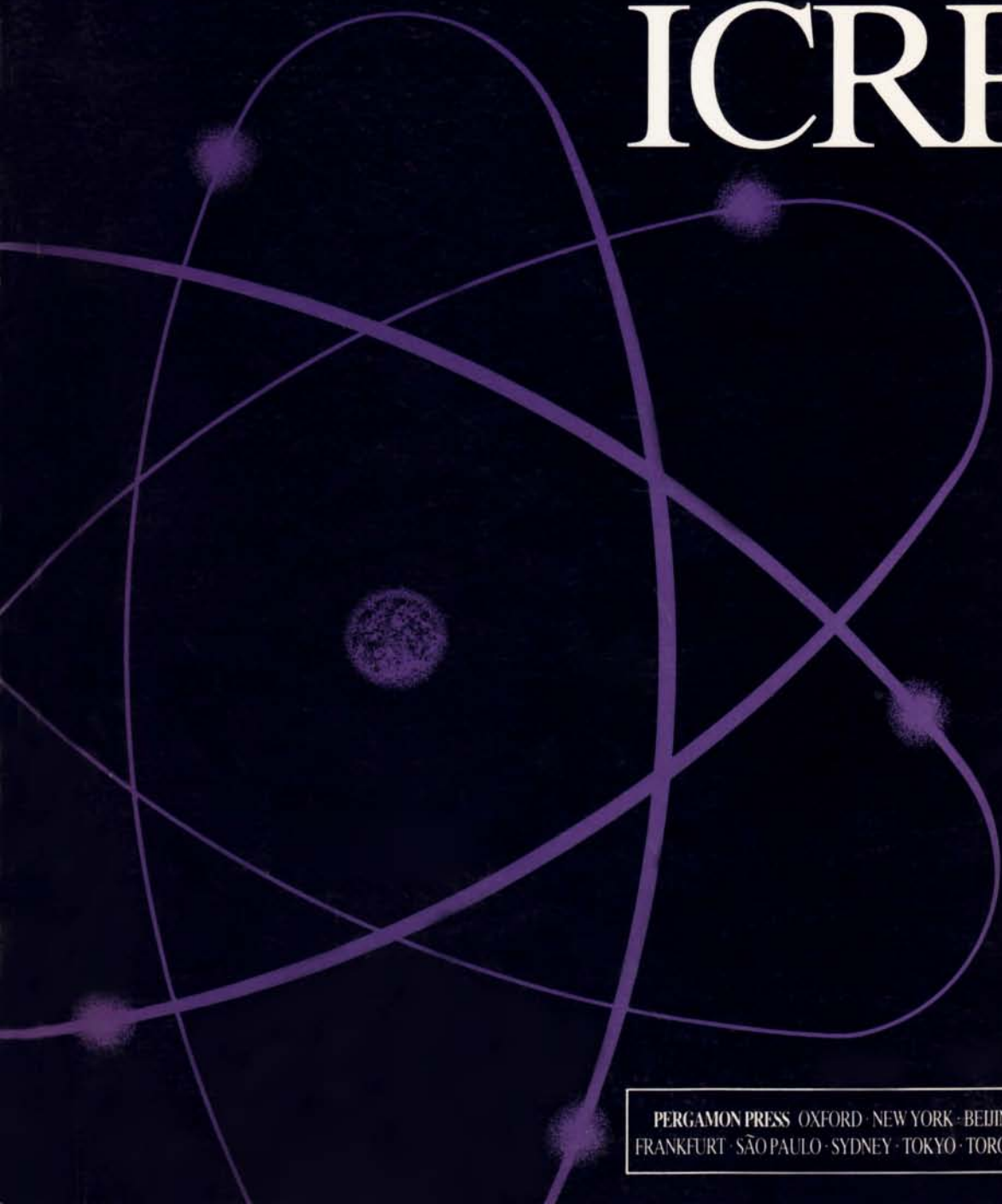
The International Commission on Radiological Protection

ICRP Publication 26

Recommendations of the ICRP



PERGAMON PRESS OXFORD · NEW YORK · BEIJING
FRANKFURT · SÃO PAULO · SYDNEY · TOKYO · TORONTO

RADIATION PROTECTION

ICRP PUBLICATION 26

Recommendations of the International Commission on Radiological Protection

(ADOPTED JANUARY 17, 1977)

PUBLISHED FOR
The International Commission on Radiological Protection
BY
PERGAMON PRESS
OXFORD · NEW YORK · TORONTO · SYDNEY · FRANKFURT

U.K.	Pergamon Press, Headington Hill Hall, Oxford OX3 0BW, England
U.S.A.	Pergamon Press, Maxwell House, Fairview Park, Elmsford, New York 10523, U.S.A.
PEOPLE'S REPUBLIC OF CHINA	Pergamon Press, Qianmen Hotel, Beijing, People's Republic of China
FEDERAL REPUBLIC OF GERMANY	Pergamon Press, Hammerweg 6, D-6242 Kronberg, Federal Republic of Germany
BRAZIL	Pergamon Editora, Rua Eça de Queiros, 346, CEP 04011, São Paulo, Brazil
AUSTRALIA	Pergamon Press Australia, P.O. Box 544, Potts Point, N.S.W. 2011, Australia
JAPAN	Pergamon Press, 8th Floor, Matsuoka Central Building, 1-7-1 Nishishinjuku, Shinjuku-ku, Tokyo 160, Japan
CANADA	Pergamon Press Canada, Suite 104, 150 Consumers Road, Willowdale, Ontario M2J 1P9, Canada

First edition 1977
Reprinted (with additions) 1978
Reprinted (with additions) 1981
Reprinted 1982
Reprinted (with additions) 1987

Typeset by Cotswold Typesetting Ltd., Gloucester
Printed in Great Britain by A. Wheaton & Co. Ltd., Exeter

PREFACE

ICRP Publication 26 was first published in 1977 and, since that time, the recommenda- ions which it includes have been increasingly incorporated into national legislation. This

new edition reproduces the complete text of the original publication, but supplements it with the statements issued by the Commission in 1978, 1980, 1983, 1984 and 1985. These st ements clarify and, in some cases, modify the recommendations given in Publication 26.

In addition to its basic recommendations, the ICRP publishes a wide range of other reports relating to the basis of the recommendations and to their application in particular

circumstances. The first edition of Publication 26 contained a bibliography of other publications of the Commission up to 1977. This has now been updated to include all reports either published or in preparation for publication up to the end of 1986.

CONTENTS

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 ensure 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 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_∞) in water at the point of interest. Interpolated values of Q as a function of L_∞ can be obtained from the figure, which is based on the values shown in the table.

L_∞–Q RELATIONSHIP

L_∞ in water (keV/μm)	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_∞ is not known at all points in the volume of interest, it is permissible to use approximate

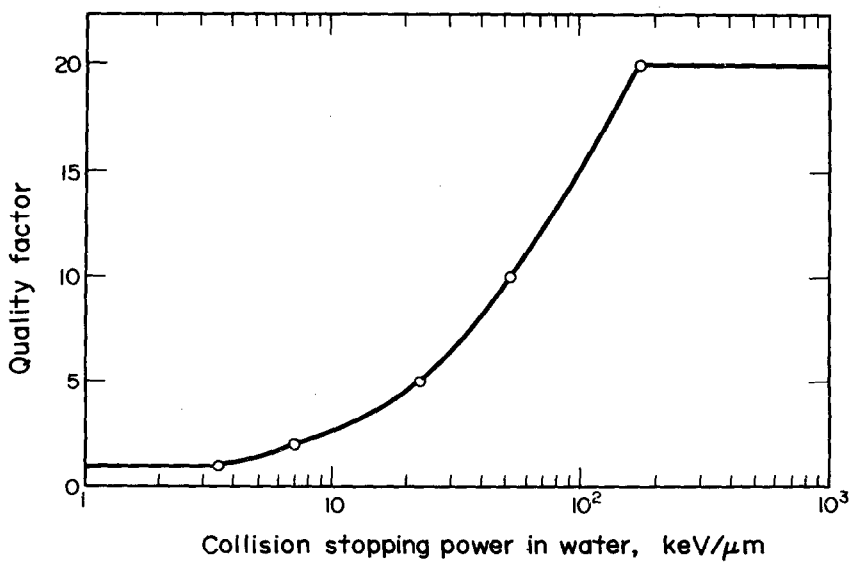


FIG. 1. Quality factor as a function of collision stopping power in water.

