REPORT OF THE UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION

GENERAL ASSEMBLY

OFFICIAL RECORDS: THIRTY-SECOND SESSION

SUPPLEMENT No. 40 (A/32/40)

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NOTE

Symbols of United Nations documents are composed of capital letters combined with figures. Mention of such a symbol indicates a reference to a United Nations document.

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APPENDICES

I. INTRODUCTION

1. The preparation of the present report of the United Nations Scientific Committee on the Effects of Atomic Radiation 1/ took place at the twenty-third to the twenty-sixth sessions of the Committee. Professor L. R. Caldas (Brazil), Professor F. H. Sobels (Belgium) and Dr. C. B. Guzmán Acevedo (Peru) served as Chairman, Vice-Chairman and Rapporteur, respectively, at the twenty-third session. Professor F. H. Sobels (Belgium), Dr. M. Klímek (Czechoslovakia) and Professor Z. Jaworowski (Poland) served as Chairman, Vice-Chairman and Rapporteur, respectively, at the twenty-fourth and twenty-fifth sessions; and Dr. M. Klímek (Czechoslovakia), Professor F. E. Stieve (Federal Republic of Germany) and Dr. K. Sundaram (India) served in the same capacity, respectively, at the twenty-sixth session.

2. As in the case of previous substantive reports, 2/ most of the work of the Committee was done in meetings of groups of specialist scientists who considered working papers prepared by the Secretariat on the basis of the Committee's request. The names of those specialists who attended one or more of the sessions of the Committee during the preparation of the report as members of national delegations are listed in appendix I below.

3. The Committee was assisted by a small scientific staff and by consultants appointed by the Secretary-General. Although the Committee itself assumes full responsibility for the report, it wishes to acknowledge the assistance given by

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1/ The terms of reference of the Scientific Committee, which was established by the General Assembly at its tenth session in 1955, are set out in resolution 913 (X). It was originally composed of the following Member States: Argentina, Australia, Belgium, Brazil, Canada, Czechoslovakia, Egypt, France, India, Japan, Mexico, Sweden, Union of Soviet Socialist Republics, United Kingdom of Great Britain and Northern Ireland and United States of America. By resolution 3154 C (XXVIII), the General Assembly decided to increase the Committee's membership by up to five additional members, and the following Member States were appointed members of the Committee by the President of the Assembly in consultation with the Chairmen of the regional groups: Germany, Federal Republic of, Indonesia, Peru, Poland and Sudan.

2/ For the previous substantive reports of the Committee see *Official Records of the General Assembly, Thirteenth Session, Supplement No. 17* (A/3838); *ibid.*, *Seventeenth Session, Supplement No. 16* (A/5216); *ibid.*, *Nineteenth Session, Supplement No. 14* (A/5814); *ibid.*, *Twenty-first Session, Supplement No. 14* (A/6314 and Corr.1); and *ibid.*, *Twenty-fourth Session, Supplement No. 13* (A/7613 and Corr.1). They will be referred to as the 1958, 1962, 1964, 1966 and 1969 reports, respectively. See also *Ionizing Radiation: Levels and Effects. A report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, with Annexes*, vols. I and II (United Nations publication, Sales Nos. E.72.IX.17 and 18), which will be referred to as the 1972 report. The report without its appendices and annexes appears as *Official Records of the General Assembly, Twenty-seventh Session, Supplement No. 25* (A/8725 and Corr.1).

those scientists who were responsible for the preliminary review and analysis of the technical information received by the Committee or published in the scientific literature and whose names are listed in appendix II.

4. The technical reports received between 18 April 1972 and 22 April 1977 by the Committee from States Members of the United Nations and members of the specialized agencies and of the International Atomic Energy Agency (IAEA), as well as from these agencies themselves, are listed in appendix III. Reports received before 18 April 1972 were listed in earlier reports of the Committee to the General Assembly. The information received officially by the Committee was supplemented by information available in the scientific literature or obtained from unpublished communications of individual scientists. The Committee wishes to acknowledge with appreciation the information on exposures from various radio-active sources received in response to the Committee's request.

5. Representatives of IAEA, the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO) and of the United Nations Environment Programme (UNEP), as well as of the International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU), attended the twenty-third to the twenty-sixth sessions of the Committee.

6. The Committee has formulated plans to continue to keep under review and to assess the levels of radiation to which the world population is or may become exposed, and to improve the assessments of risk entailed by exposure to radiation. Such activities can contribute significantly to UNEP and the Committee has established an active co-operation with the Programme in the preparation of criteria documents for selected radionuclides.

7. The present report, as the previous comprehensive reports, consists of a main text, which outlines the conclusions of the Committee's discussions, and scientific annexes reviewing in detail the available scientific information and the analytical procedures on which rest the Committee's conclusions. Following the practice of the 1972 report, only the main text of the present report is submitted to the General Assembly. The full report, however, including the scientific annexes, is being made available in a separate publication 3/ and the Committee wishes to draw the attention of the Assembly to the fact that the separation of the submitted main text from its annexes is for convenience only, and that the major importance attaches to the scientific analysis presented in the annexes.

8. The Committee summarizes the biological effects of radiation in the following section (paras. 9-51) and describes the radiation exposures received from the various sources and practices in the ensuing section (paras. 52-106), including some general conclusions based on this information.

3/ United Nations publication, Sales No. E.77.IX.1.

II. EFFECTS OF RADIATION

A. General aspects

9. In the five years that have elapsed since the publication of the Committee's last comprehensive report, 4/ a considerable amount of new information has become available not only on the frequency with which certain harmful effects may be induced by ionizing radiation, but also on the amounts of radiation exposure that are involved in various circumstances. It has become possible, therefore, to estimate with rather more confidence than previously the types and frequencies of detrimental effects that are likely to result from various procedures as a consequence of the radiation exposure of people that they involve.

10. The present report therefore deals in some detail with the most important effects of radiation on man, concentrating upon those effects which are liable to be caused by low doses of radiation and which may appear, or continue to appear, at long intervals of time after exposure in the individual irradiated (the so-called somatic effects) or in his progeny (the genetic effects). In respect of both classes of effect, the Committee has reviewed in detail the evidence from which estimates can be derived of the frequency with which such effects are likely to occur in man, per unit radiation dose. The effects of heavy irradiation of the whole body are not discussed in the present report.

11. Both for somatic and for genetic effects, it is important to estimate the likely frequency with which harmful effects may follow the low doses of radiation to which people may be exposed from fall-out from nuclear explosions, from radio-active consumer products, from many medical uses of radiation and from the environmental or occupational exposures involved in power production from nuclear sources, as well as from natural sources and from human activities resulting in enhanced exposures to natural sources, as discussed below. In most cases, however, the available evidence as to the frequency with which harmful effects are induced by radiation is only obtained following exposure to substantially higher radiation doses.

12. Particular attention is paid, therefore, to the uncertainties involved in inferring the frequency of harmful effects to be expected following low doses from those actually observed following higher doses, and to the guidance that can be obtained in making this inference from research into the mechanism by which radiation causes harmful effects. For this purpose, investigations of the effects of radiation on animals or, in some cases, on plant material, may be informative and considerable advances have been made in analysing the mechanisms of radiation damage and repair in biological systems.

13. In general, however, the only secure basis for quantitative estimates of the frequency with which harmful effects may be produced in man must depend upon

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4/ 1972 report of the Committee.

surveys of human populations who have been exposed to known doses of radiation, and in whom the effects of these exposures have been adequately studied.

14. The risks of developmental defects associated with pre-natal exposure or of genetic defects, however, cannot be derived, or derived solely, from human epidemiological information and use must be made of the results of experiments on animals to estimate the radiation-induced frequency of forms of developmental or genetic defects. For the somatic effects developing in the exposed individuals, several such sources of information are now available for estimating the risks of radiation exposure, both of the body as a whole and of many of the body organs if exposed individually. In such cases, the corresponding risk estimates are of considerable importance, even though they are not of high precision and apply at higher dose levels than are likely to be encountered in the working or in the general environment. For these quantitative purposes, epidemiological studies are of greater value than estimates of the frequencies with which malignancies are induced experimentally in animals, since the frequency of a given type of somatic effect may vary in different species of animals and may therefore give limited guidance as to the frequency to be expected in man.

15. In addition, human epidemiological studies on radiation-induced cancer have commonly involved much larger populations and better ascertainment of the types of harmful effects produced than has been practicable in most experimental studies on animals. In principle, therefore, the effects of lower doses may be detectable by studies on human populations, provided that a number of conditions are satisfied. It is necessary that the total frequency of harmful effects should be fully ascertained, if necessary by observation over periods of several decades in the case of most somatic effects, and compared with their frequency in an unirradiated but otherwise similar population. The initial radiation exposure should be known, and should be of a type and distribution in the body that is relevant to the risk estimate required. Furthermore, the frequency of the effect observed, relative to that in the comparison populations, should be sufficiently high for a statistically valid estimate of the effect of radiation to be determined. As discussed below, most of these conditions are not adequately satisfied in various surveys of the frequency with which radiation induces malignant diseases in man.

16. For most types of harm that may be induced by radiation, the frequency with which the effect is induced varies with the quantity of radiation absorbed in the body tissues concerned. All the various types of "ionizing" radiation dealt with in the present report cause harm as a consequence of the ionization which they cause in the chemical constituents of the body tissues, and of the energy delivered to important molecular structures of the tissues, particularly the desoxyribonucleic acid (DNA). To a large extent, therefore, the likely harmful effect of any particular exposure to radiation can be related to the energy delivered in this way per unit mass of tissue. The unit of this absorbed dose of ionizing radiation is named the "rad", one rad corresponding to the absorption of 0.01 joule of energy per kilogram of the tissue concerned.

17. The same relationships between the likely frequency of a given type of effect and the absorbed dose in a given tissue apply for most types of radiation with which the present report is concerned (for example, X-rays, beta or gamma radiation), regardless of whether the energy is delivered to the tissue from radiation sources outside the body or from radio-active materials deposited within the body tissues. For certain types of radiation, however, e.g., for neutrons and for the alpha radiation emitted by some radio-active materials, the likely frequency

of effects for a given absorbed dose is greater - often by a factor of 5 to 20 - than that from the same dose of other, and more common, forms of radiation. This is believed to be due to the fact that dose is delivered over short tracks in tissue along which ionization is dense. When references are made in the present report to the estimated frequency of effects per rad, it should be noted that, where the estimates relate to neutrons or to alpha radiation, the frequencies per rad of other forms of radiation are likely to be lower by a substantial factor. The size of this factor, the relative biological effectiveness (or RBE) of the neutron or alpha radiation under the particular condition of the exposure, is discussed in the report.

