Recommendations of International Commission on Radiological Protection. (Adopted Sept. 17, 1965) (ICRP Publication 9)

INTRODUCTION

(1) The Commission's previous recommendations were adopted in 1958 and were published in 1959 as *ICRP Publication* 1. In 1964 a new volume of the recommendations was issued as *ICRP Publication* 6,[11] which contained the text of the 1958 recommendations, modified to include all the revisions and amendments that had been adopted up to 1962. Since 1962 the Commission has extensively reviewed its basic recommendations, and the present report represents the Commission's position in 1965. The Commission intends the present report to be a complete and comprehensive account of its basic principles; thus, as far as possible, the need to refer to previous publications is avoided. As many of the principles advocated by the Commission remain unchanged, it has been necessary in this report to repeat or to summarize a number of the statements made in previous publications. However, in some instances reference is made to reports of the Commission's committees and task groups, and, for the convenience of readers wishing to consult the original reports, a list of all the Commission's publications is given at the end of this report.

A. THE BASIC PRINCIPLES UNDERLYING THE RECOMMENDATIONS OF ICRP

GENERAL

(2) The policy adopted by the Commission in preparing its recommendations is to consider the fundamental principles upon which appropriate radiation* protection measures can be based, while leaving to the various national protection bodies the responsibility of formulating the specific advice, codes of practice or regulations that are best suited to the needs of their individual countries. The Commission wishes to emphasize that its recommendations are intended to guide the experts responsible for putting radiation protection into practice. Because of their advisory character, the form in which the recommendations are worded will not necessarily be suitable for direct assimilation into regulations or codes of practice.

OBJECTIVES OF RADIATION PROTECTION

(3) The objectives of radiation protection are to prevent acute radiation effects, and to limit the risks of late effects to an acceptable level. (See later discussions of Acceptable Risk—paragraphs 34 to 39.) Acute effects usually manifest themselves within a few weeks after the exposure; late effects may have a latent period of tens of years.

(4) Radiation effects are called somatic if they become manifest in the exposed individual and hereditary if they affect his descendants. Developmental disturbances produced by irradiation of the embryo or foetus can be considered as a special case of a somatic effect.

(5) Acute exposure (an exposure in which the dose is delivered in a period of hours or less), involving absorbed doses of the order of hundreds of rads to all or most of the body, will cause early somatic injury—the acute radiation syndrome. Death resulting from such exposures is usually due to failure of the haemopoietic tissues. At higher doses, death may be due to extensive damage to the gastrointestinal tract, and absorbed doses of tens of thousands of rads result in very early death, caused essentially by damage to the central nervous system. Acute local exposure with absorbed doses of the order of several hundreds of rads may cause localized effects. The manifestation of acute effects is such that the relationship to the causative radiation exposure is usually obvious.

* In these recommendations the word "radiation" refers exclusively to *ionizing* radiation.

(6) Late somatic injuries include leukaemia and other malignant diseases, cataracts, skin damage, impaired fertility and, possibly, " non-specific ageing " (ageing leading to premature death which is not attributable to single specific causes). In an individual case it may be extremely difficult, indeed impossible, to relate such effects to a causative radiation exposure. Effects such as leukaemia and non-specific ageing illustrate the two extreme types of possible long-term somatic effects that must be considered in setting an appropriate limitation of dose; leukaemia is a serious effect occurring in some irradiated individuals, whereas non-specific ageing might presumably contribute slight effects in each irradiated individual.

(7) The mechanism of the induction by radiation of leukaemia and other types of malignancy is not known. Such induction has so far been clearly established after doses of more than 100 rads, but it is unknown whether a threshold dose exists below which no malignancy is produced. If such a threshold dose did exist, there would be no risk of the induction of malignancy, as long as the threshold was not exceeded. As the existence of a threshold dose is unknown, it has been assumed that even the smallest doses involve a proportionately small risk of induction of malignancies. Also, because of the lack of knowledge of the nature of the dose–effect relationship in the induction of malignancies in man—particularly at those dose levels which are relevant in radiological protection—the Commission sees no practical alternative, for the purposes of radiological protection, to assuming a linear relationship between dose and effect, and that doses act cumulatively. The Commission is aware that the assumptions of no threshold and of complete additivity of all doses may be incorrect, but is satisfied that they are unlikely to lead to the underestimation of risks. Information is not available at the present time which would lead to any alternative hypothesis.

(8) Concerning the effects of radiation on the life-span, mice exposed to large doses of radiation show a reduction in their life-span, which can be accounted for by an increased incidence of other diseases in addition to cancer. It is uncertain whether any effect on the life-span is produced by low doses. In man there is some evidence to suggest that radiation exposure may have an effect on mortality from causes other than cancer, but it is not yet fully established whether there is any life shortening effect in addition to that attributable to specific causes. Life lengthening has been reported in some animals exposed to small accumulated doses delivered at low dose rates, but the experimental conditions under which the work was performed may have caused this effect. The sum of the present evidence is, therefore, inconclusive, although the possibility cannot be excluded that small doses of radiation may have a non-specific and deleterious effect on life-span apart from the effects to be expected from the induction of any leukaemia or other malignancies.

(9) Changes affecting the genes include point and chromosome mutations, the effects of which are usually detrimental. Where the genic* changes occur in germ cells, hereditary consequences are to be expected among the descendants of irradiated individuals. The mutated genes or chromosomes are distributed through a population by the mating of exposed individuals or their descendants with other members of the population. A hereditary defect may be of any degree of severity from inconspicuous to lethal. A defect causing slight physical or functional impairment will tend to continue in the descendants for many generations, whereas a severe defect will be eliminated rapidly through the early death of the zygote or individual carrying the defective gene. The main consideration in the control of hereditary damage, in addition to the occurrence of individual misfortune, is the burden to society in future generations that is imposed by an increase in the proportion of individuals with deleterious mutated genes. From this point of view it is immaterial in the long run whether the defective genes are introduced into the popu-

* In previous reports the adjective *genetic* was used as an antithesis to *somatic*. However, recent research has shown that somatic damage may result from disturbance of genetic mechanisms in somatic cells. As far as possible, therefore, use of the word *genetic* has been confined to *genetic dose* or *genetically effective dose*, that is, in specifically defined terms.

lation by many individuals who have received small doses of radiation, or by a few individuals who have received correspondingly larger doses. The control of hereditary damage will be effected by limiting the genetically effective population dose (see paragraphs 84 and 85). Additionally, to minimize the risk of a dominant mutation—genic or chromosomal—in an individual's children or grandchildren, it is desirable to limit the dose received by an individual.

