NUCLEAR TESTS CASES

AFFAIRES DES ESSAIS NUCLÉAIRES

(Australia v. France)

REQUEST FOR THE INDICATION OF INTERIM MEASURES OF PROTECTION SUBMITTED BY THE GOVERNMENT OF AUSTRALIA

9 May 1973.

Case to Which this Request Relates

I have the honour to refer to the Application dated today, 9 May 1973, by which Australia has instituted proceedings against the French Republic.

2. In conformity with Article 33 of the General Act for the Pacific Settlement of International Disputes, 1928, Article 41 of the Statute of the Court and Article 66 of the Rules of Court, I now have the honour to submit a request[1] for the laying down or indication by the Court of provisional measures of protection for the preservation of the rights of Australia pending the final decision of these proceedings.

Rights to Be Protected

3. The following are the rights of Australia which are entitled to protection: Australia's rights under international law and the Charter of the United Nations to be safeguarded from further atmospheric nuclear weapon tests and their consequences, including:

(i) The right of Australia and its people to be free from atmospheric nuclear weapon tests by any country;
(ii) the inviolability of Australia's territorial sovereignty;
(iii) its independent right to determine what acts shall take place within its territory, and, in particular, whether Australia and its people shall be exposed to radiation from artificial sources;
(iv) the right of Australia and her people fully to enjoy the freedom of the high seas;
(v) the right of Australia to the performance by the French Republic of its undertaking contained in Article 33 (3) of the General Act for the Pacific Settlement of International Disputes to abstain from all measures likely to react prejudicially upon the execution of any ultimate judicial decision given in these proceedings and to abstain from any sort of action whatsoever which may aggravate or extend the present dispute between Australia and the French Republic.

Grounds of Request

4. The following are amongst the principal considerations which justify the present request:

(i) As may be gathered from the Application herein, the French Government has declined to give a permanent undertaking that no further atmospheric nuclear tests will take place in the Pacific Ocean; and has not denied an intention to carry out further tests this year. There is a virtual certainty that further atmospheric testing by the French Republic in the Pacific Ocean will lead to the additional deposit of radio-active material upon Australian territory. The French Government has refused to supply any information as to the proposed size and yields of nuclear devices which it intends to explode in the course of further tests. It may well be that the next devices to be exploded will be more powerful than in the past and

[1] II, p. 337.

that the quantity of radio-active material to be deposited on Australian territory as a result will exceed that already and yet to be deposited as a result of any previous explosion.

(ii) Any radio-active material deposited on Australian territory will be potentially dangerous to Australia and its people. Any injury caused by such deposit would clearly be irreparable. It goes without saying that the deposit could not be removed by any action of the French Government, by any judgment or order of the Court, or by any payment of damages.

(iii) The deposit of additional radio-active material on Australian territory as a result of further French tests pending a decision of the Court would, if the Court were to uphold the contentions of Australia, be in breach of its sovereign rights over its territory. Such acts would frustrate and impair the exercise in essential respects of Australia's right to decide whether Australia and its people are to be exposed to any man-made ionizing radiation.

(iv) Any such deposit would anticipate the judgment of the Court and if such judgment were given in favour of Australia, would deprive Australia of the full benefit thereof.

(v) If the final judgment of the Court in these proceedings was not pronounced for several years, the French Republic's programme for testing could by then be finished and Australia would thereby be deprived completely of the benefit of any Order of the Court which adjudged that the French Republic not conduct atmospheric nuclear tests at its Pacific Test Centre.

(vi) Once measures which may affect the resources of the sea or the conditions of the environment have been carried out, they cannot be undone. Whatever dispute there may be about the nature and extent of the changes effected by the French actions, natural conditions can never be restored, and no eventual payment of damages will suffice to rectify matters.

(vii) The same is true of the interference with the rights of Australia and of her people to freedom of movement over the high seas and in the superjacent airspace. Although a restriction upon such freedom of movement once imposed can be revoked, the infringement of rights caused thereby cannot be undone.

(viii) Further, the conduct of the tests and the accompanying disturbance of the elements and deposit of radio-active material is, in the words of Article 33 (3) of the General Act, a measure "likely to react prejudicially upon the execution of the judical... decision" and is action "which may aggravate or extend the dispute".

(ix) By undertaking in February 1973 to refrain from further testing pending the outcome of negotiations, the French Republic has recognized that continued testing is incompatible with the process of peaceful settlement of the dispute between Australia and the French Republic. If tests were suspended during negotiations, *a fortiori* they should be suspended during proceedings before the Court.

Consequences of Further French Atmospheric Testing of Nuclear Weapons in the Pacific

5. It is of considerable significance that in this Request Australia is seeking to assert the inviolability of its sovereign territory against the irreversible consequences of conduct which has not only been the subject of concern to Australia and its people and of scientists throughout the world, but also of universal apprehension, opposition and condemnation.

6. The French Republic has in each of the years from 1966 to 1972 (with the exception of 1969) carried out atmospheric tests of nuclear devices on, over or near Mururoa Atoll in the Pacific (Annex 1). In connection with these tests the French Government has created Prohibited Zones for aircraft and Dangerous Zones for aircraft and shipping. The steps taken by the French Government to create these Zones are set out in paragraph 45 of Australia's Application in this case. Each of these tests led to the deposit and dispersal of radio-active material on and over Australian territory. In addition, radio-active material resulting from these tests still remains in the atmosphere, and will in the future be deposited and dispersed on or over Australian territory.

7. A short description of the nature and effects of nuclear explosions in the atmosphere is contained in paragraphs 22 to 39 of Australia's Application in these proceedings. It is clear that if the French Republic conducts further atmospheric nuclear tests in the Pacific pending the ultimate decision of the Court, the consequences will be:

(i) that further radio-active material resulting from such tests will be injected into the troposphere and, depending upon the power of the device, into the stratosphere;

(ii) that as a direct result of this injection, some of the radio-active material injected will be deposited both in the short term and the long term on Australian territory;

(iii) that the material so deposited will be inherently harmful and potentially dangerous to the Australian people and could have deleterious somatic and genetic effects on them;

(iv) that notwithstanding that Australia objects to and sees no benefit to Australia in the conduct of tests by the French Republic in the atmosphere, Australia would be unable to prevent its territory and its people from being subjected to the ionizing radiation consequent upon the deposit of this additional radio-active material.

8. The specific consequences for Australia of the deposit of radio-active material from further tests are but one aspect of atmospheric nuclear testing which virtually the whole international community has come to fear and condemn. Such fear and condemnation cannot be regarded as unfounded. They testify to the harm to peoples, their environment and biosphere inherent in such tests. An essential element upon which they rest is the terrible and irreversible contribution which such tests make to the pollution of man's environment in all States, of which Australia is one.

9. It is appropriate at this point to recall the evolution of this general apprehension and to indicate the bases upon which it rests.

10. In 1955 the General Assembly of the United Nations decided to include on the agenda of its tenth session, an item entitled "Effects of atomic radiation"; and on 3 December 1955 it adopted resolution 913 (X) under which the United Nations Scientific Committee on the Effects of Atomic Radiation (hereinafter called "UNSCEAR") was established to collect and study radiological information. This resolution (which includes the terms of reference of UNSCEAR) is set out in Annex 2 herein.

11. UNSCEAR held its first session in March 1956 and its most recent session in March 1972. In all, it has held 22 sessions and presented six substantive reports to the General Assembly, in 1958, 1962, 1964, 1966, 1969 and 1972. UNSCEAR's reports are objective statements of scientific facts, based on data received from States Members of the United Nations, and members of the specialized agencies of the United Nations and of the International Atomic

Energy Agency. The above data have been supplemented by, and interpreted by UNSCEAR, in light of information available in the scientific literature or obtained from unpublished communications of individual scientists. In its discussions the Committee has had the benefit of the presence of representatives of the International Labour Organisation, the Food and Agriculture Organization of the United Nations, the World Health Organization, the World Meteorological Organization and the International Atomic Energy Agency as well as of the International Commission on Radiological Protection and the International Commission on Radiation Units and Measurements. Australia and the French Republic are, and since its inception have been, members of UNSCEAR.

12. Each of the reports of UNSCEAR has dealt at length with environmental contamination arising from the testing of nuclear devices in the atmosphere and has discussed various effects of ionizing radiation on man, revising its earlier statements on these effects, and including possible new effects, when new scientific data justified such a procedure. The various reports have consisted of a main text supported by detailed technical annexes. Annexes 3, 4, 5, 6, 7 and 8 to this Request reproduce some of the relevant portions of the reports of the Committee.

13. At least two themes run through the UNSCEAR reports—one identifies the testing of nuclear devices as an important source of environmental contamination; a second emphasizes the uncertainties regarding the long-term somatic and genetic effects of low doses of ionizing radiation.

14. The first report of UNSCEAR was presented to the thirteenth session of the General Assembly in 1958. The report identified nuclear explosions as one of the sources of environmental contamination. On 13 December 1958 the General Assembly by resolution 1347 (XIII) noted UNSCEAR's first report and requested it to continue its useful work.

15. The second report of UNSCEAR was submitted to the General Assembly in 1962. This report contained a detailed statement of the mechanics of radioactive contamination. This section of the report is contained in Annex 4. In its "Conclusions", UNSCEAR said:

> "48. It is clearly established that exposure to radiation, even in doses substantially lower than those producing acute effects, may occasionally give rise to a wide variety of harmful effects including cancer, leukaemia and inherited abnormalities which in some cases may not be easily distinguishable from naturally occurring conditions or identifiable as due to radiation. Because of the available evidence that genetic damage occurs at the lowest levels as yet experimentally tested, it is prudent to assume that some genetic damage may follow any dose of radiation, however small."

16. The second report of UNSCEAR later continued:

> "52. The Committee therefore emphasizes the need that all forms of unnecessary radiation exposure should be minimized or avoided entirely, particularly when the exposure of large populations is entailed; and that every procedure involving the peaceful uses of ionizing radiation should be subject to appropriate immediate and continuing scrutiny in order to ensure that the resulting exposure is kept to the minimum practicable level and that this level is consistent with the necessity or the value of the procedure. As there are no effective measures to prevent the occurrence of harmful effects of global radioactive contamination from nuclear explosions, the achievement of a final cessation of nuclear tests would benefit present and future generations of mankind."

17. On 6 November 1962, the General Assembly, by resolution 1762 A (XVII), condemned all nuclear weapon tests. This resolution is set forth in Annex 9.

18. On 20 November 1962, the General Assembly, by resolution 1764 (XVII) noted UNSCEAR's second report. The first and second reports of UNSCEAR were prepared during the period of intensive atmospheric testing of nuclear weapons carried out in the Northern hemisphere. Hence the greater part of the radio-active contamination noted during this period was located in that hemisphere.

19. However, on 5 August 1963 the Governments of the United Kingdom of Great Britain and Northern Ireland, the Union of Soviet Socialist Republics and the United States of America, desiring, amongst other things, "to put an end to the contamination of man's environment by radio-active substances", concluded the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water. The text of the Treaty appears as Annex 10. On 27 November 1963 the General Assembly adopted resolution 1910 (XVIII) entitled "Urgent need for suspension of nuclear and thermonuclear tests". It noted with approval, and called upon all States to become parties to the Treaty "and to abide by its spirit and provisions". The resolution is set out in Annex 11 hereto.

20. In 1964 UNSCEAR submitted its third report to the General Assembly. Chapter II of this report was entitled "Radioactive Contamination of the Environment by Nuclear Tests". It is included in Annex 5.

21. On 3 December 1965 the General Assembly once again urged "that all nuclear weapon tests be suspended". This resolution 2032 (XX) is set forth in Annex 12. On 18 December 1965 the General Assembly by resolution 2078 (XX) noted UNSCEAR's third report.

22. The first series of French tests in the Pacific took place between 3 July and 5 October 1966 (Australian time).

23. The fourth report of UNSCEAR was submitted in 1966. UNSCEAR affirmed that nuclear tests were the main source of world-wide radio-active contamination of the environment (para. 16 of Chap. II, set forth in Annex 6). In paragraph 31 of Chapter III (also set forth in Annex 6) the Committee reported:

> "31. Although there are insufficient data for making satisfactory estimates of risk, it is clear that, with any increase of radiation levels on earth, the amount of genetic damage will increase with the accumulated dose. While any irradiation of the human population is genetically undesirable because of its implications for future generations, it should be pointed out that the proper use of radiation in medecine and in industry is important for the health of the individual and for the welfare of the community."

On 17 December 1966 the General Assembly by resolution 2213 (XXI) noted UNSCEAR's fourth report.

24. In that year the General Assembly by resolution 2163 (XXI) of 5 December 1966 noted "with great concern that nuclear weapon tests in the atmosphere and underground are continuing". It then called upon "all nuclear-weapon States to suspend nuclear weapon tests in all environments". The resolution is set forth in Annex 13.

25. The second series of French tests in the Pacific took place between 6 June and 3 July 1967 (Australian time).

26. The General Assembly reverted to the matter at its next session in 1967, when on 19 December 1967 it adopted resolution 2343 (XXII) which, in the parts

here relevant, is almost identical with that adopted in 1966 on the urgent need to suspend testing in all environments. The resolution is set out in Annex 14 hereto.

27. The third series of French tests took place between 8 July and 9 September 1968 (Australian time).

28. In 1968 the General Assembly by resolution 2455 (XXIII) of 20 December 1968 described its concern as "increasing" and again called for a suspension of nuclear weapon tests in all environments. The resolution is set forth in Annex 15.

29. In 1969, France did not conduct any tests in the Pacific.

30. The fifth report of UNSCEAR was submitted to the General Assembly in 1969 and was noted on 28 October 1969 by resolution 2496 (XXIV). UNSCEAR reported that debris from atmospheric nuclear tests continued to be the most important man-made contaminant of the environment. Relevant chapters of the report are set out in Annex 7.

31. On 16 December 1969 the General Assembly by resolution 2604B (XXIV) reiterated its concern at the continuance of nuclear weapon tests and once more called for the suspension of such tests in all environments. The resolution is set forth in Annex 16.

32. In 1970 French tests were held in the Pacific between 16 May and 7 August (Australian time). At the twenty-fifth session of the General Assembly the plea for the cessation of nuclear tests was repeated by resolution 2663 B (XXV) adopted on 7 December 1970. The resolution is set forth in Annex 17.

33. In 1971 French tests were held in the Pacific between 6 June and 15 August (Australian time).

34. Yet again, on 16 December 1971 the General Assembly by resolution 2828 (XXIV) renewed its call for a halt to all nuclear weapon tests. This time, however, the tone of the preambular provisions of the resolution altered and demonstrated more strikingly the anxiety of members:

> "*Viewing with the utmost apprehension* the harmful consequences of nuclear weapon tests for the acceleration of the arms race and for the health of present and future generations of mankind,
>
> . . . .
>
> *Noting with special concern* that the continuation of nuclear weapon tests in the atmosphere is a source of growing pollution . . ."

