recognized as having high standards of safety.

(97) Other criteria than fatality rates could be used in ensuring that radiation exposure, as controlled by recommended dose-equivalent limits, involves no greater hazard than in other safe industries. Ideally, account should be taken of all components of the harm, or detriment, involved in the various occupations—including the sum of all accidents, illnesses, genetic defects and fatalities involved, as well as the anxieties of workers or their families about the hazards or conditions of work in different industries. As a first approximation it can be stated that an assessment based only on the mortality criterion can be regarded as conservative since experience has shown that the non-fatal effects of irradiation are much less frequent than the non-fatal effects encountered in other safe occupations. However, the summation and comparison of the diverse contributions to total detriment are difficult to make on an objective basis.

(98) Account can be taken of some components of disability by estimating the average amount of time lost (e.g. per worker year) from full activity—whether from accidents, industrial disease or, in the extreme case, by death from occupational causes. A review of the problems involved in developing

any "Index of Harm" on this basis is given in a report on this topic being prepared for the Commission; however, no such criterion can be regarded as more than indicative of broad differences in risk. It should be mentioned, however, that an accidental death appears to involve an average loss of about 30 years of life in many industries, and to be associated with an approximately equal total loss of working time from industrial accidents. A fatal malignancy induced by occupational exposure to radiation would be expected to involve the loss of about 10 years of life, owing to the long latency in the development of such a condition, without appreciable associated time loss from accidents.

(99) When making comparisons with other safe occupations, it should be realised that the level of risk representative of a safe occupation relates to the *average* risk for all workers in that occupation, the risk for individual workers varying with their job and being distributed around this average. A similar distribution of individual risks also occurs in radiation work; in many cases of occupational exposure where the Commission's system of dose limitation has been applied, the resultant annual average dose equivalent is no greater than one-tenth of the annual limit. Therefore the application of a dose-equivalent limit provides much better protection for the average worker in the group than that corresponding to the limit.

(100) In the case of uniform exposure of the whole body, in circumstances where the Commission's recommendations, including the annual dose-equivalent limit of 50 mSv, have been applied, the distribution of the annual dose equivalents in large occupational groups has been shown very commonly to fit a log-normal function, with an arithmetic mean of about 5 mSv, and with very few values approaching the limit. The application of the risk factors given in paragraphs 40-60 to the above mean dose indicates that the average risk in these radiation occupations is com-

parable with the industries (but see

(101) The Commission's limits are primarily adequate protection for exposed individual workers who are subject to equivalent limits of doses each year or it would be the equivalent of the individual risk, comparable with individual risks randomly to high exposures. Exposures would be comparable with higher-than-average for certain individual workers.

(102) However, in any particular case, a worker may receive a dose equivalent to the annual limit, or rise substantially above it. There would thus be a higher average risk, even if the dose equivalent limit were individual worker. The risk of a considerable period or near the dose-equivalent limit would be acceptable if a case had shown that it would be justified.

*Recommended dose*  
The Commission's limits are intended to prevent and to limit the effects to an acceptable level. The Commission believes that a dose equivalent limit of 0.5 Sv (50 mSv) except the lens, for which it recommends a limit of 0.1 Sv per year. These limits are intended to prevent whether the tissue is exposed together with other

\*See the Commission's report on Problems Involved in Developing an Index of Harm (in preparation).

†See Annex E of the 1977 Report of the United Nations Scientific Committee on the Effects of Atomic Radiation.

parable with the average risk in other safe industries (but see also paragraph 29).

(101) The Commission's dose-equivalent limits are primarily intended to ensure adequate protection even for the most highly exposed individuals. In many occupations workers who are exposed near the dose-equivalent limits are unlikely to receive such doses each year of their occupational life and it would be their expected lifetime dose equivalent that would indicate their total individual risk. In this sense they are comparable with individuals who are exposed randomly to higher risks in "safe" occupations. Exposures consistently near the limits would be comparable with a situation where a higher-than-average risk has been identified for certain individuals in non-radiation industries.

(102) However, if the exposure of workers in any particular occupation were to be planned so that a large fraction of workers received dose equivalents which approached the annual limit, the average exposure could rise substantially above one-tenth of the limit. There would thus be a corresponding rise in the average risk, even though the annual dose-equivalent limit was not exceeded by any individual worker. Long-continued exposure of a considerable proportion of the workers at or near the dose-equivalent limits would only be acceptable if a careful cost-benefit analysis had shown that the higher resultant risk would be justified.

*Importance Ltd. benefit only.*  
 Recommended dose-equivalent limits. (103) The Commission's recommendations are intended to prevent non-stochastic effects and to limit the occurrence of stochastic effects to an acceptable level. The Commission believes that non-stochastic effects will be prevented by applying a dose-equivalent limit of 0.5 Sv (50 rem) in a year to all tissues except the lens, for which the Commission recommends a limit of 0.3 Sv (30 rem) in a year. These limits apply irrespective of whether the tissues are exposed singly or together with other organs, and they are

intended to constrain any exposure that fulfils the limitation of stochastic effects (see paragraphs 104-110).

(104) For stochastic effects the Commission's recommended dose limitation is based on the principle that the risk should be equal whether the whole body is irradiated uniformly or whether there is non-uniform irradiation. This condition will be met if

$$\sum_T w_T H_T \leq H_{wb,L}$$

where,  $w_T$  is a weighting factor representing the proportion of the stochastic risk resulting from tissue ( $T$ ) to the total risk, when the whole body is irradiated uniformly,  $H_T$  is the annual dose equivalent in tissue ( $T$ ),  $H_{wb,L}$  is the recommended annual dose-equivalent limit for uniform irradiation of the whole body, namely 50 mSv (5 rem).

(105) The values of  $w_T$  recommended by the Commission are shown below:

Tissue	$w_T$
Gonads	0.25 TP 60
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

The value of  $w_T$  for the remaining tissues requires further clarification. For the reasons stated in paragraphs 58 and 59 the Commission recommends that a value of  $w_T = 0.06$  is applicable to each of the five organs or tissues of the remainder receiving the highest dose equivalents, and that the exposure of all other remaining tissues can be neglected. (When the gastro-intestinal tract is irradiated, the stomach, small intestine, upper large intestine and lower large intestine are treated as four separate organs.)

(106) It is recognized that the risk associated with a given exposure will vary with the age and sex of the individual exposed. However, the values of  $w_T$  given in paragraph 105 are recommended as appropriate for the protection of

any worker, regardless of these sources of variability (see also paragraph 38).

(107) The values of  $w_T$  presented in paragraph 105 are intended as guidance for those concerned with calculating secondary and derived limits (see section F). In particular, they are used by ICRP Committee 2 in calculating values of annual limits of intake (ALI) for radionuclides, which take account of the dose equivalent in each tissue. In practical situations, however, it will usually suffice to use the two secondary limits that are applicable to external and internal exposure, namely, the limit to the dose-equivalent index  $H_I$  (see paragraph 108) and ALI (see paragraph 109).

(108) With *external exposures* to penetrating radiation, on those occasions when information is lacking concerning the actual distribution of dose equivalent in the body, it is possible to assess the *maximum* value of dose equivalent that would occur in a 30 cm sphere (the *deep dose equivalent index,  $H_D$* ). The limitation of the dose-equivalent index to an annual value of 50 mSv would afford a level of protection that would be at least as good as that provided by the method recommended in paragraph 104.

(109) With *internal exposure* resulting from the intake of radionuclides protection can be based on annual limits of intake (ALI). These are calculated by ICRP Committee 2, from knowledge of the various organ committed dose equivalents per unit intake, by application of the principles discussed in paragraphs 104 and 105; such exposures are also subject to the limits for non-stochastic effects given in paragraph 103.

(110) When external and internal exposures are received together, the Commission's recommended dose limitation for stochastic effects will not be exceeded if:

$$\frac{H_1}{H_{wb,L}} + \sum_j \frac{I_j}{I_{j,L}} \leq 1$$

where,  $H_1$  is the annual dose-equivalent index,  $H_{wb,L}$  is the annual dose-equivalent limit,  $I_j$  is the annual intake of radionuclide  $j$ ,  $I_{j,L}$  is the annual limit of intake for radionuclide  $j$ .

(111) Although the Commission no longer proposes separate annual dose-equivalent limits for individual tissues and organs irradiated singly, the implied values of such limits may be obtained, if required, by dividing the dose-equivalent limit  $H_{wb,L}$  (50 mSv in a year) by the relevant value of  $w_T$ . Such values would be subject to the limits, based on non-stochastic effects, given in paragraph 103.