THE DOSE EQUIVALENT

(10) Equal absorbed doses may not always give rise to equal risks of any given biological effect, since the biological effectiveness may be affected by differences in type of radiation or in irradiation conditions. To apply risk estimates obtained under a given set of conditions to situations in which other types of radiation are used or the conditions of irradiation differ, e.g. with regard to the spatial distribution of absorbed dose, it is necessary to multiply the absorbed doses by one or more weighting factors. In radiological protection the quantity obtained by weighting the absorbed dose is called the Dose Equivalent. In these recommendations the shorter term "Dose" is sometimes used for the sake of convenience, even though the meaning is strictly that of " Dose Equivalent ". This particularly applies in the case of terms such as Maximum Permissible Dose, dose limit, and genetic and somatic dose.

(11) If suitable data were available from biological experiments performed at the low levels of dose applicable to radiation protection, it would be possible to give overall weighting factors for particular irradiation conditions. However, such data are seldom available, and therefore at the present time it is not possible to give a specific biological weighting factor for every circumstance of irradiation. Instead, it is necessary to select those factors that are thought to influence the main components of the varying biological effectiveness of different irradiation conditions. To accomplish this the Commission recommends that a Quality Factor (QF)* be used to account for differences in linear energy transfer (LET_∞).

(12) Further modifying factors are necessary in certain cases. When bone is irradiated by radionuclides deposited in it, the Commission recommends the use of a modifying factor n, which is likely to relate, among other things, to non-uniform spatial distribution of absorbed dose, the essentiality of the damaged tissue and the radiosensitivity of particular types of irradiated cells. A modifying factor is also recommended for certain irradiations of the eye (see paragraph 16). At a later time it may be possible to recommend modifying factors to allow for, say, differences in absorbed dose rate or for fractionation of absorbed dose.

(13) The quantity that is obtained by the weighting of the absorbed dose by these modifying factors is called the Dose Equivalent. The Dose Equivalent is numerically equal to the dose in rads multiplied by the Quality Factor and any other modifying factors recommended by the Commission. The unit of Dose Equivalent is the rem. It is important to note that the use of the product of all the modifying factors represents an attempt to relate the absorbed dose to the risk of a resulting biological effect.

(14) The actual values of QF *, that the Commission recommends are related to the LET of the radiation, independently of other exposure factors; the basic parameter that is recommended to specify the radiation quality

* Previously this weighting factor was termed the "RBE", but the use of this term for both radiobiology and protection purposes presents certain problems, which are discussed in detail in the Report of the RBE Committee to the ICRP and the ICRU.[16]

* The relationship between QF and LET_∞ recommended for radiation protection calculations is the following:

LET_∞ keV per micron in water	QF
3·5 or less	1
7	2
23	5
53	10
175	20

For a detailed explanation of the symbol LET_∞, see the Report of the RBE Committee to the ICRP and the ICRU.[16]

is LET_{∞}. Ideally, the Quality Factor for any given type of radiation should be calculated as a mean of the values of QF along the track, but in practice the complexities of such calculations will make it difficult to estimate the QF for each type of radiation, and for these cases the Commission recommends the use of the values given below; it must be recognized that at present these values are necessarily somewhat arbitrary.

(15) For *external exposure* the Commission recommends that the QF for X- and gamma-rays be taken as 1; for electrons it will be greater than 1 only at very low energies. Recommended values for the QF for neutrons and protons as a function of energy up to 1000 MeV are given in detail in *ICRP Publication* 4[14] and are considered further in the report *Calculation of Radiation Dose from Protons and Neutrons to* 400 *MeV.*[24] A QF of 20 is recommended for heavy recoil nuclei (including recoil atoms following alpha-disintegration), for recoil fission fragments, and for heavy particles from accelerators.

(16) When the lens of the eye is irradiated, an additional modifying factor may need to be used as well as the QF. The value of the modifying factor should be 3 when the QF is 10 or greater, but should be 1 when the QF is 1. The value of an appropriate modifying factor to be used with values of QF between 1 and 10 may be obtained by interpolation between 1 and 3.

(17) For *internal exposure* QF should be taken as 1 for β^-, β^+, $\gamma-$ and X-radiation, and for conversion electrons (except in the case of β^-, β^+ and e^- radiations with maximum energy E_m, $\leqq 0{\cdot}03$ MeV, for which the QF is taken to be 1·7), 10 for α-particles, and 20 for fission fragments and for nuclei recoiling during α-emission. For internal exposure, QF is taken as 8 for neutrons resulting from spontaneous fission.

(18) The Dose Equivalent for radiations having components of different LET is obtained by adding the products of the absorbed doses delivered at any LET_{∞} and the appropriate modifying factors. Simplifications of this procedure are justifiable provided they do not result in an underestimate of the Dose Equivalent. An example of such a simplification is the use of a single QF value of 10 for all fast neutrons instead of the values that can be derived from *ICRP Publication* 4.[14]

(19) There are certain conditions of radiation exposure in protection work where the QF concept as outlined above can only be applied with major qualifications. Important examples are those where gross non-uniformity of absorbed dose distribution occurs, as with the bone-seeking radioactive nuclides or with radioactive particles in the lung. For bone-seeking radionuclides special procedures, involving the use of an additional modifying factor, have been developed for the determination of " maximum permissible body burdens ". The concept of Dose Equivalent for the bone-seekers, in relation to its application to external radiation, presents a number of problems, on which further work is required.

(20) In the case of non-homogeneous distribution of absorbed dose in the lung, an estimate of the Dose Equivalent to the whole lung, determined merely by the product of QF and the mean absorbed dose, may be greatly in error, but our full understanding of this problem must await further experimental evidence. In the meantime there is no clear evidence to show whether, with a given mean absorbed dose, the biological risk associated with a non-homogeneous distribution is greater or less than the risk resulting from a more diffuse distribution of that dose in the lung. When irradiation results from the inhalation of thoron or radon and daughter products, the relevant Dose Equivalent is that in the bronchial mucosa which is the tissue considered to be most heavily irradiated. Here the use of the whole lung would be an inadequate substitute for that of the irradiated tissue.