B. Carcinogenic effects of radiation 5/

18. It has become clear that the most important late somatic effect of low doses of radiation is the occasional induction of malignant diseases, as shown by their increased incidence in the exposed populations. The extensive and careful studies of A-bomb survivors in Hiroshima and Nagasaki, which have now been continued to over about 30 years from exposure, still show no excess in mortality rate from conditions other than malignant disease in those who were irradiated. The Committee has therefore studied all available information on the carcinogenic effects of radiation on which valid estimates can be based. The world "carcinogenic" is used to include the induction of all forms of malignancy - whether of leukaemia or of the solid, or focal, types of cancer developing in the different body organs or tissues.

19. In the present study, it has been of the greatest importance to examine the results of experimental work on animals, on the types of tumour induced by irradiation in different species and the way in which the frequency of tumours varies with the absorbed dose of radiation in the body organ in which the tumours develop. In some of the studies of the effects of radiation in man, it is possible to obtain some indication of the way in which the frequency of cancers varies with the size of the absorbed dose. In general, however, the human epidemiological evidence is too limited, either in the range of radiation exposures or in the precision of estimated cancer induction at each dose, to establish clearly the mathematical form of this dose-effect relationship. The animal studies, therefore, are of great value in showing the way in which the frequency of induced cancers may vary with the dose, under conditions in which reliable estimates are made of the frequencies at different defined dose levels, and when the type and conditions of radiation exposure and the numbers and strain of animals exposed are accurately controlled and known. Under these conditions, it is commonly found that tumours become detectable at varying periods of time, up to some years, after exposure, and that the total number of tumours which finally develop varies consistently with the size of the dose which each group of animals had received. In some instances the frequency becomes larger with progressively larger doses up to a dose of a few hundred to a few thousand rad, higher doses causing in these cases no greater - and often smaller - frequency of tumours. Following doses substantially lower than that causing this maximum yield, and in the region of a few tens of rad, the frequency

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5/ This subject is treated in detail in annex G (Radiation carcinogenesis in man) and in annex I (Experimental radiation carcinogenesis).

is sometimes found directly proportional to the size of the dose, but more commonly the frequency per rad is greater at higher doses than at lower ones.

20. Experiemental studies in animals have been of great value also in establishing the greater carcinogenic effect per rad of alpha radiation or of neutrons, than of other types of radiation, and in suggesting that the form of the dose-effect relationship differs in these two groups of radiation. For alpha radiation and for neutrons, which cause dense ionization along a path of short length in tissues, the frequency of cancer induction often appears to be more strictly proportional to the size of the dose than in the case of other types of radiation. Studies in animals have been of value also in assessing the significance of the rate at which a given dose is delivered, or of the way in which its delivery is made in separate fractions rather than continuously.

21. In many cases it has also been easier to study systematically in animals, rather than in irradiated human populations, the influence that certain biological variables may have on radiation carcinogenesis. Thus the sex, the age of the animal at the time of irradiation, the associated effects of other carcinogenic agents or the genetic characteristics of an inbred strain of animals may have an important influence on the frequency with which tumours are induced at a given dose, and these variables may be adequately studied by experimental methods.

22. For assessing risks it is necessary not only to evaluate the total frequency of malignancies that may be induced by irradiation of the whole body at any given dose. In many circumstances, single organs or groups of organs are selectively irradiated, for example following medical exposures or the inhalation or ingestion of a radio-active nuclide, which becomes selectively concentrated only in certain tissues or organs. It is thus necessary also to evaluate the frequency with which malignant changes are induced in the various body organs individually, and where possible to examine and assess the influence of age, sex and other biological factors on the organ sensitivity.

23. It is of importance, therefore, that several surveys have now been made and continued for prolonged periods of time on the frequency with which cancers of various types develop in certain irradiated human populations in excess of that observed in comparison populations who have not been similarly irradiated. The most important of these surveys is that of the A-bomb survivors at Hiroshima and Nagasaki, in which a large group have been closely examined in regard both to the development of malignant diseases and to death from all diseases, including different types of malignant disease. Comparisons can be made between those who were exposed at various dose levels and those who were unexposed to any significant radiation. From the point of view of risk estimation, this study has the great advantage of being based on substantially uniform "whole-body" irradiation of large numbers of people of all ages, who have now been closely followed for almost 30 years. The irradiation at Hiroshima included a substantial contribution from neutrons, of which the biological effectiveness relative to that from other radiations is hard to determine, but approximate estimates of the carcinogenic risk of irradiation of many body organs can now be determined from these surveys. Some evidence on the risk for one organ, the thyroid gland, can also be derived from the occurrence of cancers of this gland in populations of two Pacific islands, who were exposed to irradiation and radioiodine concentration in the gland from fall-out from a weapon test in 1954. Extensive information on lung cancer induction is also obtainable in a number of countries from the increased mortality from this disease in uranium miners who inhale radio-active gases in the course of their

work. Here, however, the relevant exposure is from alpha radiation, for which the relative biological effectiveness is not known with certainty.

24. A number of other carcinogenic risk estimates are obtainable from studies made on groups of patients who have been irradiated, either in the course of frequently repeated diagnostic examinations or during treatment of their diseases by radiotherapy. In the former group, patients treated for pulmonary tuberculosis by injections of air into the chest to maintain collapse of the diseased lung have sometimes received substantial radiation exposures to the chest from the examinations required to control the degree of collapse; female patients have been found to develop breast cancer in excess of normal expectation. Increased numbers of cancers in locally irradiated organs have been observed in a substantial number of surveys following X-ray treatment to the spine for ankylosing spondylitis, to the pelvis for diseases of the uterus, to the breast for diseases of these glands, or to the head and neck region, for ringworm of the scalp, for pharyngeal infections or for supposed enlargement of the thymus gland. In some instances radium preparations have been administered for the treatment of spinal or other conditions, or thorium compounds as radiological contrast media, and have given rise to increased frequencies of malignancies in irradiated tissues. It has also been found that exposure of the foetus in the course of diagnostic X-ray examinations of the mother's pelvis during pregnancy has been followed by increased frequencies of certain malignant diseases during childhood.

25. From these extensive and varied surveys, it has been possible to derive approximate estimates of the carcinogenic risk of radiation for a substantial number of important body tissues, and to exclude any high risk for others. Reasonably consistent estimates are obtainable from several different sources for certain organs or tissues, such as the thyroid, the breast in females, the lung, the bone and the bone marrow (as regards induction of leukaemia). For some others, including the brain, the salivary glands, the stomach and other parts of the gastro-intestinal tract, the bladder, the lymphoid tissues and probably the liver, the estimates are more tentative, often because the risk appears to be lower and therefore less easily detected or evaluated in human surveys. For one type of leukaemia (the chronic lymphatic type), no induction has been detected in any survey, and for malignant diseases of muscle, adipose tissue, the prostate gland or many other tissues, the risk must be very low since no unequivocal evidence of such a risk has been found.

26. In general it appears that relatively high cancer induction rates apply to the breast in females and to the thyroid, although the mortality rate from induced thyroid cancers is low. The induction rates for lung and for leukaemia are somewhat lower, and those for other organs for which estimates are obtainable appear to be lower again.

27. In evaluating the somatic risks of radiation, however, an estimate is required for the total risk of all malignancies, and particularly of all fatal malignancies, from irradiation of the whole body at low doses. This estimate cannot be derived with confidence by adding the risks for all body organs, since some, and particularly those with low values, are not known with any precision. Several sources of information, however, indicate that the total risk for all fatal malignancies as an average for both sexes and all ages is likely to be in the region of five times that for leukaemia alone, and that the corresponding risk for

leukaemia is about 2 10^{-5} rad^{-1} (that is, 2 per 100,000 persons, per rad of absorbed dose) for moderately low doses of most types of radiation (that is of X-rays and gamma radiation, rather than of neutron and alpha radiation) (see para. 15). The average risk of inducing a fatal malignancy is thus taken as being in the region of 10^{-4} rad^{-1} and that of inducing a non-fatal malignancy is probably of about the same magnitude. The estimated risks for individual organs and tissues appear consistent with this total, and indicates that no organ with a high induction rate is likely to have been omitted from these estimates. It must be emphasized, however, that such estimates are derived predominantly from rates observed following absorbed doses of over 100 rad. While the rate per rad from doses of a few rad is unlikely to be higher than this value, it might be substantially lower. In particular, at low doses in the region of those received annually from natural sources, no direct information is available as to the level of induction of malignancies that might apply. When body tissues are subject to "internal radiation" from radio-active nuclides within the body, no evidence has been obtained of rates of tumour induction differing from those from external radiation, when account is taken of the absorbed dose to tissues from the internal radiation.

28. Many aspects of this subject require fuller investigation, particularly the variations of risk for many organs with the age and sex of those exposed, and the relationship between risk from low dose and that inferred at higher dose. However, for doses of over 100 rad, the total risk of induction of malignancies and the average risks for many body organs appear to be determined with sufficient consistency from different sources to give guidance as to the radiation protection precautions that should be taken in occupations that involve radiation exposure, for which the doses received are discussed later in the present report.

C. Radiation effects on pre-natal development 6/

29. It has been shown repeatedly in experiments on animals that irradiation of the embryo or foetus may cause defects of a wide range of severity. Some are so profound that they cause death of the animal while still within the uterus. Others cause structural changes which are recognizable at birth. Still others are only manifested after birth as functional deficiencies. It has been shown also that the types of changes produced and the sensitivity to the induction of these effects differ considerably at different stages of pre-natal development, and vary according to whether the exposure to radiation occurs before the implantation of the conceptus in the uterine wall, or during the main phase of "organogenesis", when body organs or tissues are becoming differentiated in the embryo, or during subsequent foetal growth.

30. It is evident also that similar types of injury may be caused in man by pre-natal exposure to radiation at corresponding stages in development. Very few human data are available, however, on which to base any quantitative estimate of risks from radiation at these stages, and it is clear that values derived from animal studies cannot be directly applied to man. The Committee has, however, reviewed the effects produced in a number of mammalian species at various stages of development and has attempted to correlate them with changes observed in man at

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6/ This subject is treated in detail in annex J (Developmental effects of irradiation *in utero*).

corresponding stages, where known. The present section of the report is thus concerned with the developmental effects produced by radiation on the embryo or foetus. Those effects caused by irradiation of the germ cells before conception, but expressed during subsequent development, will be discussed in section D on genetic effects of radiation, while the induction of malignant change by irradiation of the foetus has been dealt with in paragraphs 18-28.

31. The effects of radiation before the implantation of the conceptus in the uterus have been examined in the mouse, rat, hamster, rabbit and dog. Exposure to radiation at this stage may cause the death of the embryo and failure of implantation, with variable frequency in the different species. Those embryos which survive the exposure and become implanted would appear, however, to develop normally, with little evidence of an increased frequency of intra-uterine death or of induced abnormality shown at birth or subsequently.