(112) It should be recognized that the limits have been derived for application in average situations, for all adult ages and for both sexes and without regard to individual circumstances which might enhance the risk. The Commission believes that, for example, any variation in risk with age will not influence the total risk from a lifetime exposure unless the exposure is limited to a special group. Additional precautions and dose limitations may be necessary, however, to limit the irradiation of an embryo or foetus in the case of occupational exposure of pregnant women (see paragraphs 115 and 116).

*Planned special exposures.* (113) Situations may occur infrequently during normal operations when it may be necessary to permit a few workers to receive dose equivalents in excess of the recommended limits. In such circumstances external exposures or intakes of radioactive material may be permitted provided the dose-equivalent commitment does not exceed twice the relevant annual limit in any single event, and, in a lifetime, five times this limit. The Commission wishes to

emphasize that e of this magnitu alternative techn such exposure unavailable or paragraph 171).

(114) Planned: be permitted if received abnormal equivalents in ex annual limit. F should not be per ductive capacity. from planned sy recorded with th but any excess ove paragraphs 103 & constitute a reas from his usual o emergency exposi G).

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(116) It is likely th than 2 months' c recognized by th physician. For reat 65, the Commissi pregnancy has bee should be made to continue to work c B, specified in para

\*International Commission on Radiation Units and Measurements, The Conceptual Basis for the Determination of Dose Equivalent, ICRU Report 25, International Commission on Radiation Units and Measurements, Washington, 1976.

emphasize that external exposures or intakes of this magnitude are only justified when alternative techniques, which do not involve such exposure of workers, are either unavailable or impracticable (see also paragraph 171).

(114) Planned special exposures should not be permitted if the worker has previously received abnormal exposures resulting in dose equivalents in excess of five times the relevant annual limit. Planned special exposures should not be permitted for women of reproductive capacity. Dose equivalents resulting from planned special exposures should be recorded with those from usual exposures, but any excess over the limits recommended in paragraphs 103 *et seq.* should not by itself constitute a reason for excluding a worker from his usual occupation. (Accidental and emergency exposures are discussed in section G).

*Occupational exposure of women of reproductive capacity.* (115) When women of reproductive capacity are occupationally exposed under the limits recommended in paragraph 108, and when this exposure is received at an approximately regular rate, it is unlikely that any embryo could receive more than 5 mSv during the first 2 months of pregnancy. Having regard to the circumstances in which such exposures could occur, the Commission believes that this procedure will provide appropriate protection during the essential period of organogenesis.

*Occupational exposure of pregnant women.* (116) It is likely that any pregnancy of more than 2 months' duration would have been recognized by the woman herself or by a physician. For reasons described in paragraph 65, the Commission recommends that, when pregnancy has been diagnosed, arrangements should be made to ensure that the woman can continue to work only in Working Condition B, specified in paragraph 161.

*Dose-equivalent limits for individual members of the public.* (117) Radiation risks are a very minor fraction of the total number of environmental hazards to which members of the public are exposed. It seems reasonable therefore to consider the magnitude of radiation risks to the general public in the light of the public acceptance of other risks of everyday life. This acceptance (when related to risks that could not be reduced or avoided entirely) is motivated by the benefits that would not otherwise be received, by an assessment of the social cost of achieving a possible reduction of risk, or by an implicit judgment that the risk is negligible.

(118) The acceptable level of risk for stochastic phenomena for members of the general public may be inferred from consideration of risks that an individual can modify to only a small degree and which, like radiation safety, may be regulated by national ordinance. An example of such risks is that of using public transport. From a review of available information related to risks regularly accepted in everyday life, it can be concluded that the level of acceptability for fatal risks to the general public is an order of magnitude lower than for occupational risks. On this basis, a risk in the range of  $10^{-6}$  to  $10^{-5}$  per year would be likely to be acceptable to any individual member of the public.

(119) The assumption of a total risk of the order of  $10^{-2} \text{ Sv}^{-1}$  (see paragraph 60) would imply the restriction of the lifetime dose to the individual member of the public to a value that would correspond to 1 mSv per year of life-long whole body exposure. For the reasons given in the following paragraphs, the Commission's recommended whole body dose-equivalent limit of 5 mSv (0.5 rem) in a year, as applied to critical groups, has been found to provide this degree of safety and the Commission recommends its continued use under the conditions specified in paragraphs 120-128.

(120) The application of an annual dose-equivalent limit of 5 mSv to individual members of the public is likely to result in

average dose equivalents of less than 0.5 mSv, provided that the practices exposing the public are few and cause little exposure outside the critical groups (see paragraph 85). When applying the dose-equivalent limit for members of the public, consideration must be given to the possibility that some individuals may belong to more than one critical group. In fact, due to the maximizing assumptions usually made in selecting critical groups, the doses actually received by the most highly exposed individuals will in most cases be considerably lower than the doses postulated for the critical group.

(121) The actual value of the average dose depends upon both the result of the optimization process of a large number of justified practices causing radiation exposures and the value selected to limit the individual doses. If at some time in the future the combined exposure resulting from optimized exposures resulted in average dose equivalents higher than 1 mSv in a year, the situation might still be justifiable, even though the average risk for members of the public would be higher than the range  $10^{-6}$  to  $10^{-5}$  per year.

(122) In some cases optimization, which could be the overriding protection criterion, will necessitate a more realistic selection of the critical group, because to overestimate the risk would introduce a bias which would invalidate the optimization. In these cases, the dose-equivalent limit to individual members of the public, referred to in paragraph 120, would still adequately restrict the average dose equivalent, but the few individuals exposed to the dose-equivalent limit could run a risk in the range of  $10^{-5}$  to  $10^{-4}$  per year. This annual risk would then be one order of magnitude higher than the risk range quoted in paragraph 118. Since exposures at the dose-equivalent limit are not likely to be repeated over many years, however, an adequate restriction of the life-time dose is still likely to be achieved. In any rare cases where the doses to a few individuals were actually found to be received at high rates over prolonged periods, it would be prudent to take measures to restrict

their life-time dose as implied in paragraph 119.

(123) In such cases, where optimization is the deciding protection criterion and where critical groups are selected on the basis of realistic assumptions, it would be appropriate to use as a boundary condition of any single optimization process an individual dose limitation such as indicated in paragraph 122. Even the few individuals who would actually receive doses of this magnitude over a long period of time would not be subject to risks appreciably above the level that is generally considered acceptable (see paragraph 118).

(124) In most applications, however, administrative planning is based on operational limits derived from very crude cost-effectiveness considerations of protective measures and quite conservative estimates of the resulting doses in critical groups. For such planning it is usually quite appropriate to assess the doses in the critical group in relation to the dose-equivalent limit of 5 mSv in a year, and the Commission has found no reason to recommend a change in this practice. The main reason for this decision is that the Commission's system of dose limitation, with the dose-equivalent limit of 5 mSv in a year, is found to provide the necessary degree of safety, under the boundary conditions stated in paragraphs 120-123, and that a change in the upper limit would not be of the same importance from the radiation protection point of view as the rigorous application of the principle of keeping all doses as low as is reasonably achievable.

(125) For non-homogeneous exposures with organ doses  $H_T$ , the limitation condition is  $\sum_T w_T H_T \leq H_{wb,L}$ , where  $H_{wb,L}$  is the dose-equivalent limit for uniform irradiation of the whole body for a member of the public. Due to different age distributions when members of the public are irradiated, the risks will not be quite the same as for occupational exposures. The relative risks, however, will differ but little and the Commission has not found the differences significant enough to recommend a separate set of weighting

factors, different in paragraph 10:

(126) In order to prevent tissue from receiving a dose that would contribute significantly to the total dose-equivalent. This limit is a boundary condition of any single optimization process. Even the few individuals who would actually receive doses of this magnitude over a long period of time would not be subject to risks appreciably above the level that is generally considered acceptable (see paragraph 118).

(127) In the case of occupational exposure, the dose equivalent limit of 5 mSv in a year is recommended to provide the necessary degree of safety. The main reason for this decision is that the Commission's system of dose limitation, with the dose-equivalent limit of 5 mSv in a year, is found to provide the necessary degree of safety, under the boundary conditions stated in paragraphs 120-123, and that a change in the upper limit would not be of the same importance from the radiation protection point of view as the rigorous application of the principle of keeping all doses as low as is reasonably achievable.

(128) As with occupational exposure, the dose equivalent limit of 5 mSv in a year is recommended to provide the necessary degree of safety. The main reason for this decision is that the Commission's system of dose limitation, with the dose-equivalent limit of 5 mSv in a year, is found to provide the necessary degree of safety, under the boundary conditions stated in paragraphs 120-123, and that a change in the upper limit would not be of the same importance from the radiation protection point of view as the rigorous application of the principle of keeping all doses as low as is reasonably achievable.