The Assembly then reiterated: "*Solemnly and most emphatically* its condemnation of all nuclear weapon tests." The resolution is set forth in Annex 18.

35. A further series of French tests was conducted in the Pacific between 26 June and 28 July 1972 (Australian time). In contrast to its previous practices, the French Republic did not make any announcements of its intention to conduct these tests.

36. The consideration of nuclear testing by the General Assembly in 1972 took place against the background of the achievements of the United Nations Conference on the Human Environment held at Stockholm from 5 to 16 June 1972 as well as the sixth report of UNSCEAR.

37. The Stockholm Conference adopted a resolution (resolution 3 (I)) which recited the belief of the Conference: "... that all exposure of mankind to radiation should be kept to the minimum possible and should be justified by benefits that would otherwise not be obtained." The Conference then resolved:

> "*(a)* To condemn nuclear weapons tests, especially those carried out in the atmosphere;
>
> *(b)* To call upon those States intending to carry out nuclear weapons tests to abandon their plans to carry out such tests since they may lead to further contamination of the environment."

Resolution 3 (I) is set forth in Annex 19.

38. In addition, the Conference adopted a Declaration of Principles of which Principles 6, 7 and 21 provide as follows:

> "*Principle 6.* The discharge of toxic substances or of other substances and the release of heat, in such quantities or concentrations as to exceed the capacity of the environment to render them harmless, must be halted in order to ensure that serious or irreversible damage is not inflicted upon ecosystems. The just struggle of the peoples of all countries against pollution should be supported.
>
> *Principle 7.* States shall take all possible steps to prevent pollution of the seas by substances that are liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea."
>
> "*Principle 21.* States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction."

The full text of the Declaration appears in Annex 20 hereto.

39. The sixth Report of UNSCEAR was also submitted to the General Assembly in 1972. UNSCEAR reported that, more than any other subject, radio-active contamination of the environment by nuclear test explosions had been a matter of continued interest for UNSCEAR (para. 147, Part Two, of Annex A of the Report). Relevant parts of the Report are set out in Annex 8.

40. On 17 October 1972 the General Assembly by resolution 2905 (XXVII) noted UNSCEAR's sixth Report. The concern of the General Assembly in 1972 over nuclear testing was more detailed and more specific than ever before. A series of resolutions, 2934 A-C (XXVII), which are set forth in Annex 21, were adopted under the agenda item "Urgent need for suspension of nuclear and thermonuclear tests". Resolution 2934 A(I) is especially relevant.

The Assembly expressed its—

> "*serious concern* that testing of nuclear weapons in the atmosphere has continued in some parts of the world, including the Pacific area, in disregard of that [the Test Ban] Treaty and of world opinion"

and noted "the statements made by the Governments of various countries in and around the Pacific area, expressing strong opposition to those tests and urging that they be halted". The Assembly then stressed anew the urgency of bringing to a halt all atmospheric testing of nuclear weapons in the Pacific or anywhere else in the world. This resolution was adopted by 105 votes in favour, 4 against, with 9 abstentions.

41. This summary of the reports of UNSCEAR of the actions of the General Assembly and of the 1972 Stockholm Conference serves three purposes:

First, the Reports of UNSCEAR can be accepted as objective statements of the scientific facts in the light of scientific knowledge at the time of each Report.

Second, the resolutions of the General Assembly and of the Stockholm Conference evidence the fact of universal concern regarding, and condemnation of, the conduct and consequences of nuclear tests—especially atmospheric tests.

Third, the trend reflected in these resolutions is not one of diminishing anxiety but of growing fear and apprehension.

42. The main purpose of referring to the resolutions of the General Assembly is to demonstrate *facts*. The General Assembly had before it the most up to date information available in the form of the reports of UNSCEAR; the General Assembly considered those reports, and in the opinion of the General Assembly that scientific information warranted a demand for the cessation of atmospheric tests.

43. Never does it appear to have been suggested that the testing of nuclear devices in the atmosphere was other than an abnormal occurrence and a cause of unique and special concern to the international community. The item relating to the urgent need for the suspension of nuclear tests is of such transcending international importance that it has appeared without interruption on the agenda of every General Assembly since 1962. Atmospheric nuclear testing is comparable to no other State activity. It is not an "ordinary" activity of the State the consequences of which, if they give rise to damage, can be disposed of by a payment of pecuniary damages. No State has ever seen nuclear testing in that light; and the international community has rejected that interpretation by calling for the cessation of atmospheric tests.

44. In the light of these overwhelming considerations the Government of Australia considers that it would be quite inappropriate to recommence at this juncture scientific debate on the precise degree of harm to human life which the conduct of any particular test is likely to cause. It is sufficient to point to the factors of uncertainty which affect every aspect of the discussion of the consequences of atmospheric testing. It is impossible to predict with certainty the nature or extent of the fall-out from any particular test. The yield of the device may be considerably in excess of that expected. It may not explode at the predetermined height if dropped from an aircraft or delivered by rocket. The direction of the wind and the local and more remote meteorological patterns may change unexpectedly. Unforeseen rain may occur. Factors such as these may produce a radical departure from the predicted fall-out pattern. Such an event occurred during the tests conducted by the French Government during 1966 when, after the test of 12 September, radio-active debris was unexpectedly transported in the reverse direction, i.e., from east to west instead of the forecast west to east direction. (Such a phenomenon is usually described as "blow back".) It was also reported in *Le Monde* of 17 August 1971 that on the night of 12 and 13 June 1971 (local time) there was over the Tureia atoll an unforeseen conjunction of a contaminated air layer and rain, a phenomenon described as "rain out". All these elements can lead to a significant variation in the amount of fall-out from the test.

45. Two further complicating factors may be mentioned: first, the lapse of time which occurs between a nuclear test and both its somatic and genetic consequences; and, second, the difficulty of diagnosing with precision or confidence the origin of illnesses which may also be attributable partly or wholly to causes other than the deposit of radio-active material. It is, however, these very uncertainties regarding the consequences of nuclear tests and the irreparable nature of any harm which might be caused thereby, which justify, at the very least, the interim prohibition of further tests.

46. World-wide scientific study of the nature and effect of low levels of ionizing radiation has not been confined to UNSCEAR. In November 1972 the National Academy of Sciences of the United States published the Report of an Advisory Committee on the Biological Effects of Ionizing Radiation (known as the "BEIR Report") which reaffirmed the principles that any radiation should be regarded as harmful and that no exposure to ionizing radiation should be permitted without the expectation of a compensating benefit.

47. In 1928 there was established a non-governmental international body of scientists known as the International Commission on Radiological Protection (ICRP)[1]. Since then, ICRP has issued recommendations for radiological protection which have been recognized and adopted by most if not all States as a basis for such protection.

48. ICRP Publication 9 containing the most recent recommendations of ICRP stated that its policy in preparing its recommendations was—

> "to consider the fundamental principles upon which appropriate radiation (ionizing radiation) protection measures can be based, while leaving to the various national protection bodies the responsibility of formulating the specific advice, codes of practice or regulations that are best suited to the needs of their individual countries".

49. The approach of ICRP to radiation protection is illustrated in the following paragraphs extracted from the same publication:

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

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

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

[1] The current rules governing the selection of the ICRP state: "The selection of the members shall be made by the ICRP from nominations submitted to it by the National Delegations to the International Congress of Radiology by the ICRP itself. The selections shall be subject to approval by the International Executive Committee (IEC) of the Congress. Members of the ICRP shall be chosen on the basis of their recognised activity in the fields of medical radiology, radiation protection, physics, health physics, biology, genetics, biochemistry and biophysics with regard to an appropriate balance of expertise rather than to nationality."

50. The recommendations made by ICRP are in respect of controllable sources of radiation. ICRP takes the view that dose limits prescribed for radiation exposure from controllable sources should not be applied for general use in the assessment of risk of radiation exposures resulting from uncontrolled sources:

> "(96) It has been stated already that the Commission's dose limits are agreed values, established so as to make it possible to plan and design operations involving foreseen but acceptable radiation exposures. These limits are intended to apply only to those conditions where the source of exposure is under control."

In paragraph 97 of the above-mentioned publication ICRP identified nuclear weapon explosions as a source of radiation which is uncontrollable.

51. The Government of Australia has accepted the recommendations of ICRP and has taken action to implement them through a variety of measures, notably by legislation and codes of practice. In the measures currently adopted by it (which are continually under review) with respect to minimizing radiation doses to individuals and members of the public from controllable sources of ionizing radiation used within its territory, Australia strongly subscribes to the recommendations of ICRP set out in paragraph 49 above and particularly to these three basic principles:

(i) Any exposure to radiation should be assumed to entail a risk of deleterious effects.
(ii) The radiation dose should be limited to a level at which the assumed risk to individuals and society is deemed acceptable in view of compensating benefits.
(iii) Dose limits prescribed for radiation exposures from controllable sources should not be applied for general use in the assessment of the risk of radiation exposures resulting from uncontrolled sources.

52. Australia is opposed to atmospheric nuclear testing by the French Republic in the Pacific. Australia sees no benefit and only harm following from the exposure of its territory and its people to radiation from radio-active material deposited on or dispersed over its territory from such tests.

53. Having regard to the fact that it is the right of the Government of Australia to ensure the protection not only of the population of Australia in general but of every individual included therein, it is no answer to the Australian case for a suspension of the tests to say that the risk to Australia is very small and that only a few Australians may be injured thereby. The right of the Government of Australia in this matter is absolute. Every individual has a right to life and the French Government is not entitled to imperil the health, safety and well-being of even a single individual.

54. During the period in which the French Republic has conducted atmospheric nuclear tests at its Pacific Tests Centre, Australia has maintained a comprehensive programme for monitoring radio-active fall-out, and in particular fall-out resulting from the French tests. The fall-out monitoring programme has included measurements of:

(i) the radio-activity of all fresh fission products in fall-out at 25 centres to determine the whole body radiation doses delivered externally to persons living in Australia by this material when deposited on the ground;
(ii) concentrations of iodine-131 in the nine major Australian milk supplies to establish average internal radiation dose from iodine-131 to thyroid for those consuming fresh milk in Australia;
(iii) strontium-90 in fall-out deposit and in total diet and bone tissue of the population to enable computation of the internal radiation dose to bone to which the Australian population is committed by reason of such fall-out;
(iv) caesium-137 in fall-out deposit, in milk supplies and in the bodies of the Australian population to allow derivation of the external and the internal radiation dose commitments to body tissues from this source;
(v) other radio-active nuclides in fall-out deposit and in air to provide supplementary scientific information.

55. The geographical coverage of the said programmes in Australia is shown in the map, Annex 22. The 25 centres for monitoring fresh fission products for fall-out are shown thereon with a black dot. In addition to the 25 monitoring stations in Australia, the programme for the monitoring of fresh fission products includes Lae in the Trust Territory of New Guinea. The shaded areas on the map indicate the locations of the nine major milk supplies assayed for iodine-131. The continuing surveys of strontium-90 and caesium-137 fall-out embrace the five major population centres shown in a circle and the nearby regions from which milk and other food supplies are drawn.

56. These monitoring programmes have detected radio-active fission products in fall-out throughout Australia following and as a result of each of the nuclear tests conducted by the French Republic at its Pacific Tests Centre. The main fission products detected in this fall-out are listed in Annex 23. Some of these fission products, notably caesium-137, iodine-131, strontium-90 and fresh fission product deposits, have been monitored in detail to enable radiation dose commitments to the Australian population to be evaluated. The measurements of radio-active fall-out so monitored have been published in official reports and in the *Australian Journal of Science*. These reports and publications have been formally submitted to UNSCEAR as official Australian information.

57. It is not necessary, for the purposes of this request, to set out in detail the actual measurements taken in the course of these monitoring programmes. It is sufficient to refer to summaries of the main data. Annex 24 contains a summary of the measurements in picocurie-days per litre of the concentration of iodine-131 in milk supplies following and as a result of the French nuclear tests in the Pacific from 1966 to 1972. The data on strontium-90 and caesium-137 in fall-out deposit on Australia from 1966 to 1971 are summarized in Annex 25. These annual fall-out deposits include contributions from all nuclear tests in the northern hemisphere up to 1962 and by China from 1966 and in the southern hemisphere by the French Republic from 1966. An estimate (using established scientific procedures) of the contribution made by French tests to this strontium-90 and caesium-137 fall-out deposit in Australia is included at the foot of Annex 25 and depicted in Annex 26. The data for the whole of 1972 are not yet complete and therefore cannot be shown in either of these Annexes.

58. At the end of 1971 approximately 180 kilocuries of strontium-90 and 220 kilocuries of caesium-137 remained in the stratosphere of the southern hemisphere from releases of these radioisotopes to the atmosphere in nuclear tests. It is estimated, using established scientific principles, that about 75 per cent. of this inventory was due to French nuclear tests in Polynesia and that when this is deposited in fall-out, mainly in the southern hemisphere, it will contribute an additional 0.70 millicuries per square kilometre of strontium-90 and 0.88 millicuries per square kilometre of caesium-137 to the fall-out deposit in Australia, 1966 to 1971, from these tests (Annex 25 and shown in Annex 26).

59. The French nuclear tests from 1966 to 1972 have resulted in increased radiation doses to the Australian population both externally from fall-out deposited on the ground and internally from the consumption of milk and other foodstuffs contaminated by iodine-131, caesium-137, strontium-90, carbon-14 and tritium. Using approaches adopted by UNSCEAR in its second to sixth reports, these doses may be expressed as dose commitments to the Australian population. Again, it is not necessary for the purposes of this request to set out detailed figures and calculations relating to such dose commitments. It cannot be disputed that as a result of French tests there has been increased radiation doses to the Australian population and these dose commitments, calculated from the measurements taken in the course of the monitoring programmes previously described, and in accordance with the scientific principles employed by UNSCEAR, are of the following order:

dose commitment to whole body and gonads—5-6 millirad
dose commitment to bone marrow—11-12 millirad
dose commitment to bone living cells—14-15 millirad
dose commitment to thyroids
infants under 2—110-125 millirad
persons 2 and over—14-18 millirad.

60. These dose commitments may be used together with estimates of risk (risk factors) for the induction of cancer and for diseases of genetic origin to compute harm commitments to the Australian population expressed as the expected number of additional cases of cancer and diseases of genetic origin. Adopting the assumption used by ICRP and set out in paragraph 49 (1) above that "down to the lowest levels of dose, the risk of inducing disease or disability increases with the dose accumulated by the individual", the risk factors determined by UNSCEAR and by the BEIR Committee may be used to compute the above-mentioned harm commitments.