(21) The recommended QF values are intended solely for radiation protection at those levels of dose below the limits specified by the Commission. They should not necessarily be taken to indicate the true relative biological effectiveness of various types of radiation at the high doses and dose-rates which may be encountered in radiation accidents, when the problems are entirely different from those encountered in normal protection work. Accidental exposures have to be evaluated on the basis of the special circumstances characterizing each individual case.

INFLUENCE OF DOSE RATE

(22) It has long been recognized that the effects of radiation may be dependent not only on the accumulated dose received but also on the way in which this total is fractionated in time, and on the dose-rate at which each fraction is given. For example, acute radiation effects are more pronounced following a short period of irradiation than if the same dose is fractionated over a period of several days or weeks. This applies particularly to radiation of low LET such as X-rays, γ-rays and β-rays, which are by far the commonest ionizing radiations encountered in occupational exposure at the present time. In the present state of knowledge, and on some theoretical and experimental grounds, it appears reasonable to assume that, when either the dose or the dose-rate is very low, any effects will be directly proportional to the dose and independent of dose-rate. This assumption is implicit in past recommendations on maximum permissible levels and although evidence supporting this hypothesis is scant, it is believed to be the best basis for the assessment of biological effects in the present state of our knowledge.

(23) However, recent experiments on recessive visible effect mutations in mice have shown that in spermatogonia and oocytes the rate of induction is distinctly lower if the dose rate is diminished in a certain range (see section 3.2.4 of the report *The Evaluation of Risks from Radiation*[20]). No such dependency on time distribution of dose has been observed in more mature male germ cells of the mouse. The Commission's previous recommendations have been based on numerical considerations derived from genetic experiments using high dose-rates and may seem somewhat conservative in the light of these newer experiments. For the time being, however, the Commission does not consider it advisable to draw too general conclusions before additional information is available, or to modify its former recommendations to allow for a probable influence of dose-rate on the hereditary effects of radiation in man.

CRITICAL ORGANS AND TISSUES

(24) The probability of radiation damage manifesting itself during the lifetime of an individual varies with the particular tissue or tissues exposed, with the importance of the function of the constituent cells, with the capacity of the impaired cells to replicate, and possibly, with the means of disposal or replacement of damaged cells. In practice, therefore, irradiation of different tissues will have a significance which will vary with the importance of the tissue to the organism, the probability that any impairment results in malignant or other serious change, and the likelihood of any such change being readily diagnosed and successfully treated.

(25) In the case of approximately *uniform irradiation of the whole body*, the greatest hazard to health (of the individual or of his descendants) will be due to irradiation of particular tissues or organs; these tissues are referred to as "critical" for the case of uniform exposure of the whole body. Also, with exposure of the whole body the maximum number of cells is irradiated and for a given dose there is the maximum probability that damage may occur to a single cell, or group of cells, resulting in malignancy or other effects. Dose limitation for an individual is determined mainly by the dose that can be regarded as acceptable for the most critical tissues, which, in these recommendations are taken to be the red bone-marrow, the gonads and, with regard to radiation of high LET, the lenses of the eyes. For pregnant women, dose limitation is determined by possible effects on the foetus.

(26) When the various body tissues or organs are *unequally exposed*, the irradiation of one organ or tissue will be of greatest importance on account of the dose that it receives, its sensitivity to radiation, or the importance to health of any damage that results. This tissue or organ is referred to as the critical one under the particular circumstances. Dose limitation for the individual is determined by the dose regarded

as acceptable for this tissue or organ. For internal dose calculations the critical organ is the organ in which damage from a given internally deposited radionuclide results in the greatest body injury. This is usually, but not always, assumed to be the body organ in which there is the greatest concentration of the radionuclide.

(27) It must be recognized that sufficient information is not available as to the possible forms of injury that may result from irradiation of various tissues. Nevertheless, apart from the acute effects of large doses, it appears likely that the most important effects will be carcinogenesis, the production of degenerative effects such as cataracts, developmental abnormalities in foetal tissue, and hereditary defects. There is also inadequate knowledge on which to compare the doses to different tissues that may be associated with equal likelihoods of damage of comparable importance. The dose levels at present considered as acceptable when particular organs or tissues are irradiated must therefore be regarded as requiring further investigation.

(28) Within the range of the Maximum Permissible Doses (see paragraph 37) specified for occupational exposure, when it is assumed that there is no threshold and that effects are linearly related to dose, it is justifiable to consider the average dose to the whole organ or tissue, although it is recognized that when more information is available, it will be more appropriate to use the mean dose for cells of any given type, as is already done when the bronchial mucosa is irradiated by daughter products of radon and thoron. The use of the mean dose has practical advantages in that the significant volume can be taken as that of the organ or tissue under consideration. In fact, this principle has necessarily been used already in calculating maximum permissible burdens of radionuclides in tissues. However, with extreme inhomogeneity of dose (for example, with particulate radioactive material of high specific activity) such a procedure may be inappropriate. This is a matter upon which further work is needed. Also, for external exposure of the skin, especially when the distance to the source is very short or when the exposed area is very small, it would not be appropriate to average the dose over the entire skin. Instead, it is recommended that the dose be averaged over an area of a square centimetre in the region receiving the highest dose; however, with very narrow beams of extremely high intensity, such as those used for X-ray analysis, the value of such an average dose may be misleading, and protection measures have to be based on qualitative considerations.

THE CONCEPT OF RISK

(29) A basis of the Commission's recommendations is the cautious assumption that any exposure to radiation may carry some risk for the development of somatic effects, including leukaemia and other malignancies, and of hereditary effects. The assumption is made that, down to the lowest levels of dose, the risk of inducing disease or disability increases with the dose accumulated by the individual. This assumption implies that there is no wholly "safe" dose of radiation. The Commission recognizes that this is a conservative assumption, and that some effects may require a minimum or threshold dose. However, in the absence of positive knowledge, the Commission believes that the policy of assuming a risk of injury at low doses is the most reasonable basis for radiation protection.