Exposure of the public (129) In its p

Appeals to radiation doses & risk etc  
though risk would be lower

factors, different from the values of  $w_T$  given in paragraph 105 (see also paragraph 60).

(126) In order to prevent any one organ or tissue from receiving a total dose which could contribute significantly to the induction of non-stochastic effects, an overriding annual dose-equivalent limit of 50 mSv should apply. This limit is considerably lower than the corresponding limits recommended for prevention of non-stochastic effects after occupational exposure. The intention is to ensure that the longer exposure period and the practical difficulties in controlling the total exposure from all sources will not result in threshold doses for non-stochastic effects being reached. The weighting procedure recommended in paragraph 125 will generally provide the necessary limitation also for non-stochastic effects, but the special limitation is needed for the skin and the lens of the eye.

(127) In the calculation of the dose equivalent incurred by members of the public from intake of radionuclides, account must be taken of differences in organ size or metabolic characteristics of children. Data on such differences may be found in the report of the task group on Reference Man (*ICRP Publication 23*).

(128) As with workers (see paragraph 102) an increase in the average dose to members of the public could result from any large increase in the number of sources of exposure, even though each satisfactorily met the criteria of justification and optimization (see paragraphs 68-76) and caused no exposures above the recommended limits. National and regional authorities should therefore keep under surveillance the separate contributions from all practices to the average exposure of the whole population so as to ensure that no single source or practice contributes an unjustified amount to the total exposure, and that no individual receives undue exposure as a result of membership of a number of critical groups.

#### *Exposure of populations*

(129) In its previous recommendations the

Commission suggested a genetic dose limit, although it expressed reservations about proposing generally applicable dose limits for populations. It has become increasingly clear that the previously suggested level is not likely to be reached, and it is very improbable that responsible authorities would permit the average dose equivalent in a population to reach values that are more than small fractions of the former genetic dose limit of 5 rem in 30 years. Therefore, continuance of the former genetic dose limit could be regarded as suggesting the acceptability of a higher population exposure than is either necessary or probable, and a higher risk than is justified by any present or easily envisaged future development. Furthermore, knowledge gained over the past two decades indicates that genetic effects, while important, are unlikely to be of overriding importance, and would need to be related to the sum of all other effects.

(130) In these recommendations, therefore, the Commission does not propose dose limits for populations. Instead it wishes to emphasize that each man-made contribution to population exposure has to be justified by its benefits, and that limits for individual members of the public refer to the total dose equivalent received from all sources (except as already noted). The limit for irradiation of a whole population is thus clearly seen as the total reached by a summation of minimum necessary contributions, and not as a permissible total apparently available for apportionment. Consideration of the principles enunciated in paragraphs 117-125, together with the Commission's system of dose limitation, is likely to ensure that the average dose equivalent to the population will not exceed 0.5 mSv per year.

(131) In any cost-benefit assessment of a given practice (see paragraphs 60 and 68-76) the specification of the collective dose equivalent is a relatively straightforward procedure if the dose equivalent is limited to the population that shares the benefit of the source. If the exposure will involve other

populations (or groups, etc.) the total collective dose equivalent should be kept below that which would have applied had the cost-benefit assessment been confined to the population that receives the benefit.

(132) For the purposes envisaged in paragraph 128 it would be useful to develop long-term forecasts of the trend of the various contributions to the total collective dose equivalent delivered from various sources of exposure. This would facilitate discussions of the appropriate national and international arrangements in regard to justification for particular contributions to population exposures. Contributions that are not primarily controllable nationally, or on an agreed regional basis, call for international agreement on levels of exposure or collective dose equivalents from various sources. In order to achieve these objectives, such authorities may find it appropriate to apply collective dose-equivalent limits for various practices or sources of exposure.

#### *Accidents and emergencies*

(133) Under conditions in which accidental exposures occur, questions arise as to what remedial actions may be available to limit the subsequent dose. In such cases, the hazard or social cost 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 "intervention levels" that would be appropriate for all occasions. However, with certain types of accident that are to some extent foreseeable it may be possible to gauge, by an analysis of the

costs of the accident and of remedial action, levels below which it would *not* be appropriate to take action.

(134) The decision to initiate remedial action will have to take account of the particular circumstances that prevail. In general it will be appropriate to institute countermeasures only when their social cost and risk will be less than those resulting from further exposure. Nevertheless, at the operational level (at a reactor establishment, for example) those responsible for the health and safety of workers, and of individuals outside the establishment, will need to have an emergency plan, including dose levels at which various countermeasures would have to be considered. The setting of such levels for particular circumstances is considered to be the responsibility of the national authorities. (See also section G.)

(135) It has been indicated in paragraph 81 that the Commission's dose-equivalent limits are agreed values, established so as to make it possible to plan and design operations involving foreseen but acceptable radiation exposures. These limits are intended to apply only to those conditions where the source of exposure is under control, and relate to average workers without taking any account of age or child expectancy. The Commission's recommended limits are set at a level which is thought to be associated with a low degree of risk; thus, unless a limit were to be exceeded by a considerable amount, the risk would still be sufficiently low as not to warrant such countermeasures as would themselves involve significant risks or undue cost. It is therefore clear that it is not obligatory to take remedial action if a dose-equivalent limit has been or might be exceeded (see section G).

#### F. G

(136) The recommendations of the report deal with operational radiological initial conception of exposure to ionizing radiation, limitation of operations, to cases of accident.

(137) As has been stated, it is convenient to deal with these recommendations

the exposure of their work;  
the exposure of medical examination  
other exposure

These points are G.

(138) More details on some aspects are given by committees (see section G). Judgment is called for in these recommendations.

(139) Responsibilities for radiation protection: employers, the authorities, the manufacturers of products giving rise to radiation, and, in some cases, the management of all the necessary facilities. In particular, it should be noted that special duties for radiation protection are assigned to operators of radiation protection products.

(140) All products of radiation protection operations, all facilities and operational products contain

## F. GENERAL PRINCIPLES OF OPERATIONAL RADIATION PROTECTION

### INTRODUCTION

(136) The recommendations of this part of the report deal with the general principles of operational radiation protection, from the initial conception of a proposal involving exposure to ionizing radiations, through the limitation of such exposures in normal operations, to the procedures required in cases of accident or emergency.

(137) As has been stated in paragraph 83, it is convenient to define three types of exposure to which these recommendations apply:

the exposure of individuals in the course of their work;

the exposure of individuals due to their medical examination or treatment, and other exposures of individuals.

These points are discussed further in section G.

(138) More detailed recommendations on some aspects appear in reports of ICRP committees (see References). Professional judgment is called for in the application of all these recommendations.

(139) Responsibilities for achieving appropriate radiation protection fall on the employers, the statutory competent authorities, the manufacturers and the users of products giving rise to radiation exposure and, in some cases, the exposed persons. The management of an institution must provide all the necessary facilities for the safe conduct of the operations under its control. In particular, it should designate persons with special duties for protection, such as members of radiation protection teams.

(140) All proposed installations and new operations, all changes in existing installations and operations, and all new or modified products containing radioactive materials or

emitting ionizing radiation, should be examined at the design stage from the point of view of restricting the resulting occupational and general exposure. Such examinations can often be carried out by comparison with detailed technical standards prepared taking into account the recommendations of the Commission.

(141) Before commissioning an installation, starting an operation or distributing a product, it should be established that the installation, operation or product conforms with the approved proposals and that the appropriate radiation protection requirements have been met. In the case of installations and operations, there should be continuing checks on the effectiveness of the organizational arrangements made to achieve protection, and on the availability and application of appropriate working instructions.

(142) The assessment of exposure of individuals or groups, carried out by calculation or measurement, is an essential component of the procedures for restricting exposure and for intervention (see paragraph 143). The emphasis at the design and early operational stages is on predictive assessments and, where necessary, is confirmed by monitoring during subsequent operations. Predictive assessments are also needed in the planning of intervention procedures but, in addition, monitoring carried out during normal operations will often provide the basis for any decisions to intervene.

(143) Intervention is the term used when steps have to be taken to depart from normal operating procedures in abnormal situations, including accidents. Its aim is to restrict the exposure of individuals and to minimize the consequences of unavoidable exposures.

Intervention usually involves action to regain control of the abnormal situation and countermeasures applied to individuals or their environment. The broad structure of the procedures for intervention should be the subject of advanced planning, taking into

account the probability as well as the consequences of the various situations for which intervention might be required. The details may need to be settled in the light of the prevailing circumstances.

## PROTECTION STANDARDS

(144) It is important to distinguish between distinct types of protection standards: basic limits (dose-equivalent limits and secondary limits), derived limits, authorized limits and reference levels.