61. In its Note dated 7 February 1973 to Australia, the French Government referred to and sought support for its point of view in the reports of Australia's National Radiation Advisory Committee originally set up in May 1957 (referred to herein as the "NRAC"). However, these have only a limited, if any, bearing on the situation. The NRAC has produced a report on each series of tests but it has not reported on the possible cumulative consequences of fall-out from all series of the tests.

62. In formulating its views on each series of tests, the NRAC chose to adopt an approach of determining the relative risk for each series rather than that of assessing the cumulative harm to the Australian population from all the nuclear tests carried out in the Pacific in the atmosphere by the French Republic. The approach adopted by the NRAC involved in the main the comparison of the expected effects from the tests with those from natural background radiation and viewing the significance of the expected effects against the incidence of death and disability in the Australian population. Because of the growing concern in the Australian population about the possible effects of the continued atmospheric nuclear testing by the French Republic in the Pacific, Australia is obliged to consider the cumulative effect of these tests and to assess the risks not in relative terms, but in absolute terms.

63. On Tuesday, 1 May 1973, there was tabled in the Australian Parliament a report of the Australian Academy of Science which had been requested by the Prime Minister relating to the following question:

"The actual or potential harm to Australia, including its human and animal population, its resources and environment, from the explosion of nuclear devices in the atmosphere, under water, or on or near the surface of the earth, with particular regard to the past and prospective explosions by France in the Pacific."

A copy of the report has been supplied to the French Government. Its principal conclusions as summarized therein are as follows:

"1. We find no reason to question the estimates of radio-active fall-out used in the reports from other authorities; our own independent assessment is given in the Appendix.
2. At low doses of radiation on animals or on man, it is not known whether the effects are proportional to dose. There may be a threshold below which lower levels of radiation have no effect. Current work on repair by living cells, of damage they have suffered at high doses of radiation, suggests that low doses may not cause cancer or genetic defects at a rate proportional to dose.
3. It is assumed (as all official reports have hitherto done) that the responses to dose are proportional over the whole range. Australia, as the result of the French tests which have already taken place, could have 1 case of thyroid cancer per year due to the isotope iodine-131 and 1 to 4 other cancer cases per year due to strontium-90, caesium-137 and carbon-14. Due to the same isotopes, Australia could have one mutation in every 10 years leading to death or disability in the first generation, and up to 50-100 deaths or disabilities in all subsequent generations.
4. We draw attention to the improbable event in which the explosion of a high-powered bomb was combined with quite exceptional meteorological conditions giving a high fall-out over Australia. Though this would be a singular episode, some increase in the above figures would be expected. Thyroid cancer cases due to iodine-131 could be about 10. Other cancer cases due to the other isotopes could increase to much higher figures than at present levels of radiation. Mutations could lead to two deaths and disabilities per year in the first generation and to more than a thousand deaths and disabilities in all subsequent generations.

Though the average levels of radiation due to the French explosions are unlikely to make a statistically detectable increase in the cancer or genetic effects in Australia, we emphasize that there should be no unwarranted exposure to radiation. Further, with the long-lived isotopes produced as the result of nuclear explosions in either the southern or northern hemisphere, the effects on the Australian population, though small, would be cumulative."

The report of the Academy was originally submitted to the Prime Minister and a summary of the conclusions as they then stood were published prior to the discussions in Paris on 18, 19 and 20 April. Between 20 April and the tabling of the report, on 1 May, the Academy amended certain of its conclusions in order to correct what it considered a mathematical inconsistency appearing in the report. The French Government has been made aware of these amendments.

64. The figures contained in the summary of conclusions of the report assessing the number of cases of cancer and of genetic effects from French tests in the Pacific are consistent with a proper application to the dose commitments

set out in paragraph 59 of this request of the risk factors assessed by UNSCEAR and those adopted in the BEIR Report.

65. As the reports already mentioned indicate, accepted scientific opinion is that exposure to radiation in the smallest dosages is potentially dangerous to human life. The precise limits of that danger are not yet known. The imprecision and uncertainty of the limits of danger are matters of grave concern to the Australian Government and are a factor relevant to the exercise by the Court of its powers to grant provisional measures.

66. Whatever uncertainties might be said to apply to these figures they are genuine estimates of risk, which the Australian Government, faced as it is with a clear violation of its territorial sovereignty and seeing no compensating benefit, must regard with serious concern. In view of the refusal of the French Republic to desist from testing, Australia has no option but to invoke the jurisdiction of this Court if it wishes to protect its rights and avoid the possibility of further serious and irreparable harm from radiation resulting from French tests.

67. The clear anxiety and concern of the Australian people at the conduct of atmospheric tests by the French Republic has been shown in many ways. During 1972, political representatives, scientists, trade unions and churches, as well as ordinary members of the public, protested by demonstrations, letters to the press, public statements, deputations, boycotts and other means. In some cases the protests unfortunately took the form of violence against French property in Australia. All these actions are disturbing to Australia and its people. The fact that they are directed against the French Republic, an old ally with whom Australia has always enjoyed the most friendly relations, is equally disturbing. The Government of Australia cannot, however, ignore these protests.

68. The concern—and the rights—of Australia go further than the immediate protection of Australian territory and Australian lives therein. Radio-active products released over the ocean inevitably settle on the surface of the sea, whatever precautions are taken, and are absorbed into the water and eventually into the life chains which comprise the marine ecosystems. Species of such living natural resources being contaminated with radio-active material might, depending on their migratory habits, contaminate the diet of other species, including man, in widely distributed zones.

The Extreme Urgency of the Request

69. As is stated in the Application, Australia has sought to obtain from the French Republic a permanent undertaking to refrain from further atmospheric nuclear tests in the Pacific. However, the French Republic has expressly refused to give any such undertaking. It was made clear in a statement in the French Parliament on 2 May 1973 by the French Secretary of State for the Armies that the French Government, regardless of the protests made by Australia and other countries, does not envisage any cancellation or modification of the programme of nuclear testing as originally planned.

70. Moreover, in the past some warning of the occurrence of the tests was usually given by the circulation a few weeks in advance of information to diplomatic missions indicating the existence of Dangerous Zones; the details are referred to in paragraph 45 of the Application. The French Government has stated that no such similar warning is to be given in 1973. The French Government has already made the preparations necessary to activate Dangerous Zones on the very shortest notice. Accordingly, urgent advice of the activation of the Zones could be given at any moment.

71. In the past, the dates (Australian time) on which the tests have commenced were as follows:

1966	3 July	1970	16 May
1967	6 June	1971	6 June
1968	8 July	1972	26 June

There appears to be a real likelihood that this year's tests may be advanced so as to take place earlier than in the past.

72. These circumstances impress the present request with special urgency.

Interim Measures Proposed

73. In the light of the foregoing considerations, Australia submits that this is a proper and necessary case for the Court to exercise its power to lay down or indicate provisional measures of protection.

74. The measures which Australia respectfully requests are simple and are directly and exclusively related to the rights for which Australia seeks protection in these proceedings. "The provisional measures should be that the French Government should desist from any further atmospheric nuclear tests pending the judgment of the Court in this case."

(Signed) P. BRAZIL,
Agent for the Government of Australia.

ANNEXES TO THE REQUEST FOR THE INDICATION OF INTERIM MEASURES OF PROTECTION

Annex 1

Table Setting out Nuclear Tests Carried out at the Pacific Tests Centre

The table set out below shows the tests involving a nuclear explosion carried out by the French Government at its Pacific Tests Centre. Each of the tests have been conducted in the atmosphere. Included amongst the devices which have been exploded in the course of these tests have been several hydrogen bombs (one of one megaton and two of two megatons), a number of devices of high and medium power as well as some of low power.

Year	*Date* (Australian time)	*Year*	*Date* (Australian time)
1966	3 July 20 July 12 September 25 September 5 October	1970	16 May 23 May 31 May 25 June 4 July 28 July 3 August 7 August
1967	6 June 28 June 3 July	1971	6 June 13 June 4 July 9 August 15 August
1968	8 July 16 July 4 August 25 August 9 September	1972	26 June 1 July 28 July
1969	(No nuclear tests in the Pacific)		

Annex 2

United Nations General Assembly Resolution 913 (X) of 3 December 1955 on "Effects of Atomic Radiation"

The General Assembly,

Recognizing the importance of, and the widespread attention being given to, problems relating to the effects of ionizing radiation upon man and his environment,

Believing that the widest distribution should be given to all available scientific data on the short-term and long-term effects upon man and his environment of ionizing radiation, including radiation levels and radio-active "fall-out",

Noting that studies of this problem are being conducted in various countries,

Believing that the peoples of the world should be more fully informed on this subject,

1. *Establishes* a scientific committee consisting of Argentina, Australia, Belgium, Brazil, Canada, Czechoslovakia, Egypt, France, India, Japan, Mexico, Sweden, the United Kingdom of Great Britain and Northern Ireland, the United States of America and the Union of Soviet Socialist Republics, and requests the Governments of these countries each to designate one scientist, with alternates and consultants as appropriate, to be its representative on this Committee;

2. *Requests the Committee*

(a) To receive and assemble in an appropriate and useful form the following radiological information furnished by States Members of the United Nations or members of the specialized agencies:

(i) Reports on observed levels of ionizing radiation and radio-activity in the environment;

(ii) Reports on scientific observations and experiments relevant to the effects of ionizing radiation upon man and his environment already under way or later undertaken by national scientific bodies or by authorities of national Governments;

(b) To recommend uniform standards with respect to procedures for sample collection and instrumentation, and radiation counting procedures to be used in analyses of samples;

(c) To compile and assemble in an integrated manner the various reports, referred to in subparagraph *(a)* (i) above, on observed radiological levels;

(d) To review and collate national reports referred to in subparagraph *(a)* (ii) above, evaluating each report to determine its usefulness for the purposes of the Committee;

(e) To make yearly progress reports and to develop by 1 July 1958, or earlier if the assembled facts warrant, a summary of the reports received on radiation levels and radiation effects on man and his environment together with the evaluations provided for in subparagraph *(d)* above and indications of research projects which might require further study;

(f) To transmit from time to time, as it deems appropriate, the documents and evaluations referred to above to the Secretary-General for publication and dissemination to States Members of the United Nations or members of the specialized agencies;

3. *Requests* the Secretary-General to provide the Committee with appropriate assistance in organizing and carrying on its work, and to provide a secretary of the Committee;

4. *Calls upon* all concerned to co-operate in making available reports and studies relating to the short-term and long-term effects of ionizing radiation upon man and his environment and radiological data collected by them;

5. *Requests* the specialized agencies to concert with the Committee concerning any work they may be doing or contemplating within the sphere of the Committee's terms of reference to assure proper co-ordination;

6. *Requests* the Secretary-General to invite the Government of Japan to nominate a scientist, with alternates and consultants as appropriate, to be its representative on the Committee;

7. *Decides* to transmit to the Committee the records of the proceedings of the General Assembly on the present item.

Annex 3

EXTRACT FROM REPORT OF THE UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION
(*GA*, *OR*, 13th Session, Supplement No. 17 (A/3838), 1958)

Chapter VII

SUMMARY AND CONCLUSIONS

1. In estimating the possible hazards of ionizing radiation, it is clearly necessary to know both the levels of such radiation received by man and his environment from various sources, and the present and future effects likely to be produced thereby. It is of particular importance to assess the effects of radioactive fall-out from nuclear weapons, since this source of general environmental contamination is of recent origin, has been of uncertain significance, and has led to concern in the minds of many people. All sources of radiation must, however, be reviewed for a complete evaluation of the situation.

2. The Committee, aware of the complexity of this task, knows that our present information about radiation levels and effects is inadequate for an accurate evaluation of all hazards, and that many of the estimates will necessarily be approximate or tentative.

3. The physical characteristics of ionizing radiation, and the amounts of human exposures to it, are at present more accurately known than its biological consequences, especially where small doses and dose rates are concerned. In the present chapter, therefore, we review first the amounts of radiation received by man, both in regard to the exposure of individuals and of whole populations, and in respect to present and possible future levels. We then attempt to estimate the biological effects of varying amounts of radiation of different types, and to evaluate the hazard resulting from certain sources of particular significance.

4. The relevant physical data refer to the world's population as a whole, as well as to individuals and groups of people receiving relatively higher exposures because of their occupation or place of living. These exposures may involve the whole body uniformly, or may be greater for certain organs or tissues, as when radioactive material is selectively concentrated in them.

5. Tissues of the embryo, of the bone and bone marrow, and of the gonads are of particular importance. Irradiation of the embryo (and of the foetus) may lead to abnormalities of development or may prove fatal. Irradiation of bone marrow and of bone may give rise to leukemia and to bone tumours, and these tissues are subjected to higher doses than other tissues of the body by radioactive materials such as strontium-90 and radium which become concentrated in bone. Irradiation of the gonads is able to bring about changes in the hereditary material; and these may be transmitted to subsequent generations if the irradiation is received before or during the years of reproductive activity.

6. As with any scientific assessment, the conclusions of this report must be subject to revision in the light of advancing knowledge; and the Committee hopes that the report itself, after submission to the General Assembly, will assist this advance by stimulating critical discussion amongst scientists. In view of the complex nature of the subject, individual sentences or assessments may easily be misunderstood unless related to the context of the report as a whole.

I. LEVELS OF RADIATION

7. Table I summarizes our estimates of the average amounts of radiation likely to be received by populations during specified periods, and gives the basis for a comparison between the amounts received from natural and artificial sources. The method of calculation is described in chapter III, the averaging periods of 30 and 70 years being used as relevant respectively to transmissible genetic changes and to somatic injury during the lifetime of an individual. The estimates for medical examinations and occupational exposures are based upon the present situation in certain countries with developed facilities, rather than on a forecasted world average. The values quoted for various hypothetical future circumstances are not intended as predictions, but are calculations based on assumptions discussed in chapter III, and the values and ranges are subject to all the uncertainties outlined there.

Radiation from natural sources

8. The radiation received by man from natural sources varies somewhat from place to place according to the local radioactivity of the earth's surface; and that of only occasional populated areas exceeds the average by a factor of 10. Studies on populations living in these areas are of extreme interest for the development of our knowledge on the effects of small doses of radiation. The contribution from cosmic rays differs at different altitudes and geomagnetic latitudes. That from the normal radioactive potassium and carbon content of the body is about the same in different people, but the radiation due to radium, thorium and their decay products varies considerably. The radioactivity of the masonry used for some types of dwelling may appreciably increase the radiation exposure of the occupants. The variations in levels of irradiation from natural sources are discussed in chapter III; the magnitude of these variations, as well as of the average level, is informative in making comparisons with exposures due to artificial sources. Harmful effects attributable to radiation from natural sources are not known with any certainty, but it seems likely that some genetic, and possibly some somatic, injury is caused in this way.