*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 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, γ rays and electrons	1
Neutrons, protons and singly-charged particles of rest mass greater than one atomic mass unit of unknown energy	10
α particles and multiply-charged particles (and particles of unknown charge), of unknown energy	20

In the case of thermal neutrons the L_∞ 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

$$S_k = \int_0^\infty HP(H)\,\mathrm{d}H$$

where $P(H)\,\mathrm{d}H$ is the number of individuals receiving a dose equivalent in the whole body or any specified organ or tissue in the range H to $H + \mathrm{d}H$. 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, ΔG, 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, $\dot{\bar{H}}(t)$, in a given organ or tissue for a specified population:

$$H_c = \int_0^\infty \dot{\bar{H}}(t)\,\mathrm{d}t$$

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:

$$H_{50} = \int_{t_0}^{t_0+50\mathrm{y}} \dot{H}(t)\,\mathrm{d}t$$

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

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 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 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:

$$E = aD + bD^2\dagger$$

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 Jkg^{-1} (= 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.)

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.

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

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 progessively 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^{-1}, 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 $2\ 10^{-3}$ Sv^{-1}.

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

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 $2\ 10^{-3}\ Sv^{-1}$.

Pulmonary lymphoid tissue (52) A particular case of importance concerns the retention of inhaled particles containing insoluble compounds 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 $5\ 10^{-4}\ Sv^{-1}$.

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 radiosensitive 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 $2.5\ 10^{-3}\ Sv^{-1}$ (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 $5\ 10^{-3}\ Sv^{-1}$, 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 $10^{-2}\ Sv^{-1}$, 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 $4\ 10^{-3}\ Sv^{-1}$. 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 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 μm (or 5–10 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 μm 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 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

*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 therefore be instances in which judgment will have to be exercised as to whether the component of increased natural radiation should or should not be subject to the Commission's recommended system of dose limitation.

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

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

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

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-

*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.

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

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

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), $H_{\mathrm{wb},L}$ 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
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_I)*. 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:

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

where, H_I 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

*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} 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 $\sum_T w_T H_T \leq H'_{\mathrm{wb},L}$, where $H'_{\mathrm{wb},L}$ 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 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. 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 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.

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 sufficient 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 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 dosemeters 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^2. Routine monitoring for skin contamination should therefore be interpreted on this basis and the limit applied to the average dose equivalent over 100 cm^2.

(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^2 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 preoperational 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 preoperational 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, 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 associ- 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 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 women 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 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 preoperational 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

*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 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 invervention 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.

APPENDIX

Rules governing the selection and work of the Commission

The following are the Commission's rules, as approved by the International Congress of Radiology.

1. (a) The International Commission on Radiological Protection (ICRP) shall be composed of a Chairman and not more than twelve other members. The selection of the members shall be made by the ICRP from nominations submitted to it by the National Delegations to the International Congress of Radiology and by the ICRP itself. The selections shall be subject to approval by the International Executive Committee (IEC) of the Congress. Members of the ICRP shall be chosen on the basis of their recognized activity in the fields of medical radiology, radiation protection, physics, health physics, biology, genetics, biochemistry and biophysics, with regard to an appropriate balance of expertise rather than to nationality.

(b) The membership of the ICRP shall be approved during each International Congress, for service until the end of the succeeding Congress, or until new members are appointed. Not less than three but not more than five members shall be changed at any one Congress. In the intervening period vacancies may be filled by the ICRP.

(c) In the event of a member of the ICRP being unable to attend the ICRP meetings, a substitute may be selected by the ICRP as a temporary replacement. Such a substitute shall not have voting privileges unless specifically authorized by the ICRP.

(d) The ICRP shall be permitted to invite individuals to attend its meetings to give special technical advice. Such persons shall not have voting privileges, but their opinions may be recorded in the minutes.

2. The Chairman shall be elected by the ICRP from among its members to serve until the end of the succeeding Congress, or until his successor is elected. The choice shall not be limited to the country in which it is proposed to hold the succeeding Congress. The Chairman shall be responsible for reporting the proceedings and recommendations of the ICRP at the next Congress.

3. The ICRP shall elect from among its members a Vice-Chairman who will serve in the capacity of Chairman in the event that the Chairman is unable to perform his duties.

4. Minutes of meetings and records of the ICRP shall be made by a Scientific Secretary selected by the Chairman of the ICRP, subject to the approval of its members. The Scientific Secretary need not be a member of the ICRP. The records of the ICRP shall be passed on to the succeeding Scientific Secretary.

5. The Chairman, in consultation with the Vice-Chairman and the Scientific Secretary, shall prepare a program to be submitted to the Commission for discussion at its meetings. Proposals to be considered shall be submitted to the Chairman for circulation to all members of the ICRP and other specially qualified individuals at least 2 months before any meeting of the ICRP.

6. Decisions of the ICRP shall be made by a majority vote of the members. A minority opinion may be appended to the minutes of a meeting if so desired by any member upon his submission of the same in writing to the Scientific Secretary.

7. The ICRP may establish such committees as it deems necessary to perform its functions.

Membership

The Commission's rules require that its members be elected every 4 years. The membership of the Commission and of its committees for 1973–1977 was as follows:

C. G. STEWART, *Chairman*
B. LINDELL, *Vice-Chairman*
D. J. BENINSON
H. JAMMET
J. LINIECKI
A. S. MCLEAN
Y. I. MOSKALEV
H. B. NEWCOMBE
E. E. POCHIN
S. TAKAHASHI
A. C. UPTON
J. VENNART
B. WINDEYER
K. Z. MORGAN, *Member Emeritus*
L. S. TAYLOR, *Member Emeritus*
F. D. SOWBY, *Scientific Secretary*

Committee 1 on Radiation Effects

A. C. UPTON, *Chairman*
S. ABRAHAMSON
G. W. BARENDSEN
J. M. BROWN
A. M. BRUES
O. HUG
B. MODAN
R. H. MOLE
G. MORLAT
P. OFTEDAL
A. G. SEARLE
V. ZELENÝ

Committee 2 on Internal Exposure

J. VENNART, *Chairman*
W. J. BAIR
G. C. BUTLER
G. W. DOLPHIN
L. E. FEINENDEGEN
W. JACOBI
J. LAFUMA
C. MAYS
P. E. MORROW
P. V. RAMZAEV
W. S. SNYDER
R. C. THOMPSON

Committee 3 on External Exposure

B. LINDELL, *Chairman*
A. KELLERER
E. E. KOVALEV
L.-E. LARSSON
C. MEINHOLD
R. OLIVER, *died 1976*
P. PELLERIN
R. A. ROWLEY
K. A. STEVENS
S. TAKAHASHI

Committee 4 on Application of the Commission's Recommendations

H. JAMMET, *Chairman*
D. J. BENINSON
H. J. DUNSTER
K. KOREN
E. KUNZ
D. MÉCHALI
A. A. MOISEEV
H. MUTH
C. POLVANI
L. ROGERS
D. J. STEVENS
E. G. STRUXNESS
K. SUNDARAM

Method of Work

Much of the work of the International Commission on Radiological Protection is performed by *ad hoc* task groups, by means of which the Commission has been able to call on the services of a large number of individuals who are not members of a committee. In this way the Commission is able to bring together the appropriate experts rapidly and effectively so that work can be completed and reports published within the short time that is essential if the Commission's recommendations are to ensure the safe and rapid development of new techniques in the light of the most recent information. Reports that have been published are shown at the end of the appendix.