### Limits

(145) The *dose-equivalent limits* (see paragraphs 103 and 104, 119 and 126) apply to the dose equivalent or, where appropriate, the committed dose equivalent, in the organs or tissues of the body of an individual or, in the case of exposure of the population, to the average of one of these quantities over a group of individuals.

(146) *Secondary limits* are given for external irradiation and for internal irradiation. In the case of external irradiation of the whole body the secondary limit applies to the maximum dose equivalent in the body at depths below 1 cm (see paragraph 108). The secondary limits for internal exposure are the annual limits of intake by inhalation or ingestion (see paragraph 109). These limits of intake relate to adult Reference Man. When, however, a critical group of the public differs substantially in biological characteristics from Reference Man, it may be appropriate to take account of such differences (see also paragraph 127).

(147) In practical radiation protection, it is often necessary to provide limits associated with quantities other than dose equivalent, committed dose equivalent, or intake, and relating, for example, to environmental conditions. When these limits are related to

the basic limits by a defined model of the situation and are intended to reflect the basic limits, they are called *derived limits*. Derived limits may be set for quantities such as dose-equivalent rate in a workplace, contamination of air, contamination of surfaces and contamination of environmental materials. The accuracy of the link between derived limits and basic limits depends on the realism of the model used in the derivation.

(148) Limits laid down by a competent authority or by the management of an institution are called *authorized limits*. These should, in general, be below derived limits though, exceptionally, they may be equal to them. The process of optimization may be used in the establishment of authorized limits and they apply only in limited circumstances. It is important that any such limitations should be clearly laid down. Where an authorized limit exists it will always take precedence over a derived limit.

### Reference levels

(149) Reference levels may be established for any of the quantities determined in the course of radiation protection programs, whether or not there are limits for these quantities. A reference level is not a limit and is used to determine a course of action when the value of a quantity exceeds or is predicted to exceed the reference level. The action to be initiated may range from simply recording the information, through investigations into causes and consequences, up to intervention measures. It is important to define the general

scope of this action level. The action level are reference levels and intervention

(150) Many monitoring programs to be of interest discarded with helpful to define dose equivalent result is of sufficient recording and kept be covered by them were all below. These unrecorded zero for assessment intake for the population. This approximation of results.

(151) Investigation values of dose

(153) The action optimization to and, in particular protection, requirements situations. In particular protection strategies radiation exposure going from one evaluated. Both pressed in comparison stage that pose also paragraph

(154) As stated assume that the additional to the critical exposed group detriment may highest dose equivalent the relationship relevant limit. worth consider

scope of this action when defining the reference level. The most common forms of reference level are recording levels, investigation levels and intervention levels.

(150) Many measurements made in monitoring programs show results that are too low to be of interest and such results are often discarded without being recorded. It is often helpful to define a formal *recording level* for dose equivalent or intake above which the result is of sufficient interest to be worth recording and keeping. Other results can then be covered by the simple statement that they were all below the defined recording level. These unrecorded results should be treated as zero for assessing annual dose equivalent or intake for the purposes of radiation protection. This approach results in a considerable simplification of the records of monitoring results.

(151) *Investigation levels* can be defined as values of dose equivalent or intake above

which the results are considered sufficiently important to justify further investigations. For any defined type of measurement it is possible to establish a derived investigation level such that a measured result below the derived investigation level will, with reasonable certainty, correspond to a value of dose equivalent or intake below the relevant investigation level (see paragraphs 178-181).

(152) Although the details of intervention will depend on the situation prevailing at the time, experience has shown that it is often useful to have pre-established *intervention levels* so that if the value of a quantity does not exceed or is not predicted to exceed the intervention level, then it is highly improbable that intervention will be required. Because intervention is liable to interfere with normal operation or, in some cases, to disrupt the normal chain of responsibilities, it should not be undertaken lightly.

## OPERATIONAL OPTIMIZATION

(153) The application of the process of optimization to the restriction of exposure and, in particular, to the selection of levels of protection, requires a case-by-case review of situations. In practice, a series of radiation protection strategies is defined. The change in radiation exposure and the differential cost of going from one strategy to the next are then evaluated. Both variations need to be expressed in comparable terms, and it is this stage that poses the greatest difficulties (see also paragraphs 72-76).

(154) As stated in paragraph 24 it is usual to assume that the detriment to health is proportional to the collective dose equivalent in the exposed group, but other components of the detriment may be influenced more by the highest dose equivalent and, in particular, by the relationship between this value and the relevant limit. Two extreme situations are worth considering. In the first, the detriment

to health in the exposed group is the predominant component of the total detriment and the required comparison is the differential change in the cost of protection strategies and the corresponding differential change of the collective dose equivalent. The second extreme situation is where the detriment to health is likely to be very small, for example where the numbers of individuals are extremely limited. Optimization in this case involves the highest individual dose equivalent as opposed to the collective dose equivalent and it is necessary to take account of exposure contributions from procedures other than that under review.

(155) Some exposures are due to minor mishaps and it is then necessary to consider not only the level of exposure but also its probability, or more simply, to look at the long-term average of the exposure of individuals resulting from both continuous and

intermittent exposure. This technique allows choices to be made between the resources to be devoted to the reduction of routine exposures and those to be devoted to the avoidance of minor mishaps.

(156) It would also be convenient to identify the possible additional benefit that would result from the provision of monitoring resources in addition to the minimum necessary to demonstrate compliance with the optimized level of exposure. However, it is usually very difficult to quantify this kind of benefit, and consequently decisions are based largely on judgment.

(157) As most forms of intervention involve some detriment, the optimal method of intervention depends on a balance between the detriment caused by the intervention and the benefit expected by the reductions of dose achieved by the intervention. Such a balance necessarily depends on local circumstances at

the time of the situation calling for intervention, but preliminary planning should be done in advance on a contingency basis.

(158) A considerable contribution is made to radiation protection by the use of technical standards and specifications. The case-by-case optimization of widely used equipment is not appropriate because it would nullify the advantages of standardization and would cause a net social loss. Optimization should, however, play a part in the setting of such standards and specifications and in their subsequent application.

(159) When appropriate data for true optimization are lacking, a much cruder process may be adopted. This process consists of applying a fairly arbitrary reduction factor to a limit, or of applying similarly arbitrary safety factors in plant design. The resulting exposures may then be either higher or lower than the optimum value.

## G. APPLICATION TO THE DIFFERENT TYPES OF EXPOSURE

### OCCUPATIONAL EXPOSURE

(160) The main responsibility for the protection of workers rests with the normal chain of management in an institution possessing any radiation source that causes exposure of workers. It is necessary to identify technically competent persons to provide advice on all relevant aspects of radiation protection, both inside and outside the institution, and to provide such technical services as are needed in the application of the appropriate recommendations for radiation protection.

#### *Conditions of work*

(161) For the purposes of this report occupational exposure comprises all the dose equivalents and intakes incurred by a worker

during periods of work (excluding those due to medical and natural radiation). The scale and form of the problems of radiation protection of workers vary over very wide ranges, and there are practical advantages in introducing a system of classification of conditions of work. Conditions of work can be divided into two classes:

Working Condition A: this describes conditions where the annual exposures might exceed three-tenths of the dose-equivalent limits;

Working Condition B: this describes conditions where it is most unlikely that the annual exposures will exceed three-tenths of the dose-equivalent limits.

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The value of three-tenths of the basic limits for occupational exposure is thus a reference level used in the organization of protection. It is not a limit. Where the exposure is unconnected with the work, and where the work is in premises not containing the radiation sources giving rise to the exposure, the working condition should be such that the limits applicable to members of the public are observed.

(162) The main aim of the definition of Working Condition A is to ensure that workers who might otherwise reach or exceed the dose-equivalent limits are subject to individual monitoring so that their exposures can be restricted if necessary. In Working Condition B, individual monitoring is not necessary, although it may sometimes be carried out as a method of confirmation that conditions are satisfactory.

(163) The practical application of this system of classification of working conditions is greatly simplified by the introduction of a corresponding system of classification of workplaces. The minimum requirement is to define controlled areas where continued operation would give rise to Working Condition A and to which access is limited. The demarcation of controlled areas will depend on the operational situation and it will often be convenient to use existing structural boundaries. The controlled area should in any case be large enough to make it most unlikely that the annual dose-equivalents to workers outside the controlled area will exceed three-tenths of the limits.

(164) It is sometimes convenient to specify a further class of workplace. It is called a "supervised area", and has a boundary chosen so as to make it most unlikely that the annual dose equivalents outside the supervised area will exceed one-tenth of the limits.

(165) There is no simple parallelism between the classification of areas and the classification of working conditions, because the classification of areas takes no account of the time spent by workers in the area during the course of the year and because conditions are rarely uniform throughout an area.