Exposure due to medical procedures

9. It is useful to estimate this exposure, appropriately averaged over whole populations, since the genetic, and perhaps some somatic, effects of these procedures will depend upon this average value. In the countries with extensive medical facilities where its magnitude has been estimated, the radiation given for medical purposes makes the largest artificial contribution to the irradiation of the population, but no data are available for countries with fewer such facilities. The reported values of genetically significant doses are of the same order as the doses from natural sources. Among medical procedures, the contribution from diagnostic X-ray examinations greatly exceeds that from radiotherapy and radioisotope applications, the latter making only a small contribution; and

TABLE I. ESTIMATED DOSE FROM DIFFERENT RADIOACTIVE SOURCES
(*Computed from world-wide averages*)

Source	*Genetically significant dose Maximum for any 30-year period (rem)*[D115]		*Per capita mean marrow dose Maximum for any 70-year period (rem)*[D191]			
Natural sources	3		7			
Man-made sources (except environmental contamination and occupational exposure)[a]	0.5–5		Ranges beyond 7			
Occupational exposure[b]	Less than 0.06		0.1–0.2			
Environmental contamination (hypothetical cases)[c, d]			*Estimates for countries deriving most of dietary calcium from milk*[e]		*Estimates for countries deriving most of dietary calcium from rice*[e]	
Weapon tests cease at end of 1958	0.010		0.16		0.96	
	Assumption a[f]	*Assumption b*[f]	*Assumption a*[f]	*Assumption b*[f]	*Assumption a*[f]	*Assumption b*[f]
Weapon tests continue until equilibrium is reached in about a hundred years[g]	0.060	0.12	1.3	2.8	7.5	17
	Estimated percentages of the maximum doses for continued weapon tests					
	Assumption a[f]	*Assumption b*[f]	*Assumption a*[f]		*Assumption b*[f]	
Weapon tests cease						
1958	17	9	13		6	
1968	42	33	24		16	
1978	64	56	34		26	
1988	79	67	42		35	
Weapon tests continue	100	100	100		100	

[a] For countries having an extensive use of the radiation sources listed and reporting data to the Committee.

[b] Doses for certain technologically highly developed countries only.

[c] Computed from population weighted world-wide average of stratospheric fall-out rate and deposit.

[d] Regional values may differ by a factor of about ⅓ to 2 from the estimated population weighted world-wide average values because of the latitudinal variation of fall-out rate and deposit. In some areas of the world the tropospheric fall-out may tend to raise the upper limit of this range, especially in the vicinity of test sites.

[e] The extent to which these estimates apply to populations of different dietary habits and to those living in areas of differing soil conditions is discussed in paragraph 69 of chapter III.

[f] Assumption *a* is that the injection rate is such as to maintain a constant fall-out rate of strontium-90 and caesium-137, whereas assumption *b* is that weapon tests equivalent in release and stratospheric injection of fission products to the whole sequence of weapon tests from the beginning of 1954 to the end of 1958 will be repeated at constant rate. This second assumption will give an equilibrium value for the fall-out rate and deposit approximately a factor of 2 higher than that calculated by using the first assumption.

[g] The values for the 30-year doses have been corrected for tropospheric fall-out in accordance with paragraph 57 of chapter III, using a value of 0.5 mrem/year for the period of testing.

80 to 90 per cent of the total diagnostic dose to the gonads is due to relatively few types of examination of the abdomen and pelvis.

10. Most of these values are preliminary estimates, and further investigations are needed, for which procedures have been suggested by the International Commissions on Radiological Protection and on Radiological Units and Measurements in a report prepared at the request of this Committee and submitted to it in document A/AC.82/G/R.117.

11. The significant dose to bone and bone marrow from medical procedures has been less closely studied than the genetically significant dose, although it may be of importance if bone tumours or leukemia are induced by radiation at low dose levels. Although individual marrow exposures vary very widely, the average is unlikely to differ greatly from that received by the marrow from all natural sources.

12. The contribution made by medical procedures to the radiation exposure of populations has only lately been estimated and has increased very rapidly in some countries in recent years, so that it is difficult to evaluate such genetic and somatic effects as are associated with an increasing employment of radiological procedures in medicine. No information is yet available for prediction of the future trend of medical exposures. It is expected that improvements in equipment and techniques may considerably reduce individual exposures, but the ever-expanding use of X-rays may well increase the world population dose. Precautions of the type described by the International Commissions on Radiological Protection and on Radiological Units and Measurements should make possible such reduction of exposure to radiation as is without detriment to the medical value of these procedures.

Occupational exposure

13. At present, the exposure to ionizing radiation received occupationally forms only a small contribution to the total irradiation of the population as a whole, amounting to about 2 per cent of that from natural sources in countries in which occupational exposure is probably largest. With an increasing use of nuclear reactors, of radioactive materials and probably of medical and industrial radiological procedures, this is clearly a figure which should be kept under close review. Although this source does not appear likely to make a substantial contribution to the total radiation exposure of populations in the immediate future, the occupational exposure of some individuals may represent a large fraction of their total radiation exposure.

14. Since 1928, the International Commission on Radiological Protection has recommended "maximum permissible doses" for those who are occupationally exposed to radiation, and has proposed appropriate methods of measurement. Their present recommendations, which have recently been reviewed in the light of progress in radiobiological knowledge and which propose reductions in dose levels, may not be final but are at present widely accepted as a sound basis for the protection of those exposed occupationally to ionizing radiation.

Radioactive wastes

15. The discharge of radioactive waste in countries with nuclear reactors has not led to appreciable radiation exposure of populations, and only small proportions of the wastes produced need to be discharged. The likely future extension in the use of such reactors, however, and the possibility of accidental releases of fission products, clearly require that this subject be kept under review. It is important that work should be actively continued on methods of minimizing environmental contamination from these causes.

Radiation from fall-out

16. Fall-out from nuclear weapon tests causes radiation exposure in several ways (chapter III). Exposure of the world population results from the slow fall-out of fission products which have been distributed in the stratosphere. Exposures also result from any fall-out from the radioactive "cloud" which passes through the troposphere without having reached the higher stratosphere, and from the fall-out which may occur in areas adjacent to weapon tests or within some thousand kilometres of them.

17. We also consider the ways in which fall-out material causes irradiation to different parts of the body, to people on different diets or under different agricultural conditions, and to people of different ages; and the change in the amounts of radiation that would result from altered or unaltered rates of injection of radioactive materials into the stratosphere.

Fall-out adjacent to tests

18. The early fall-out of radioactive materials near to the sites of nuclear explosions, which is influenced by various meteorological and testing conditions, may cause high radiation exposure to individuals within these areas. The amount of such radiation exposures varies very greatly with the weapon tested, with the height of firing, with the distance from the point of explosion, with the direction of winds at various altitudes and with the chance occurrence of rainfall through radioactive material in the early hours after the test. Therefore, at present, these doses cannot in general be calculated. Under very special conditions, high radiation exposure and deleterious effects have been reported, as in the cases of the Marshall Islanders and the crew of a Japanese fishing vessel. Not enough information is available as to the general circumstances in which such local deposition may occur, and the extent and duration of the exposures liable to be involved.

Fall-out from the troposphere

19. Radioactive materials injected into the atmosphere below the tropopause (at about 14 km) are brought down to the earth's surface by rainfall and sedimentation. This process takes a few months during which they are carried several times around the world. This tropospheric fall-out consists of a mixture of radioactive materials, most of which are short-lived isotopes. At the present time, the tropospheric fall-out is deposited intermittently during the year and a certain deposit of short-lived activities is built up and maintained. When appropriate factors for shielding and weathering effects are included, the gonad and average marrow dose from this deposit, as an external source, is calculated to be about 0.5 mrem per year.

20. Transient increases of the doses from tropospheric fall-out have been observed in limited areas shortly after weapon tests. These transient increases may give rise for a few days to dose rates of the order of those from natural sources.

21. The radioisotopes of tropospheric fall-out may be taken up into the body by inhalation and ingestion. Since the radioisotopes of principal concern are short-lived, storage of the contaminated food products reduces the dose which they contribute. The gonad dose over the whole population from inhaled and ingested tropospheric material is negligible as compared with the contribution from this material as an external source. The average bone marrow dose from internal sources is about 0.2 mrem per year.

22. Increases in radioactivity of the thyroid gland have been found during periods of several weeks or a few months following weapon tests. In human thyroids a dose from iodine-131 of about 5 mrem per year has been estimated for 1955-1956 in the United States excluding areas immediately adjacent to weapon test sites. Doses of this order are unlikely to cause detectable damage or functional change in the gland.

23. Irradiation of bone may result from incorporation of intermediate and short-lived fission products. Although these materials do not cause prolonged irradiation, they may become selectively concentrated into those areas of bone in which active growth is taking place at the time, and so cause more intense radiation locally than if the same amounts of these materials were distributed throughout the whole skeleton.

24. The Committee has insufficient information on local variations and temporary increases of tropospheric fall-out in populated areas at different distances from weapon test sites, and emphasizes the lack of further data which would permit evaluation of the biological significance of this source of environmental contamination.

World-wide fall-out from the stratosphere

25. Radioactive materials injected into the stratosphere, especially by high-yield nuclear explosions, constitute a reservoir from which they fall onto the whole of the earth's surface for many years. The rate of fall-out varies with latitude and is greater in the northern hemisphere, where most of the tests are carried out. Within any given small area, fall-out rate may also vary with local meteorological conditions. The figures given in table I are computed from world-wide average deposits from stratospheric fall-out. The radiation due to stratospheric fall-out from weapons exploded so far will contribute a 30-year gonad dose of 10 mrem, and a 70-year *per capita* mean marrow dose of 160 mrem and 960 mrem for two populations deriving most of their dietary calcium from milk and rice respectively.

26. Owing to the relatively gradual fall-out from the stratosphere, most of the subsequent radiation is due to two radioactive isotopes of slow decay, other fission

products already having largely undergone decay. These two radioactive isotopes are caesium-137 and strontium-90. The physical properties and chemical behaviour of the two differ.

27. Caesium-137 is responsible for most of the gonad radiation from fall-out noted in table I. When it is taken into the body, it becomes distributed more or less evenly throughout the tissues, causing uniform irradiation of the whole body; and when present in the surroundings, its penetrating gamma radiations cause a similarly uniform irradiation of tissues.

28. Strontium-90, on the other hand, is not a gamma-emitter and does not contribute significantly to the irradiation of any part of the body from without. However, on being taken into the body, it becomes incorporated in bone because of its chemical similarity to the normal bone-forming element calcium. This similarity with calcium and selective concentration in bone raises problems which do not occur with caesium-137.

29. The average concentration of strontium-90 in the bones of children, in whom new bone is continuously being formed, is higher than in adults whose bones were largely formed before the environment, and consequently the food supply, became contaminated with strontium-90. The highest concentrations of strontium-90 in bone have in fact been observed in children from a few months to five years old. The bone marrow exposures from fall-out given in table I are due to the strontium-90 content of bone and refer to the concentrations estimated for children of these ages. The corresponding exposures of bone cells from fall-out are; on the average, about three times the values for bone marrow. Marrow cells almost enclosed by bone would receive doses similar to those in compact bone. The maximum marrow dose could differ by a factor of about 5 from the average level.

30. The radiostrontium concentration in bone is also affected by dietary habit and by the ratio of the amounts of strontium-90 to calcium in the diet. At present this ratio differs in various dietary constituents; it is higher in brown rice than in white, somewhat higher in many vegetables than in milk products, higher in rain-water than in river water, and lower in sea fish than in fresh-water fish.

31. Agricultural conditions may also affect the content of strontium-90 in the diet, since the available calcium of the soil will, within certain limits, influence the ratio of strontium-90 to calcium in crops derived from the soil. The distribution of soils which are highly deficient in calcium and their utilization require further study. More work is also needed to understand the distribution of strontium-90 in the soil, its chemical availability to plants and uptake through their roots, its behaviour under ploughing and the leaching of it from soil by the action of water, since the figures in table I for future strontium-90 levels in bone are calculated on the assumption that this material will not be leached from soil, and this assumption may lead to unduly high values.

32. Bone marrow exposures from fall-out are given in table I for two conditions: one based on observations in the United States of America and the United Kingdom, where milk is the main source both of dietary calcium and of strontium-90, and where soil calcium contents are commonly high; and the other based upon data from Japan where milk products are much less used and where rice and other vegetable products form the main source of dietary calcium and strontium-90, and where low calcium soils are frequent. These two estimates demonstrate the present range of known dietary contaminations. They will be used in an attempt to estimate the hazard of radiation from fall-out in paragraph 57 below, when the nature and frequency of the biological effects of radiation have been considered.

33. It is evident that the radiation exposures from fall-out which are most likely to be of significance are:

(*a*) Those from short-lived fission products and radioactive material due to local or tropospheric fall-out;

(*b*) Those of the gonads and other organs from caesium-137 due to stratospheric fall-out;

(*c*) Those of bone and adjacent tissue from strontium-90 which also comes largely from the stratosphere. The relative importance of these contributions varies from region to region.

II. Biological effects of radiation

34. The biological effects of ionizing radiation are exhibited in different ways according to whether isolated cells, tissues, organs or organisms are examined. In passing from unicellular to higher organisms, the primary physicochemical consequences of radiation become increasingly influenced by secondary effects due to the reactions of the organism to the primary events. Detailed knowledge of these reactions is needed for a full understanding of the results and mode of action of radiation. The following paragraphs deal first with the cellular effects of radiation; then with the somatic effects on the irradiated individual and with the genetic effects on his progeny.

35. The effects of ionizing radiations on living matter are extremely complicated, and their exact mechanisms are still largely unknown. The initial disturbance is associated with ionization (and excitation) of molecules which lead to alterations in their properties. Many functions of the cell are thus affected by radiation, and, although some specific effects may be caused by one or a few events in the cell, many are probably the combined result of numerous such events.

36. The minimum doses causing certain detectable biological effects differ very much in different organisms, but for most mammals they are of about the same magnitude, so that the results of experiments on such animals can, as a first approximation, be applied to man. The sensitivity of different tissues to radiation varies considerably, however. Our knowledge of the biological effects of low radiation levels is meagre because of experimental difficulties and the lengthy observations necessary to obtain results in this field. At present, opinions as to the possible effects of low radiation levels must be based only on extrapolations from experience with high doses and dose rates.

Effects of radiations on man

37. Man may prove to be unusually vulnerable to ionizing radiations, including continuous exposure at low levels, on account of his known sensitivity to radiation, his long life, and the long interval between conception and the end of the period of reproduction.