Relationships with other bodies

The Commission has an official relationship with the World Health Organization and the International Atomic Energy Agency. Close working relationships are also maintained with the United Nations Scientific Committee on the Effects of Atomic Radiation, the United Nations Environment Programme, the International Labour Office, the International Electrotechnical Commission, the Nuclear Energy Agency and the European Economic Community. The Commission is represented by observers at a number of meetings organized by these bodies; all of the above bodies are invited to send representatives to the Commission's meetings with its committees.

Financial support

Meetings of the Commission with its committees are held approximately every 2 years, and the Commission itself meets about once a year. In addition, committees and task groups meet on their own to discuss and prepare their reports. The Commission has been able to support the travel costs of some of the individuals attending these meetings, thanks to grants of money generously made to it by the World Health Organization, the International Atomic Energy Agency, the United Nations Environment Programme, the International Society of Radiology, the International Radiation Protection Association, the Nuclear Energy Agency, the European Economic Community, and national sources in Canada, Japan and the United Kingdom. Nevertheless, the contribution that the Commission can make to travel expenses is severely limited, and during recent years between one-half and two-thirds of the total travel costs have been borne by the institutions of the ICRP members. The Commission is grateful for the amount of time made available to its work by the institutions of its members, and for all the financial support, without which it would not be possible to carry out its work.

PUBLICATIONS OF THE COMMISSION

1. *X-ray and Radium Protection.* Recommendations of the 2nd International Congress of Radiology, 1928. Circular
No. 374 of the Bureau of Standards, U.S. Government Printing Office (January 23, 1929). *Br. J. Radiol.*, **1**, 359 (1928).

2. Recommendations of the International X-ray and Radium Protection Commission. Alterations to the 1928 Recommendations of the 2nd International Congress of Radiology. 3rd International Congress of Radiology, 1931. *Br. J. Radiol.*, **4**, 485 (1931).
3. International Recommendations for X-ray and Radium Protection. Revised by the International X-ray and Radium Protection Commission and adopted by the 3rd International Congress of Radiology, Paris, July 1931 *Br. J. Radiol.*, **5**, 82 (1932).
4. International Recommendations for X-ray and Radium Protection. Revised by the International X-ray and Radium Protection Commission and adopted by the 4th International Congress of Radiology, Zurich, July 1934. *Radiology*, **23**, 682–5 (1934). *Br. J. Radiol.*, **7**, 695 (1934).
5. International Recommendations for X-ray and Radium Protection. Revised by the International X-ray and Radium Protection Commission and adopted by the 5th International Congress of Radiology, Chicago, September 1937. British Institute of Radiology (1938).
6. International Recommendations on Radiological Protection. Revised by the International Commission on Radiological Protection at the 6th International Congress of Radiology, London, 1950. *Radiology*, **56**, 431–9 (1951). *Br. J. Radiol.*, **24**, 46–53 (1951).
7. Recommendations of the International Commission on Radiological Protection (Revised December 1, 1954). *Br. J. Radiol.*, Suppl. 6 (1955).
8. Report on Amendments during 1956 to the Recommendations of the International Commission on Radiological Protection (ICRP). *Radiat. Res.*, **8**, 539–542 (1958). *Acta Radiol.*, **48**, 493–495 (1957). *Radiology*, **70**, 261–262 (1958) *Fortschritte* a.d. Gebieted. Röntgenstrahlen u.d. Nuclearmedizin, **88**, 500–502 (1958).
9. Recommendations of the International Commission on Radiological Protection (Adopted September 9, 1958). *ICRP Publication 1*, Pergamon Press, London (1959).
10. Report on Decisions at the 1959 Meeting of the International Commission on Radiological Protection (ICRP). *Radiology*, **74**, 116–119 (1960). *Am. J. Roentg.*, **83**, 372–375 (1960). *Strahlentherapie*, **112**, 3 (1960). *Acta Radiol.*, **53**, 2 (1960). *Br. J. Radiol.*, **33**, 189–192 (1960).
11. Recommendations of the International Commission on Radiological Protection (as amended 1959 and revised 1962). *ICRP Publication 6*, Pergamon Press, Oxford (1964).
12. Recommendations of the International Commission on Radiological Protection Report of Committee II on Permissible Dose for Internal Radiation (1959). *ICRP Publication 2*, Pergamon Press, Oxford (1960). *Health Phys.*, **3**, (1960).
13. Recommendations of the International Commission on Radiological Protection Report of Committee III on Protection against X-rays up to Energies of 3 MeV and Beta- and Gamma-rays from Sealed Sources (1960). *ICRP Publication 3*, Pergamon Press, Oxford (1960).
14. Recommendations of the International Commission on Radiological Protection Report of Committee IV (1953–1959) on Protection against Electromagnetic Radiation above 3 MeV and Electrons, Neutrons and Protons (Adopted 1962, with revisions adopted 1963). *ICRP Publication 4*, Pergamon Press, Oxford (1964).
15. Recommendations of the International Commission on Radiological Protection Report of Committee V on the Handling and Disposal of Radioactive Materials in Hospitals and Medical Research Establishments. *ICRP Publication 5*, Pergamon Press, Oxford (1965).
16. Principles of Environmental Monitoring related to the Handling of Radioactive Materials. A report prepared by a Task Group of ICRP Committee 4, *ICRP Publication 7*, Pergamon Press, Oxford (1966).
17. The Evaluation of Risks from Radiation. A report prepared by a Task Group of ICRP Committee I, *ICRP Publication 8*, Pergamon Press, Oxford (1966). *Health Phys.*, **12**, 239–302 (1966).
18. Recommendations of the International Commission on Radiological Protection. (Adopted September 17, 1965). *ICRP Publication 9*, Pergamon Press, Oxford (1966).
19. Report on amendments to *ICRP Publication 9. Health Phys.*, **17**, 389–390 (1969). *Acta Radiol.*, **8**, 258 (1969).
20. Report on the 1971 meeting of ICRP. *Health Phys.*, **21**, 615–616 (1971). *Phys. Med. Biol.*, **16**, 693–695 (1971).
21. Report on the 1972 meeting of ICRP. *Health Phys.*, **24**, 360 (1973). *Am. J. Roentg.*, **117**, 211 (1973).
22. Report of Committee 4 on evaluation of radiation doses to body tissues from internal contamination due to occupational exposure. *ICRP Publication 10*, Pergamon Press, Oxford (1968).
23. The assessment of internal contamination resulting from recurrent or prolonged uptakes. A report of ICRP Committee 4. *ICRP Publication 10A*, Pergamon Press, Oxford (1971).
24. A review of the radiosensitivity of the tissues in bone. A report prepared by a Task Group for ICRP Committees 1 and 2. *ICRP Publication 11*, Pergamon Press, Oxford (1968).
25. General principles of monitoring for radiation protection of workers. A report prepared by a Task Group of ICRP Committee 4. *ICRP Publication 12*, Pergamon Press, Oxford (1969).