32. Irradiation after implantation, and during the period in which body structures are becoming differentiated and organs are developing, causes broadly similar types of malformation or harm in a number of different mammalian species if they are irradiated at comparable stages of development. It appears, from collected reports of the rare cases of therapeutic pelvic irradiation of pregnant women, that the same applied in humans if irradiation took place during the period from about 9 to 40 days following conception.

33. Studies on irradiated animals, largely on rats and mice but with some observations on a number of other species, show that three main types of effect may occur. From relatively high doses, especially if delivered early in this period, death of the conceptus may result either in the uterus or soon after birth, the doses causing 50 per cent lethality in these conditions being about 100 rad or higher. Alternatively, growth of the embryo may be impaired at these or lower doses, and this impairment of normal growth may persist during post-natal life. And thirdly, more localized defects in development may result, causing malformations in particular body structures or metabolic functions.

34. From studies on animals, it is found that malformations of the eye, the brain and nervous system, or the head, skeleton and extremities may typically result from irradiation during the period of organogenesis, and that the particular malformation which is most likely to occur depends very critically upon the time within this period at which radiation exposure occurs. Not much information is available as to the way in which the frequency of any particular malformation, or of all malformations, varies with dose. An increased incidence of some malformations has, however, been observed at doses as low as 5 rad in the mouse, and at 5 to 10 rad in the rat, for exposures at times appropriate to induce these malformations. At absorbed doses of 10-100 rad of sparsely ionizing radiation several types of malformations may be induced, each with a frequency of about 10^{-3} rad^{-1} or more, but adequate data are not available in general to show what these frequencies may be at lower doses.

35. While it is evident that radiation-induced malformations occur in man, of types depending upon the stage of development at which the exposure occurs, there is little information indicating the likely frequency, particularly at low dose. In its 1969 report, the Committee estimated a possible incidence of mental retardation, associated with small head size (microcephaly), in the region of 10^{-3} rad^{-1} for doses over 50 rad delivered at high dose rate. Recent data have shown an increased

incidence of microcephaly and mental retardation as a function of dose at Nagasaki following exposures within 3 to 17 weeks of gestation. At Hiroshima, where the neutron component was appreciably higher, a comparable incidence was observed at lower doses. However, various studies of the effects of embryonic exposure during radiological procedures, usually in the region of a few rad, have failed to show a significantly increased incidence of malformations.

36. In animals, irradiation during the foetal stage of development, as in earlier stages of intra-uterine life, may cause death of the foetus, impairment of growth or malformations. In this stage, however, the likelihood of death decreases progressively and the induction of malformations becomes considerably less likely, at least as regards the defects in major anatomical structures which result in important functional disabilities. Some major defects continue to be caused, particularly after high doses. Such malformations as occur at lower doses, however, are largely confined to lesions detectable microscopically. The body size and weight at birth, however, are commonly found to be decreased following irradiation during this foetal stage of development.

37. In man the foetal period extends over the last 33 weeks of gestation. Irradiation during this period has been shown to be associated with defects in growth and with some mortality at high dose levels. The induction of microcephaly may still occur if doses are high, but substantial malformations are less likely to be induced at this stage than during organogenesis, although heterochromia (irregular colouration of the iris) has been shown to have been induced by diagnostic radiological exposure during the fourth and fifth months of gestation.

38. Japanese children who had been exposed in utero as a result of A-bomb explosions in Hiroshima and Nagasaki at doses exceeding 50 rad have shown, at the age of 17 years, clear evidence of reduction in body size.

39. From experimental studies in animals it may be concluded that the developing embryo and foetus show a pronounced sensitivity to the induction of malformations by radiation, particularly during the main phases of organogenesis. The pattern of response in various species is so similar that man may not be expected to be an exception in this respect. However, no satisfactory data are yet available for deriving reliable quantitative estimates of the risk from pre-natal human irradiation at comparable developmental stages, particularly at the low doses and dose rates. The Committee emphasizes therefore the importance of further studies on a number of special aspects of this subject.

D. Genetic effects of radiation 7/

40. When cells are exposed to ionizing radiation, the chromosomes of the cell nuclei may be damaged by the production of gene mutations, involving alterations in the elementary units of heredity which are localized within the chromosomes, or by the induction of chromosome aberrations, consisting of changes in the structure or number of the chromosomes. When such changes are induced in the germ cells, they may be transmitted to descendants of the irradiated persons. The gene mutations

7/ This subject is treated in detail in annex H (Genetic effects of radiation).

and chromosome aberrations which occur spontaneously in man are a source of considerable hardship, being responsible for a substantial fraction of all spontaneous miscarriages and congenital malformations, causing mental and physical defects. It is of importance therefore to estimate the amount by which radiation exposure may increase the frequency of these genetic defects. The Committee has reviewed the frequency estimates obtainable for different types of gene mutations and chromosome aberrations, particularly as applicable to the two germ cell stages which have been found to be of the major importance. These are the spermatogonia and the oocytes, which constitute the permanent germ cell population in the male and female, respectively.

41. Gene mutations are classified for convenience as dominant or recessive, according to the extent to which the effect of the mutation is expressed in a descendant inheriting the mutated gene from one parent only. A fully dominant mutation has a maximal effect in the descendant even if only transmitted from one parent. A fully recessive mutation has no effect in a descendant unless he has received genes with the same abnormality from both parents (or unless it is received in the X-chromosome). The effects of many mutations in man and experimental mammals are intermediate between the fully dominant and the fully recessive.

42. Chromosome aberrations are of two kinds: (a) structural aberrations arising from breakage and rejoining of chromosomes, which may involve decreases (deletions) or increases (duplications) in the number of certain genes within a chromosome or changes in the sequence of arrangement of genes (inversions or translocations); (b) numerical aberrations, involving the addition or loss of chromosomes.

43. The Committee has reviewed in detail recent work on the processes of radiation damage and repair of DNA, since it is evident that the genetic effects of radiation are likely to be due predominantly to damage induced in this molecular structure.

44. In estimating the genetic risks of radiation, particularly for low doses, very little quantitative information is available from observations of the effects of human exposure. To a large extent, therefore, these estimates need to be based upon the effects observed in studies on animals, and particularly on the mouse, in which the genetic effects of radiation have been extensively investigated. In using such data, it has to be assumed that the amounts of genetic damage induced by radiation under a given set of conditions is equal in mouse and human germ cells, and that physical and biological variables affect the magnitude of the damage in similar ways and to similar extents. In some instances these assumptions can be checked by data obtained in man or in other primates.

45. Two methods have been used in the present report to estimate the genetic risk of radiation in man. By the first, or "direct" method, the risks are expressed in terms of the expected frequencies of various types of genetic change induced per unit dose. By the second, or "doubling-dose" method, estimates are made of the radiation doses that double the natural frequencies of various types of genetic abnormality. The expected effect of a given dose is then estimated, on a proportional basis, from the known natural frequencies of the various forms of genetic abnormality in man and from the value assumed for the doubling dose.

46. Using the direct method, the total rate of induction of recessive mutations is estimated as 60 10^{-6} per gamete per rad. The value is derived from the rate with which autosomal recessive lethal mutations are induced by irradiation at high dose rate in mouse spermatogonia, with corrections for mutations that

are not likely to have been detected and for radiation conditions applicable to man. For evaluation of the risk in the first-generation progeny of the exposed parents, it is the degree of dominance of these mutations that is of importance.

47. An over-all estimate of the risk from the induction of mutations causing dominant effects (and this includes the recessives with partial dominance referred to in para. 46, as well as dominant visibles) can be derived from the rate of induction of mutations causing skeletal abnormalities in the mouse, which have been studied in detail. The induction rate for skeletal mutations in mice has been used to estimate the rate of induction of dominants affecting all body systems in man. A study of the nature of the skeletal effects has also permitted an evaluation of the proportion of these mutations that would, in man, entail serious handicaps. The over-all estimate thus obtained is 20 10^{-6} rad^{-1} for irradiation of males. For irradiation of females at low doses and low dose rates, the mutational risk is expected to be very low, provided that the human ovary responds to irradiation as does that of the mouse.

48. In estimating the risk of induction of chromosomal aberrations by the direct method, some data are available from observations on man and also on certain primate species. The data from primates show considerable variability, but those indicating the higher risk (in the marmoset rather than in the rhesus monkey) have been used in conjunction with those from man. On these bases, the risks from induction of reciprocal translocations are taken to be of from 2 to 10 congenitally malformed liveborn children per million conceptuses, per rad of paternal irradiation, with about five times this number of recognizable abortions and about 10 times the number of losses at the early embryonic stage. The corresponding risk from maternal irradiation is likely to be small, as are those from other structural aberrations and from sex-chromosome losses, while those from chromosome gains cannot at present be estimated quantitatively. Direct methods thus suggest that the genetic risk in the first generation following irradiation of parents with 1 rad is likely to be of the order of 20 to 30 seriously affected cases per million liveborn (20 by mutations with dominant effects and 2 to 10 resulting from structural chromosome aberrations). This estimate excludes the risk from the induction of numerical chromosome abnormalities for which no reliable figure is yet available.

49. The doubling-dose method involves the assumption that the radiation-induced mutation rate is for each kind of genetic defect proportional to the rate with which it originates spontaneously. It has been observed in the mouse that the dose required to double the natural frequency of several different forms of genetic abnormality is of roughly the same magnitude and can be taken as about 100 rad for radiations such as X-rays, beta or gamma radiation delivered at low dose rate. In this connexion it is of considerable importance that data on the mortality of children born to survivors of the atomic bombs at Hiroshima and Nagasaki indicate that for man, in both sexes, the doubling-dose is unlikely to be lower than this value. The increase of genetically determined diseases per rad is thus unlikely to exceed 1 per cent of the corresponding natural rates.

50. By this method, the Committee estimates that, in a million liveborn children in the first generation of offspring of a population exposed to 1 rad at low dose rate during the generation, there would be 20 cases suffering from dominant or X-linked diseases, 38 with chromosomally determined diseases and 5 with diseases of complex aetiology, induced by the radiation. The total genetic damage expressed

over all generations (or the value in each generation reached after prolonged continuous exposure) is estimated to be 185 10^{-6} rad^{-1} by the doubling-dose method.

51. The kinds of genetic damage discussed and the risk estimates derived do not take full account of the class of mutational events which lead to minor deleterious effects and which, by their large number, might impose a greater total genetic burden on the population than that from a smaller number of relatively more serious conditions.