(30) On the assumption that the risk of radiation injury is directly proportional to the accumulated dose, it follows that exposure from natural background radiation carries a probability of causing some somatic or hereditary injury, which would be present even without the addition of man-made exposures. Furthermore, other environmental factors and innate causes, quite unconnected with radiation, may add to the risk of developing those same injuries that might be caused by radiation exposure. Thus, provided there is no synergistic effect between irradiation and other factors, the total risk of injury will be the sum of the risk from irradiation (from either natural or man-made sources) plus the risks resulting from environmental and other causes.

(31) The Commission regards the components of risk caused by environmental factors other than radiation as lying outside its field of activities, although in applying the Commission's recommendations the magnitude of risks from other sources should be borne in mind. The Commission also believes that the risk resulting from exposures received from natural background radiation should not affect the justification of an additional risk from man-made exposures, and this will be the case if the frequency of effects is proportional to dose so that risks due to different sources of exposure are simply additive. Accordingly, any dose limitations recommended by the Commission refer only to exposure resulting from technical practices that add to natural background radiation. The dose limitations are therefore intended to include such exposures as those that result from mining, from flight at high altitudes or from the presence of radioactive materials such as radium, uranium or thorium in concentrated form.

(32) The dose limitations recommended in this report are concerned entirely with exposures other than those received by the patient in the course of medical procedures.* This separation is warranted to the extent that the frequency of effects is again proportional to the total dose received and that the risks of medical and other exposures are additive. The Commission considers that radiation doses resulting from medical exposures should not in general be included in any of the Commission's recommended dose limitations, although they would need to be taken into account in any assessment of the total risk to an individual or to a population from radiation exposures.

(33) Concerning the exposure of patients for medical reasons, the Commission believes that it would not be possible to make specific recommendations on dose limitation that would be appropriate for all examinations on individual patients. Nevertheless, the Commission wishes to emphasize the need for limiting the doses from radiological procedures to the minimum amount consistent with the medical benefit to the patient.

The Acceptable Risk

(34) Any exposure to radiation is assumed to entail a risk of deleterious effects. However, unless man wishes to dispense with activities involving exposures to ionizing radiations, he must recognize that there is a degree of risk and must limit the radiation dose to a level at which the assumed risk is deemed to be acceptable to the individual and to society in view of the benefits derived from such activities. Such a dose might be called an acceptable dose, with the same meaning as was implied by " permissible dose ".

(35) If the quantitative relationship between dose and the risk of an effect were known, societies or individuals could judge the degree of risk that would be acceptable, taking into account the particular circumstances requiring a radiation exposure. Ideally, such a judgement would involve a balancing of the benefits or necessities of the practice against the risks of the given exposure, which could also be related to that of other risks in the particular society. In addition, the difficulties of limiting the exposures would have to be taken into account.

(36) If the dose–effect relationship were known, and if it were possible to decide on a degree of risk that would be considered acceptable in a particular circumstance, it would thus be a secondary matter to fix the acceptable dose that would correspond to this risk. However, at the present time the relationship between dose and risk is not known with precision, nor is it usually possible to make quantitative evaluations of the benefits. Despite this, and in view of the continuing need for practical advice for planning purposes, the Commission recognizes its responsibility to maintain its practice of recommending appropriate dose limitations.

(37) The term Maximum Permissible Dose has become established to describe the doses that are regarded as being the maximum that should be permitted under particular circum-

* For the purpose of these Recommendations, and in order to include all types of diagnostic and therapeutic exposure to ionizing radiation, the term " medical uses " is extended to apply to all types of medical exposure of patients administered by radiologists, general practitioners, dentists, obstetricians, osteopaths, chiropractors, etc.

stances. The Commission recognizes that the term is not an entirely satisfactory one to describe values that must necessarily, at present and in the foreseeable future, involve a considerable element of judgement. Nevertheless, until increased knowledge of the risks of radiation is available to make a more quantitative assessment of acceptable doses, the Commission proposes to retain the term Maximum Permissible Dose for exposures of radiation workers to controllable sources (see also paragraph 47). For planned exposures of individual members of the public, and of populations, the Commission recommends the use of the term Dose Limit, and for unplanned exposures from uncontrolled sources the term Action Level is recommended.

(38) Long experience in the use of X-rays, radium and other radioactive materials, together with information on radiation injuries in man and other organisms, has indicated that values for Maximum Permissible Doses can be set such that there is a low probability of radiation injury without undue restriction of the uses and benefits of ionizing radiations. These facts form the present basis of the Commission's recommended values.

(39) The magnitude of the dose received by an individual, and the implied risk, contribute only one, although an important, element to the assessment of the circumstances which would determine whether he should continue his radiation work if he has been subject to an exposure in excess of the appropriate Maximum Permissible Doses (see also paragraph 102). Other factors would, for example, relate to his general health and welfare and his social and economic responsibilities.

CATEGORIES OF EXPOSURE

(40) The Commission's recommendations are intended to limit somatic effects in individuals and hereditary effects in the population as a whole. It is therefore necessary to consider doses to individuals and the mean dose to the population.

Exposure of Individuals

(41) The Commission's previous recommendations specified three categories of exposed individual. The first two of these comprised adults who are exposed to radiation either regularly or occasionally in the course of their work, and the third category consisted of individual members of the public, including persons living in the neighbourhood of controlled areas (see paragraph 113). The Commission now recommends that the former two categories of workers who might be exposed as a result of their occupation should be amalgamated, and that occupational exposure should now be considered to refer to the radiation exposure received by any worker in the course of his work (see also paragraph 53). Thus, the two categories of individual for which the Commission now gives recommendations are:

(a) adults exposed in the course of their work;
(b) members of the public.

Members of the Public

(42) It is not desirable to expose members of the public to doses as high as those considered to be acceptable for radiation workers; members of the public include children who might be subject to an increased risk and who might be exposed during the whole of their lifetime; members of the public (in contrast to radiation workers) do not make the choice to be exposed, and they may receive no direct benefit from the exposure; they are not subject to the selection, supervision and monitoring required for radiation work, and they are exposed to the risks of their own occupations.