38. Embryonic cells are especially sensitive to radiation, and some evidence suggests that exposure of the foetus to small doses of radiation may result in leukemia during childhood. Irradiation of pregnant mammals has shown that doses exceeding 25 rem to the foetus during

certain stages of its development can cause abnormalities in some organs. Some embryonic cells (neuroblasts) of certain species cultivated *in vitro* respond to doses as small as 1 rad. If these results should be applicable to man and since they relate to the development of the brain, the opinion seems justified that even a very small dose to the human foetus may involve some risk of injurious effects if received during a critical period of pregnancy. Radiostrontium must be expected to enter foetal bone when calcification starts in the second trimester of pregnancy, and so cause irradiation of the adjacent developing nervous system and hypophysis with exposures ranging up to that occurring in the bone. The uptake of radiostrontium in foetal bone tissue is, however, at present very small, contributing less radiation than 1 per cent of that due to natural sources; but if the present rate of test explosions is continued, it will rise ultimately to some 10 per cent of that due to natural sources.

39. Children are regarded as being more sensitive to radiation than adults, although there is little direct evidence on this subject, except for an indication that cancer of the thyroid may result from doses of a few hundred rad which do not induce this change in adults.

40. In human adults it is difficult to detect the effect of a single exposure to less than 25 to 50 rem, or of continuing exposure to levels below 100 times the natural levels. The first sign of radiation damage to the blood-forming tissues seems to be a drop in the number of lymphocytes and platelets and the appearance of abnormalities such as bilobed lymphocytes.

41. Rapid but transient disturbances have been observed in mammals after exposure to a single dose of 25 to 200 mrem. Appropriate biochemical and physiological techniques have, however, only recently been applied to the study of irradiated organisms, and have not yet given a clear picture of what happens to organisms irradiated with small doses or dose rates. Too few mammalian species have hitherto been studied in this respect, and there is a clear need to widen this basis, from which inferences can be drawn concerning man.

42. Processes of repair play an important role in the final outcome of radiation damage. They are one cause of the existence of a threshold dose (or dose rate) characterized by the fact that this dose or greater ones produce a particular biological effect which does not appear when the dose is less than the threshold. In the latter case, physicochemical events have occurred, but recovery processes have prevented the final appearance of the biological damage. Threshold doses are found for some somatic effects, such as erythema of skin. Other forms of radiation damage to cells, tissues or organisms, however, appear to be cumulative; for instance, mutational damage, once established, is not repaired.

43. Damaged cells or tissues may be eliminated and replaced by regenerated normal cells, this process being most active in embryos and young animals and in certain tissues of the adult. The affected cells may also re-establish apparently normal biochemical functions. During the process of regeneration of tissues damaged by radiation, malignant tumours may be induced.

44. The power of repair differs considerably in different organisms and types of cells, and varies to a high degree with the physiological conditions. No chemical treatment has yet been discovered which will induce or accelerate recovery from radiation damage in man. The grafting of blood-forming tissue has so far been successful only in small mammals irradiated with a lethal dose to the whole body, and no attempt to apply this treatment to irradiated man has yet been reported.

45. Prevention of the effects of radiation is rendered more difficult, and complete protection against it impossible, because changes which already occur during the irradiation lead to later damage. The discovery of chemical protectors, although important theoretically, has not yet yielded methods which appreciably reduce radiation damage in man. At present, effective protection from external radiation sources can only be achieved by adequate shielding or by keeping at a safe distance from the source. Much work is in progress on the effect of certain (chelating) agents in discharging from the body radioisotopes incorporated there, and so diminishing exposure to internal irradiation.

46. Morphologically recognizable damage may be induced by total or partial, continuous or intermittent irradiations much in excess of the currently accepted "maximum permissible levels" of occupational exposure. Such damage includes leucopenia, anemia and leukemia. Other pathological conditions such as cataract, carcinoma of the thyroid, and bone sarcoma are known to have resulted from partial body irradiations, but with rather high doses involving hundreds or even thousands of rem given to these organs.

47. The shortening of the life-span in small rodents exposed to large doses has suggested the possibility that certain degenerative processes may be aggravated by continued exposure to low radiation levels. Such a shortening has also been inferred from an analysis of the published death rates of United States radiologists compared with those of certain other groups of medical men. However, studies in the United Kingdom have failed to demonstrate such an effect.

48. Present uncertainty about the effects of low dose levels makes it imperative that as much relevant information as possible be collected about groups of persons chronically exposed at these levels and for whom adequate control groups exist, for instance, certain populations in areas of high natural radiation and workers in uranium mines.

49. Exposure of gonads to even the smallest doses of ionizing radiations can give rise to mutant genes which accumulate, are transmissible to the progeny and are considered to be, in general, harmful to the human race. As the persons who will be affected will belong to future generations, it is important to minimize undue exposures of populations to such radiation and so to safeguard the well-being of those who are still unborn.

50. The present assumption of the strictly cumulative effect of radiation in inducing mutations in man is based upon some theoretical considerations and a limited amount of experimental data obtained by exposure of experimental organisms to relatively high dose levels. This assumption underlies all present assessments of the mutational consequences of irradiation. Therefore, extension of the experimental data to the lowest practicable dose levels is needed.

51. The knowledge that man's actions can impair his genetic inheritance, and the cumulative effect of ionizing radiation in causing such impairment, clearly emphasize the responsibilities of the present generation, particularly in view of the social consequences laid on human populations by unfavourable genes.

52. Besides increasing the incidence of easily discernible disorders, many of them serious but each comparatively rare, increased mutation may affect certain universal and important "biometrical" characters such as intelligence or life-span. In this way, it is possible that continued small genetically significant exposures of a population may affect, not only a correspondingly small number of individuals seriously, but also most of its members to a correspondingly small extent. While less easy to detect, this second kind of effect on a population could also be serious. Unfortunately, the great majority of the genes affecting the "biometrical" characters are not individually detectable and so can only be studied collectively and with difficulty. In consequence, far less is known about them than about genes responsible for individually detectable changes and very little indeed about their response to irradiation, even in the best-studied experimental organisms. Hence it is impossible, at the present time, to estimate with any assurance the effect upon biometrical characters of any given level of irradiation of human populations. Much further research throughout this field is therefore needed.

53. The Committee emphasizes the urgent necessity for well-planned investigations which may lead to a better understanding of the mechanism of mutation and the eventual possibility of controlling this process. More information is needed on the effect of radiation in inducing mutations in man. Indeed, even the dose required to double the normal mutation rate in man is not known with any accuracy. There is also need for a much closer co-operation between geneticists and demographers in elucidating the nature of the complex process of human selection. Many important subjects of relevant genetical research have been reviewed by a study group of the World Health Organization in their report "Effects of Radiation upon Human Heredity", document A/AC.82/G/R.58.

III. General conclusions

54. The exposure of mankind to ionizing radiation at present arises mainly from natural sources, from medical and industrial procedures, and from environmental contamination due to nuclear explosions. The industrial, research and medical applications expose only part of the population while natural sources and environmental sources expose the whole population. The artificial sources to which man is exposed during his work in industry and in scientific research are of value in science and technology. Their use is controllable, and exposures can be reduced by perfecting protection and safety techniques. All applications of X-rays and radioactive isotopes used in medicine for diagnostic purposes and for radiation therapy are for the benefit of mankind and can be controlled. Radioactive contamination of the environment resulting from explosions of nuclear weapons constitutes a growing increment to world-wide radiation levels. This involves new and largely unknown hazards to present and future populations; these hazards, by their very nature, are beyond the control of the exposed persons. The Committee concludes that all steps designed to minimize irradiation of human populations will act to the benefit of human health. Such steps include the avoidance of unnecessary exposure resulting from medical, industrial and other procedures for peaceful uses on the one hand and the cessation of contamination of the environment by explosions of nuclear weapons on the other. The Committee is aware that considerations involving effective control of all these sources of radiation involve national and international decisions which lie outside the scope of its work.*†

55. Certain general conclusions emerge clearly from the foregoing part of this report:

(*a*) Even the smallest amounts of radiation are liable to cause deleterious genetic, and perhaps also somatic, effects.

*The USSR submitted a draft proposal for paragraph 54 which, as amended by Czechoslovakia with the agreement of the USSR, read as follows:

"The scientific information received by the Committee indicates that the genetic effects of radiation must be considered reactions for which there is no threshold. This means that any increase in the exposure of the human organism to radiation will lead to an increase in the incidence of hereditary diseases. According to one body of scientific opinion, malignant neoplasms and also leukemias are diseases the incidence of which may increase as the level of radiation rises. These data, together with the fact that there is very little likelihood that the human organism can adapt itself to conditions of increased environmental radiation, indicate that any increase in the radiation dose above the natural radiation level must be considered undesirable for mankind. Efforts should accordingly be made to improve the physical basis and the technique of the medical use of radiation by formulating more precise indications for the use of radiation and by eliminating adverse side effects. It is also essential to develop, on the basis of broad international co-operation among scientists, research on the improvement of protection and safety techniques in atomic industry and in science and technology. The physical and biological data presented in the report make it plain that efforts should be made to eliminate the uncontrolled source of radiation, i.e., to end experimental nuclear and thermonuclear explosions, and enable the Committee to draw the conclusion that there should be an immediate cessation of test explosions of nuclear weapons."

This proposal was rejected by the following roll-call vote:

In favour: Czechoslovakia, Union of Soviet Socialist Republics, United Arab Republic.

Against: Argentina, Australia, Brazil, Canada, France, Japan, Mexico, Sweden, United Kingdom of Great Britain and Northern Ireland, United States of America.

Abstaining: Belgium *(Chairman)*, India.

The above text expresses the dissenting view of Czechoslovakia, the United Arab Republic and the USSR to the wording of paragraph 54, which was approved by a majority of the Committee.

† India also submitted a draft proposal for paragraph 54 which, with amendments accepted by India, read as follows:

"The exposure of mankind to ionizing radiation at present arises mainly from natural sources, from medical and industrial procedures, and from environmental contamination due to nuclear explosions. The industrial, research and medical applications expose only part of the population while natural sources and environmental sources expose the whole population. The artificial sources to which man is exposed during his work in industry and in scientific research are of value in science and technology. Their use is controllable, and exposures can be reduced by perfecting protection and safety techniques. All applications of X-rays and radioactive isotopes used in medicine for diagnostic purposes and for radiation therapy are for the benefit of mankind and can be controlled. Radioactive contamination of the environment resulting from explosions of nuclear weapons constitutes a growing increment to world-wide radiation levels. This involves new and largely unknown hazards to present and future populations; these hazards, by their very nature, are beyond the control of the exposed persons. The physical and biological data contained in the report lead to the conclusion that it is undesirable to allow any general rise in the level of world-wide contamination because of its harmful effects and that any activity which produces such a rise should be avoided. Nuclear tests are the main source at present which produce such a rise."

This proposal was rejected by the following roll-call vote:

In favour: Brazil, France, India, Japan, United States of America.

Against: Argentina, Australia, Mexico, Sweden, United Kingdom of Great Britain and Northern Ireland.

Abstaining: Belgium *(Chairman)*, Canada, Czechoslovakia, Union of Soviet Socialist Republics, United Arab Republic.

(*b*) Both natural radiation and radiation from fall-out involve the whole world population to a greater or lesser extent, whereas only a fraction of the population receive medical or occupational exposure. However, the irradiation of any groups of people, before and during the reproductive age, will contribute genetic effects to whole populations in so far as the gonads are exposed.

(*c*) Because of the delay with which the somatic effects of radiation may appear, and with which its genetic effects may be manifested, the full extent of the damage is not immediately apparent. It is, therefore, important to consider the speed with which levels of exposure could be altered by human action.

It is clear that medical and occupational exposure, and the testing of nuclear weapons, can be influenced by human action, and that natural radiation and the fall-out of radioactive material already injected into the stratosphere, cannot.

56. Present knowledge concerning long-term effects and their correlation with the amounts of radiation received does not permit us to evaluate with any precision the possible consequence to man of exposure to low radiation levels. Many effects of irradiation are delayed; often they cannot be distinguished from effects of other agents; many will only develop once a threshold dose has been exceeded; some may be cumulative and others not; and individuals in large populations, or particular groups such as children and foetuses may have special sensitivity. These facts render it very difficult to accumulate reliable information about the correlation between small doses and their effects either in individuals or in large populations. Even a slow rise in the environmental radioactivity in the world, whether from weapon tests or any other sources, might eventually cause appreciable damage to large populations before it could be definitely identified as due to irradiation. Appearance and elimination of adverse genetic effects would be very slow; and, as the radioactive contamination accumulated, it might so act as to increase the likelihood of somatic injury in individuals due to the additional exposure. Such a situation requires that mankind proceed with great caution in view of a possible underestimation. At the same time, the possibility cannot be excluded that our present estimates exaggerate the hazards of chronic exposure to low levels of radiation. Only further intensive research can establish the true position.**

57. Any present attempt to evaluate the effects of sources of radiation to which the world population is exposed can produce only tentative estimates with wide margins of uncertainty. Estimates are given in chapter III for the radiation exposure of populations from such sources, and in chapters V and VI for the likely somatic and genetic effects of given exposures. On the basis of these, the Committee has tried to evaluate the possible effect of natural and of fall-out radiation in causing leukemia, tumours of bone and major genetic defects (table II) since these are conditions which may possibly be induced by irradiation at low dose levels. The methods of calculation, and the main sources of uncertainty in these estimates, are described in chapters III, V and VI, where factors of correction are also given for the different estimates corresponding to differences in the assumptions on which the calculations are based. It will be evident that the estimates indicate only the order of magnitude of the frequency with which effects may be produced, and that our ignorance as to whether thresholds exist for the induction of leukemia or bone tumours by radiation cause the greatest uncertainty in the estimates.

Indications for research

58. This report presents evidence both of the increasing levels of radiation exposure, and of our uncertainties as to the nature and extent of the effects of radiation on man, particularly when received at low dose rates over long periods. It is most important, therefore, that scientific research and the collection of information on the effects of radiation should be actively continued and developed so that the uncertainties in all branches of radiobiology are reduced or removed.

** The maximum permissible levels of exposure and maximum permissible body burdens of radioactive isotopes recommended in 1954–1955 by the International Commission on Radiological Protection as applying in the case of *occupational* exposure must not be misinterpreted to apply in the case of exposure of *whole populations*.

TABLE II. ESTIMATES OF CERTAIN POSSIBLE ANNUAL CONSEQUENCES OF RADIATION RECEIVED BY WORLD POPULATION FROM CERTAIN SOURCES

			Source of radiation		
				Fall-out from weapon tests	
Consequence	*World population assumed (in millions)*	*Natural occurrence assumed per year*	*Natural radiation*	*Tests stopping in 1958*	*In equilibrium after prolonged continuation of tests*
Leukemia					
If threshold 0 rem	3,000	150,000	15,000	400 to 2000[a]	—
	5,000	250,000	25,000	—	5,000 to 60,000
If threshold 400 rem	3,000	150,000	0[b]	0[c]	—
	5,000	250,000	0[b]	—	0[d]
Major Genetic Defects[e]	5,000	700,000 to 3,000,000	25,000 to 1,000,000	[f]	500 to 40,000

[a] Maximum rate during peak period. An estimated total of less than 25,000 to 150,000 would ultimately occur.