(166) In order to simplify the arrangements for medical supervision and for individual monitoring, it is usual to classify individual workers. In principle, this can be done in terms of the class of working conditions in which they operate, but in practice it almost always has to be done in terms of the areas where they work, the type of work done and, if this can be forecast with sufficient reliability, the time to be spent in the area.

#### *Provisions for restricting exposure*

(167) As far as is reasonably practicable, the arrangements for restricting occupational exposure should be those applied to the source of radiation and to features of the workplace. The use of personal protective equipment should in general be supplementary to these more fundamental provisions. The emphasis should thus be on intrinsic safety in the workplace and only secondarily on protection that depends on the worker's own actions.

(168) Access to controlled areas should be restricted, at least by the use of warning signs. Inside controlled areas it may sometimes be necessary to define regions where compliance with the relevant limits can be achieved only by limiting the time spent in the region or by using special protective equipment. The access of workers to controlled areas should be limited to those who are assigned to the area and to others who have been authorized to have access. The access of workers to supervised areas should be the subject of local operating instructions. Visitors, either workers or members of the public, should be admitted to workplaces only with the approval of an appropriate level of the management responsible for the workplace.

(169) External exposure may be restricted by the use of shielding, distance and limitation of time of exposure. Shielding produces intrinsically safe conditions in the workplace. Distance and limitation of time of exposure require the careful training and supervision of workers. Complete protection is afforded by the use of "closed" installations providing

virtually complete shielding for the radiation source and effectively preventing access. However, the failure of such equipment as interlock systems may cause excessive exposure. Operating procedures should therefore include routine checks of such systems.

(170) Contamination by radioactive materials may be restricted by containment and cleanliness. Containment, which provides intrinsic safety, consists of a series of barriers, their number being a function of the potential hazards involved. Total containment is not always justified and partial containment may be sufficient provided that it is supplemented by a high standard of cleanliness. Ventilation plays a significant part in both containment and cleanliness. When contamination of the workplace cannot be excluded, personal protective equipment has a part to play in the protection of workers.

(171) Although the Commission gives recommendations relating to planned special exposures to internal contamination (see paragraph 113) the use of protective equipment should make such exposures unnecessary.

(172) All workers who may have access to supervised or controlled areas should be properly trained and given appropriate information about the hazards of their work and about the precautions they should take to protect themselves. They should be made aware of the importance of complying with the working instructions.

#### *Monitoring of exposure*

(173) Workers designated as operating in Working Condition A should be the subject of individual assessment of dose equivalent, committed dose equivalent or intake, as the case may be. This consists of individual monitoring for external irradiation and for internal contamination as appropriate. In some cases it will be necessary to use indirect methods. An individual assessment of exposure is not required for workers designated as working in Working Condition B. It is suffi-

cient to assess the conditions in the working environment, following the principles and recommendations set out in ICRP Publication 12.

(174) Monitoring programs should be designed to meet clearly defined objectives: routine monitoring, associated with continuing operations, monitoring of an operation, applied to a particular operation, and special monitoring in an actual or suspected abnormal situation. In addition to the primary aims, most monitoring programs have supplementary functions. The programs should be reviewed both periodically in the light of experience, and in the event of any major modification of the installation or the operations, to ensure that they continue to meet their objectives.

*The use of protection standards to interpret monitoring results.* (175) Use can be made of derived limits or authorized limits in the application of individual monitoring programs. Such limits are essential in the monitoring of operations where, in general, only part of the dose-equivalent limit or secondary limit can be committed to the operation.

(176) Only in a few circumstances can the results of programs of monitoring of the workplace be used to estimate the dose equivalents or intakes of individual workers. The use of derived or authorized limits is essential in the interpretation of environmental monitoring programs.

(177) A substantial part of all monitoring programs is confirmatory in nature and, given satisfactory results, no further action needs to be taken. In these circumstances there is a possibility that the occasional significant result will be overlooked, unless use is made of investigation levels and derived investigation levels. The initial action to be taken when a result exceeds an investigation level should be determined in advance.

(178) It is possible to give general guidance on investigation levels for individual monitoring that applies in a large number of situations. Since there is no Commission recom-

mendation on Working Condition A, it is unlikely that tenths of the secondary or derived limit is appropriate to use for setting investigation levels for routine monitoring. However, to be useful, has to be measurement, equivalent or derived limit appropriate to the fraction of the secondary limit corresponding to the individual monitoring. Corresponding can then be deduced and measured.

(179) Some of the recommendations apply in the setting of investigation levels for monitoring programs of special exposures, although not in principle, the Commission depends on the occasions on which during the year the Commission recommendation level should of the annual level bears the dose equivalent limit level for routine that events requiring monitoring may individual about

(180) Investigation monitoring will form of the monitoring type of investigation common form monitoring of expected consistent conditions.

(181) Although able for initiating situations, it is dose equivalent The Commission

mentation on individual monitoring in Working Condition B (i.e. where it is most unlikely that the exposure will exceed three-tenths of the appropriate dose equivalent, secondary or derived limits) it is often appropriate to use this figure of three-tenths in setting investigation levels for individual monitoring. However, an investigation level, to be useful, has to be set in relation to a single measurement, not the accumulated dose equivalent or intake in a year, and it is most appropriate to base the investigation level on the fraction of three-tenths of the limit corresponding to the fraction of a year to which the individual monitoring measurement refers. Corresponding derived investigation levels can then be deduced for the quantities directly measured.

(179) Somewhat different considerations apply in the setting of investigation levels for programs of special monitoring. Here the monitoring is associated with a single event, ~~though not necessarily a unique one. In principle, the choice of an investigation level depends on the expectation of the number of occasions on which similar events will occur during the year. In ICRP Publication 10, the Commission recommends that the investigation level should correspond to one-twentieth of the annual dose-equivalent limits. This level bears the same relationship to the dose-equivalent limit as does the corresponding level for routine monitoring, if it is assumed that events requiring a program of special monitoring may occur in relation to a single individual about six times in a year.~~

(180) Investigation levels for other types of monitoring will depend on the objectives and form of the monitoring program and on the type of investigation to be carried out. One common form of investigation level for the monitoring of workplaces is based on the expected consistency of results during normal conditions.

(181) Although investigation levels are suitable for initiating investigations into specific situations, it may be convenient to record dose equivalents at somewhat lower levels. The Commission recommends that recording

levels should be based on an annual dose equivalent or intake of one-tenth of the annual dose-equivalent limit or intake limit.

(182) For the special case of monitoring of skin, two situations occur in routine practice. For external radiation a dose equivalent is measured by one or two dosimeters and the results are treated as representative of the whole, or of substantial areas, of the skin. No problem of averaging then arises and the results are related directly to the relevant dose-equivalent limit. In the second situation, the irradiation results from surface contamination on the skin. This is never uniform and occurs preferentially on certain parts of the body, notably the hands. However, it does not persist over many weeks and does not always occur again at exactly the same places. For routine purposes, it is adequate to regard the contamination as being averaged over areas of about 100 cm<sup>2</sup>. Routine monitoring for skin contamination should therefore be ~~interpreted on this basis and the limit applied to the average dose equivalent over 100 cm<sup>2</sup>.~~

(183) In accidents or suspected accidents, more detailed information should be sought on the distribution of absorbed dose, dose equivalent or contamination. An estimate should be made of the average dose equivalent over 1 cm<sup>2</sup> in the region of the highest dose equivalent. This dose equivalent should then be compared with the dose-equivalent limit. If the dose distribution is extremely non-uniform, as is that from very small particles in contact with the skin, the local distribution of absorbed dose should be assessed and used to predict possible local skin reactions. It is inappropriate, however, to relate such localized absorbed doses to the absorbed doses corresponding to the dose-equivalent limit.

#### *Medical surveillance*

(184) The medical surveillance of workers exposed to radiation is based on the general principles of occupational medicine. It has the following aims:

- to assess the health of the worker;
- to help in ensuring initial and continuing

compatibility between the health of the workers and the conditions of their work; to provide a base line of information useful in the case of accidental exposure or occupational disease.

Deleterious effects cannot be unequivocally associated with exposures within the dose-equivalent limits, and medical surveillance has no part to play in confirming the effectiveness of a radiation protection program. Medical surveillance may include both pre-operational and routine examinations, the latter being determined mainly by the worker's general state of health and by the conditions of work.

(185) Workers designated as operating in Working Condition A should be given a pre-operational medical examination before starting this kind of work, though not necessarily before employment. One objective of this examination is the recognition of conditions or characteristics that limit the type of exposure to which the individual should be subjected. For these purposes, the physician needs information about the conditions of work, including details of the job description.