26. Radiation protection in schools for pupils up to the age of 18 years. A report by Committee 3 of ICRP. *ICRP Publication 13*, Pergamon Press, Oxford (1970).
27. Radiosensitivity and spatial distribution of dose. Reports prepared by two Task Groups of ICRP Committee 1. *ICRP Publication 14*, Pergamon Press, Oxford (1969).
28. Protection against ionizing radiation from external sources. A report of ICRP Committee 3. *ICRP Publication 15*, Pergamon Press, Oxford (1970).
29. Protection of the patient in x-ray diagnosis. A report prepared by a Task Group of ICRP Committee 3. *ICRP Publication 16*, Pergamon Press, Oxford (1970).
30. Patient exposures in diagnostic radiology: protection problems of current concern. A statement issued by the International Commission on Radiological Protection (ICRP). July 1973. *Br. J. Radiol.*, **46**, 1086–1088 (1973).
31. Protection of the patient in radionuclide investigations. A report prepared for ICRP and adopted by the Commission in September 1969. *ICRP Publication 17*, Pergamon Press, Oxford (1971).
32. The RBE for high-LET radiations with respect to mutagenesis. A report prepared by a Task Group of ICRP Committee 1. *ICRP Publication 18*, Pergamon Press, Oxford (1972).
33. The metabolism of compounds of plutonium and other actinides. A report prepared by a Task Group of ICRP Committee 2. *ICRP Publication 19*, Pergamon Press, Oxford (1972).
34. Alkaline earth metabolism in adult man. A report prepared by a Task Group of ICRP Committee 2. *ICRP Publication 20*, Pergamon Press, Oxford (1973).
35. Data for protection against ionizing radiation from external sources: supplement to *ICRP Publication 15*. A report of ICRP Committee 3. *ICRP publication 21*, Pergamon Press, Oxford (1973).
36. Implications of Commission recommendations that doses be kept as low as readily achievable. A report of ICRP Committee 4. *ICRP Publication 22*, Pergamon Press, Oxford (1973).
37. Report of the Task Group on Reference Man. A report prepared by a Task Group of ICRP Committee 2. *ICRP Publication 23*, Pergamon Press, Oxford (1975).
38. Radiation protection in uranium and other mines. A report of ICRP Committee 4. *ICRP Publication 24*, Pergamon Press, Oxford (1977).
39. The handling, storage, use and disposal of unsealed radionuclides in hospitals and medical research establishments. A report of a Task Group of ICRP Committees 3 and 4. *ICRP Publication 25*, Pergamon Press, Oxford (1977).
40. Recommendations of the ICRP. *ICRP Publication 26*, Pergamon Press, Oxford (1977).
41. Problems involved in developing an index of harm. A report for the International Commission on Radiological Protection. *ICRP Publication 27*, Pergamon Press, Oxford (1977).
42. Principles and general procedures for handling emergency and accidental exposures of workers. A report of a Task Group of ICRP Committee 4. *ICRP Publication 28*, Pergamon Press, Oxford (1978).
43. Radionuclide release into the environment: assessment of doses to man. A report of a Task Group of ICRP Committee 4. *ICRP Publication 29*, Pergamon Press, Oxford (1979).
44. Limits for intakes of radionuclides by workers. A report of a Task Group of ICRP Committee 2. *ICRP Publication 30*, Pergamon Press, Oxford (1980).
45. Biological effects of inhaled radionuclides. A report of a Task Group of ICRP Committee 1. *ICRP Publication 31*, Pergamon Press, Oxford (1980).
46. Limits of inhalation of radon daughters by workers. A report of the ICRP. *ICRP Publication 32*, Pergamon Press, Oxford (1981).
47. Protection against ionizing radiation from external sources used in medicine. A report of a Task Group of ICRP Committee 3. *ICRP Publication 33*, Pergamon Press, Oxford (1982).
48. Protection of the patient in diagnostic radiology. A report of a Task Group of ICRP Committee 3. *ICRP Publication 34*, Pergamon Press, Oxford (1982).
49. General principles of monitoring for radiation protection of workers. A report of a Task Group of ICRP Committee 4. *ICRP Publication 35*, Pergamon Press, Oxford (1982).
50. Protection against ionizing radiation in the teaching of science. A report of a Task Group of ICRP Committee 4. *ICRP Publication 36*, Pergamon Press, Oxford (1983).
51. Cost-benefit analysis in the optimization of radiation protection. A report of ICRP Committee 4. *ICRP Publication 37*, Pergamon Press, Oxford (1983).
52. Radionuclide transformations: energy and intensity of emissions. A report of a Task Group of ICRP Committee 2. *ICRP Publication 38*, Pergamon Press, Oxford (1983).
53. Principles for limiting exposure of the public to natural sources of radiation. A report of the ICRP. *ICRP Publication 39*, Pergmaon Press, Oxford (1984).
54. Protection of the public in the event of major radiation accidents: principles for planning. A report of a Task Group of ICRP Committee 4. *ICRP Publication 40*, Pergamon Press, Oxford (1984).
55. Nonstochastic effects of ionizing radiation. A report of a Task Group of ICRP Committee 1. *ICRP Publication 41*, Pergamon Press, Oxford (1984).
56. A compilation of the major concepts and quantities in use by ICRP. A report of a Task Group of ICRP Committee 4. *ICRP Publication 42*, Pergamon Press, Oxford (1984).

57. Principles of monitoring for the radiation protection of the population. A report of Committee 4 of ICRP. *ICRP Publication 43*, Pergamon Press, Oxford (1984).
58. Protection of the patient in radiation therapy. A report of a Task Group of ICRP Committee 3. *ICRP Publication 44*, Pergamon Press, Oxford (1985).
59. Quantitative bases for developing a unified index of harm. A report prepared for the ICRP. *ICRP Publication 45*, Pergamon Press, Oxford (1985).
60. Radiation protection principles for the disposal of solid radioactive waste. A report of ICRP Committee 4. *ICRP Publication 46*, Pergamon Press, Oxford (1986)
61. Radiation protection of workers in mines. A report of ICRP Committee 4. *ICRP Publication 47*, Pergamon Press, Oxford (1986).
62. The metabolism of plutonium and related elements. A report of a Task Group of ICRP Committee 2. *ICRP Publication 48*, Pergamon Press, Oxford (1986).
63. Developmental effects of irradiation on the brain of the embryo and fetus. A report of a Task Group of ICRP. *ICRP Publication 49*, Pergamon Press, Oxford (1986)
64. Lung cancer risk from indoor exposures to radon daughters. A report of a Task Group of the International Commission on Radiological Protection. (In preparation.)
65. Data for use in protection against external radiation. A report of a Task Group of ICRP Committee 3. (In preparation.)
66. Exposure of man to ionizing radiation arising from medical procedures. An enquiry into methods of evaluation. A report of the International Commissions on Radiological Protection and on Radiological Units and Measurements. *Phys. Med. Biol.*, **2**, 107–151 (1957).
67. Exposure of man to ionizing radiation arising from medical procedures with special reference to radiation induced diseases: An enquiry into methods of evaluation. A report of the International Commissions on Radiological Protection and on Radiological Units and Measurements. *Phys. Med. Biol.*, **6**, 199–258 (1961).
68. Report of the RBE committee to the International Commissions on Radiological Protection and on Radiological Units and Measurements. *Health Phys.*, **9**, 357–384 (1963).
69. A review of the physiology of the gastrointestinal tract in relation to radiation doses from radioactive materials. A report prepared by a consultant to ICRP Committee 2. *Health Phys.*, **12**, 131–161 (1966).
70. Dosimetry of the gastrointestinal tract. A report prepared by consultants to ICRP Committee 2. *Health Phys.*, **12**, 163–172 (1966).
71. Deposition and retention models for internal dosimetry of the human respiratory tract. A report prepared by a Task Group of ICRP Committee 2. *Health Phys.*, **12**, 173–207 (1966). Errata and revisions to report. *Health Phys.*, **13**, 1251 (1967).
72. Radiobiological aspects of the supersonic transport. A report by a Task Group of ICRP Committee 1. *Health Phys.*, **12**, 209–226 (1966).
73. Calculation of radiation dose from protons and neutrons to 400 MeV. A report prepared by a Task Group of ICRP Committee 3. *Health Phys.*, **12**, 227–237 (1966).
74. Radiation dose from neutrons and protons in the energy range from 400 MeV to 2 GeV. A report prepared by a Task Group of ICRP Committee 3. *Health Phys.*, **17**, 449–457 (1969).

INDEX

Individual items in this publication are indexed by paragraph number.

STATEMENT FROM THE 1978 STOCKHOLM MEETING OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

The International Commission on Radiological Protection (ICRP) held its annual meeting in Stockholm in May, 1978, together with its four expert committees. Sixty-five individuals from seventeen countries were present to review the Commission's current work and to decide on a programme of work for the next 4-year period. Representatives or observers were also present from the Commission of the European Communities, the International Atomic Energy Agency, the International Commission on Radiation Units and Measurements, the International Electrotechnical Commission, the International Radiation Protection Association, the International Society of Radiology, the OECD Nuclear Energy Agency, the United Nations Environment Programme, the United Nations Scientific Committee on the Effects of Atomic Radiation and the World Health Organization.