[b] Unless individual bone marrow dose exceeds mean value by a factor of 60.

[c] Unless individual bone marrow dose exceeds mean value by a factor of 80 to 500.

[d] Unless individual bone marrow dose exceeds mean value by a factor of 5 to 60.

[e] Conditions which are at least a serious handicap to those affected, as listed in table XI of annex H.

[f] A total of 2,500 to 100,000 would occur over subsequent years.

NOTES.—The methods of estimating incidences of leukemia and major genetic defects are described in annex D, paras. 127 to 130.

The quantitative evaluation of an increase in incidence of primary bone tumour attributable to radiation presents great difficulties. If it were assumed that 5 to 10 cases per million normally occurred per year, and that 10 per cent of these were induced by natural radiation the following figures could be calculated from the 70-year osteocyte doses if a non-threshold hypothesis were assumed:

For tests stopping in 1958 and world population 3,000 million, 70 to 900 per year (as the maximum rate).

In equilibrium after prolonged continuation of tests and world population 5,000 million, 1,000 to 25,000 per year (as the continuing rate).

If a threshold of 400 rem were assumed, the incidences would be zero unless individual osteocyte doses exceeded the mean value by a factor of 80 to 500 in the case of tests stopping in 1958 and by a factor of 5 to 60 in equilibrium after prolonged continuation of tests.

59. Our knowledge of radiation and of its hazards is not however static; although still limited, it has been expanding rapidly. In recent years, considerable and sometimes spectacular advances have been made in our understanding of many of these matters. In the light of general scientific experience, the Committee confidently expects that continuing research on an increasing scale will furnish the knowledge urgently needed to master those risks which we know to be associated with the development and scope of the uses of nuclear energy for the welfare of mankind.

Indications for research into radiation levels

60. The doses received by both individuals and whole populations from various sources are not yet adequately known. Consequently,

(*a*) The range of tissue dose rates due to natural radioactivity, particularly in heavily populated areas with adequate demographic records, as well as the variations in content of natural radioactive substances in human beings need further examination;

(*b*) Fuller information is required as to the exposure of various populations to radiation during industrial procedures and during medical procedures, especially in so far as this involves children or foetuses and exposure of the bone marrow or gonads. It would be valuable if these further investigations could provide (i) a more representative estimate for some countries already studied, (ii) a fuller study of the dosage associated with the varied extent of medical facilities in different countries, (iii) clearer estimates of the radiation given to different tissues, including bone, (iv) the contribution from radiotherapy and (v) a continuing study of future developments and of changes in the medical radiation exposure;

(*c*) More extensive research is required on the fate of industrial radioactive effluents of various types and on the prevention of radiation exposures of populations from this source;

(*d*) Many factors which determine the distribution of local, tropospheric and stratospheric fall-out from experimental nuclear explosions require further investigation. In particular, more evidence is required on the behaviour of fission products in the stratosphere. Collation of information is needed to determine the pattern and extent of global fall-out on land and oceans. Far more extensive information is needed as to the mechanisms whereby fission products, particularly strontium-90 and caesium-137, reach food-chains and enter the human body, as well as the concentration of those materials in human tissues, particularly under the conditions where this is likely to be greatest.

Indications for research into biological effects

61. Information concerning the biological effects of irradiation of man is derived from experimental biology, and from clinical observations and statistical surveys.

(*a*) All advance in radiobiology depends upon progress in general cellular biology, and requires intensive study of the fields concerned.

(*b*) Fundamental biological knowledge is required for our understanding and control of the way in which radiation influences cells and their hereditary material, and how it brings about carcinogenesis. Further studies of these phenomena are needed, and form the only satisfactory basis for measures which could be adopted to prevent or cure the harmful effects of radiation.

(*c*) To identify any occasional harmful effects of low doses and dose rates requires systematic and long-term observation and the recording of relevant facts, especially concerning the frequency of certain somatic disorders and the genetic structure of populations. It is a task to which this Committee urgently draws the attention of demographers and medical statisticians, especially in regard to possible correlation of certain diseases with high natural or artificial radiation exposure.

Training for research

62. The advance of research in all these fields depends upon appropriate training of scientific workers.

Annex 4

Extract from Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (*GA*, *OR*, 17th Session, Supplement No. 16 (A/5216), 1962)

CHAPTER II

PHYSICAL AND BIOLOGICAL ASPECTS OF THE INTERACTION OF IONIZING RADIATION WITH MATTER

1. Discussion of the effects of radiation on human populations requires an elementary knowledge of physics and biology and of the relevant terminology. The present chapter is intended to meet this requirement as well as to give such a description of the processes induced by radiation in cells as is necessary to make the following chapters understandable.

2. Formal definitions of physical quantities and units are given in annex A and a detailed account of the interactions between radiation and living matter at the cellular and molecular level in annex B.

Physical aspects

TYPES OF IONIZING RADIATIONS

3. Radiation is one way in which energy is emitted and transferred. While the term radiation refers to a wide range of modes of emission, propagation and absorption of energy, this report on the effects of ionizing radiations will be concerned specifically with alpha rays, beta rays, gamma rays, X-rays, neutrons, and all those forms of radiation occurring in cosmic rays.

4. These radiations may be considered jointly as they all give rise, either directly or indirectly, to a common phenomenon, ionization, when they interact with matter. *Ionization* is the removal of electric charges from, or their addition to, electrically neutral atoms and molecules, which then become either negatively or positively charged. In this process molecules may split into separate fragments of either charge. Electrically charged atoms, molecules or fragments of molecules are called *ions*.

5. Despite the common result of their interacting with matter, the radiations considered in this report are sufficiently different in their origin and physical properties to warrant separate description. X- and gamma rays are electro-magnetic waves like light; other radiations consist of streams of individual particles. Alpha, beta and gamma rays and occasionally other radiations are emitted during nuclear disintegration. Unstable nuclei* are, in one or in a sequence of such disintegrations, converted to stable nuclei. Intermediate nuclides arising in a series of disintegrations are called radio-active *daughters*.

6. Nuclear disintegrations of an unstable isotope do not occur in all atoms at the same time. They are random events occurring with a certain probability per unit time. The time required for 50 per cent of the atoms of a nuclide to disintegrate is a measure of the rate of disintegration and is called the *half-life*. It is constant and characteristic of the nuclide, and it may range from over a thousand million years to a small fraction of a second.

7. The *activity* of a radio-active sample is determined by the number of distintegrations occurring per unit time. The unit by which it is usually expressed is the curie. One curie corresponds to 3.7×10^{10} distintegrations per second. A millicurie, a microcurie and a micromicrocurie (or picocurie) correspond to 3.7×10^7, 3.7×10^4 and 0.037 disintegrations per second, respectively. It is convenient to remember that one micromicrocurie is approximately two disintegrations per minute. It should also be noted that radio-nuclides of very long half-lives show only a slight radio-activity per unit mass (e.g. one curie of uranium-238 with a half-life of 4.5×10^9 years, has a weight of three tons, whilst one curie of radium-226 with a half-life of 1.63×10^3 years, has a weight of one gram and one curie of iodine-131 with a half-life of 8 days has a weight of 8 micrograms).

8. *Alpha rays* are positively charged particles (helium nuclei) emitted with definite and characteristic kinetic energy by nuclei of some radio-nuclides during disintegration. Alpha rays produce dense ionization in matter but their range, or penetration, is small, usually less than 0.1 mm in water and in living tissues.

9. *Beta rays* are electrons emitted by nuclei of certain radio-active nuclides.† They also produce ionization in the matter through which they pass. The range of beta rays, however, is much greater than that of alpha rays. Few radio-active nuclides emit beta particles of range greater than 2 cm in water and in living tissues, and none of range greater than 8 cm.

10. *Gamma rays* are electro-magnetic radiation emitted by nuclei of some radio-active nuclides; they have definite energies characteristic of the nuclide by which they are emitted. Gamma rays ionize matter indirectly through the ejection of high speed electrons from the material in which they are absorbed. These electrons may be ejected at a considerable depth in matter; each electron then dissipates its energy within a short distance (from less than a millimetre to a few centimetres depending on its energy). No definite range can be given for gamma rays since they penetrate any thickness of matter but with progressively decreasing intensity. The

* Atomic nuclei are complex structures forming the core of atoms. They are made up of positively charged protons and electrically neutral neutrons which are both elementary particles of approximately the same mass as the hydrogen atom. A *nuclide* is a species of atom characterized by the number of protons and the number of neutrons contained in its nucleus. The positively charged nucleus is surrounded by a number of negatively charged electrons which move in orbits around it. The charge of the electron is the same as that of a proton but of opposite sign so that the number of orbiting electrons in neutral atoms is equal to the number of protons in the nucleus. These orbital electrons participate in the formation of chemical bonds. The number of protons defines the chemical element to which the atom belongs. For a given element, various nuclides with the same chemical properties may be recognized which differ only in the number of neutrons and therefore in the mass of their nucleus. These are called *isotopes* of the element.

† In many cases beta rays consist of particles of the same mass as the electrons, but of opposite charge.

thickness of matter required to decrease the gamma-ray intensity by one-half is known as the half-value thickness.

11. *X-rays* are also electro-magnetic radiation and interact with matter and produce biological effects in the same way as gamma rays. They differ from gamma rays only in that emission is extra-nuclear rather than nuclear. In practice, X-rays are usually produced by retardation of high speed electrons in the anode of an X-ray tube. These electrons have been accelerated by the application to the tube of a difference of potential, the magnitude of which determines the maximum energy of the X-rays produced and, therefore, their penetrating power. The X-rays used for diagnostic medical procedures are less energetic and less penetrating than gamma rays from most radio-active nuclei. It is possible, however, using special electron-accelerating machines, to generate X-rays that are more penetrating than gamma rays from any radio-active nuclei.

12. *Neutrons* are constituents of atomic nuclei, from which they are ejected during nuclear processes such as fission (para. 20). Neutrons are uncharged and cannot produce ionization directly.

13. Fast neutrons (of energy greater than 10 keV) lose energy mainly by collision with nuclei of light atoms, especially those of hydrogen. These nuclei recoil and, being charged, produce ions as they dissipate the energy transferred from the neutron. The transmission of energy from fast neutrons to recoil nuclei can take place at a considerable depth in tissue; like X-rays and gamma rays, fast neutrons have no definite range.

14. Slow neutrons have little energy to lose in collision with nuclei. They interact with matter mainly by nuclear reactions that result in emission of charged particles or gamma rays while new nuclides (some of them radio-active) are produced. Matter is ionized by these particles or gamma rays as well as by the radiation emitted during the subsequent disintegration of the induced radio-isotopes.

15. *Cosmic rays*[E4-6] reach the earth from outer space; they consist of a complex group of heavy particles with different energies, of galactic and solar origin (primary cosmic radiation). The highly energetic fraction of primary radiation interacts with atoms present in the upper atmosphere giving rise to secondary cosmic radiation which is composed of particles and of electro-magnetic radiation. Each component of secondary cosmic radiation produces ionization in its own characteristic manner. The low energy fraction of primary cosmic radiation, trapped by the magnetic field of the earth, becomes part of the inner and outer belts that girdle the globe at two different altitudes.

Energy of radiations

16. The energy of radiation is normally measured in electron-volts (eV) and its multiples, kiloelectron-volts (keV = 10^3 eV), and million electron-volts (MeV = 10^6 eV). It may be emphasized that the electron volt is a unit that may be used for any kind of energy, radiant, thermal, kinetic, etc., although it is primarily used for ionizing radiation.

External and internal irradiation

17. Radiation sources may give rise to external and internal irradiation of living beings. In the former, radiation reaches the body from sources outside it. In the latter, radiation comes from radio-active materials incorporated within the body after ingestion, inhalation, injection, etc.

18. In external exposure, highly penetrating radiations are generally the most significant although, in certain circumstances, hard beta radiation from outside the body may reach important tissues such as the male gonads or the lenses of the eyes. Alpha and beta radiations are usually more significant in internal exposure, since radio-active substances may enter into the metabolism of the organism and become preferentially deposited in particular organs rather than being uniformly distributed throughout the body. In these circumstances, even short range particles can damage these or adjacent organs. *Critical organs* are those for which the effects of radiation, under any given conditions of exposure, are most likely to cause impairment of essential body functions, because of the radio-sensitivity, the level of radiation exposure, or the importance of such organs in body function.‡

Nuclear reactions

19. Radio-active materials occur naturally in the environment, but man has recently been adding to this natural radio-activity by artificially producing radio-active atoms on a considerable scale mainly through two reactions, nuclear fission and nuclear fusion.

20. *Fission* is the splitting of a heavy nucleus into two fragments with release of energy. While with a few nuclei fission may occur spontaneously, it may be induced artificially in a range of heavy nuclei by neutron interaction. As a consequence of fission, two lighter nuclei are produced, accompanied by one or more neutrons. Some of these neutrons may in turn be made to interact with neighbouring nuclei to produce further fissions and, under appropriate conditions, a chain reaction may be started. When the chain reaction occurs quasi-instantaneously, a nuclear explosion is produced. In nuclear reactors, however, the chain reaction is controlled, so that the energy released can be used industrially or for research purposes. The release of substantial amounts of energy by the fission process, whether controlled or explosive, is accompanied by the production of large quantities of radio-active fission products.

21. In *fusion* processes two light nuclei are made to react to produce one heavier nucleus. The total amount of energy that may be obtained is high; few radio-active nuclei are directly produced but their formation is usually accompanied by the emission of neutrons.

22. Neutrons emitted in fusion or fission may react with nuclei in the environment, giving rise to the formation of radio-active nuclides (*induced activity*). In particular, when neutrons are released into the atmosphere they are likely to react with nuclei of nitrogen, and give rise to the radio-active nuclide carbon-14.

Radiation doses and units§

23. *Rad.* When matter, including living matter, is exposed to any ionizing radiation, the resulting effects depend on the energy absorbed in the exposed object. The amount of radiation received by a given tissue is therefore defined as the energy absorbed per unit mass of the tissue; this is called the *absorbed dose* and is measured in *rad*.

‡ The definition of critical organ given here essentially corresponds with the fuller definitions given by ICRP (report of the Commission, 1958; report of Committee II, 1959).

§ Formal definitions are given in annex A.

24. *Roentgen.* In some cases, for instance in medical radiology, the quantity of X- or gamma rays is usually measured in terms of the number of ionizations produced by those radiations in a given mass of air under certain conditions. This quantity is called *exposure dose* and its unit is called *roentgen*. In this report, when the term "dose" is used, it shall be understood to refer to "absorbed dose" except where the possibility of confusion makes it necessary to use the complete expression.