(43) The amount by which dose limits for members of the public should be less than those set for radiation workers depends upon factors for which no commonly accepted quantitative values exist. However, for planning purposes it is considered appropriate to set the dose limits for members of the public a factor of ten below those for radiation workers. No undue biological significance should be attached to the magnitude of this factor, as at present the radiobiological information in this respect is inadequate.

(44) It has to be recognized that dose limitation for members of the public is a some-

what theoretical concept, intended for planning purposes, and that it will seldom be possible to ensure that no single individual exceeds the dose limit. This matter is considered again in paragraphs 70 and 74.

Exposure of Populations

(45) When whole populations or large sections of populations are exposed, it becomes necessary to consider not only the magnitude of individual risks but also the numbers of persons exposed. Even when individual exposures are sufficiently low so that the risk to the individual is acceptably small, the sum of these risks, as represented by the total burden arising from the somatic and genetic doses (see paragraphs 82–95) in any population under consideration, may justify the effort required to achieve further limitation of exposure.

CONTROLLABLE AND UNCONTROLLED SOURCES OF EXPOSURE

(46) It must be made clear that the Commission deals quite differently with two distinct conditions of exposure:

(i) in which the occurrence of the exposure is foreseen and can be limited in amount by control of the source, and by the development of proper operating procedures;

(ii) in which the particular exposure is accidental (i.e. has not been planned), and which can be limited in amount only, if at all, by remedial actions.

Limitation of Exposures from Controllable Sources

(47) In conditions where the source of exposure is subject to control, it is desirable and reasonable to set specific dose limitations, so that the associated risk is judged to be appropriately small in relation to the benefits resulting from the practice. Furthermore, the limitation must be set at a sufficiently low level so that any further reduction in risk would not be considered to justify the effort required to accomplish it. In the case of occupational exposure the hazards should not exceed those that are accepted in most other industrial or scientific occupations with a high standard of safety. The risks to members of the public from man-made sources of radiation should be less than or equal to other risks regularly accepted in everyday life, and should be justifiable in terms of benefits that would not otherwise be received.

(48) Once dose limits have been established, the objective should be to plan the use of sources of exposure in such a way that, in normal practice, these doses will not be exceeded. The dose limits assume the additional critical function of acting as a check on proper and adequate working practices at the source of exposure. When dose 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.

(49) It should be emphasized that dose limits for exposures from controllable sources are not intended for general use in the assessment of the risk of exposures resulting from uncontrolled sources.

(50) The recommended limits for exposures of individuals and populations from controllable sources are discussed in paragraphs 52–95.

Action Levels for Exposures from Uncontrolled Sources

(51) Under conditions in which unforeseen exposures occur, it is no longer a matter of balancing an appropriate risk against any benefit. Instead, questions now arise as to what remedial actions may be available to limit the amount of exposure and increase chances of recovery. 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 "action levels" that would be appropriate for all occasions. However, for the guidance of national bodies having the responsibility of taking remedial action, the Commission now includes a section dealing with the problems involved in setting action levels (see Section C).

B. LIMITATION OF DOSES FOR EXPOSURES FROM CONTROLLABLE SOURCES

GENERAL

(52) As any exposure may involve some degree of risk, the Commission recommends that any unnecessary exposure be avoided, and that all doses be kept as low as is readily achievable, economic and social considerations being taken into account. It should be noted that the dose limits are intended for planning the design and operation of sources leading to foreseeable conditions of exposure; the setting of " action levels " for exposures from uncontrolled sources depends on other considerations (see Section C).

EXPOSURE OF INDIVIDUALS

Occupational Exposure

(53) In any organ or tissue, the Dose Equivalent due to occupational exposure shall comprise that contributed by external and internal sources resulting from the circumstances imposed by the occupation. It shall not be held to include the dose from any medical exposure, from exposure to natural background radiation or from other exposures received by the individual as a member of the public. The Commission wishes to emphasize that " medical exposure " refers to the exposure of *patients* in the course of medical procedures and *not* to the exposure of the personnel conducting or incidentally associated with such procedures.

(54) In practice, the problem of chief concern is chronic exposure either at low dose rates or by intermittent small doses at high dose rates. Under these conditions it is reasonable to assume that the dose accumulated over a period of years is the controlling factor in determining the risk, provided the intermittent doses are sufficiently small. The Commission believes that a period of one year is the most reasonable length of time over which to assess accumulated exposures, but that it is also necessary to limit the magnitude of a single dose. The Commission therefore recommends that in any one year the Maximum Permissible Doses shown in paragraph 56 should not be exceeded, but that in a period of a quarter of a year up to one-half of the annual Maximum Permissible Dose, or, for internal exposure, a dose commitment resulting from an intake of a radionuclide equivalent in amount to the intake for one half-year at the Maximum Permissible Concentration, may be accumulated in conformity with the considerations on additivity and multiple organ irradiation given in paragraphs 53 and 68. The recommended values for the quarterly quotas may be rounded upward to the next whole number. If necessary, the quarterly quota may be received as a single dose, but the Commission believes that it would be undesirable for doses of this magnitude to be repeated at close intervals.

(55) Any worker who, for prolonged periods, receives doses annually at the maximum permissible levels, might accumulate lifetime doses of the order of hundreds of rems, or, for exposure of the extremities, thousands of rems. Even though there may be some uncertainty about the risk associated with the accumulation of such large lifetime doses, this is not at present considered to justify any additional limitation on the lifetime accumulated dose; the Commission is nevertheless keeping the matter under review.

(56) The Maximum Permissible Doses recommended by the Commission are:

Gonads and red bone-marrow (and, in the case of uniform irradiation, the whole body)	5 rems in a year*
Skin; thyroid; bone	30 rems in a year
Hands and forearms; feet and ankles	75 rems in a year
All other organs	15 rems in a year

* The gonads and the red bone-marrow are considered to be the critical organs when the whole body is exposed uniformly; therefore, throughout these recommendations, dose limits given for these organs also apply to all cases of uniform irradiation of the whole body.