ICRP PUBLICATION 26

The Commission also reviewed its 1977 recommendations *(ICRP Publication 26)* and identified the following points that require clarification.

Estimates of radiation risk

The risk factors given by the Commission in *ICRP Publication 26* (paragraphs 36–60) are based on advice received from its committee on radiation effects. They are consistent with data available in the scientific literature and with information included in the 1977 report of the UNSCEAR.

In the light of its continuing review of the published information on the epidemiological and radiobiological evidence of radiation risks to man, the Commission has concluded that the information available up to May 1978 does not call for changes in the risk factors given in *ICRP Publication 26*. These risk factors are intended to be realistic estimates of the effects of irradiation at low annual dose equivalents (up to the Commission's recommended dose-equivalent limits).

In dealing with the stochastic effects of ionizing radiation the Commission recommended (in paragraph 105 of *ICRP Publication 26*) weighting factors for application to the dose equivalent in various organs and tissues. The Commission wishes to point out that it did not intend the hands and forearms, the feet and ankles, the skin and the lens of the eye to be included in the "Remainder". These tissues should therefore be excluded from the computation of $\Sigma_T w_T H_T$. In order to prevent the occurrence of non-stochastic effects, the Commission recommends that the relevant dose-equivalent limits given in paragraph 103 should apply to these tissues.

In the assessment of detriment from exposure of population groups a small risk of fatal cancer resulting from exposure of

the skin may need to be taken into account, for example in the case of exposure of the whole skin from soft beta radiation. In this case a risk factor in the region of 10^{-4} Sv^{-1} may be applied to the mean dose over the entire surface of the skin, which would correspond to a value of w_T of about 0.01.

The Commission's occupational dose limits are intended to apply to all workers, and are based on average values of risk factors for male and female adults. The variations of risk with exposure at different ages in the two sexes, referred to in paragraph 38 of *ICRP Publication 26*, are discussed in *ICRP Publication 27,* a report to the Commission on "Problems involved in developing an index of harm". This report also reviews the basis for the selection, in *ICRP Publication 26* (paragraph 60) of an average genetically significant fraction (0.4) of occupational exposure and the mean mortality risk factor (10^{-2} Sv^{-1}) for both sexes and all ages.

Effective dose equivalent

The Commission recommends that the sum $\Sigma_T w_T H_T$ (see paragraph 104 of *ICRP Publication 26*) be called the effective dose equivalent (denoted H_E).

Modifications to the text of ICRP Publication 26

The Commission believes that the following textual revisions to certain paragraphs in *ICRP Publication 26* will clarify their meaning.

(38) The fourth and fifth sentences should read:

> For protection purposes therefore, sufficient accuracy is obtained by using a single effective dose-equivalent limit for all workers regardless of age or sex. This limit is based upon the average risk levels described below for the various organs or tissues.

(79) The first sentence should read:

> The Commission's dose-equivalent limits for workers are intended to apply to the sum of the dose equivalent resulting from external exposure during 1 year and the committed dose equivalent from that year's intake of radionuclides.

(79) Add the following sentence at the end of the paragraph:

> Similar principles apply to the dose-equivalent limits for members of the public.

(89) In the second sentence the following should be deleted:

> "are intended as guides for planning purposes, and thus"

(93) In the first sentence the following should be deleted:

> "are intended for planning purposes and"

(107) The end of the last sentence should read:

> . . . namely, the limit to the deep and shallow dose-equivalent indices $H_{I,d}$ and $H_{I,s}$ (see paragraph 108) and ALI (see paragraph 109).

(108) The last part of the first sentence should read:

> . . . it is possible to assess the *maximum* value of dose equivalent that would occur at a depth of 1 cm or more in a 30 cm diameter sphere (the deep dose-equivalent index, $H_{I,d}$).

(108) The following sentence should be added at the end of the paragraph:

> In addition, the shallow dose-equivalent index (the maximum dose equivalent in the shell from 0.07 mm to 10 mm depth in the 30 cm sphere) should be limited to 500 mSv to

provide protection for the skin. In practical situations, these limits on the deep and shallow dose-equivalent indices will limit the annual dose equivalent in the lens of the eye to less than 300 mSv.

(110) The paragraph should read:

When external and internal exposures are received together, the Commission's recommended dose limits will not be exceeded if both the following conditions are met:

$$\frac{H_{I,d}}{H_{E,L}} + \sum_j \frac{I_j}{I_{j,L}} \leq 1$$

and

$$\frac{H_{I,s}}{H_{sk,L}} \leq 1$$

where $H_{I,d}$ is the annual deep dose-equivalent index, $H_{I,s}$ is the annual shallow dose-equivalent index, $H_{E,L}$ is the annual limit of the effective dose equivalent (50 mSv), $H_{sk,L}$ is the annual limit of dose equivalent in the skin (500 mSv), I_j is the annual intake of radionuclide j, $I_{j,L}$ is the annual limit of intake for radionuclide j.

(113) The second sentence should read:

In such circumstances external exposures and intakes of radioactive material may be permitted provided that the sum of the dose equivalent from the external exposure and the committed dose equivalent from the intake of radionuclides does not exceed twice the relevant annual limit in any single event, and, in a lifetime, five times this limit.

(187) In the first sentence, the term "dose-equivalent limit" should be replaced by "system of dose limitation".

(238) In the last sentence the term "monitoring of control" should read "monitoring or control".

SECONDARY LIMITS FOR INTERNAL EXPOSURE

The first group of values of annual limits of intake (ALI) for radiation workers, together with the text of a report that includes the methods of calculation and metabolic data for 22 elements, were available at the Commission's meeting in Stockholm, and are now in the course of publication in a report to be entitled "Limits for intakes of radionuclides by workers". Similar information on additional elements will be published as soon as it becomes available.

Organ dose estimates for members of the public cannot be derived directly from the data given for workers because of differences in metabolism, organ size and duration of exposure. The Commission is therefore planning to issue specific guidance on the assessment of internal exposure of members of the public.

CURRENT WORK OF ICRP

Four reports are being completed, preparatory to publication in the *Annals of the ICRP*. The titles of the reports are: –

- Biological effects of inhaled radionuclides.
- Limits for intakes of radionuclides by workers (to replace *ICRP Publication 2*).
- Radionuclide releases into the environment: assessment of doses to man.

- Monitoring for internal contamination due to occupational exposure (to replace *ICRP Publications 10* and *10A*).
- Risks to the human embryo and foetus – with special reference to occupational exposure of women.
- Doses to patients from radiopharmaceuticals.
- Protection in all fields in which ionizing radiations are employed in medicine.
- The practical application of the Commission's recommendations.
- Application of the ICRP system of dose limitation to practices that modify man's exposure to natural background radiation.

A full programme of work is planned for the Commission and its committees and task groups in the immediate future. Subjects receiving urgent review include the following:

- Non-stochastic effects of irradiation.
- Risks and RBEs of high-LET radiation for carcinogenesis.
- Somantic and hereditary risks of irradiation at low doses.

During its term of office the Commission plans to prepare revised versions of its Publications 7, 10, 12, 13, 15/21, 16, 17 and 24.

June, 1978

F. D. Sowby,
Scientific Secretary,
ICRP,
Clifton Avenue,
Sutton, Surrey, SM2 5PU

STATEMENT AND RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION FROM ITS 1980 MEETING

The International Commission on Radiological Protection (ICRP) held its annual meeting in Brighton, England from March 17–26, 1980, together with all four of its committees. In addition, representatives attended from the Commission of the European Communities, the International Atomic Energy Agency, the International Commission on Radiation Units and Measurements, the International Commission for Protection against Environmental Mutagens and Carcinogens, the International Electrotechnical Commission, the International Organization for Standardization, the International Radiation Protection Association, the OECD Nuclear Energy Agency, the United Nations Environment Programme, the United Nations Scientific Committee on the Effects of Atomic Radiation and the World Health Organization.

The Commission and its committees reviewed the extensive programme of work being performed within the ICRP, including reports on occupational exposure limits for radon, on the dose-equivalent limit for the lens of the eye, and a survey of the currently available information on estimates of radiation risk. The conclusions of these three points are included in this statement (*q.v.*).