III. RADIATION SOURCES AND EXPOSURES TO RADIATION

A. General aspects 8/

52. The Committee has collected and assessed data on human radiation exposures for two main purposes. The first purpose is to present individual exposure data which would indicate the possible levels of risk to which individuals are subjected under various circumstances. The second purpose is to present data which could be used to indicate the total consequences in radiation harm from given sources of radiation. The two types of assessment, the individual-related assessment and the source-related assessment, therefore, serve different purposes.

53. The basic quantity in all assessments is the absorbed dose, which for certain types of radiation needs to be weighted for an enhanced biological effectiveness (para. 17). In the present report, the shorter term "dose", unless otherwise qualified, refers to the mean absorbed dose over an organ or tissue. In presenting dose data, the period of time over which the dose is accumulated is always stated in the individual-related presentations, while the period of time over which the dose is delivered is of less importance in the source-related assessments.

1. Individual-related assessments

54. Depending upon the purpose of the assessment, the time period to which the individual dose is related may be one year, a lifetime, the limited time of a single exposure or some other time of relevance. Continued practices inevitably give rise to accumulations of radio-activity in the human body or in the environment until a steady-state situation is reached. This would be the case, for example, if the practice caused releases of long-lived radionuclides which remained in the environment for a long time. For such situations, the "dose commitment" from, for example, one year of practice is assessed as the sum of the individual's future annual doses. This summation is also applied for an average individual and, in the general case, extended over future generations. It can be shown that the annual dose, when it reaches its maximum value in the future, will not exceed the dose commitment from one year of practice. Dose commitments to various populations, such as the groups of most highly exposed individuals, or the whole world population, are assessed in order to account for those future dose contributions to which human populations are committed from present practices and which would give rise to higher annual doses than at present if these practices were continued.

2. Source-related assessments

55. For the source-related assessments it is necessary to derive a quantity which

8/ Concepts used in the assessment of radiation exposures are treated in detail in annex A (Concepts and quantities in the assessment of human exposures).

would be related to the detriment from the practice. On the assumption of proportionality between radiation dose and individual risk within the range of doses encountered, the "collective dose" is a quantity which is proportional to the radiation detriment. The collective dose is the product of the number of people in the exposed population and their average dose. If the purpose is to assess the total detriment of a given practice, all individuals must be included in the assessment, that is, the global collective dose should be calculated. For the assessment of the total radiation detriment, future dose contributions committed by the practice should also be included. Therefore, "collective dose commitments" have been calculated as the sum of the annual global collective doses over all future years. The collective dose commitment is always related to a limited amount of practice, the release of a certain quantity of a radio-active substance into the environment, the production of a certain amount of electric energy or the result of any single decision.

56. The values of the collective dose commitment may be used for the assessment of the radiation detriment, provided that the radiation detriment per unit of collective dose (man rad) is known. Even without this provision, collective doses from various practices may be compared for relative detriment assessments. This could provide a useful input for cost-effectiveness decisions on various alternative applications of radiation protection measures, under the assumption that the likelihood of harm is proportional to dose.

B. Sources of human radiation exposures

57. In the previous reports of the Committee, data on human radiation exposures have been presented separately for various classes of exposure, such as occupational exposures, medical exposures of patients, exposures from environmental contamination and miscellaneous exposures. Basically, the same procedure has been followed in the scientific annexes to the present report. 9/ In the following paragraphs, however, a number of sources and practices are reviewed with regard to the total resulting exposures, including all contributions whether occupational or environmental, with the aim of providing data for source-related assessments.

58. Radiation exposure due to natural sources is a result of both terrestrial and cosmic irradiation and varies somewhat with geographic location, primarily owing to differences in altitude and radionuclide distributions in the terrestrial environment. For illustrative purposes, the collective dose commitment from other sources of radiation exposure is sometimes given in the present report in terms of the equivalent duration of exposure to natural sources which would cause the same global collective dose commitment (see table 3).

59. Exposure to natural radiation may be enhanced by human activities such as high-altitude flights, construction of buildings using materials of high radium content, reduction of ventilation rate in homes and boring deep wells into radon-

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9/ More detailed information on these exposures, as well as on others, is presented in the relevant annexes to the present report: annex B (Natural sources of radiation), annex C (Radio-active contamination due to nuclear explosions), annex D (Radio-active contamination due to nuclear power production), annex E (Doses from occupational exposure) and annex F (Medical irradiation).

rich water. Enhanced exposures to natural radiation are also variable, ranging from slight increases to those of orders of magnitude. These enhanced exposures may well be subject to source-related assessments when they result from human decisions to which a collective dose commitment may be related as a measure of the consequent detriment. Other sources or practices for which the Committee provides estimates of exposures are medical uses of radiation (including the exposure of patients and other exposures), electric-power generation from nuclear fission, nuclear explosions and radiation-emitting consumer products.

1. Normal exposures to natural radiation sources 10/

60. Man has always been exposed to ionizing radiation from various natural sources. A distinguishing characteristic of this natural irradiation is that it involves the entire population of the world and that it has been experienced at a relatively constant rate over a very long period of time. On the other hand, even the normal natural exposure various substantially from place to place, as well as locally, for example even within one building.

61. The assessment of the radiation doses in man from natural sources is of particular importance because natural irradiation is the largest contributor to the collective dose of the world population. Furthermore, the extent of variation of natural exposures with location and habits is of practical interest.

62. The various natural radiation sources include external sources, such as cosmic rays and radio-active substances in the ground and in building materials, and internal sources in the form of naturally occurring radio-active substances in the human body, particularly potassium-40.

63. Table 1 below summarizes the average contribution of natural sources to the radiation exposure of human populations living in areas of normal radiation background. The annual *per capita* dose has been assessed for four tissues: the gonads, the whole lung, the cells lining the bone surfaces and the red bone marrow, with the contributions from all types of radiation included. In those tissues the annual dose from normal exposure to natural sources is estimated to be of the order of 100 mrad (1 mrad = 0.001 rad). For purposes of comparison, the estimates of the 1972 report are given in brackets in table 1. The new estimates are a few per cent lower than the previous ones for the gonads and the bone-lining cells and a few per cent higher for the red bone marrow. The difference is mainly due to better knowledge of the doses from "terrestrial" radiation (taken here as including gamma radiation from the ground and that from building materials), which are now estimated to be about 30 per cent lower than indicated in the 1972 report. The increase in the estimate of the dose in the red bone marrow is caused by a higher estimate of the contribution from potassium-40 than previously.

10/ This subject is treated in detail in annex B (Natural sources of radiation).

Table 1

Annual per capita doses from normal exposure to natural sources of radiation

(in mrad) a/

	Gonads		Whole lung	Bone-lining cells		Red bone marrow	
External irradiation							
Cosmic rays	28	(28)	28	28	(28)	28	(28)
Terrestrial radiation	32	(44)	32	32	(44)	32	(44)
Internal irradiation							
Potassium-40	15	(19)	17	15	(15)	27	(15)
Radon-222 (with daughters)	0.2	(0.07)	30	0.3	(0.08)	0.3	(0.08)
Other nuclides	2	(1.4)	5.5	9.1	(4.3)	4	(1.9)
Total	78	(93)	110	84	(92)	92	(89)

a/ Figures in brackets refer to estimates made in the 1972 report. All values and the totals are rounded to two significant figures.

64. As the result of inhalation of radon-222 and its daughter products, the dose in the entire lung - which is now being assessed for the first time by the Committee - is between 20 and 45 per cent higher than the dose in the other tissues. Moreover, a substantial fraction (31 per cent) of this dose is caused by alpha radiation, which is expected to have a higher relative biological effectiveness than do the beta and gamma radiations, which cause more than 90 per cent of the dose in the other tissues. It may be mentioned that an annual dose of the order of 200 mrad is received by the epithelial cells of the tracheo-bronchial tree, mainly from alpha particles.

65. The variability of individual doses from potassium-40 in the body is small. The individual lung doses, however, are subject to rather large variations because of the varying concentrations of radon and its daughter products in indoor air. The normal variation of the dose contributions from these sources ranges from 4 to 400 mrad in a year.

66. Much higher external doses are received by population groups living at high altitudes or in regions of high natural radiation. Some population groups are also exposed to elevated internal doses. Such population groups are, for example, the caribou or reindeer eaters in the northern regions, or those people living in houses with low rate of ventilation, as may be the case in the colder climates. The ventilation rate determines the average concentration of radon in indoor air at a given emanation rate (from the building material, from the basement floor or from radon-rich tap water).

67. In relative risk assessments, the total exposure due to a limited amount of a practice involving radiation (para. 55) may be expressed in terms of the duration of an exposure at a constant rate of a specified population which would be expected to cause the same detriment. This comparison is particularly illustrative if the practice gives a relative uniform exposure and the reference is made to the equivalent duration of exposure of the world population to natural radiation sources. As in previous reports, therefore, the Committee has indicated the equivalent durations of exposure to natural sources which would cause the same collective dose commitments as the practices discussed in the present report. The annual collective dose from natural sources to the world population is of the order of $3\ 10^{8}$ man rad for most of the body tissues but is about 30 per cent higher for the whole lung.

2. Technologically enhanced exposures to natural sources 11/

68. In some situations the exposure to natural radiation sources is enhanced as a result of technological developments. Some examples of such exposures are the irradiation by cosmic rays in aircraft, the irradiation resulting from the phosphate industry or the irradiation due to the release of natural radionuclides from coal-fired power plants.

69. Building materials. The use of some building materials leads to substantially elevated exposure levels indoors. These building materials may be of natural origin, as is the case of pumice stone, granite or light concrete derived from alum shale. They may also be made from by-products from industrial processes, such as slag or phosphogypsum. If all the phosphogypsum derived from one tone of marketable phosphate ore were used in the building industry, the resulting collective dose commitment might be a few man rad per ton of rock. The dose rates in air from gamma radiation in buildings constructed of such materials may be substantially higher than the average normal dose rate from terrestrial radiation. The radon levels will also be considerably enhanced, for a given ventilation rate.

70. Reduced ventilation. Changes in the ventilation in a poorly ventilated room influence the radon level considerably. The ventilation rate in houses varies in different countries owing to climate, heating systems and building standards. Between two and five exchanges of air per hour are not unusual in many countries. In countries with cold climates, however the ventilation rate may sometimes be as low as 0.1 to 0.2 exchanges per hour, and this could result in annual doses of several rad in the lung from alpha radiation. Radon in water will cause exposures not only after ingestion, but also after inhalation of radon emanating from the water. When the radon concentration in tap water is large, the lung dose due to inhalation indoors is larger than the dose in the stomach resulting from the ingestion of normal quantities of water.