(57) It may sometimes be necessary to provide flexibility for the Maximum Permissible Dose for exposure involving the whole body, where the gonads and the red bone-marrow are the critical organs. In such cases (and the Commission believes that they will be infrequent) it will be justifiable to permit the quarterly quota to be repeated in each quarter of the year, provided that the total dose accumulated at any age over 18 years does not exceed $5(N-18)$ rems, where N is the age in years. Under special conditions discussed in paragraphs 66 and 67, single doses or a series of doses up to a total of twice the annual limit may be permitted to critical organs, subject to certain restrictions.

Application to Special Cases

(58) The flexibility in the Maximum Permissible Dose to the whole body, gonads and red bone-marrow, as determined by the procedure recommended in paragraph 57, introduces certain practical complications. Thus, some workers (previously exposed at levels within the then permissible limits) may have already accumulated a dose in excess of the maximum determined by the above procedure. There are also special cases listed below in which exceptions to the application of the procedure given in paragraph 57 may be desirable for practical reasons. The following recommendations are intended to provide guidance on administrative policy, which may well vary according to local circumstances.

(59) *Previous exposure unknown.* If the dose previously accumulated in radiation work by the worker over any given period is not known, it shall be assumed that the worker has received the currently recommended Maximum Permissible Dose in each year of that period.

(60) *Persons exposed in accordance with former maximum permissible doses.* Persons who were exposed in accordance with former maximum permissible doses recommended in earlier publications of the Commission, and who have accumulated a dose higher than that determined by the procedure recommended in paragraph 57, should not be exposed at a rate higher than 5 rems in any one year, until the accumulated dose at a subsequent time is lower than that determined by the above procedure.

(61) *Persons starting work at an age of less than 18 years.* In some countries the minimum age at which occupational exposure is legally permitted is lower than 18 years. When a person begins to be occupationally exposed at an age of less than 18 years, the dose equivalent to the gonads and the red bone-marrow should not exceed 5 rems in any one year under age 18, and the dose accumulated to age 30 should not exceed 60 rems.

(62) *Exposure of women of reproductive capacity.* The recommendation permitting dose accumulation at rates up to 3 rems in a quarter (as derived from paragraphs 54 and 56) should not apply in circumstances involving abdominal exposure of women of reproductive capacity. Such women should be occupationally employed only under conditions where the dose to the abdomen is limited to 1·3 rems in a quarter, corresponding to 5 rems per year delivered at an even rate. Under these conditions, the dose to an embryo during the critical first two months of organogenesis would normally be less than 1 rem, a dose which the Commission considers to be acceptable.

(63) *Exposure of pregnant women.* It is likely that a pregnancy of more than two months duration would be recognized by the woman herself or by her physician. While many of the critical stages of embryogenesis are now past, recent evidence indicates that even after the second month the foetus is still especially radiosensitive. In particular, the possible induction of leukaemia and other malignant conditions must be considered. Recent studies in children indicate that exposure of the foetus *in utero* to doses of a few rads of X-rays can increase the incidence of malignant disease within the subsequent decade. Furthermore, investigation has shown that exposure of foetuses to doses of a few rads of X-rays can give rise to detectable somatic mutations, resulting in the condition of pigment mosaicism, although this condition does not appear to be hazardous.

(64) Therefore, the Commission recommends that when a pregnancy has been diagnosed, arrangements should be made to ensure that the exposure of the woman be such that the dose to her foetus, accumulated during the remaining

period of the pregnancy, does not exceed 1 rem. Practical experience indicates that the dose to the foetus during this period is usually substantially less than 1 rem.

(65) In practice, many of the women in this category work with diagnostic X-ray equipment. For exposures resulting from X-ray equipment poerated at low kilovoltage, the recommendation will usually be satisfied even if the pregnant woman continues to be occupationally employed under circumstances where the dose to the abdomen is limited to 1·3 rems in a quarter. In the case of exposures received from X-ray equipment operated at high kilovoltage, it will usually be necessary to assess the dose received by the foetus.

Planned Special Exposures

(66) Situations may occur infrequently during normal operations when it may be necessary to permit a few workers to receive exposures in excess of the recommended quarterly limits. In such circumstances exposures or intakes of radioactive material may be permitted provided the dose commitments do not exceed twice the annual dose limit in any single event, and, in a lifetime, five times this limit. The Commission wishes to emphasize that doses or intakes of this magnitude are only justified when alternative techniques, which do not involve such exposure of workers, are either unavailable or impractical.

(67) Planned special exposures should not be permitted if the addition of the intended dose to the worker's accumulated dose exceeds the amount determined by the procedure recommended in paragraph 57; or if the worker has received, in the previous 12 months, a single exposure or intake of radioactive material with a dose commitment in excess of the quarterly quota; or if the worker has previously received abnormal exposures (see paragraphs 99–102) in excess of five times the annual dose limit. Such special exposures should not be permitted for women of reproductive capacity. Doses resulting from planned special exposures should be recorded with those from usual exposures, but any excess over the recommended limits should not constitute a reason for excluding a worker from his usual occupation.

Exposure of Several Organs

(68) Exposure to radioactive materials in the environment may entail significant exposure of several organs. Under such conditions the situation is somewhat comparable to that of irradiation of the whole body. The additional risk when several organs are involved needs to be recognized, although our present knowledge does not permit precise evaluation.*

Short-term Exposures to Radioactive Materials

(69) Subject to the basic requirements for the annual Maximum Permissible Doses, one or more short-term exposures to radioactive materials within a period of a quarter of a year is considered acceptable if the dose commitment resulting from the total *intake* of radioactive material during this period does not exceed one-half of the annual Maximum Permissible Dose.† For certain radionuclides the chemical toxicity of this quantity of material would be limiting.

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* When several organs or tissues of the body are exposed, the principle stated in paragraph 53 applies. It is at present uncertain to what extent the effects of irradiating several organs simultaneously are simply additive. The Commission considers, however, that the principle stated in paragraph 53 will be adequately met by a procedure such as the following:

> If external exposure of the whole body has resulted in an excess of one-half of the Maximum Permissible Dose to the gonads or to the red bone-marrow, no two or more organs shall be exposed at more than one-half their respective Maximum Permissible Doses. If three or more body organs are each receiving more than one-half of their respective Maximum Permissible Doses, the exposure shall be regarded as excessive.