The Commission authorised Committee 1 to establish a new task group to define non-stochastic effects and to advise on their bearing on ICRP recommendations. The Commission reviewed the committee's work proceeding on other topics, such as the effects of high LET radiation, the risks to the embryo and foetus from irradiation, and the combined carcinogenic effect of ionising radiation and chemicals.

Committee 2 is completing its report Limits for Intakes of Radionuclides by Workers (*ICRP Publication 30*). Part 1 of the report, containing ALIs for radioisotopes of twenty-one elements has already been published. Parts 2 and 3, to include ALIs for 30 and 44 further elements, will be published in 1980/81, along with supplements to each of the parts. The committee is also preparing a report on doses to patients from radiopharmaceuticals, and is planning to prepare a statement on the exposure of members of the public to radioactive material.

Committee 3 is currently preparing revised versions of the medical aspects of *ICRP Publication 15 and 21*—Protection Against Ionizing Radiation from External Sources—as well as of *ICRP Publication 16*—Protection of the Patient in X-ray Diagnosis; these are expected to be completed in 1981.

A task group of Committee 4 has submitted a draft of a report on the application of the Commission recommendation on the need for the optimisation of radiation protection. This is expected to be completed in 1981. Committee 4 is also preparing revised versions of *ICRP Publication 7*—Principles of Environmental Monitoring Related to the Handling of Radioactive Materials: *Publication 10*—Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposure: *Publication 10a*—The Assessment of Internal Contamination Resulting from Recurrent or Prolonged Uptakes: *Publication 12*—General Principles of Monitoring for Radiation Protection of Workers: *Publication 13*—Radiation Protection in Schools: and *Publication 24*—Radiation Protection in Uranium and Other Mines, which will then conform to the policies enunciated in the Commission's recommendations in *ICRP Publication 26*. Other topics being considered by the committee include practices that modify man's exposure to natural background, and the general principles for protection of the public in the event of radiation accidents.

As a result of its discussions at the Brighton meeting, the Commission decided to issue statements on the following points:

Lens of the eye

In *ICRP Publication 26* the Commission concluded that a dose equivalent in the lens of the eye accumulated over a working lifetime of 15 Sv would not produce opacities that would interfere with vision. The Commission's committee on radiation effects (Committee 1) has reviewed the available human information and has concluded that, at this level of accumulated dose equivalent, some opacities might be produced which, while not in themselves detrimental to vision, might develop without further exposure to the point of causing deterioration of vision.

Although the combined effects of the present dose-equivalent limit for skin and the effective dose-equivalent limit make it very unlikely that dose equivalents in the lens would reach 15 Sv in a working lifetime, the Commission has decided to reduce its recommended dose-equivalent limit for the lens of the eye from 0.3 Sv in a year to 0.15 Sv in a year.

In most practical situations, the limits on the deep and shallow dose-equivalent indices will achieve compliance with the revised limit for the lens. The Commission therefore continues to recommend the use of the deep and shallow indices for estimates of dose equivalent at corresponding depths.

Recent estimates of radiation risk

The Commission in its 1978 Statement* referred to information available to May 1978. The Commission has reviewed the very extensive epidemiological and radiobiological information that has become available up to March 1980. Apart from the change recommended for the lens of the eye, the Commission has concluded that the new information does not call for changes in the risk factors for stochastic effects or the dose-effect relationships for nonstochastic effects underlying the dose-equivalent limits recommended in *ICRP Publication 26*.

Annual limits for intakes of radionuclides

In *ICRP Publication 30* the Commission is now in process of recommending Annual Limits for Intakes (ALIs) of Radionuclides by Workers that replace its earlier recommendations in *ICRP Publication 2* (1960). The system of dose limitation now used by the Commission takes account of all body tissues that are irradiated following intake of the radioactive material instead of only the critical organs as previously. The system ensures that the total risk from irradiation of any combination of organs does not exceed that from irradiation of the whole body at the recommended dose-equivalent limit. This summation of risks from individual organs can now be made on the basis of the much better knowledge of the sensitivity of each organ to radiation damage than was available 20 years ago. These improvements have in themselves caused only small changes in the values of ALI for individual radionuclides, but might require a reduction in the limits for some mixtures of radionuclides.

Much larger changes, however, have resulted from improved knowledge of the uptake and retention of radionuclides in body tissues, and of the radioactive decay schemes of some radionuclides. As a result of this new information, a few values of ALI now recommended in Part 1 of *Publication 30* (1979) are substantially greater, and others substantially smaller, than those that can be derived from *ICRP Publication 2*.

*Reference: 1978 Statement. Annals of ICRP, Vol. 2, No. 1, 1978.

Occupational exposure to Radon-222 and its daughters

The Commission reached a conclusion about the appropriate limit for occupational exposure to radon and its daughter nuclides. It took as the basis for this limit the level of risk corresponding to the present limit on effective dose-equivalent of 50 mSv in a year. There are several ways of assessing the relationship between the inhaled amount of radon and its daughters and the level of risk. The dosimetric method used for most radioactive materials in *ICRP Publication 30* and a similar method, slightly modified because of the special problems of the short-lived daughters of radon, have both been used. Epidemiological studies have provided a third method. There is a reasonably close agreement between the results of these methods, and the Commission recommends a limit which is at the low end of the dosimetric results and which is consistent with the epidemiological conclusions. These conclusions are not specific to radon because they relate to the consequences of exposure to the whole mining environment which includes some potentially hazardous nonradioactive agents. A Commission report is being prepared for publication.

The recommended annual limit for intake by inhalation, the ALI, for radon-222 daughters, in terms of inhaled potential α-energy, is 0.02 J in a year. The corresponding derived air concentration (see *ICRP Publication 30*) expressed in the practical units previously widely used is then 0.4 working levels.

The system of dose limitation of the Commission requires the addition of exposures to external radiation and intakes of radioactive material. In the special case of exposure in uranium mines this additivity has the effect of requiring the inhalation of radon and its daughters to be kept below the recommended limit by an amount that depends on the exposure to external radiation and ore dust. A reduction of 20% is common.

These recommendations are intended for competent authorities for general application and they may not always be appropriate for application in particular cases. The Commission is aware that some mining conditions are such that it may not be possible to operate within the combined limits recommended by the Commission on a year to year basis. The national authorities will then have to take decisions on how best to deal with these few, but difficult, situations.

Assessment of total detriment

In *ICRP Publication 26*, the Commission introduced the effective dose equivalent as the sum of the dose equivalents in individual organs H_T, each weighted by an organ weighting factor w_T:

$$H_E = \sum_T w_T H_T.$$

The organ weighting factors were chosen by the Commission to reflect the relative risk of death from cancer or occurrence of severe hereditary effects in the first two generations after uniform whole body exposure. It was considered that, in assessing the risk for an individual, in contrast to that for the population as a whole, the hereditary effects of essential importance were those that might be expressed in the children or grandchildren of the exposed individual. If only one organ (T) were exposed, the risk would be $w_T H_T$.r, where r is the risk per unit dose equivalent in the case of uniform whole body exposure. As reported in *ICRP Publication 27*, the value of r was assumed to be $1.65 \cdot 10^{-2}$ Sv^{-1} ($1.25 \cdot 10^{-2}$ Sv^{-1} for fatal cancers and $0.4 \cdot 10^{-2}$ Sv^{-1} for the hereditary effects).

The effective dose equivalent was introduced as the quantity to be compared with the Commission's basic dose limits in the protection of individual workers or members of the public. It was recognised, and further illustrated in *ICRP Publication 27*, that the actual risk at a given effective dose equivalent would depend on sex and age, but the Commission regarded these

variations as sufficiently small to justify the use of average values to apply under most circumstances (paragraphs 38 and 106 of *ICRP Publication 26*).