71. Passengers in aircraft. A total of about 10^{9} passenger hours are spent travelling by air each year. Under average solar conditions, the annual collective dose contributed by air travel is about $3\ 10^{5}$ man rad. The risk of high dose rates from cosmic radiation at high altitudes due to large solar flares has made it necessary to equip supersonic aircraft with radiation monitors in order to warn the pilot when a solar flare is developing. The aircraft will then be moved to lower altitudes if the dose rate reaches a predetermined level. High

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11/ This subject is treated in detail in annex B (Natural sources of radiation).

radiation levels at high altitudes during solar flares are infrequent events which will not add significantly to the collective dose to the world population.

72. Use of phosphate fertilizers. Mineral phosphate deposits usually contain relatively high concentrations of radio-active nuclides of the uranium-238 decay series. Very large quantities of phosphate rock are mined. Some of the material is converted to fertilizers and some is disposed of as waste. Both practices may lead to exposure of the public. In addition, one by-product is chemical gypsum, which may be used as a building material and is therefore a radiation source of particular interest. The assessment of the collective dose commitment per ton of marketable rock shows that the contribution from phosphate fertilizers is small, of the order of $3\ 10^{-4}$ man rad per ton of fertilizer. For a world-wide annual use of 10^8 tons of phosphate fertilizers, the collective dose commitment from a year's use of these fertilizers is of the order of $3\ 10^4$ man rad.

73. Coal-fired power plants. Burning of coal is one source of enhanced radiation exposure to naturally occurring elements, particularly radium, thorium and uranium. The concentrations of the significant radionuclides have been measured both in coal of various origins and in slag and fly-ash. The Committee has assessed the collective dose commitment per megawatt year production of electric energy due to the deposition of fly-ash but has found that this is a small contribution, being between 0.002 and 0.02 man rad per MW(e)y in the various body tissues from discharged material deposited on the ground and also between 0.002 and 0.02 man rad per MW(e)y from the material inhaled.

74. Use of natural gas. Natural gas used for kitchen ranges and space heaters is a source of radon in buildings. The radon, which is produced in the ground, diffuses from the geological formations into the wells for natural gas. This source of radon, however, is found to be insignificant in comparison with the other sources of radon.

3. Radiation-emitting consumer products 12/

75. A variety of consumer products contain radionuclides which have been deliberately incorporated to satisfy a specific purpose. In addition, some electronic products, such as television sets, may emit X-rays. The most widespread radiation-emitting consumer products are radioluminescent time-pieces compasses, luminous signs, smoke detectors, antistatic devices and television sets. The extent to which exposures from these products are permitted by national regulations varies from country to country. The most commonly used radionuclides in consumer products are tritium, krypton-85 and promethium-147, the use of which involves trivial amounts of penetrating radiation.

76. Until the 1960s, radium-226 was the most common nuclide in radioluminescent paint and therefore also in watches and alarm clocks. The wearer of an average radium-activated wristwatch receives a gonad dose of few mrad in a year. Although this external irradiation is eliminated by the present use of tritium for the same purpose, some tritium may escape from watches and cause internal irradiation producing a whole-body dose of about 0.5 mrad per year. The present use of

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12/ This subject is treated in detail in the appendix to chap. IV of annex B, and in annex E (Doses from occupational exposures).

radioluminescent paint in the watch industry may cause a collective dose to the world population of the order of 10^6 man rad in a year. It also causes some occupational exposure.

77. Luminizers have traditionally been among the groups of workers receiving higher than average doses. The marked improvement which could be brought about by an energetic programme of radiation protection was demonstrated in the 1972 report. The collective doses from the occupational exposures are small in comparison with those from the exposure of the public, but high individual doses may still occur.

78. Household colour television receivers are the most common consumer product with the potential of exposing the public to X-rays. In the 1972 report, some cases of leakage of X-rays from certain types of television sets were reported. Since then, however, solid-state circuitry has been widely adopted. It is therefore likely that the X-ray emission from recently-built colour television receivers is negligible under conditions of normal operation and proper servicing.

79. The assessment of dose from the use of radiation-emitting consumer products is rendered difficult by the lack of extensive information on the number of such products on the market and the amount of activity involved. Owing, however, to international recommendations and some national regulations, there is a gradual improvement of control, and it is likely that the annual per capita gonad dose from the use of radiation-emitting consumer products is less than 1 mrad at present.

4. Power generation from nuclear fission 13/

80. The use of nuclear reactors in the production of electrical power has continued to increase, although not at the rate predicted, since the Committee's first attempt to assess the releases of radio-active material from the nuclear fuel industry and the resulting global dose commitment. The total installed nuclear generating capacity in the world in 1976 was about 80 GW(e) from 187 power reactors operating in 19 countries. The projected capacity by the year 2000 is about 2,000 GW(e).

81. Nuclear power production involves a series of steps, comprising the processes of mining and milling of uranium, conversion to fuel material (in most cases including enrichment in the isotope uranium-235), fabrication of fuel elements, utilization of the fuel in nuclear reactors, storage of the spent fuel, reprocessing of this fuel with a view to recycling, transportation of materials between the various installations and ultimate disposal of radio-active waste.

82. Almost all the radio-active material associated with the nuclear industry is present in the reactors and in spent fuel or in well-contained fractions separated from the fuel during the reprocessing operations. However, at most steps of the operations, releases of small quantities of radio-active material into the

13/ This subject is treated in detail in annex D (Radio-active contamination due to nuclear power production) and in annex E (Doses from occupational exposures).

environment occur. Most of the radionuclides released are only of local or regional concern, because their half-lives are short compared to the time required for dispersion to greater distances. Some radionuclides, however, having longer half-lives or being more rapidly dispersed, can become globally distributed.

83. The Committee is interested in assessing the collective dose commitments due to releases of radio-active substances from all operations in the present nuclear industry. As the scale of each step is related to the nuclear capacity it serves, it seems reasonable to express such assessments in terms of collective dose commitments per unit energy generated, that is, per MW(e)y. These collective doses to the world population from nuclear-power production comprise the contributions from four components, namely, the occupationally exposed groups, the local populations, the regional or intermediate populations and the world population.

84. A special presentation problem arises in the case of a few radionuclides which have very long half-lives. The most important examples are uranium-238 ($4.5\ 10^9$ y) and iodine-129 ($1.6\ 10^7$ y). Although these nuclides will not accumulate in sufficient quantities in the biosphere to cause more than one mrad per year, even if nuclear-power production were continued for 500 years at a rate of 2,000 GW(e) with the present technology, the exposure periods of many million years may make the dose commitments high.

85. Since the exposure periods involved in these cases are so extremely long in human perspectives, the collective dose commitments are not realistic. For example, in order to accumulate a collective dose of 1 man rad per MW(e)y, a world population of 10^{10} persons would need to be exposed to uranium-238 over a period of the order of 10 million years or to iodine-129 over a period of 10,000 years. Because of the small annual doses, as indicated in paragraph 84, the exposures from these nuclides are not included in the following considerations.

86. Carbon-14 is a nuclide which presents similar problems, although it has a much shorter half-life (5,730 y). The collective dose commitment from carbon-14 released from light-water reactors and related reprocessing plants is estimated to be about 5 man rad per MW(e)y in soft tissues and 14 man rad per MW(e)y in bone-lining cells and red bone marrow. One half of this collective dose will be delivered within 5,700 years. However, because it takes some time for carbon-14 to become dispersed in the oceans, as much as one fourth of the collective dose will be delivered within 500 years. This means that if the nuclear industry were operating at a constant rate for 500 years, the maximum future annual collective dose would be about 1 man rad per MW(e)y in soft tissues and 3 man rad per MW(e)y in bone-lining cells and red bone marrow. These figures will be used in the following comparison of collective dose contributions.

87. In reviewing the dose contributions from the various steps in the nuclear-power production, it must be kept in mind that the individual exposures are limited by national regulations, often based on the recommendations of the International Commission on Radiological Protection. This means that the annual whole-body dose to those who are occupationally exposed is limited at a maximum of 5 rad of the most frequent types of radiation. National authorities usually make provisions to ensure that the annual doses to the most highly exposed individual members of the public amount to a small fraction of the dose limit of 0.5 rad in a year recommended by ICRP for the sum of all exposures in addition to those from natural sources and medical exposures of patients. Present radiation protection

policies also include the principle of eliminating any exposures which are not necessary and of keeping all doses as low as is reasonably achievable. The effect of these precautions is that exposure at the limits is rare and that the dose distributions are usually such that the average dose in each group of persons to which a limit applies is much lower than the limit. It is the source-related assessment of collective dose commitments that is of primary interest for the present report.

88. In reviewing the various steps of nuclear energy production, the Committee has found the following contributions to the exposure of the personnel and the public:

(a) Mining, milling and fuel fabrication. These steps involve mainly occupational exposures. The whole-body collective dose commitment to the workers is 0.05 man rad per MW(e)y in the mining and 0.15 man rad per MW(e)y in the milling and fuel fabrication industry. In addition, mining will cause lung exposure from radon daughter products, adding 0.1 man rad per MW(e)y. The exposure of the public is small (see, however, paras. 84 and 85).

(b) Reactor operation. The local and regional exposures of the public will cause a collective dose commitment of 0.2 to 0.3 man rad per MW(e)y due to releases into the air and 0.03 to 0.06 man rad per MW(e)y due to releases into water. The global exposures from reactor operations are small in comparison with those from the reprocessing industry, in circumstances in which all the spent fuel is reprocessed using present technology. The occupational collective dose commitment is in the vicinity of 1 man rad per MW(e)y.

(c) Fuel reprocessing. The local and regional collective doses from reprocessing are by necessity low, because each plant serves a large nuclear energy producti n expressed in MW(e)y and it is the dose limits to the most highly exposed individuals in the neighbourhood that is the limiting factor. Global collective dose commitments from tritium (0.05 man rad per MW(e)y), carbon-14 (1 to 3 man rad per MW(e)y, see para. 86) and krypton-85 (0.09 to 0.25 man rad per MW(e)y) would contribute significantly to the total from the nuclear industry if all spent fuel were reprocessed and if these nuclides, as at present, were released. The occupational contribution from the relatively small amounts of fuel from the nuclear power industry that have yet been reprocessed is estimated to have been 1.2 man rad per MW(e)y. This contribution, however, is not expected to apply to a nuclear industry as a whole because fewer workers would be involved per MW(e)y than in the case quoted above, while the individual occupational doses would continue to be limited by regulation. For example, with the present occupational whole-body dose limit, it would be unlikely to exceed a collective dose commitment to the workers of the order of 1 man rad per MW(e)y if, as seems likely, a reprocessing plant could serve a nuclear capacity of 20,000 MW(e)y per year and have an operating staff of several thousand persons.