25. *Relative biological effectiveness.* Despite the basic similarity of their interaction with living matter, ionizing radiations of different kinds and energies differ in that the dose required to produce a given biological effect (e.g. cell death or lens opacity) may vary. The relative biological effectiveness (RBE) of one radiation with respect to another is defined as the inverse ratio of the respective doses necessary to bring about a given effect. If, for a certain biological system, the RBE of alpha rays is 10, this means that for such system, an alpha-ray dose of 0.1 rad will produce the same biological effect as one rad of the reference radiation. Conventionally, X-rays within a certain energy range are used as the reference radiation. It must be understood that values of RBE strictly apply only to those conditions under which measurements are made, since the RBE for two given radiations can vary with a number of factors, including the effect being observed, the dose level and the dose rate.

26. *Rem.* For purposes of radiation protection, and the calculation of maximum permissible levels, values of RBE have been adopted for various types of radiation to allow for the greater effectiveness of these radiations in causing harmful effects. The dose in rad multiplied by the relevant RBE factor is termed the *RBE dose* and is expressed in *rem*.||

27. A similar method is useful when it is necessary to compare the biological importance of doses of different types of radiation, or to give a biologically relevant dose for a total exposure to which different forms of radiation contribute. In neither case is it strictly appropriate to use the RBE values that are intended for protection purposes and hence are designed to express the maximum likely effectiveness of a radiation in causing any harmful effect under the conditions of exposure relevant to protection work. Since the RBE of a given radiation may vary according to the type of effect considered, as well as with the dose level, dose-rate, species examined, and various other factors, a special value of RBE should ideally be used for each situation. This would be impossible in the present state of knowledge as well as unmanageable in a general account of radiation effects. For purposes of either comparing or summating doses of different types of radiation, therefore, the RBE factors adopted for protection purposes are used in this report. For all other purposes, e.g. when the effect of any one particular form of radiation is reported (as in chapter III and in annex D), it is more appropriate to quote the absorbed dose directly (in rad) since further assumptions as to the effectiveness of one, relative to other types of radiation, are here unnecessary and irrelevant.

28. *Dose-rate.* Since radiation may be delivered over a varying and sometimes extended period of time, either the total dose over that period may be considered, or the dose delivered per unit time, which is called the dose-rate. The importance of considering both dose-rates and total doses when dealing with protracted irradiations will become apparent later in this report. Dose-rates are expressed in rad, rem or roentgen per unit time (e.g. per minute, per hour, etc.) depending on the dose unit used.

29. *Distinction between activity and dose.* It is essential to bear in mind the distinction between "activity" measured in curies (para. 7) and dose, measured in rad or rem. Activity is defined in terms of the number of disintegrations occurring in the radio-active material in a given time; such disintegrations may be accompanied by the emission of a variety of radiations of different qualities and energies. Dose, however, is a measure of energy absorbed at some given point in tissue.

|| The values of these RBE factors are given in annex A.

Biological aspects

30. Organisms are made of cells, the number of which may range from one (unicellular organisms) to many billions (multicellular organisms). This report deals mainly with multicellular organisms and, unless otherwise stated, the word organism will indicate a multicellular one.

31. In multicellular organisms cells differentiate during embryonic development into tissues, each with a specialized function; different tissues may be assembled to form specific functional and morphological units, systems and organs.

32. While the action of noxious agents affects individual cells, the over-all result of such action has much wider repercussions in complex organisms. These must in fact be viewed as integrated units where each change in any constituent reflects to a lesser or greater extent on the whole.

33. Most cells contain a recognizable nucleus and surrounding cytoplasm. Both nucleus and cytoplasm are highly complex; they contain about 70 per cent water as well as other small molecules such as sodium chloride and more complex molecules. Threadlike structures—the chromosomes—become apparent in the nucleus during division; their number is fixed for each species. The hereditary factors, the genes, are located linearly along these chromosomes. Chromosomes consist mainly of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) associated with protein to form nucleoproteins. DNA is believed to be the essential constituent of the genes, whereas RNA carries the information from nuclear DNA to the cytoplasmic structures. Among these mitochondria and ribosomes, which consist mainly of proteins and nucleoproteins, are the site of intense metabolic activity. Their integrated operation is a condition for normal cell function.

34. Individual organisms generally develop from single cells through binary divisions (mitosis). In bisexual species the original cell, called a zygote, is the product of a process of fusion (fertilization) between two cells, called *gametes*, contributed by male and female, respectively, and originating in the gonads (testes and ovaries). After the first few divisions following fertilization the cellular progeny of the zygote differentiates into different lines. One of these lines eventually

gives rise either to male (sperms) or female (eggs) gametes and is called the *germ line*, all other lines being called somatic. Since the zygote originates from the union between gametes, it constitutes a material bridge between successive generations, whereas the somatic cells of an individual are destined to die when the individual has completed its life-course.

35. The inherited characteristics of cells and organisms are determined by *genes*. They are characterized by an inherent stability which ensures that at each duplication two identical genes are produced. The stability is not absolute, however, and changes of a gene, resulting in an alteration in some hereditary characteristic, can occasionally occur. Such changes are called *gene mutations;* their frequency is increased by a number of chemical and physical agents, ionizing radiations being among the most studied mutagens.

36. Cellular division is accompanied by duplication of the chromosomes and their separation into daughter cells. Radiation damage to the chromosomes themselves may also be observed. These are called *chromosome mutations* or *chromosome aberrations* and consist of breaks of chromosomes and their consequences. Chromosome mutations may also result from unequal distribution of chromosomes during cell division.

37. Somatic cells contain two sets of chromosomes, one inherited through the sperm of the father, the other through the egg of the mother. Since the zygote originates from the union of two gametes, the chromosomes, and therefore the genes, would double at each generation if, during their development, cells of the germ line did not undergo a process of reduction. Cells with two sets of genes thus give rise to gametes having only one set through a sequence of two divisions called *meiosis*. As a result of meiosis one chromosome from each pair, irrespective of its paternal or maternal origin, goes to form a gamete.

38. The gametes, which contain one set of chromo-somes, are called *haploid* cells, whereas germ-cells prior o meiosis (oögonia and spermatogonia) and somatic ·ells, contain two sets and are called *diploid*. The *ploidy* of a cell represents the number of haploid sets of chromosomes contained in its nucleus. Polyploids, cells with loidy higher than two (triploids, tetraploids, etc.) are :nown in some organisms and tissues. Malignant tissues, as a rule, have some cells with chromosome num-ers different from those of normal cells.

39. The distinction between germ cells and somatic ells is important, since injuries produced in somatic ells will be confined to the individual, whereas those ffecting germ-cells can be transmitted to the next gen-rations, and may therefore give rise to hereditary ffects. Since somatic cells give rise to cellular progenies hich can be affected by damage to their genetic mate-al (somatic mutation) and perpetuate such damage ithin the individual, it is evident that "genetic" effects in be produced in both somatic and germ cells. In the esent report the expression "genetic effects" will refer genic or chromosomal alterations irrespective of their curring in somatic or in germ cells. The term "heredi-ry effects" will be limited to those genetic effects that n be transmitted to the next generation.

40. Cells of different organs and tissues differ widely their morphology, metabolism, and proliferative ac-ity. Cells of the nervous system, which divide during e embryonic life, practically cease to do so after birth, ereas the cells lining the digestive tract are continu-y replaced.

41. Also rapid is the renewal of the circulating blood-cells, erythrocytes, leukocytes, and platelets, which are continuously supplied by the blood-forming tissue. Unlike the active blood-forming system which is localized in specific organs, red bone-marrow and lymph nodes, another system associated with it, the reticulo-endothelial system, is present throughout most tissues. One of its main functions is to scavenge the tissues of cellular debris and of particulate foreign substances.

Effects of ionizing radiation on cells

42. Comprehension of the action of radiation on living cells is still far from complete and is limited by lack of knowledge of the normal cellular structures and functions likely to be injured. Cellular radio-biology cannot be separated from cellular biology; any progress in either discipline can be expected to be accompanied by advances in the other.

43. The achievements of biochemistry and biophysics in the past few years have meant a remarkable progress in cellular biology and have enabled us to obtain a better picture of the complex chain of events initiated when cells are irradiated. A detailed discussion of these events is given in annex B. Here only those will be mentioned which are necessary to follow the argument of the next chapters of the report. The main end-effects of irradiation in cells will also be briefly described and an account will be given of the factors which may alter the response to radiation.

44. Radiation-induced injuries are largely non-specific; many other agents, both physical and chemical, are able to cause the same effects as those produced by radiation.

45. The first effects of radiation on living matter are physical, in that they affect atoms and molecules irrespective of their arrangement in living structures.[B 4-9] A result is the splitting of molecules into fragments known as radicals and ions. These fragments are deprived of the chemical stability characteristic of the original molecule.

46. Radicals may interact both between themselves and with unaltered molecules, thus giving rise to new chemical compounds and upsetting the chemical balance of cells.[B 36-93] Since water constitutes about 70 per cent of the cell, radicals arising from the splitting of water molecules are important in the initial chemical changes induced by radiation.

47. All the essential constitutents of cells and in particular complex molecules like proteins[B 62-78] and nucleoproteins,[B 83-88] may be affected through the action of radicals. They may also be injured by radiation directly, however, without the intervention of radicals. The respective role of the direct and indirect action of radiation in bringing about cellular lesions is not yet clear; it is probable that in most effects both modes of action operate.[B 23-26]

48. Radiation damage can also be caused by decay of a radio-active nuclide incorporated into cellular constituents.[B 216-225] The localization of such a nuclide in cellular structures is therefore important. An example is carbon-14, a nuclide with a very long half-life, which decays, on emission of a beta particle, to the stable nitrogen-14. The beta emission may obviously give rise to radiation effects. However, since carbon is a basic constituent of all essential living structures, it has also been suggested that the change of carbon-14 into nitrogen will sometimes occur in a key molecular structure; this change may appreciably add to the effects of the radiation released by that nuclide in the form of beta particles. Although direct evidence regarding the effects of transmutation of carbon-14 is still limited, the local effects of disintegrations have been convincingly demonstrated with other isotopes such as phosphorus-32.

49. Depending on the dose of radiation, processes leading to the synthesis of essential cellular constituents are retarded to varying degrees and may even be completely inhibited; this is particularly true for the synthesis of nucleic acids.[B 116-122] The integrity of these synthetic mechanisms is essential for the maintenance of morphological structures and for ensuring growth and division of cells. Inhibition of mitosis is, in fact, one of the earliest effects of irradiation, but probably most cellular functions and structures are to a greater or lesser extent impaired by radiation.[B 166-177] Cellular death is an over-all and ultimate result of irradiation; it can be brought about by different mechanisms, and has in some cases been ascribed to nuclear damage, in the form of chromosome breaks.

50. Chromosome breaks sometimes repair through rejoining of the broken ends shortly after the breakage event; however, a proportion fail to repair. Fragments of chromosomes may be lost if cellular division takes place before healing; then the damage becomes permanent.[B 207-216] Certain rearrangements of chromosome material through union of broken ends in new combinations may likewise cause death at cell division (para. 57).

51. The particular effectiveness of irradiation of the nucleus as compared to that of the cytoplasm might be due to the fact that the nucleus contains the chromosomes, each of which usually occurs only once or twice per nucleus. Cytoplasmic structures on the other hand normally occur in great numbers so that the elimination of one or more of them may be of less consequence. The role of cytoplasmic damage should however not be discounted, since such damage can be held responsible for some cases of cellular death. It is, however, much more difficult to prove, as only exceptionally do radiation-induced morphological changes in the cytoplasm become apparent. Yet, the mere fact that metabolic processes are always affected by radiation, and that most of these processes take place in the cytoplasm, suggests that cytoplasm may have more critical importance than suspected.

52. Extensive quantitative work has been done on the dependence of the frequency of cellular death on dose.[B 10-20] When a cell population is exposed to radiation, a fraction only of the cells becomes unable to reproduce, the size of the fraction depending on dose. It is not predictable whether an individual cell will fail to reproduce, but the proportion of deaths reflects the probability that individual cells may be killed. At low doses proportionality between dose and fraction of cells killed is frequently seen, but sometimes more complex situations arise. In any case, however, the proportion of affected cells increases with increasing doses.

53. The relationship between dose and effect is being studied at lower and lower doses for a number of radiation effects. Since the frequency or the degree of any effect is directly related to the dose, effects at very low doses are very small and may be demonstrated only when very large numbers of cells are irradiated. The possibility of detecting effects at the lowest doses has therefore practical limitations determined by the size of the experiment that would be necessary to reveal them. The detectability decreases with the dose, since at very low doses the frequency or the degree of any effect becomes so small as to require unmanageably large numbers of cells to become apparent. Radiation-induced lysogenesis (the release of bacterial viruses from bacteria which do not normally release them) is detectable at doses as low as 0.3 rad.

54. The dose of radiation necessary to produce a given effect in a given fraction of different cellular populations is inversely related to their relative sensitivity. When the effect investigated is cellular death, the nature of the cells (protozoa and bacteria are more resistant than mammalian cells), the size of the nucleus (in a number of plant cells sensitivity is related to the volume of the nucleus) and ploidy (haploid cells have a sensitivity different from diploid cells) are among the various cellular factors which affect sensitivity.[B 178-188]

55. Sensitivity is also related to physiological conditions of the cells. Thus, bacteria grown in complex, nutritionally rich media are often more sensitive than cells grown in simple media.

56. Various factors influencing the development of radiation effects are known.[B 94-110] Cell sensitivity varies with the temperature and moisture content of the cells; it is also modified by a number of chemical factors that may raise or decrease sensitivity. Among those which reduce sensitivity, lack of oxygen is the best known, most radiation effects arising at higher doses or becoming less pronounced when cells are poorly oxygenated. Certain chemical compounds, on the other hand, when applied before or during irradiation, are able to some extent to protect cells from radiation damage. Those chemicals may act by reducing the amount of oxygen available to cells or by competing with radicals produced by the irradiation. Their study is important since it may lead to methods of reducing radiation injury in man.

57. One of the major effects of radiation is the production of genetic damage.[B 189-228] This can be caused by two different mutational mechanisms, chromosome mutation and gene mutation. The former is the consequence of chromosome breaks. When two or more breaks are produced in the same or in different chromosomes, the unions which may occur frequently involve alterations of the original sequence of genes. Alteration of the gene sequence as well as loss of parts of chromosomes or even of whole chromosomes often leads to cellular death. In some cases, however, the chromosomal damage is transmitted to daughter cells.

58. The nature of gene mutations has been greatly clarified by studies on bacteria and viruses. Nucleic acids, along which genes are arranged within chromosomes, consist of a sequence of elementary units in various specific permutations. Changes in the sequence of these units result in mutation.

59. The mechanism of mutation is, however, far from being understood. Studies in lower organisms have shown that mutation is a complex process going through a first stage in which the damage may, at least to a limited extent, be reparable and only after a certain time become irreversible.