The variation of the genetic risk with age was given special attention. The average risk of hereditary harm of a severe nature in the first two generations was assumed to be 10^{-2} Sv^{-1} in a population if based on the genetically significant dose. In a general population with normal age distribution, the risk would be expected to be 40% (the ratio of mean reproductive age to mean life expectancy) of this value. This gave the weighting factor $w_T = 0.4/1.65 = 0.25$ recommended for the gonads.

If a population of *workers* had uniform age distribution, the genetic risk (for the first two generations) may be assumed to be 25% (the ratio of 30–18 to 65–18) of the risk per unit of genetically significant dose, because of the shorter period of risk within the reproductive age. This difference, which would strictly have meant a total risk of $1.50 \cdot 10^{-2}$ Sv^{-1} and a gonad weighting factor $w_T = 0.25/1.50 = 0.17$ for workers, was not considered sufficiently large to justify the use of different weighting factors and reference risk values for workers and members of the public. The Commission has found no reason to change this policy: the accuracy of the risk and dose estimates would not justify any more accurate procedure in the application of the dose limits.

The weighting factors and the risk estimates did not include the genetic harm *after* the first two generations, because this was considered less relevant in the limitation of the risk to which individuals are exposed. Nor did they include non-lethal cancer. The justification of the latter—deliberate—omission was that the acceptability of the detriment in relation to the dose limit had been based on comparison with the risk of *lethal* effects in safe industries. In paragraph 97 of *ICRP Publication 26*, the Commission noted that this is likely to be a conservative comparison, since experience has shown that the non-lethal effects of radiation are much less frequent than the non-lethal effects encountered in other safe occupations.

Since the publication of *ICRP Publication 26*, there has been an increased use of the effective dose equivalent not only for comparison with the dose limits but also in assessments of collective dose in optimisation procedures. Questions have been raised whether it is then appropriate to use the effective dose equivalent without consideration of the total genetic harm and the non-lethal cancers.

The Commission has reviewed this matter and has reached the following conclusions with regard to the use of the effective dose equivalent in optimisation assessments. The addition of the future genetic harm in the case of uniform whole body exposure would add a further risk of $0.4 \cdot 10^{-2}$ Sv^{-1} in the case of the public, or rather less in the case of the average worker, to the total assumed risk of $1.65 \cdot 10^{-2}$ Sv^{-1}; i.e. it would increase the total detriment by at most 24%. In the less likely case that the gonads would receive the dominating dose, the genetic harm would be twice that implied by the effective dose equivalent alone.

The weight of the additional detriment attributed to nonlethal cancer would depend upon the weight to be attached to a given length of time lost from normal health (during illness prior to cure) relative to an equal period of life lost as a result of death from fatal cancer. If that relative weight (K) is taken to be 0.1 (as in *ICRP Publication 27*), the addition of the detriment due to nonlethal cancer and the induction of benign tumours would only increase the total non-genetic detriment by 2% in the case of uniform whole-body exposure. If organs such as thyroid and skin, for which cancers have a low fatality rate, are irradiated alone and K is taken to be as high as 0.5, the total detriment will approach about twice that implied by the use of the effective dose equivalent alone. In most cases of external exposure or exposure to mixtures of radionuclides, however, the use of the effective dose equivalent alone would not significantly underestimate the total detriment.

It may be added that, in the original use of the dose equivalent for the protection of the worker, the non-stochastic dose limit will limit the maximum risk after exposure of single organs to a greater extent than indicated by the organ weighting factors derived on the basis of the risk of stochastic effects.

In the case of selective irradiation of the thyroid, the non-stochastic limit of 0.5 Sv y^{-1} is more restrictive than the implied stochastic limit based on the induction of fatal thyroid cancers (1.7 Sv y^{-1}). It would remain more restrictive than the stochastic limit even if this were based on the induction of all thyroid cancers, whether fatal or not, and of benign tumours also. If all tumours were taken into account in this way, the implied stochastic limit would become 1.3 Sv y^{-1} if K were taken as 0.1, or 0.7 Sv y^{-1} for $K = 0.5$, as discussed above.

Future meetings

The Commission's committees will each meet again towards the end of 1980 to review the progress of their work and to complete reports that will be considered by the Commission when it meets in Tokyo in March 1981.

March 1980

F. D. Sowby
Scientific Secretary
ICRP
Clifton Avenue
Sutton, Surrey, SM2 5PU
England

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

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

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

Introduction

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

Dose-equivalent Limits

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

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

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

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

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

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

Body Size

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

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

Metabolism

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

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

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

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

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

Chemical Form

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

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

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

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

Other Factors

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

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

Conclusion

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

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

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

References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The Derived Air Concentration (DAC)

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

Average Annual Doses in a Work Force

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

Exposure of Women to Ionizing Radiation

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

Occupational Exposure of Pregnant Women

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

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

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

Occupational Exposure of Women of Reproductive Capacity

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

---

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

Diagnostic Exposure of Women

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

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

STATEMENT FROM THE 1984 STOCKHOLM MEETING OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

The International Commission on Radiological Protection (ICRP) held its annual meeting in Stockholm in May 1984, together with its four expert committees. Seventy individuals from seventeen countries attended and reviewed the Commission's current work. Representatives or observers were also present from the Commission of the European Communities, the International Atomic Energy Agency, the International Commission on Radiation Units and Measurements, the International Electrotechnical Commission, the International Radiation Protection Association, the OECD Nuclear Energy Agency, the International Commission for Protection against Environmental Mutagens and Carcinogens, and the United Nations Scientific Committee on the Effects of Atomic Radiation.

The Commission approved five reports for publication in the Annals of the ICRP later in the year. These are:

Non-stochastic effects of ionizing radiation
Protection of the patient in radiation therapy
Major concepts and quantities in use by ICRP
Protection of the public in the event of major radiation accidents
Principles of monitoring for the radiation protection of the public.

The Commission reviewed the work of its committees and task groups, and noted that a number of reports are expected to be completed in the next year or so on the following topics:

Developmental effects of irradiation of the embryo and fetus;
Metabolism of plutonium and related elements;
Doses to patients from radiopharmaceuticals;
Protection of the patient in nuclear medicine;
Data for evaluating the exposure of workers to external radiation;
A revision of *ICRP Publications 10, 10A, 24* and *27*;
Exposure of the public to radon.

In addition, task groups have been established to review the ICRP lung model, to review and upgrade the ICRP Reference Man, to report on the application of basic radiation protection principles to radioactive waste disposal, and to develop the application of techniques other than cost-benefit analysis in the optimization of radiation protection.

Committed Effective Dose Equivalent

At the Stockholm meeting the Commission reviewed those aspects of its policy underlying the use of committed dose equivalent. The Commission confirms that its policy is to limit the risk *committed* by each year of operation, no credit being taken for earlier years if these have committed lower risks or for future years in the expectation of improved conditions of exposure.

This objective is achieved by the use of annual limits on intake calculated from the committed dose equivalent, using a 50-year integrating period.

The Commission recognizes that there are practical difficulties in using monitoring results to estimate annual intakes of some materials, notably plutonium, but it believes that these difficulties can be overcome and that their existence does not invalidate the above conclusions.

Sealed Source Beam Therapy

In paragraph 157 of *ICRP Publication 33* ("Protection against ionizing radiation from external sources used in medicine") the Commission made the following recommendation:

> Every sealed γ-ray source used for beam therapy shall be enclosed in a housing such that, with the beam control mechanism in the OFF position, the air-kerma rate from the leakage radiation measured at a distance of 1 m from the source does not exceed 10 μGy h^{-1}. At any readily accessible position 5 cm from the surface of the housing, the air-kerma rate from the leakage radiation shall not exceed 200 μGy h^{-1}.

This recommendation replaced one given in *ICRP Publication 15* ("Protection against ionizing radiation from external sources") in which the exposure rate at one meter from the source, while in the off position, was limited to 2 mR/h. This reduction by a factor of 2 was recommended by the Commission because the previous limit was based on designing the equipment to ensure that the dose limits were not exceeded rather than by the process of optimization of protection.