A procedure appropriate for making proper allowance for addition of doses from penetrating external radiation and from internal irradiation from *long-lived bone-seeking* radionuclides was recommended in *ICRP Publication* 6.[11]

† An intake of radionuclide corresponding in amount to the intake at the Maximum Permissible Concentration for one half-year results in a dose commitment to the critical organ over the occupational lifetime (50 years) equal numerically to one-half the annual Maximum Permissible Dose for that organ, since an annual Permissible Dose Commitment results from an intake of a radionuclide equivalent in amount to continuous intake of the nuclide at the Maximum Permissible Concentration for one year.

MEMBERS OF THE PUBLIC

(70) The Maximum Permissible Doses that have been established for occupational exposure are regarded as upper limits, and the doses may have to be individually monitored and controlled to ensure that the Maximum Permissible Doses are not exceeded. The dose limitation for members of the public is a more theoretical concept, intended to provide standards for the design and operation of radiation sources so that it is unlikely that individuals in the public will receive more than a specified dose. The effectiveness of this is checked not by observing individuals but by assessments through sampling procedures in the environment and statistical calculations, and by a control of the sources from which the exposure is expected to arise. For these reasons it is seldom meaningful to speak of Maximum Permissible Doses for individual members of the public; instead, the Commission recommends that the term Dose Limit should be used in connection with limitation of the exposure of members of the public (see paragraph 37).

(71) In any organ or tissue the Dose Equivalent is the sum of the Dose Equivalents (see paragraph 13) contributed by both external and internal sources. It shall not be held to include any exposure from natural background radiation or medical procedures.

(72) The annual Dose Limits for members of the public shall be one-tenth of the corresponding annual occupational Maximum Permissible Doses given in paragraph 56.

(73) There is an exception to the above recommendation in the special case of the exposure of the thyroid of children below the age of 16. There is evidence that the thyroid tissue of juveniles may be more radiosensitive than that of an adult, and because of this the Commission recommends that the annual dose should be limited to 1·5 rems.

(74) The basis for the limitation of exposures of members of the public is the dose to the various body organs and not the derived criteria 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. The variation resulting from these sources makes it impossible to determine the maximum doses that might be received individually. In practice, it is 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 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, and the Commission believes that it will be reasonable to apply the appropriate Dose Limit for members of the public to the mean dose of this group. Because of the innate variability within an apparently homogeneous group, some members of the critical group will receive doses somewhat higher than the Dose Limit; however, at the very low levels of risk implied, it is likely to be of minor consequence to their health if the Dose Limit is marginally or even substantially exceeded.

(75) In some situations, especially in the planning of proposed operations or installations, it may not be practicable to make the detailed studies necessary for the identification of the critical group. To allow for individual variability it will then be necessary to apply an operational "safety factor" to the derived concentration limits applicable to a member of the public. In previous publications the Commission has suggested values for safety factors for environmental exposures to radionuclides. However, as the values to be recommended for such factors would vary over a wide range, depending on the particular circumstances, no generally applicable values are given in this report.

* For a more detailed discussion of the critical group see also *Principles of Environmental Monitoring Related to the Handling of Radioactive Materials.*[35]

SUMMARY OF DOSE LIMITS FOR INDIVIDUALS

Organ or tissue	Maximum Permissible Doses for adults exposed in the course of their work	Dose Limits for members of the public
Gonads, red bone-marrow	5 rems in a year*	0·5 rem in a year
Skin, bone, thyroid	30 rems in a year*	3 rems in a year†
Hands and forearms; feet and ankles	75 rems in a year*	7·5 rems in a year
Other single organs	15 rems in a year*	1·5 rems in a year

* Subject to the limitations given in paragraphs 54 and 57, up to one-half of the annual dose limit, or one-half of the annual permissible dose commitment, may be accumulated in any period of a quarter of a year (see, however, special recommendation for women of reproductive capacity—paragraph 62).

† 1·5 rems in a year to the thyroid of children up to 16 years of age.

RADIOLOGICAL EXAMINATIONS OF WOMEN OF REPRODUCTIVE CAPACITY

(76) The Commission wishes to call attention to reports of embryonic and foetal sensitivity to ionizing radiation and to emphasize that the possibility of pregnancy must be taken into account by the attending physician when deciding on radiological examinations that involve the lower abdomen and pelvis of women of reproductive capacity. The Commission also wishes to point out that the ten-day interval following the onset of menstruation is the time when it is most improbable that such women could be pregnant. Therefore, it is recommended that all radiological examinations of the lower abdomen and pelvis of women of reproductive capacity that are not of importance in connection with the immediate illness of the patient, be limited in time to this period when pregnancy is improbable. The examinations that it will be appropriate to delay until the onset of the next menstruation are the few that could without detriment be postponed until the conclusion of a pregnancy or at least until its latter half.

EXPOSURE OF POPULATIONS

GENERAL

(77) The mean dose for whole populations is determined not only by the doses to individual members but also by the number of persons exposed. The main contributions, in addition to that from the natural background radiation, are at present made by the medical uses of radiation for diagnostic purposes, the increasing use of radioactive substances, and the release of radioactive material into the environment. Protection measures will include both reduction of individual doses and, wherever appropriate, limitation of the number of persons exposed.

(78) Medical exposures constitute at present and for the foreseeable future the main source of population exposure. Since it is likely that in most countries the number of persons medically exposed will increase, owing to the development of new procedures as well as to improved conditions for medical care, it becomes increasingly important that these technological improvements should be matched by appropriate consideration of the radiation protection of the patient. As stated in paragraph 33, the Commission does not believe that it is possible to make any specific recommendations on dose limitation that could be appropriate for all examinations on individual patients, but it wishes to emphasize the need for limiting the doses from radiological procedures to the minimum amount consistent with the medical benefit to the patient.

(79) 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.* To achieve this reduction, the Commission points out the value of adequate training in radiological protection for all persons who administer radiation exposures to patients.

* For further details, the reader is referred to *ICRP Publication* 3.[13]

(80) Proper planning for nuclear power programs and for other practices involving exposure to ionizing radiation requires a limitation of the exposure of whole populations, partly by limiting the individual doses and partly by limiting the number of persons exposed. It is of the utmost importance in this connection to make sure that nothing is done now that may prove to be a serious hazard later, at which time it may be impossible or extremely expensive to correct.