(d) Transportation. External exposures from all transportation is estimated to give only 0.003 man rad per MW(e)y.

(e) Waste storage. The Committee is satisfied that the collective dose contribution from present waste storage practices is very small compared to the contributions from other parts of the nuclear fuel cycle. The occupational contribution may be considered to be included in the contribution mentioned above for reprocessing.

(f) Waste disposal. Because high-level wastes from nuclear power production continue to be maintained in storage by national authorities, with the precise method of disposal at present undecided, the Committee feels that it is unable at this stage to make an adequate assessment of collective dose commitment for the world population from disposal of these wastes.

(g) Research and development. A part of the exposures incurred in research and development establishments are attributable to support for continued operation or future development of the nuclear power industry. It is estimated that about 1.4 man rad per MW(e)y is contributed by these occupational exposures. The collective dose commitment to the public is at least one order of magnitude lower.

89. The total of the exposures mentioned in the previous paragraph is near 7 man rad per MW(e)y, with a variation between different tissues of less than 30 per cent from that value (the thyroid and lungs are organs which receive the highest doses, while the gonads are in the lower range). The major contributions are shown in table 2.

Table 2

Step in fuel cycle	Collective dose commitment [man rad/MW(e)y]
Mining, milling and fuel fabrication	
(a) Occupational exposure	0.2-0.3
Reactor operation	
(a) Occupational exposure	1.0
(b) Local and regional population exposure	0.2-0.4
Reprocessing	
(a) Occupational exposure	1.2
(b) Local and regional population exposure	0.1-0.6
(c) Global population exposure	1.1-3.3
Research and development	
(a) Occupational exposure	1.4
Whole industry	5.2-8.2

In this summation the occupational contributions dominate. For the reasons given in paragraph 88, however, the contribution of 1.2 man rad per MW(e)y from reprocessing would not be representative for a closed fuel cycle involving the whole nuclear industry. Neither would research and development be expected to give high contributions in the developed industry. Therefore, the total collective dose commitment in the future, with existing technology, would not be expected to exceed 3 to 6 man rad per MW(e)y. Because of the age distribution of those exposed, only about 30 per cent of the lower value of the range of collective doses for the whole industry in table 2 is of genetic significance.

5. Nuclear explosions 14/

90. Since the publication of the Committee's 1972 report, several nuclear tests have taken place, including 20 atmospheric tests, six of which were in the northern hemisphere and 14 in the southern hemisphere. The Committee's 1972 report contained estimates of dose commitments to populations from all atmospheric tests up to the end of 1970. In the present report, the Committee has evaluated dose commitments from atmospheric tests up to the end of 1975. From increases in the world inventory of strontium-90 and caesium-137, the Committee estimates that dose commitments in the northern and southern hemisphere have increased by about 2 and 6 per cent, respectively, owing to tests carried out from 1971 through 1975.

91. The total global dose commitment from all nuclear explosions carried out before 1976 ranges from about 100 mrad (in the gonads) to about 200 mrad (in bone-lining cells). In the northern temperate zone the values are about 50 per cent higher, and in the southern temperate zone about 50 per cent lower, than these estimates. External exposures contributed by caesium-137 and short-lived gamma-emitting nuclides account for about 70 mrad of the global dose commitment for all tissues. Internal exposures are dominated by contributions from the long-lived nuclides caesium-137 and strontium-90 (in the skeleton). Their half-lives of about 30 years will determine the length of time over which the doses will be delivered. The more short-lived ruthenium-106 and cerium-144 are significant contributors to the exposure of the lung.

92. As in the case of the nuclear power industry, carbon-14 gives the highest dose commitments. Its contribution is about 120 mrad for the gonads and the lung and 450 mrad for the bone-lining cells and the red bone marrow. These doses will be delivered over a period of many thousand years. For reasons given in paragraph 86, they are not included in the estimate of the dose commitment of the previous paragraph.

93. The total global collective dose commitment in different tissues from nuclear test explosions is $4\ 10^8$ to $8\ 10^8$ man rad if the carbon-14 contribution is not included, and this commitment is equivalent to between 16 and 24 months of exposure of these tissues to radiation from normal natural sources. If the carbon-14 contribution is included, the collective dose commitment is twice as high.

94. Short-lived iodine-131 is an important contributor to the exposure of the thyroid for a few weeks after nuclear explosions. The highest doses are incurred by infants in some populations consuming fresh milk, and annual thyroid doses from a few mrad to about 200 mrad have been estimated since 1972 for those periods with atmospheric nuclear tests. The thyroid dose in adults is about one tenth of that in infants.

14/ This subject is treated in detail in annex C (Radio-active contamination due to nuclear explosions).

6. Medical uses of radiation 15/

95. The Committee has previously presented data on the medical irradiation of patients in its reports of 1958, 1962 and 1972 and of the related occupational exposures in the same reports. The medical exposures are of particular interest, since they contribute the highest man-made *per capita* doses in the population, are given with high instantaneous dose rates and cause the highest individual organ doses short of accidental exposures. From the radiation-protection point of view, they also offer the largest potential possibilities of dose reduction without loss of the information required. They differ from many other types of exposure in that they usually only involve irradiation of limited regions of the body. They also differ in the sense that the individuals who are irradiated are those who may expect to benefit directly from the particular treatment or examination.

96. In the previous reports, special emphasis was put on assessments of the annual genetically significant dose (GSD). The presentation of such data has encouraged further studies, so that it is now relatively clear to what extent medical exposures contribute to the total genetic dose both in developing countries and in countries which have already reached a high degree of technological development (see para. 99). In the developing countries the level of the annual genetically significant dose (GSD) will usually reflect the availability of X-ray facilities. Such services may need to be expanded, with appropriate emphasis on good practice, in order to meet the medical need. This is likely to increase the genetic dose in these countries.

97. The emphasis on the GSD may have distracted attention from exposure of other organs than the gonads and may therefore have led to an underestimation of the over-all risk from certain types of examination which usually cause very low gonad doses. One example is chest examinations, which involve irradiation of such radiosensitive tissues as lung, breast, marrow and sometimes also thyroid. The 1972 report, accordingly, gave more information on the dose in the active marrow. A number of groups of patients were also reported who had been identified as receiving high doses, and some had been shown to have an incidence of certain diseases higher than in comparable but non-irradiated groups. In the present report further attention has been given to identifying examinations in which particular organs may receive high doses. An attempt has also been made to give a fuller picture of the dose distribution in the patients, including data on doses in radiosensitive tissues, such as bone marrow, thyroid, lung and breast.

98. In presenting data on dose levels in medical procedures, the Committee has three different purposes in mind. Firstly, it is of interest to know individual organ doses in various types of medical irradiation, and particularly the extent of variation of such doses, as a basis for any attempt to weigh the radiation risks against the expectation of benefit to the individual patient and for differential cost-benefit analyses of protective measures. Secondly, it may be of interest to know both the individual and the collective organ doses from various medical practices as part of the presentation of man's total radiation exposure. The third purpose is the identification of some highly exposed groups which may be of interest in epidemiological studies. For that purpose, the collective dose is of interest.

15/ This subject is treated in detail in annex E (Doses from occupational exposures) and annex F (Medical irradiation).

99. The individual doses to the patients must be judged by the medical practitioners on the basis of the patient's best interest and the need for diagnosis or treatment. This means that the patient's dose in various organs and tissues may vary from entirely insignificant doses up to high doses, which cause local tissue damage near treatment areas when the purpose is to destroy a tumour with radiation. The per capita doses from medical irradiations are therefore composed of a large variety of dose levels and dose distributions in the individual cases. However, the largest contributions to the per capita doses come from types of exposures which involve large numbers of individuals, as is the case in some diagnostic x-ray examinations. In these cases, the per capita annual doses to the tissues of interest to the Committee are roughly similar in magnitude and in many technologically developed countries are in the range of 50 to 100 mrad, the genetically significant dose often being about half of the per capita gonad dose. This means that the annual collective dose from medical practices is in the range of $5\ 10^4$ to 10^5 man rad per million of population in countries with developed radiological facilities, while it is estimated to be 10^3 man rad per million of population in countries with limited facilities.

100. In all countries which have reported to the Committee, monitoring of doses to workers involved with medical uses of radiation or radio-active substances is carried out by a number of establishments ranging from individual hospitals to large personnel monitoring services. In general, the results are reported back to the employer but are usually not collated on a systematic basis. It is therefore difficult to ensure that the dose data collected by the Committee are comprehensive and representative. It is estimated that the occupational exposure of workers in the medical field gives an annual collective dose of the order of 10^2 man rad per million of population.

101. The occupational contribution to the collective dose from the medical uses of radiation is therefore insignificant compared to that from the irradiation of patients. The annual global collective dose from medical procedures may be estimated to be of the order of $5\ 10^7$ man rad for the contribution made by those countries with developed radiological facilities and $2\ 10^6$ man rad for the contribution of those countries with limited facilities.

7. Summary of global dose commitments from the various radiation sources

102. Table 3 summarizes the estimated global whole-body dose commitments for the different sources and practices discussed in the report. It is expressed as the duration of exposure of the world population to natural radiation which would cause the same dose commitment. 16/

103. Under the assumption of proportionality between increments in dose and risk, the relative contributions to the total radiation detriment from each of the various sources would be in proportion to the global dose commitments listed in

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16/ The time periods over which doses should be evaluated in the assessments of dose commitments are discussed in annex A, and the detailed qualifications related to each entry in the table are given in the corresponding annexes where the calculations are presented.

table 3. However, the Committee stresses that comparisons based on the values given in table 3 would be misleading if the qualifications discussed in previous paragraphs of the present report were not taken into account. In particular, the dose commitments from future practices are dependent on technological developments and on the evolution of relevant regulations, both of which are difficult to predict.

Table 3

Global dose commitments from various radiation sources

Source of exposure	Global dose commitment (days) a/
One-year exposure to natural sources	365
One year of commercial air travel	0.4
Use of one year's production of phosphate fertilizers at the present production rate	0.04
One-year global production of electric energy by coal-fired power plants at the present global installed capacity (10^6 MW(e))	0.02
One-year exposure to radiation-emitting consumer products	3
One-year production of nuclear power at the present global installed capacity (8 10^4 MW(e))	0.6
One year of nuclear explosions averaged over the period 1951-1976	30
One year's use of radiation in medical diagnosis	70

a/ The global dose commitment is expressed as the duration of exposure of the world population to natural radiation which would cause the same dose commitment. The occupational contribution is included.

104. The highest man-made contribution to the global collective dose is caused by the medical uses of radiation, and in particular by diagnostic X-ray procedures. It is important in many countries that facilities for the medical uses of radiation should be increased, and such increases would be associated with the increases in dose commitment in these countries. It is also important, however, that the exposure of patients involved in the course of radiological procedures shuuld be kept to the minimum required for the medical purposes concerned (paras. 95-101).