Information available to the Commission suggests that the collective dose from existing teletherapy units (designed according to the recommendation made in *ICRP Publication 15*) is unlikely to exceed 10^{-2} man.sieverts per year for each unit. For this reason, backfitting of existing equipment is not required, and design of new equipment should be based on the recommendation given in *ICRP Publication 33* unless realistic cost–benefit analysis, as described in *ICRP Publication 37*, clearly shows that this is not justified by the increased cost.

Review of the Bases of the Commission's Risk Estimates

The Commission and its expert committee on radiation effects has continued its critical review of epidemiological and related reports on the effects of human exposure to radiation. This review included a number of papers suggesting higher risks of cancer induction per unit dose at low doses than those used by ICRP for purposes of radiation protection; these papers were based mainly on studies of populations exposed as a consequence of test explosions in the USA. Other papers concerned with risk estimates were based on studies of the survivors of atomic bombs in Hiroshima and Nagasaki, and of exposures incurred during medical therapy. Reports were also examined which are described as indicating reductions in the risk of harmful effects as a result of exposure to low doses.

No reliable evidence could be derived from these reports to indicate that a change is needed in current estimates of the overall risk of cancer induction per unit dose, or in estimates for particular organs, these risk estimates being the basis of the Commission's recommendations.

Reports were received of the progress in re-evaluating the doses to which survivors in Hiroshima and Nagasaki were exposed. The implications of this re-evaluation, and of a continuing survey of reports of the cancer incidence and mortality in the survivors, will be reviewed when further information becomes available.

In 1982 the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reported a lower estimate of the genetic risks of radiation than that based on the evidence available at the time of its 1977 report, from which the Commission's genetic risk estimates were derived. The bases for this reduction are under review, as are the estimates of the amounts of detriment resulting from the forms and frequencies of inherited abnormality and congenital anomalies that are induced by radiation. These estimates will be incorporated in the Commission's future appraisals of radiation risk.

UNSCEAR is engaged also in studies of the dose-effect relationships for radiation risks at

moderate and at low doses, and the frequencies observed in different organs and tissues at moderate doses. The Commission is in close touch with this work.

The Commission has also reviewed the information published recently[1] defining the periods during pregnancy at which mental retardation appears to have been caused by radiation exposure of the developing child, and the risk per unit dose of this occurrence. Attention has already been drawn to the impact of this finding upon the protection of the embryo or fetus.[2] The Commission is informed of the further studies in progress on the induction of these abnormalities.

References

1. Otake, M. and Schull, W. J. *In utero* exposure to A-bomb radiation and mental retardation: a reassessment. *Br. J. Radiol.* **57,** 409 414, 1984.
2. ICRP. Exposure of women to ionizing radiation. Statement from the 1983 Washington meeting of ICRP. *Annals of the ICRP*, **14,** No. 1, vi-vii, 1984.

STATEMENT FROM THE 1985 PARIS MEETING OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

The International Commission on Radiological Protection (ICRP) met in Paris in March 1985. The Commission reviewed the work of its committees and task groups, and approved for future publication a report on the quantitative bases for developing a unified index of harm.

The Commission identified four topics requiring comment:

Dose Limits for Members of the Public

In the recommendation on effective dose-equivalent limits* for members of the public, made in its 1977 Recommendations (*ICRP Publication 26*[1]), two values were mentioned. The use of the limit of 5 mSv in a year was endorsed, but only under the conditions described in paragraphs 120 to 128 of *ICRP Publication 26*. For other circumstances the Commission recommended that it would be prudent to limit exposures on the basis of a lifetime average annual dose of 1 mSv.

The Commission's present view is that the principal limit is 1 mSv in a year. However, it is permissible to use a subsidiary dose limit of 5 mSv in a year for some years, provided that the average annual effective dose equivalent over a lifetime does not exceed the principal limit of 1 mSv in a year.

With this limitation on the effective dose equivalent, the non-stochastic organ dose limit of 50 mSv in a year becomes unnecessary for most organs.[2] However, since the dose equivalents in the skin and the lens of the eye are not included in the computation of effective dose equivalent for the individual,[3] organ dose limits are still needed for these two tissues. The recommended dose-equivalent limit for both the skin and the lens is still 50 mSv in a year for members of the public.

The Value of the Quality Factor in the Case of Neutrons

The information now available on the relative biological effectiveness (RBE) for neutrons for a variety of cellular effects *in vitro*, and for life-shortening in the mouse, is being reviewed by the Commission. The implications of this information will be considered as part of a larger review of recommendations to be undertaken by the Commission over the next four years or so. Meanwhile, in the case of neutrons the Commission recommends an increase in Q by a factor of 2. The permitted approximation for $\bar{Q}$ for fast neutrons thus changes from 10 to 20.

These changes relate only to neutrons, and no other changes in Q are recommended at this time.

Potentially Dangerous Radiological Practices

The Commission has been informed by its Committee on Protection in Medicine of some potentially dangerous practices in the use of fluoroscopic apparatus. Adherence to the

* The Commission's dose-equivalent limits apply to the sum of the effective dose equivalent resulting from external exposure during 1 year and the committed effective dose equivalent incurred from that year's intake of radionuclides.

recommendations and guidance given in the Commission's report Protection against Ionizing Radiation from External Sources Used in Medicine[4] could prevent such situations. Specifically, the Commission is concerned about the introduction of fluoroscopic apparatus with over-couch tubes which can give substantial x-ray exposures to operators if they are not protected by shields. With the operator wearing a protective apron and standing beside the patient, the dose from an over-couch screening set, compared with that from an under-couch set, can be 250 times higher to the hands, 100 times higher to the eyes and 35 times higher to the whole body. For an operator with a heavy work load the dose to the lens of the eye can greatly exceed the Commission's recommended occupational limit of 150 mSv (15 rem) in a year, and, if continued, could lead to permanent damage.

Other examples of practices causing concern, which have been reported to the Commission, include complex radiological procedures undertaken by physicians or surgeons without training in radiology and radiation protection. The operators may feel that the obvious needs of the patient outweigh a future risk of radiation injury to themselves. Occasionally this has even led to the removal of individual monitoring devices to avoid identification of high dose levels.

These problems are compounded by the routine use of unnecessarily high fluoroscopic currents and unnecessarily long fluoroscopic times. The Commission believes that the use of appropriate protective shielding and careful attention to technique, including the use of video storage devices, could result in a substantial decrease in radiation doses to operators. Insistence on suitable training in radiation hazards, and detailed monitoring of doses to eyes and extremities, may be particularly helpful in reducing significantly these potentially dangerous doses to operators.

Reduced Doses to Patients

In its publication Protection of the Patient in Diagnostic Radiology[5] the Commission recommended several changes of equipment and technique that would reduce the dose to patients at a very moderate cost. It now appears that these changes are not being introduced as rapidly as the Commission had hoped. The Commission therefore wishes to emphasise to manufacturers and radiological practitioners that these changes are effective and can be introduced at a cost that is much more than offset by the value of the reduction in detriment that they achieve.

In particular, the Commission recommends the wider use of rare-earth screens, and the selection of materials with very low attenuation (such as those made of carbon fibre) for cassette faces, table tops and the non-opaque parts of grids.

References

1. ICRP Publication 26, *Annals of the ICRP* **1** (3), 1977.
2. Statement from the 1983 Washington meeting of the Commission. *Annals of the ICRP* **14** (1), 1984.
3. Statement from the 1984 Stockholm meeting of the Commission. *Annals of the ICRP* **14** (2), 1984.
4. ICRP Publication 33. *Annals of the ICRP* **9** (1), 1982.
5. ICRP Publication 34. *Annals of the ICRP* **9** (2/3), 1982.

Recommendations of the ICRP

ICRP Publication 26 contains the basic recommendations of the International Commission on Radiological Protection. These recommendations are used widely throughout the world in limiting exposures of radiation workers and members of the public to ionizing radiations. This new edition of Publication 26 reproduces the original text, together with all statements made by the Commission subsequent to its publication. It also includes a new bibliography of all the publications of the Commission, its Expert Committees and Task Groups.

Pergamon Press

0 08 0215114