(186) Following a preoperational examination, consideration should be given to the need for a continuing surveillance of the health of workers. If this is needed, the physician should have access to information held by the employing organization about the working conditions (e.g. job description and working environment) and about the state of health of workers (e.g. absences due to sickness). It is principally on the basis of this information that the frequency of any routine examinations should be decided.

(187) The Commission considers that, with the present dose-equivalent limits, no special administrative arrangement is appropriate for workers as far as radiation risks are concerned. In particular, no special arrangement is required with respect to working hours and length of vacation.

#### *Intervention in abnormal situations*

(188) Arrangements should be made for

dealing with abnormal situations, not only with respect to their detection and the assessment of dose or intake, but also with respect to the form of intervention that may have to be applied. The intervention levels and the appropriate actions for limiting exposure should be the subject of operating instructions. Provision should be made for special medical surveillance and, if necessary, treatment following exposure substantially in excess of the dose-equivalent limits.

(189) The emergency plans (which should, as far as practicable, be drawn up in advance) should have three clearly distinguished objectives. The first is to restrict exposures as far as is reasonably achievable and, in particular, to attempt to avoid exposures above the dose-equivalent limits. The second is to bring the situation back under control, and the third is to obtain information for assessing the causes and consequences of the event.

(190) Although, by their nature, accidental exposures are not subject to control, their magnitude can to some extent be limited by intervention, especially if attention has been paid to this possibility during the design of installations and equipment and the preparation of operating instructions.

(191) During the immediate course of a serious incident, urgent action to save life, to prevent injuries, or to prevent a substantial increase in the scale of the incident, may require that some workers be exposed in excess of the limits applicable to a planned special exposure. Such workers should be volunteers, and it is desirable that groups of workers likely to provide such volunteers should, as part of their normal training, receive information about risks involved in exposures above the limits. It will not normally be possible to control such exposures in detail, but substantial efforts should be made to provide an upper limit to the likely exposures.

(192) Once the initial event has been brought under control, there remains the problem of remedial work. It will usually be appropriate to carry this out while maintaining compliance with the Commission's recommended limits

but, exceptional which the use of excessive expense of people and then be given to a planned number of individuals essential operations be done in compliance

(193) As a result of individual work or contaminated areas, the immediate action to collect information on the circumstances of the accidents, with a view to the individuals substantially above the limits of contamination intake by inhalation of active substances, action is indicated, which it can be seen to control contamination, followed to interfere with treatment, medical attention will often have grounds rather than

(195) The term "the exposure of individuals" examination or treatment. Most medical examinations use of radiation for diagnostic purposes, but in the case of cardiac catheterization, active power so useful part an advertisement.

(196) The objectives are:

but, exceptionally, there may be situations in which the use of the limits would involve an excessive expense or an excessive involvement of people and time. Consideration should then be given to the appropriateness of authorizing a planned special exposure for a limited number of individuals to carry out various essential operations, leaving the remainder to be done in compliance with the limits.

(193) As a result of abnormal situations, individual workers may be seriously exposed or contaminated. In respect of external exposure, the immediate action needed is essentially to collect information about the circumstances of the accident and to initiate medical tests, with a view to subsequent diagnosis, on the individuals who may have been exposed substantially above the limits. In some cases of contamination of skin or wounds, or of the intake by inhalation or ingestion of radioactive substances, immediate therapeutic action is indicated. The effectiveness of the action is largely determined by the speed with which it can be carried out. However, the need to control contamination should not be allowed to interfere with the first aid and subsequent treatment of individuals who require medical attention for other reasons. Decisions will often have to be made on qualitative grounds rather than on the basis of carefully

made and interpreted monitoring measurements. It is particularly important in this respect that there should be a close working relationship between the management of the institution, the individuals with special responsibilities for radiation protection, and the medical staff, whether these be associated with the institution or the local hospital. It is essential that such working relationships be developed in advance.

(194) The principal administrative arrangements to be made after an abnormal event are those concerned with initiating an investigation into the causes and consequences of the event and with reaching decisions about the need for any restriction on the future employment of those involved in the event. If the dose or the intake of radioactive material exceeds twice the annual limit, the case should be subject to appropriate medical review. The worker may still be allowed to continue routine work if there is no objection from the medical standpoint, due account having been taken of previous exposure, health, age and special skills, as well as social and economic responsibilities. However, the event may have demonstrated characteristics in individuals indicating unsuitability for further employment in similar work.

## MEDICAL EXPOSURE

(195) The term medical exposure refers to the exposure of individuals subject to medical examination or treatment involving radiation. Most medical exposure is concerned with the use of radiation for diagnostic or therapeutic purposes, but sometimes, for example in the case of cardiac pacemakers using a radioactive power source, the radiations play no useful part and the exposure is merely adventitious.

(196) The objectives of the medical procedures are:

- examinations or treatments directly associated with illness;
- systematic examinations undertaken for mass screening purposes or for periodic health checks;
- examinations forming part of the medical surveillance of workers or carried out for medico-legal or insurance purposes;
- examinations or treatment forming part of a medical research program.

*Examinations or treatments directly associated with illness*

(197) The decision as to whether an examination involving a certain radiation dose to a patient is justified is sometimes the responsibility of the referring physician, and sometimes of the practitioner who carries out the procedure. In either case, however, it is imperative that the decision be based upon a correct assessment of the indications for the examination, the expected yield from the examination and the way in which the results are likely to influence the diagnosis and subsequent medical care of the patient. It is equally important that this assessment be made against a background of adequate knowledge of the physical properties and the biological effects of ionizing radiation.

(198) In therapeutic exposures, the absorbed doses to organs are in general very much higher and both the dangers of the exposure and the benefits of the treatment can be assessed more quantitatively. The decision can then be based on a balance between these aspects. It is also necessary to consider alternative therapeutic procedures and to compare their effectiveness and their dangers with those associated with radiological treatment.

(199) While it is important that the decision to proceed with examinations or treatment involving exposure to radiations should take into account the dangers of such exposures, it is equally important that these dangers should not be overestimated, since this might lead to the rejection of justified examinations or treatments.

*Systematic examinations*

(200) Periodic health checks undertaken without reference to current illness may involve some radiological examinations. Their justification depends on the probability of obtaining useful information and the importance of this information for the individual's health.

(201) For the systematic examinations used in mass screening, the justification should be

based on a balance between the advantages implied for the individuals examined and for the population as a whole, together with the costs, including detriment, of the screening. In general, the advantages will depend on the yield of the screening procedure, the possibility of effective treatment of the cases detected and, for certain diseases, the advantages to the community of the control of the disease. The benefits of screening are not always the same for different groups making up the population and screening will often be justified only if it is limited to certain specified groups. The program should be subject to frequent examination to determine whether the yield in finding significant disease is sufficiently high to warrant its continuation.

*Examinations for occupational, medico-legal or insurance purposes*

(202) Examinations carried out to assess the fitness of an individual for work, to provide information for medico-legal purposes, or to assess the health of a subscriber to, or beneficiary of, an insurance may carry some direct or indirect advantages for the individual examined, but they also carry advantages for the employer, third parties and the insurer. All these aspects should be considered in assessing the justification of such examinations.

*Medical research*

(203) Examinations or treatment forming part of a medical research program sometimes involve direct benefits for the exposed individual and sometimes do not. When new and experimental methods of diagnosis or treatment are capable of benefitting the patients on whom they are tested, the justification for the procedures can be judged in the same way as for other medical exposures. Nevertheless, because of the experimental character of the procedures, they should be subject to thorough review.

(204) The deliberate irradiation of persons

for the purposes of studies in which persons are irradiated when the exposure they may have properly qualified irradiation should be with the consent of the institution where it takes place, as advised by the body and subject to the conditions. The estimate should be expected to be voluntary and their free will. The conditions should be rigorous and should be in accordance with their capabilities. It follows that the conditions of such studies should be regarded as being true consent should be expected radiations of one order of magnitude (limits applicable to the public) and if those legally defined. The individual should obtain information on exposure and ensure that they are able, and thus ever, the magnitude of the exposure with the state of health and it is not applicable. Therefore, the program.