105. The production of nuclear power is subject to national regulations usually based on internationally agreed principles. The global dose commitment corresponds to 0.6 days of natural radiation exposure for one year of energy production at the present installed capacity of 80,000 MW(e). Assuming that the present nuclear technology remains the same, one year of energy production at the projected nuclear installed capacity in the year 2000 [2 10^6 MW(e)] would lead to a global dose commitment equivalent to about 15 days of natural radiation exposure.

106. The collective dose commitment from nuclear explosions carried out to 1976 is equivalent to about two years of natural radiation exposures, if the contribution from carbon-14 is not included. If this contribution is included, the collective dose commitment is twice as high. The contributions from atmospheric explosions since 1970, that is, after the period covered by the Committee's previous report, have increased the dose commitments from strontium-90 and caesium-137 in the northern hemisphere by about 2 per cent and in the southern hemisphere by about 6 per cent.

Appendix I

LIST OF SPECIALIST SCIENTISTS, MEMBERS OF NATIONAL DELEGATIONS

1. The specialist scientists who took part in the preparation of the present report while attending Committee sessions as members of national delegations are listed below.

ARGENTINA

Dr. D. Cancio (Representative)

Dr. A. E. Placer (Representative)

Mr. C. A. Menossi

AUSTRALIA

Mr. J. R. Moroney (Representative)

Dr. D. J. Stevens (Representative)

Professor R. J. Walsh

Professor C. N. Watson-Munro

BELGIUM

Professor F. H. Sobels (Representative)

Dr. J. B. T. Aten

BRAZIL

Professor L. R. Caldas (Representative)

Dr. E. Penna-Franca

CANADA

Dr. G. C. Butler (Representative)

Mr. A. H. Booth

Mr. W. R. Bush

Dr. H. C. Rothschild

Dr. B. K. Trimble

CZECHOSLOVAKIA

Dr. M. Klímek (Representative)

EGYPT

Professor M. E. A. El-Kharadly

FRANCE

Dr. H. Jammet (Representative)

Dr. R. Coulon

Dr. B. H. Dutrillaux

Dr. C. Lafuma

Professor P. Pellerin

GERMANY, FEDERAL REPUBLIC OF

Professor F. E. Stieve (Representative)

Professor U. H. Ehling

Professor W. Jacobi

Professor H. Kriegel

Professor L. Rausch

INDIA

Dr. A. R. Gopal-Ayengar (Representative)

Dr. K. Sundaram (Representative)

INDONESIA

Professor A. Baiquni (Representative)

Mr. M. K. Tadjudin (Representative)

JAPAN

Dr. K. Misono (Representative)

Dr. R. Ichikawa

Dr. N. Ito

Dr. S. Nakai

Dr. Y. Tazima

MEXICO

Dr. M. Martinez-Baez (Representative)

Mr. J. R. Ortiz-Magaña (Representative)

Dr. A. L. de Garay

Dr. Rebeca Magidin de Nulman

PERU

Dr. C. Guzman-Acevedo (Representative)

POLAND

Professor Z. Jaworowski (Representative)

SUDAN

Dr. A. Hidayatalla (Representative)

SWEDEN

Professor B. Lindell (Representative)
Dr. S. Bergström
Dr. K. Edvarson
Professor K. G. Lüning
Mr. J. O. Snihs
Dr. Evelyn Sokolowski
Dr. G. Walinder

UNION OF SOVIET SOCIALIST REPUBLICS

Professor A. M. Kuzin (Representative)
Dr. R. Alexakhin
Dr. Angelina Gouskowa
Dr. L. Ilyin
Dr. A. Moiseev
Dr. M. M. Saurov

UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

Sir Edward Pochin (Representative)
Professor D. Carter
Mr. H. J. Dunster
Mr. F. Morley
Dr. A. G. Searle

UNITED STATES OF AMERICA

Dr. R. H. Chamberlain (Representative)

Dr. R. D. Moseley (Representative)

Dr. R. Baker

Dr. A. M. Brues

Dr. H. D. Bruner

Dr. J. H. Harley

Dr. F. Lowman

Professor H. Rossi

Dr. W. L. Russell

Dr. W. K. Sinclair

Professor A. C. Upton

Dr. H. O. Wyckoff

Appendix II

LIST OF SCIENTIFIC STAFF AND CONSULTANTS WHO HAVE CO-OPERATED WITH THE COMMITTEE IN THE PREPARATION OF THE REPORT

Dr. D. Beninson

Mr. B. G. Bennett

Dr. A. Bouville

Miss Pamela M. Bryant

Professor R. E. Ellis

Professor B. Lindell

Professor J. Liniecki

Dr. W. M. Lowder

Dr. V. Lyscov

Dr. B. J. O'Brien

Sir Edward Pochin

Dr. K. Sankaranarayanan

Professor Dr. W. Schüttmann

Dr. G. Silini

Mr. J. O. Snihs

Mr. G. A. M. Webb

Appendix III

LIST OF REPORTS RECEIVED BY THE COMMITTEE

1. Listed below are reports received by the Committee from Governments and agencies of the United Nations between 25 March 1972 and 12 April 1977.

2. Reports received by the Committee before 24 March 1972 were listed in annexes to earlier reports of the Committee to the General Assembly.

Document No.	Country and title
A/AC.82/G/L.	
	UNITED STATES OF AMERICA
1411	Global inventory and distribution of Pu-238 from SNAP-9A, 1 March 1972, HASL-250.
	ARGENTINA
1412	Radium-226 in man.
1413	Compilation of results of monitoring Sr-90 and Cs-137 due to fall-out in the Argentine Republic.
1114	Study of a case of accidental human irradiation.
	UNITED STATES OF AMERICA
1415	Fall-out program quarterly summary report, 1 April 1972, HASL-249.
1415/Add.1	Appendix to HASL-249.
	NEW ZEALAND
1416	Annual report for the year 1969.
1417	Annual report for the year 1970.
1418	Environmental radio-activity in New Zealand: quarterly report July-September 1971 and Pacific Area Monitoring 31 August-31 October 1971.
	SWEDEN
1419	Radiostrontium-induced carcinomas of the external ear.
1420	Effect of different doses of ^{90}Sr on the ovaries of the foetal mouse.
1421	Pathologic effects of different doses of radiostrontium in mice development and incidence of leukaemia.
1422	Protective effect of cysteamine at fractionated irradiation. III. Histopathologic diagnoses at death.

Document No.	Country and title
	AUSTRALIA
1423	Fall-out over Australia from nuclear weapons tested by France in Polynesia from June to August 1971.
	UNITED STATES OF AMERICA
1424	Fall-out program quarterly summary report, 1 July 1972 HASL-257.
1424/Add.1	Appendix to HASL-257.
	SWITZERLAND
1425	Fifteenth report to the Federal Council by the Federal Commission on Radioactivity, for 1971.
	UNITED STATES OF AMERICA
1426	HASL-300 "HASL Procedures Manual".
1426/Add.1	Supplement to HASL-300 "HASL Procedures Manual".
1426/Add.2	Supplement to HASL-300 "HASL Procedures Manual".
	NEW ZEALAND
1427	Environmental radio-activity in New Zealand quarterly report, April-June 1971, and Pacific Area Monitoring 4 June-31 August 1971. (NRL-F/45).
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1428	Agricultural Research Council - Letcombe Laboratory. Annual report 1971.
	UNITED STATES OF AMERICA
1429	Studies of the mortality of A-bomb survivors.
	SWITZERLAND
1430	Twelfth report to the Federal Council by the Federal Commission on Radioactivity, for 1968.
	UNITED STATES OF AMERICA
1431	Fall-out program quarterly summary report, 1 October 1972, HASL-259.
1431/Add.1	Appendix to HASL-259.
1432	Index to fall-out program quarterly summary reports, 1 October 1972, HASL-266.

Document No.	Country and title
	NEW ZEALAND
1433	Fall-out from nuclear weapons tests conducted by France in the South Pacific from June to August 1971. (NRL-F/47).
1434	Annual report for the year 1971. (NRL-AR/22).
	JAPAN
1435	Radio-activity survey data in Japan. No. 34. February 1972.
	NEW ZEALAND
1436	Environmental radio-activity. Annual report 1971. (NRL-F/48).
	UNITED STATES OF AMERICA
1437	Fall-out program quarterly summary report, 1 January 1973, HASL-268.
1437/Add.1	Appendix to HASL-268.
	ITALY
1438	Data on environmental radio-activity collected in Italy (January-December 1969).
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1439	Radio-active fall-out in air and rain. Results to the middle of 1972.
	UNITED STATES OF AMERICA
1440	Fall-out program quarterly summary report, 1 April 1973, HASL-273.
1440/Add.1	Appendix to HASL-273.
	JAPAN
1441	Radio-activity survey data in Japan. No. 36. August 1972.
	AUSTRALIA
1442	Strontium-90 and caesium-137 in the Australian environment during 1970 and some results for 1971.
1443	Fall-out over Australia from nuclear weapons tested by France in Polynesia during June and July 1972.
	FRANCE
1444	Radio-activity monitoring in 1972.

Document No.	Country and title
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1445	Radio-activity in human diet in the United Kingdom, 1972.
1446	Assay of strontium-90 in human bone in the United Kingdom. Results for 1970.
	UNITED STATES OF AMERICA
1447	Fall-out program quarterly summary report, 1 July 1973, HASL-274.
1447/Add.1	Appendix to HASL-274.
	JAPAN
1448	Radio-activity survey data in Japan. No. 37. November 1972.
	UNITED STATES OF AMERICA
1449	Fall-out program quarterly summary report, 1 October 1973, HASL-276.
1449/Add.1	Appendix to HASL-276.
	SWITZERLAND
1450	Sixteenth report to the Federal Council by the Federal Commission on Radioactivity, for 1972.
	AUSTRALIA
1451	Data on levels of radio-activity in Australia, 1971-1973.
	UNITED STATES OF AMERICA
1452	Fall-out program quarterly summary report, 1 January 1974, HASL-278.
1452/Add.1	Appendix to HASL-278.
	UNION OF SOVIET SOCIALIST REPUBLICS
1453	On the possibility of using hair analysis to determine the level of polonium-210 in human bone tissue and liver.
1454	On the behaviour of caesium-137 in the turf-podzol soils of the Ukrainian polessie.
1455	Weight indicators for the development of the human foetus skeleton and its strontium and calcium content.
1456	Interaction of radio-active isotopes with organic soil materials.
1457	Strontium-90 and caesium-137 migration in the soil-vegetation cover of terminal-moraine areas.