(81) The Commission is aware of the fact that it is not yet possible to balance risks and benefits, since it requires a more quantitative appraisal of both the probable biological damage and the probable benefits than is now possible. Furthermore, it must be realized that the factors influencing the balancing of risks and benefits will vary from country to country and that the final decision rests with each country (insofar as operations within one country do not affect others). Nevertheless, recommendations in quantitative terms are needed for the design of nuclear power plants and other radiation installations and for making plans for disposal of radioactive waste products; such recommendations are given in subsequent paragraphs.

Genetic Dose

(82) Consideration of hereditary effects plays a major role in any limitation of a population dose. Evaluations of the damage from exposure to radiation indicate that a substantial part of the whole damage is that which is expressed in the descendants of the exposed individuals. On the assumption that the hereditary effects are linearly related to the gonad dose and provided that no threshold dose exists, it is possible to define a population dose average that is relevant to the assessment of heritable injury to the whole population (paragraphs 84 and 85).

(83) Because of the need for guidance in this regard, the Commission in its 1958 Recommendations suggested a provisional limit of 5 rems per generation for the genetic dose to the whole population, from all sources additional to natural background radiation and to medical exposures. The Commission believes that this level provides reasonable latitude for the expansion of atomic energy programs in the foreseeable future. It should be emphasized that the limit may not in fact represent a proper balance between possible harm and probable benefit, because of the uncertainty in assessing the risks and the benefits that would justify the exposure.

Assessment of Genetic Dose

(84) The genetic dose to a population is the dose which, if it were received by each person from conception to the mean age of childbearing, would result in the same genetic burden to the whole population as do the actual doses received by the individuals.

(85) The genetic dose to a population can be assessed as the annual genetically significant dose* multiplied by the mean age of childbearing, which for the purpose of these recommendations is taken to be 30 years. The annual genetically significant dose to a population is the average of the individual gonad doses, weighted in each individual for the expected number of children conceived subsequent to the exposure.

Genetic Dose Limit

(86) The Commission recommends that the genetic dose to the population should be kept to the minimum amount consistent with necessity and should certainly not exceed 5 rems from all sources additional to the dose from natural background radiation and from medical procedures. The contribution to genetic dose from medical procedures should be kept to the minimum value consistent with medical requirements.

(87) The Commission wishes to point out that it is important to ensure that no single type of population exposure takes up a disproportionate share of the total. The way in which this is done will depend upon circumstances which may vary from country to country, and will be determined by national, economic and social considerations.

* The reader is referred to the 1962 report of UNSCEAR (U.N. General Assembly Official Records: Seventeenth Session—Supplement No. 16 (A/5216)) for a detailed discussion of genetically significant dose.

Contributors to the Genetic Dose

(88) In its previous recommendations the Commission included an Illustrative Apportionment, showing how national authorities might apportion the various contributions to the genetic dose. One of the main purposes of the Illustrative Apportionment was to show how the genetic dose depends on the product of individual doses and the numbers of persons exposed. It also indicated the unlikelihood of the 5 rems being approached.

(89) The Commission stated that the giving of specific values in the Illustrative Apportionment was for guidance only. Nevertheless, these values may have come to be regarded as carrying a greater significance than was originally intended. Also, the publication of the values may have given the impression that it would be acceptable to permit the exposure to rise to these specific levels. The Commission wishes to reiterate that any exposure must be justified by the need for its associated cause.

(90) Thus, in this report, the Commission does not include an Illustrative Apportionment, but gives an indication of the magnitude of the main contributors to the genetic dose.

(91) *Occupational exposure.* Data reported to UNSCEAR indicate that the present genetic dose from occupational exposure is probably less than 0·01 rem. The wider uses of atomic energy and other sources of ionizing radiation will cause an increase in the number of occupationally exposed individuals. However, provided the actual doses received by these individuals continue to conform to current practice, the genetic dose from all occupational exposure is likely to remain well below 1 rem.

(92) *Miscellaneous exposures.* Members of the public are likely to be exposed to external and internal sources of radiation. At present the main contributors to the exposure of the population at large are (with the exclusion of medical exposures) nuclear weapon debris, and a number of miscellaneous sources. The 1962 and 1964 reports of UNSCEAR include data indicating that the total genetic dose to the current generation from all these sources is being incurred at a rate such that 0·2 rem* to the current generation will not be exceeded. Exposure of the population at large will probably increase with the wider uses of atomic energy and other sources of radiation. However, it is considered unlikely that the genetic dose from these sources will exceed 1 rem.

(93) *Medical exposure.* In 1962 data were reported by UNSCEAR showing that, in countries where extensive surveys had been performed, the genetic dose to the current generation may lie between 0·2 and 2 rems with a modal value of about 1 rem. However, in some countries where radiological procedures are particularly widespread, the current genetic dose may be higher. The UNSCEAR report referred to estimates showing that the genetic dose could be reduced to the lower part of the range given above, without loss of necessary medical information.

(94) *Summary.* It appears, therefore, that exposures due to medical procedures commonly contribute about 1 rem to the genetic dose of the current generation, and, that in countries where the contribution is higher, measures can be taken to reduce it without loss of medically important information. The contribution from all other man-made sources, including occupational exposure, is at present probably less than 0·2 rem. The total genetic dose from all man-made sources actually being received by the world population thus appears to be considerably lower than 5 rems, and it seems unlikely that this figure will be approached within the foreseeable future.

SOMATIC DOSE

(95) The Commission's previous recommendations gave no value for a maximum " somatically significant " dose for a population, as no such dose could easily be defined or estimated. However, it is possible to define a population dose for a particular risk, such as leukaemia, on the assumption that the dose-effect relationship is linear without a threshold; on this basis the relevant dose is presumably mean dose to active red marrow, appropriately averaged over each individual in the population. On these assumptions it is possible to estimate, for example, the number of cases of leukaemia in a population receiving an annual mean dose of 0·5 rem to the

* Miscellaneous sources—0·06 rem; nuclear weapon debris—0·08 rem.