*The optimization*

(205) The emphasis is that would, in many cases, reduction of the exposure, without in general, the conditions should allow:

for the purposes of those research and other studies in which no direct benefit to the persons irradiated is intended, in circumstances when the exposure is unrelated to any illness they may have, should only be undertaken by properly qualified and trained persons. Such irradiation should only be given with the consent of the authorities in charge of the institution where the irradiation is to take place, as advised by an appropriate expert body and subject to local and national regulations. The estimated risks of the irradiation should be explained to those involved, who should be volunteers fully able to exercise their free will. The higher the dose the more rigorous should be the requirements on the conditions of securing true volunteers and on their capability of understanding the risk. It follows that the irradiation, for the purposes of such studies, of children and other persons regarded as being incapable of giving their true consent should only be undertaken if the expected radiation dose is low (e.g. of the order of one-tenth of the dose-equivalent limits applicable to individual members of the public) and if valid approval has been given by those legally responsible for such persons. The individuals exposed under these conditions obtain no direct benefit from their exposure and it is therefore necessary to ensure that their detriment remains acceptable, and thus to set authorized limits. However, the magnitude of the detriment associated with the exposure depends on the age and the state of health of the exposed individual and it is not possible to fix limits of general applicability. Appropriate limits should therefore be authorized for each research program.

#### *The optimization of exposure*

(205) The Commission wishes to re-emphasize that careful attention to techniques would, in many cases, result in a considerable reduction of the dose due to medical procedures, without impairment of their value. In general, the techniques and equipment used should allow:

the reduction of the doses received by tissues in the region of the body under examination to the minimum compatible with obtaining the necessary information in the particular patient;

the delivery to the treated region of the body of a therapeutic dose the magnitude of which is most likely to ensure the required response;

the limitation as far as practicable of the exposure of other parts of the body.

(206) Because of the risk of radiation injury to any embryo or foetus, the possibility of pregnancy is one of the factors to be considered in deciding whether to make a radiological examination involving the lower abdomen in a woman of reproductive capacity. Although such an examination is least likely to pose any hazard to a developing embryo if carried out during the 10 day interval following the onset of menstruation, attention should always be paid to details of radiological technique that would ensure minimization of exposure to any embryo or foetus that may be present, whether or not the woman is known to be pregnant.

(207) Before prescribing an examination or investigation, the responsible practitioner should satisfy himself that the necessary information is not already available from other previous examinations and investigations.

#### *Professional training*

(208) The Commission wishes to emphasize the importance of including adequate training on radiation protection in the general education and training of individuals entering the medical and associated professions, since all those who enter these professions may be involved in prescribing procedures involving exposure to ionizing radiation. More thorough training in radiation protection is required by those planning to enter the field of radiology and by scientists and technicians assisting in the medical uses of radiation.

(209) Recommendations and more detailed information on the protection of individuals subject to medical examinations or treatment

and on the training of the medical profession are included in *ICRP Publications 15, 16 and 17.*

### OTHER EXPOSURES

(210) As a result of human activities, individuals in the population may be subject to exposure to many sources beyond those giving rise to occupational exposure and medical exposure. Exposure to this wide range of sources is considered in the following paragraphs.

(211) The various contributions to other exposure may be grouped into broad categories to which the general principles of protection may apply but which call for different technical approaches. These categories are:

- exposure due to the dispersion in the environment of radioactive materials;
- direct exposure to radiation sources used in industry, medicine and research;
- exposure resulting from the use in everyday life of widely distributed products containing sources of ionizing radiation;
- exposure to natural sources of radiation and to practices in everyday life that cause an increase in the level of dose resulting from the natural background of radiation;
- and
- exposure due to the use of radiation sources in teaching.

#### *The assessment of exposure*

(212) In order to apply the system of dose limitation to any practice involving such exposures, it is necessary to assess both the individual dose equivalents and the collective dose equivalents. For the purpose of comparing individual dose equivalents with the appropriate limits, the doses from the normal natural radiation background are not included (see paragraphs 89 and 90).

(213) The assessment of individual dose equivalent has the aim of ensuring that the exposure of each individual remains within the appropriate limits and this assessment must therefore take into account not only the radiation resulting from the practice under consideration but also the total exposure resulting from all the practices that contribute to general exposure. The assessment of collective dose equivalent has as its main object the appraisal of the justification and optimization of the exposure. The assessment can therefore be carried out in relation to the proposed practice alone.

(214) The exposure of individuals depends on a large number of factors, some related to their way of life and their use of the environment and others concerning their biological characteristics. It is not possible to evaluate these variables for each of the exposed individuals, but it is generally possible to identify within an exposed population smaller groups comprising individuals who are broadly comparable in respect of those characteristics that determine their exposure.

(215) The dose equivalent to a specified organ or tissue in a given population group will usually be determined on the basis of a representative sample. The spread of the observed values will be an indication of the homogeneity of the sample, and thus of the group, and will provide a statistical basis for judging whether the group has been suitably defined.

(216) It is often possible to identify population groups with characteristics causing them to be exposed at a higher level than the rest of the exposed population from a given practice. The exposure of these groups, known as critical groups, can then be used as a

measure of the doses resulting from the practice. When several practices contribute significantly to the exposure of the population, either individually or collectively, the definition of the dose equivalent must take account of the total exposure.

(217) When the time or the exposure rate of the experimental contamination is high, the collective annual dose equivalent is a maximum over the period of the procedure continuing until the maximum correction of an equivalent level resulting from the practice. The average dose equivalent that should be used is the collective dose equivalent.

(218) It is also possible to define the collective dose equivalent. These are obtained by averaging the dose of the exposed population where each of the individuals is exposed during the application of the practice for a specified time, and the annual dose then reach equivalent collective dose year of practice remain constant under the conditions, the size of the population and the way in which the practice is carried out. In some instances it is assumed to allow for the time taken to reach equivalent sufficient to define the equivalent rate as this integrals

measure of the upper limit of the individual doses resulting from the proposed practice. When several practices may contribute significantly to the exposure of the same exposed population, either simultaneously or successively, the definition of critical groups must take account of these separate contributions.

(217) When the procedure is extended in time or the exposure results from environmental contamination, the individual and collective annual dose equivalents may rise to a maximum over a period of years even if the procedure continues at a constant level. Their maximum corresponds either to the achievement of an equilibrium condition or to the level resulting from the period of application of the practice. It is this maximum of the average dose equivalent in the critical groups that should be compared with the corresponding dose-equivalent limit.

(218) It is also useful in some cases to assess the dose-equivalent commitment or the collective dose-equivalent commitment. These are obtained by integrating over all time the average dose-equivalent rate throughout the exposed population and the collective dose-equivalent rate in that population, where each of these rates is that resulting from the application of a specified practice for a specified time, often a year. On the assumption that all relevant conditions remain constant, the annual mean dose equivalent and the annual collective dose equivalent will then reach equilibrium values equal to the dose-equivalent commitment and the collective dose-equivalent commitment per year of practice. The factors that have to remain constant include the rate of application of the practice, the environmental conditions, the size of the exposed population and the way people use that environment. In some instances, the practice cannot be assumed to continue for a sufficient time to allow for the annual collective dose equivalent to reach equilibrium. In this case, it is sufficient to integrate the collective dose-equivalent rate over the period of the practice, as this integral is equal to the maximum

annual collective dose equivalent to be experienced in the future from the practice.

(219) Because of its complexity, assessments of collective dose equivalent involve the use of simplifications and approximations, particularly when a large population is irradiated at low dose levels. Because of this, they may involve considerable uncertainties and these must be borne in mind when the assessments are being used to appraise the detriment associated with a practice.

#### *The restriction of exposure*

*The release of radioactive materials into the environment.* (220) The restriction of the exposure which is caused by the release of radioactive materials into the environment depends on:

- the control of releases of gaseous and liquid effluents to the environment;
- the control of disposals to the environment of solid wastes;
- appropriate arrangements for reducing the probability of accidents giving rise to the releases of radioactive materials into the environment and for limiting the magnitude of these releases, should they occur.

(221) Except for trivial amounts of activity, all releases of radioactive substances to the environment (including the disposal of solid wastes) should be subject to authorizations issued by the competent national authority. These authorizations should be based on pre-operational studies which should, if necessary, include the assessment of the dose-equivalent commitment to different population groups and, in particular, to the critical group, and the collective dose equivalents and collective dose-equivalent commitments. These studies should be carried out at an early stage of a project when it is still possible to introduce modifications.

(222) These assessments require the use of models of various degrees of complexity, representing the movement of radioactive materials through the environment from the

source to man. These models have to take into account the nature and the physical and chemical forms of the radioactive materials, together with their methods of release. The models then have to reflect the characteristics of the environment and of man that influence the consequent exposure of individuals and groups. To make such models detailed and realistic requires extremely complex studies involving a considerable effort, and it is reasonable in practice to adjust the magnitude of this effort to the importance of the particular problem.\*

(223) In practice, the first stage is to carry out a simplified preliminary study based on existing information and making use of reasonably cautious hypotheses to bridge over the gaps in the information that always exist at this stage. In almost all situations the preliminary study will show that the exposures that might be caused by the proposed releases are extremely low and that sufficient information already exists for making decisions. In some cases, however, the preliminary study will indicate the need for further work, usually of limited scale.