Document No.	Country and title
	UNION OF SOVIET SOCIALIST REPUBLICS (continued)
1458	Rate of fall-out of caesium-137 and strontium-90 aerosols from the atmosphere.
1459	Migration of global caesium-137 and strontium-90 in the food chains of the population of various regions of the Ukrainian polessie.
1460	Radio-activity in the external environment, food-stuffs and the human organism in the Ukraine, 1962-1969.
1461	Lead-210, polonium-210, radium-226, thorium-228 and plutonium-239 in the lichen-reindeer-human chain in the far northern USSR.
1462	Relative mobility, state and forms of occurrence of strontium-90, stable strontium and calcium in soils.
1463	Artificial and natural radioisotopes with long half-lives in the seeds of crops in the Moscow region.
1464	State and forms of occurrence of radioisotopes in global fall-out.
1465	Strontium-90 content in adult bone tissue and the teeth of humans of different ages.
1466	The relation between strontium-90 and various organic soil material fractions.
1467	Lead-210 and polonium-210 absorption into the gastro-intestinal tract in rats and humans.
1468	Natural radio-active isotopes in marine fishes and sea water.
1469	Strontium-90 and caesium-137 migration in soils.
1470	Ecological and geochemical aspects of strontium-90 behaviour in forest and flood-plain ecosystems of polessies.
1471	Strontium-90 migration in water.
1472	Evaluation of the population dose of internal irradiation from global caesium-137 for some peoples inhabiting the far north of the Soviet Union.
1473	The concentration of strontium-90 in food-stuffs and its occurrence in the food consumed by the population of the Georgian SSR as a result of stratospheric fall-out.
1474	Distribution of radio-active isotopes in a reservoir system.
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1475	Radio-active fall-out in air and rain. Results to the middle of 1973.

Document No.	Country and title
	NEW ZEALAND
1476	Environmental radio-activity. Fall-out from nuclear weapons tests conducted by France in the South Pacific during July and August 1973 and comparisons with previous test series.
	UNITED STATES OF AMERICA
1477	Serum immunoglobulin levels in atomic bomb survivors in Hiroshima, Japan.
1478	Spleen index in atomic bomb survivors.
1479	The health of atomic bomb survivors: a decade of examinations in a fixed population.
1480	Fall-out program quarterly summary report, 1 April 1974, HASL-281.
1480/Add.1	Appendix to HASL-281.
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1481	Radio-activity in human diet in the United Kingdom, 1973.
	INTERNATIONAL ATOMIC ENERGY AGENCY
1482	Extracts from the Agency's programme for 1975-1980 and Budget for 1975. (GC(XVIII)/526).
1483	Annual report 1 July 1973-30 June 1974. (GC(XVIII)/525).
	NEW ZEALAND
1484	Monitoring of radio-active fall-out from the 1974 French South Pacific nuclear tests.
	FRANCE
1485	Radio-activity monitoring in 1973.
	NEW ZEALAND
1486	Fall-out from nuclear weapons tests conducted by France in the South Pacific during June and July 1972 and comparisons with previous test series.
1487	Environmental radio-activity. Annual report 1972.
1488	Environmental radio-activity. Annual report 1973.
	ARGENTINA
1489	Radio-active fall-out due to explosions in the South Pacific in the period January-October 1973.
1490	Radio-active fall-out due to explosions in the South Pacific in the period 1971-1972.

Document No.	Country and title
1491	Monitoring SR-90 and Cs-137 due to fall-out in the Argentine Republic.
1492	Comparative study of the metabolism of lead-120 and polonium-120 in rats.
1493	Absorption of radiostrontium by marine organisms.
	CZECHOSLOVAKIA
1494	Values of ^{90}Sr in vertebrae and femoral diaphysis of adults in Czechoslovakia in 1971.
1495	The values of the ratio ^{90}Sr in vertebrae/^{90}Sr in diaphysis in different age groups (Czechoslovakia 1969, 1970, 1971).
	NEW ZEALAND
1496	Fall-out from French nuclear tests in the South Pacific, 1974.
	AUSTRALIA
1497	Data from the Australian fall-out monitoring programmes.
	UNION OF SOVIET SOCIALIST REPUBLICS
1498	Coefficients of the distribution of radioisotopes between the solid and liquid phases in bodies of water.
1499	Optimal interpretation of ocean radio-activity measurements.
1500	Dose commitment in mouse-like rodents living in areas of high natural radio-activity.
1501	Effect of an unseparated mixture of nuclear-fission products upon immune reactions.
1502	Strontium-90 and caesium-137 content of the food consumed by the population of the Soviet Union in 1967-1969.
1503	Determination of genetically significant doses resulting from the medical use of x-rays at Irkutsk.
1504	Immunological reactions in experimental animals under the combined effects of external irradiation and absorbed radioisotopes.
	UNITED STATES OF AMERICA
1505	Fall-out program quarterly summary report, 1 July 1974, HASL-284.
1505/Add.1	Appendix to HASL-284.
1506	Fall-out program quarterly summary report, 1 October 1974, HASL-286.
1506/Add.1	Appendix to HASL-286.

Document No.	Country and title
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1507	Radio-active fall-out in air and rain: results to the middle of 1974.
	JAPAN
1508	Radio-activity survey data in Japan. No. 38. November 1973.
1509	Radio-activity survey data in Japan. No. 39. September 1974.
	FRANCE
1510	Statistical study on 17,000 workers exposed to ionizing radiation during 1973.
	BELGIUM
1511	Radio-activity measured at Mol, 1970.
1512	Radio-activity measured at Mol, 1971.
	NEW ZEALAND
1513	Environmental radio-activity: fall-out from nuclear weapon tests conducted by France in the South Pacific from June to September 1974 and comparisons with previous test series.
	UNITED STATES OF AMERICA
1514	Autopsy study of blast crisis in patients with chronic granulocytic leukaemia, Hiroshima and Nagasaki, 1949-1969.
1515	Mortality in children of atomic bomb survivors and controls.
1516	Fall-out program quarterly summary report, 1 January 1975, HASL-288.
1516/Add.1	Appendix to HASL-288.
1517	Environmental quarterly, 1 April 1975, HASL-291.
1517/Add.1	Appendix to HASL-291.
1518	Index to fall-out program quarterly summary reports, 1 April 1975, HASL-292.
1519	Epidemiologic studies of coronary heart disease and stroke in Japanese men living in Japan, Hawaii and California: demographic, physical, dietary and biochemical characteristics.
1520	Environmental quarterly, 1 July 1975, HASL-294.
1520/Add.1	Appendix to HASL-294.
	FRANCE
1521	Radio-activity monitoring in 1974.

Document No.	Country and title
	GERMANY, FEDERAL REPUBLIC OF
1522	Environmental radio-activity and radiation levels, annual report 1973.
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1523	Radio-activity in human diet in the United Kingdom, 1974.
	UNITED STATES OF AMERICA
1524	Environmental quarterly, 1 October 1975, HASL-297.
1524/Add.1	Appendix to HASL-297.
1525	Environmental quarterly, 1 January 1976, HASL-298.
1525/Add.1	Appendix to HASL-298.
	NEW ZEALAND
1526	Environmental radio-activity: annual report 1974.
	UNITED STATES OF AMERICA
1527	A review of 30 years of study of Hiroshima and Nagasaki atomic bomb survivors.
1528	Environmental quarterly, 1 April 1976, HASL-302.
	JAPAN
1529	cancelled
1530	cancelled
1531	Estimation of population doses from diagnostic medical examinations in Japan, 1974 (1 to 4).
1532	Estimation of population doses from brachytherapy in Japan.
	SWITZERLAND
1533	Eighteenth report to the Federal Council by the Federal Commission on Radioactivity, for 1974.
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1534	Radio-active fall-out in air and rain: results to the end of 1975.
	UNION OF SOVIET SOCIALIST REPUBLICS
1535	A methodical approach to the evaluation of dose commitments from osteotropic isotopes, taking into consideration changes in metabolism parameters with organism growth.
1536	Investigation and standardization of radio-activity in building materials.

Document No.	Country and title
	UNION OF SOVIET SOCIALIST REPUBLICS (continued)
1537	Materials for the standardization and norms of maximum permissible levels of radio-active isotopes of iodine in the human organism.
	UNITED STATES OF AMERICA
1538	Environmental quarterly, 1 July 1976, HASL-306.
1538/Add.1	Appendix to HASL-306.
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1539	Radio-activity in human diet in the United Kingdom, 1975.
	FRANCE
1540	Radio-activity monitoring in 1975.
	JAPAN
1541	Radio-activity survey data in Japan. No. 40. November 1975.
	UNITED STATES OF AMERICA
1542	Environmental quarterly, 1 October 1976, HASL-308.
1542/Add.1	Appendix to HASL-308.
	GERMANY, FEDERAL REPUBLIC OF
1543	Environmental radio-activity and radiation levels in 1974.
1544	Environmental radio-activity and radiation levels, annual report 1974.
	NEW ZEALAND
1545	Environmental radio-activity: annual report 1975. (NRL-F/55).
	SWITZERLAND
1546	Nineteenth report to the Federal Council by the Federal Commission on Radioactivity, for 1975.
	CZECHOSLOVAKIA
1547	The values of the ratio ^{90}Sr in vertebrae/^{90}Sr in diaphysis in different age groups.
	UNITED STATES OF AMERICA
1548	Environmental quarterly, 1 January 1977, HASL-315.
1548/Add.1	Appendix to HASL-315.

Document No.	Country and title
	UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
1549	The data submitted by the United Kingdom to UNSCEAR for the 1977 report to the General Assembly.
	UNION OF SOVIET SOCIALIST REPUBLICS
1550	The kinetics of disease and recovery processes occurring in fresh-water fish embryos incubated in a radio-active environment.
1551	Some properties of strontium-90 migration in food chains in the conditions of the far north.
1552	Radio-activity of the external environment and food-stuffs in the Ukrainian SSR in 1970-1974.
1553	Effect of pesticide (DDT) poisoning on sodium and metabolism kinetics in rats.
1554	Tritium content of liquid media and air in working areas of USSR atomic power stations.
1555	Caesium-137 and strontium-90 in the lichen-reindeer-human chain in the far northern USSR.
1556	Strontium-90 from global fall-out in the bone tissue of the Soviet population, 1970-1973.
1557	The amount of strontium-90 and caesium-137 of global origin in the food consumed by the Soviet population, 1970-1973.
1558	Natural radio-active nuclides in topsoils and phosphorus-containing fertilizers.
1559	Effect of parathyroid hormone upon the development of radiation osteosarcomas.
1560	Metabolism of some carbon-14 compounds in animal organisms and an approach to the problem of standardization.

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