(224) When it appears that the exposures will be significant, it will usually be necessary to assess them with greater accuracy and to carry out more detailed studies directed principally at reducing the uncertainties indicated by the preliminary study.

(225) The relationship between the rate of release and exposure of the critical group allows the assessment of a derived limit of release in each case.

(226) The authorized limits of release are fixed by the national authorities at values which are generally lower than those of the derived limits. In setting such limits the authorities should apply, with an appropriate degree of detail, the processes of optimization, and should take account of other current or proposed sources of exposure.

(227) Because of the different factors considered in the process of optimization, the

authorized limit for the total release to a sector of the environment to which several installations release radioactive materials may be different from the sum of the optimized limits appropriate for each installation separately. When several installations make releases into the same sector of the environment, for example into the same river basin, it is necessary to assess the derived limit of release for the whole of the relevant sector.

*Direct external exposure from sources used for industrial, medical or scientific purposes.*

(228) The restriction of exposure in these cases is usually achieved with the aid of technical standards relating to the sources. In some cases, however, the restriction of exposure may form part of the design of the individual project. Any necessary reduction of exposure is usually obtained by the use of shielding, but exceptionally it may be necessary to define an area of restricted access or use in the vicinity of the source.

*The use of products widely distributed to the public.* (229) It is convenient to distinguish between two categories of such products:

- those which include electronic equipment that emits x rays adventitiously;
- those which contain radioactive materials.

(230) These two categories of product present different problems in the restriction of exposure. The first category gives rise only to external irradiation and that only during operations. For the second category, it is also necessary to take account of the possibility of contamination resulting from normal use, abnormal events and disposal.

(231) The restriction of exposure from both these categories of product should be based on a control system at the national level aimed at ensuring that the exposures caused by each product are justified and then limited in an appropriate way. The appraisal of the consequences of the use of these products is

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*Practices natural back practices th exposure fro radiation inc*

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(236) In ap exposure, it

\*This topic is discussed in detail in a report being prepared by ICRP Committee 4.

generally based on the magnitude of the collective dose equivalent that they cause, but in some applications it may also be necessary to take account of the individual dose equivalents. The exposure resulting from a given application can often be reduced by features of the design (for example, by the choice of the radionuclide used or by the introduction of shielding against x rays).

(232) It is often the case that the benefits of a particular application, though real, are very small, while the resulting exposures are also very small. It is then very difficult to make a quantitative appraisal of the situation, and the final decision will often be based on qualitative judgment.

(233) Although the exposures resulting from each type of these widely distributed products are usually low, the national authority should ensure that the exposures resulting from all the applications taken together remain within limits that it judges to be acceptable.

(234) The practical restriction of exposures from products whose use is justified and authorized, is achieved by compliance with technical standards dealing with the characteristics of the products and, in some cases, with the conditions of their use and, sometimes, by providing arrangements for their eventual disposal.

*Practices raising the level of exposure to natural background.* (235) Examples of the practices that may increase the level of exposure from the natural background of radiation include:

- the use of certain materials in the construction of buildings and roads;
- high-altitude flying;
- the consumption of water and foodstuffs in which the concentration of natural radioelements is unusually high because of their origin or has been enhanced, for example by the use of fertilizers.

(236) In applying the system of limitation of exposure, it is appropriate to take account

only of the change in exposure caused by the assessed practice and not of the pre-existing exposure level. The justification for most of the underlying practices (such as the construction of buildings) is self-evident, and the emphasis in the restriction of exposure is therefore on optimization. The process of optimization usually leads to the establishment of authorized limits for each significant situation.

*The use of radiation sources in teaching.*

(237) It is important to distinguish between two kinds of applications of radiation sources in teaching:

- the general teaching of science subjects;
- specialized teaching of subjects concerned with radiations and their uses.

In the first type of application the exposure resulting from demonstrations or experiments is likely to involve a very large number of people and might thus contribute significantly to the general exposure. For this reason, the Commission recommends that the annual dose equivalents received by individual pupils during their courses should not exceed one-tenth of the limits recommended for individual members of the public. The second type of application involves a much smaller number of people and is analogous to occupational exposure. Only exceptionally will the use of radiation sources in this kind of teaching require the conditions of work to be classified as Working Condition A (see paragraph 161). Working Condition A should be permitted only where students are aged 18 years or over. The general procedures for restricting exposure should be broadly similar to those for occupational exposure although, in the absence of Working Condition A, they can be substantially simplified. More detailed recommendations are given in *ICRP Publication 13*.

*Monitoring of exposure*

*Monitoring in normal conditions.* (238) Releases of radioactive materials into the

environment should be subject to appropriate monitoring to demonstrate compliance with the authorized release limits, unless other forms of assessment show this monitoring to be unnecessary. For major installations, the monitoring of releases may also contribute to the detection of abnormal situations. In most other cases, the monitoring of sources should be aimed at ensuring compliance with technical standards and the arrangements required by the national authorities. Special requirements may deal, for example, with the effectiveness of shields around sources, the characteristics of consumer products and the monitoring of control of their distribution, or the setting of activity limits for building materials.

(239) In a few cases, essentially limited to situations where the exposure results from the release of radioactive materials into the environment, it may be necessary to supplement the monitoring of sources by monitoring of the relevant sector of the environment. Such monitoring may also be useful in verifying the validity of the models used in predicting exposure. The introduction of environmental monitoring is only necessary in the few cases where preoperational studies have shown that the installation might be the cause of a significant exposure of members of the public. Situations may also arise where several installations may release radioactive materials into the same sector of the environment and, even if each is individually insignificant, they may together make it necessary to introduce a program of environmental monitoring, usually of a limited nature.

(240) Individual monitoring will not normally form a part of the monitoring of general exposure of the public, except in relation to some aspects of the use of radiation sources in teaching. In the specialized teaching associated with the characteristics or use of radiation sources, individual monitoring may be justified by the likely levels of exposure or by the fact that it forms a valuable introduction to good practice in subsequent work.

*Monitoring in abnormal circumstances.*  
(241) In abnormal circumstances following, for example, an accident in an installation or during transport, it may be necessary to carry out monitoring if radioactive materials may have been released into the environment in quantities capable of causing a significant exposure of members of the public. This monitoring has the principal objective of obtaining information necessary to assess the situation and to decide on the need for intervention. It should also provide data for the evaluation of the exposure of members of the public, taking account of any countermeasures that have been applied. Furthermore, scientific information should also be collected with the aim of improving the prediction of consequences in such situations. The program of monitoring should be designed, at least in general terms, when an installation first becomes operational or a series of transport operations is first considered.

#### *Intervention*

(242) The form of intervention suitable for limiting an abnormal exposure to members of the public will depend on the circumstances. All the countermeasures that can be applied to reduce the exposure of members of the public after an accidental release of radioactive materials carry some detriment to the people concerned, whether it is a risk to health or some social disruption. The decision to introduce countermeasures should be based on a balance of the detriment which it carries and the reduction in the exposure which it can achieve. The magnitude of the detriment of countermeasures will vary with their nature and with the circumstances in which they are applied, for example, with the size of the population involved. Their effectiveness, on the other hand, will depend on the speed with which they can be introduced. For these reasons it is not possible to fix generally applicable intervention levels above which intervention will always be required. How-

ever, it might which intervene considered to depend on th each case and guidance. The measures show information a tion levels are dose equivalent helpful in prevention levels measurements monitoring pr  
(243) To be pre-planned. therefore be p members of t significant ac gency plan shc  
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ever, it might be possible to set levels below which intervention would not generally be considered to be justified. Intervention levels depend on the particular circumstances of each case and can therefore give only general guidance. The decision to introduce countermeasures should be taken in the light of all the information available at the time. Intervention levels are expressed in terms of individual dose equivalents or intakes. It will often be helpful in practice to provide derived intervention levels applicable to the results of the measurements forming part of the special monitoring program.

(243) To be effective, intervention must be pre-planned. An emergency plan should therefore be prepared in any situation where members of the public may be subject to a significant accidental exposure. The emergency plan should include:

the special monitoring needed to assess the situation (see paragraph 241);  
the countermeasures needed to reduce the

exposure of members of the public together with the means necessary to put them into effect;

the intervention levels and derived intervention levels giving guidance on the different countermeasures.

The emergency plan should be based on a study of the radiological consequences of the releases following a reference accident. These consequences should be assessed using a method analogous to that described in paragraphs 222-234 for releases during normal operations. The plan should be sufficiently flexible to allow its adaptation to the real situation, since this will differ from that forecast. In particular, the intervention levels and the derived intervention levels should not be applied automatically; they should be treated as reference levels intended for guidance in making decisions and should be reassessed in the light of all the available information at the time of intervention.

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