60. Like all radio-biological effects, the induction of mutations is dose dependent and is proportional to the dose down to the lowest levels investigated so far. The proportionality factor, however, has been shown to vary with the dose-rate in a number of species, as will be discussed in chapter IV.

CHAPTER III

SOMATIC EFFECTS

1. This chapter discusses the effects of partial and whole-body irradiation on man. Since observations in man are few, they will be supported by, and interpreted in the light of, information from animal experiments.

2. Owing to interrelationships between parts of the organism, damage to an individual organ may induce effects in other organs or even in the whole organism. Repair mechanisms may play a major role, replacing damaged cells or tissues through regeneration of surviving cells, but complete recovery may be only apparent and residual injury may emerge long after irradiation.

3. The somatic effects of ionizing radiations in man and in animals are mainly determined by physical factors such as the nature of the radiation, the absorbed dose, its distribution in time (instantaneous irradiation, fractionated, protracted for shorter or longer periods) and its spatial distribution, in particular the extent to which the body is exposed.[D 1-11]

4. In assessing susceptibilities various end points can be used; and the apparent radio-sensitivity of a tissue or organ depends on the method of observation. Sensitivity depends on age at the time of exposure, children being more susceptible than adults.[D 21-28]

5. The initial effects produced by radiation may lead to clinical effects expressed promptly or months or years after irradiation depending not only on the nature and extent of the initial radiation injury, but also on secondary factors, such as hormonal influences, exposure to other carcinogens, nutritional and other host factors. Animal experiments suggest that even viruses may be such co-factors in carcinogenesis, but no human cancer has thus far been linked to a virus.

6. It is not possible to distinguish sharply between early and late effects since effects observed soon after radiation may persist. Nevertheless, it is convenient to consider as *early*, such effects as are observable within a few weeks after exposure. *Late* effects are those that appear many months or years later and are not always obviously related to the early effects.[D 12-14]

Early effects

7. All organs and systems in man and animals can be temporarily or permanently affected by irradiation. Injury to blood and blood-forming organs, to the alimentary tract and to the nervous system are the most critical in determining the possibly fatal outcome of total body irradiation.

8. The clinical course of acute radiation injury in man is well known from observations on individuals exposed to large doses of radiation. Evidence from the irradiated populations in Hiroshima and Nagasaki and in the Marshall Islands, from subjects irradiated therapeutically or in the course of laboratory accidents with critical assemblies, as well as animal data indicate that the best estimate of the median lethal dose (LD 50) for man is 300 to 500 rad (short-term total body radiation; the actual value depends on the type and distribution of the radiation). This does not mean that man can tolerate this amount of radiation, since all individuals exposed to this level would have serious symptoms and 50 per cent would die. It must be stressed that the results of exposure to 200 rad short-term total body radiation may sometimes cause death.

9. When individuals are exposed for a short period of time to high doses of penetrating radiation the injury to the organism may take three different forms, depending on the dose received. With doses of several thousand rad, the outcome is fatal within hours and the clinical picture is predominantly neurological.[D 199]

10. Between 500 and 2,000 rad of total body radiation, gastro-intestinal symptoms predominate.[D 200] They usually develop within a few hours, may then subside for a few days and then recur suddenly, leading to death within about one week.

11. With doses between 100 and 500 rad given within a short time, gastro-intestinal symptoms may develop within a few hours, followed by apparent recovery. Conditions worsen, however, within a period of about three weeks, when the first signs of injury to the blood-forming organs begin.[D 202] Damage to the blood-forming organs may cause bleeding and increase susceptibility to infection. When appropriately treated with general supportive therapy, patients may recover.

12. Other organs and systems are always involved concomitantly with those whose damage is or may be conducive to death. Not all observed changes are morphological; functional effects also occur, e.g. modification of conditioned reflexes in animals given local doses to the head as low as 5 rad.[D 90]

13. The radiation pathology of individual tissues and organs was dealt with extensively in the 1958 report and is again reviewed in annex D of the present report. No detailed account will therefore be given in this chapter.

Late effects

14. The difficulties in the study of the late effects of radiation are in part due to the long interval of time that may elapse between irradiation and clinical manifestations, sometimes making it difficult to establish the connexion between the effect and its cause. They are also due to the lack of specificity of the effects.

15. The late effects are, in fact, usually indistinguishable from diseases induced by other causes, and radiation only increases their incidence in the population. The causal relationship between irradiation and a possible late effect in man can only be established in individual cases from circumstantial evidence together with evidence derived from the observed induction by irradiation of similar effects in experimental animals. Large-scale human surveys may confirm in man the association between given late effects and irradiation.

16. Such surveys must be carried out on sufficiently large irradiated populations to ensure that the observed, and always small, number of individuals showing the effect under study is high in a control, untreated but otherwise similar, population where the incidence of that effect may vary owing to chance alone. When the increase in incidence of the effect in the irradiated population is higher than can be accounted for by chance fluctuations, the increase is said to be statistically significant.

17. In considering populations irradiated for medical reasons, difficult problems may arise in excluding the possibility that the disease which has prompted the irradiation is by itself responsible for an increased incidence of the effect, in which case the association between the effect and the irradiation could be misleading.

18. The main late effects comprise:

(*a*) Many types of neoplasms, including leukaemia;

(*b*) Local effects on tissues;

(*c*) Changes in the life-span;

(*d*) Effects on growth and development.

Incidence of leukaemia after radiation[D 241-286]

19. In all countries for which mortality data are available, the recorded death-rates from the various forms of leukaemia (malignant proliferation of some of the blood-forming cells) have been rising since the turn of the century. Recent statistics, however, show a perceptible and consistent decline in the rate of increase of these diseases in the United States since 1940. If this trend were to persist, the incidence could eventually stabilize or even decline. A similar trend has been noted in Japan, but at later time periods. It will be necessary to verify the uniformity of this phenomenon by data from other countries.

20. While the cause of the increased incidence of leukaemias is unknown, the recent reduction in the rate of increase appears to discredit the hypothesis that the growing exposure of human populations to radiation is the major factor responsible for the increase.

21. The relationship between external irradiation and the occurrence of leukaemia in man, first suspected when its increased incidence among radiologists was noticed, is now established by two continuing studies: the incidence of leukaemia among survivors of the atom bombs in Hiroshima and Nagasaki and among ankylosing spondylitis patients given X-ray therapy. Very few data are yet available on the induction of leukaemia by internal irradiation in man even at high doses, but this phenomenon has also been described in experimental animals.

22. Two major and closely related questions are: what is the relationship between dose and incidence? Is there a dose of radiation (threshold dose) below which leukaemia will not be induced?

23. The studies on the irradiated populations in Hiroshima and Nagasaki[D 240-288] are particularly important because the populations involved are very large and are not selected on the basis of age, physiological conditions, incidence of previous diseases or occupational habits.

24. Since the first report of the Committee, a number of new cases of leukaemia have occurred among these populations. It now seems that the incidence, after having remained fairly constant for a number of years, is declining.

25. Despite continued investigation, the doses received can only be inferred from the distance of the survivors from the hypocentre of the bombs. The doses, therefore, are highly uncertain, and this uncertainty reflects on the dose-effect relationship. The data are not inconsistent with the hypothesis of simple proportionality (linearity) between dose and incidence. However, because of the small number of cases occurring at doses below 100 rad, various other hypotheses can be envisaged.

26. The investigation of the incidence of leukaemia among irradiated patients treated for ankylosing spondylitis[D 264-282] also shows a clear dependence on dose, and the data are not incompatible with a linear relationship between dose and effect. The validity of these results is limited, however, both by the limited number of observed leukaemias and by the fact that the probability of developing leukaemia after irradiation among spondylitics may not be the same as for the general population. In any case, this study does not provide evidence of an increase in the incidence of leukaemia following doses below 500 rad.

27. Neither investigation, therefore, can definitely answer the question as to the nature of the dose-effect relationship; nor can they answer the further question as to whether the association between radiation and leukaemia occurs below a certain dose. Whatever the dose-response curve at higher doses, it is impossible either to establish or to exclude the possibility that a critical dose might be required before irradiation brings about the morphological and functional cell derangements responsible for inducing leukaemia.

28. In the ankylosing spondylitis as well as in the Hiroshima and Nagasaki surveys, no statistically significant difference can be shown between the observed incidence of leukaemia at the lowest doses investigated and what would be expected if the incidence was the same as in the general population. This cannot be construed as evidence for the existence of a threshold, since the absence of difference may only reflect the fact that the increase in the incidence of leukaemias at low doses is too small to be detected.

29. Experiments to provide critical information concerning dose-response relationships, mechanisms of radiation carcinogenesis and protection against radiation in whole organisms can only be done with animals, but their usefulness is limited by the difficulty of making valid extrapolations from one species to another, particularly to man from animals with a much shorter life-span. Extrapolations should, in any case, be made only from a species in which meaningful data can be obtained. Each type of mouse leukaemia, for instance, should be considered as a specific disease, and inferences and data drawn only from those truly analogous to diseases in man.

30. Since so little is known about the effects of low dose-rates, great care must be exercised in inferring, from the available experimental, or human data, the effects to be expected from irradiation due to those artificial nuclides that are being released into the environment. While the importance of the very low dose-rate to which they give rise may be great, it is difficult to evaluate, since their effect cannot be studied experimentally

owing to the unmanageably large numbers of animals required.

31. An increase in leukaemia and other forms of malignant disease has been reported in children irradiated *in utero*, as a result of pelvic X-ray examination during the mother's pregnancy.[D377-384] The dose of radiation may have been ~ 1-10 rad. These results and those of several other studies are equivocal. Results obtained from a different type of study have shown that the incidence of leukaemia in children born of 40,000 mothers irradiated during pregnancy was no greater than that expected among children in the population in general. Although the question remains open, it is a possibility that embryonic and foetal tissue is more susceptible than adult tissue to the induction of leukaemia following irradiation.

Other malignancies

32. Data from irradiated animals and man indicate that malignant tumours may be induced by radiation in most tissues, provided the dose is sufficiently high.

33. Radiation-induced tumours often take long to develop, and need not be preceded by observable morphological changes in the cells at the site of origin of the cancer. Radiation can also induce malignant disease through indirect mechanisms. Pituitary tumours, for instance, can be observed in mice not as a result of irradiation of the hypophysis but as a consequence of radiological destruction of the thyroid.[D149] The role of indirect mechanisms has also been shown in the induction of ovarian and thymic tumours in mice.

34. Most animal experiments, usually performed with relatively homogenous populations, have shown that there are dose levels where no increase in incidence of certain neoplasms can be detected. As in the case of leukaemia, this cannot be interpreted as evidence for the existence of a threshold. On the other hand, in the induction of at least one type of tumour in rats, minimal effective dose-levels are extremely low, so that there may be practically no threshold for the induction of tumours. In some of these experiments, the dose-effect relationship seems to permit extrapolation to zero. A difficulty with short-lived laboratory animals is that at low doses the average period required for manifestation of the tumour may exceed the life-span and hence no effect may be seen.

35. Most of the data on the induction of neoplasms by radiation in man have involved extremely high doses. Thus, skin cancers have appeared with low incidence in man after local irradiation in the range of 1,000 rad per year after prolonged latent periods of fifteen years or more.

36. Since the first report, preliminary data on the Japanese survivors of the atom bomb have become available,[D387-388] indicating an incidence of some forms of cancer other than leukaemia higher than in the non-exposed population. The increase is highest among those who were closest to the explosions. Because the latent periods of induction of most tumours are long, data are not yet available that would indicate whether this increase in the incidence of malignancies will persist, rise further or decline.

37. Data on the induction by radiation of bone tumours in man—chiefly osteogenic sarcoma, probably originating from those bone-forming cells that line bone surfaces—have been obtained from occupationally irradiated radium dial painters, patients treated with radium salts for therapeutic purposes, and patients given X-ray treatment of bones, particularly for benign or inflammatory lesions. Again, the latent periods for tumour induction are long and the dose, where known, is high, the local doses being of the order of hundreds of rad or more.

38. Assessment of the risk of carcinogenesis, including leukaemia, at low doses of radiation requires a consideration of possible mechanisms of carcinogenesis.[D146-158] In the present stage of our knowledge, nothing can, however, be said about the mechanism of radiation carcinogenesis without indulging in speculation. Various hypotheses may be formulated to account for the induction of tumours by radiation. Somatic (gene or chromosome) mutation, the action of latent viruses, differentiation anomalies, are among the possible mechanisms through which radiation could give rise to malignancies. To show how different hypotheses might lead to different dose-effect relationships at low doses while giving similar responses at higher doses, two hypothetical mechanisms of induction of tumours by radiation will be discussed. These have no particular merit in themselves but are described for their simplicity and because they point out the possible fallacies involved in applying to low doses dose-effect relationships observed at higher doses.

39. If radiation induced tumours through somatic mutation, it would be reasonable to expect proportionality between doses and corresponding incidence of tumours down to the lowest doses (no threshold). It is further conceivable that the number of tumours per unit dose may be less than anticipated at low doses, if the mutated cells are too few to develop into a tumour. But it is also conceivable that with such a mechanism low doses might give a higher incidence of tumours per unit dose, since higher doses might kill the majority of mutated cells. Alternatively, it could be assumed that irradiation first involves general tissue damage and that the tumour only arises in the secondary stage of tissue repair. Again, there is the possibility that the production of tumour cells is due to somatic gene mutation, arising indirectly as a result of the increased proliferation that accompanies the repair process. There might thus be a critical level of radiation below which the damage would be too limited to stimulate, during the repair stage, proliferation of such an extent as to give an opportunity for the occurrence of a mutation.

Lens opacity[D289-307]

40. Exposure of the optic lens to radiation may be followed by lens opacities. Normally, doses greater than 500 rad of X-rays are required to produce clinically significant cataract, but lens opacities have been reported after as low as 200 rad of mixed gamma and neutron irradiation. In most cases, lens opacities developed after a latent period which showed little relation to dose and duration of treatment. Radiation-induced lens opacities are slowly progressive for a long time, but they may remain stationary at any stage, or regress. For chronic irradiation, neutrons seem to be much more cataractogenic than X- or gamma rays.

Induction of sterility[D308-315]

41. The effects of irradiation on gonadal tissue are now fairly well known both in experimental animals—mice, dogs and monkeys—and in man. In all species, the effects are basically similar but differences are observed, due to the differences in the transformations that germ cells undergo during maturation in different species.

42. Gonadal doses causing sterility are similar for both sexes. Single local doses around 150 rad may induce brief lowering of fertility, doses around 250 rad induce temporary sterility for one or two years; at about 500 rad permanent sterility is obtained in many individuals and prolonged temporary sterility in others. At 800 rad recovery of fertility is extremely unlikely.

43. The data on which these estimates were made are rather limited. They are confirmed by observations on individuals exposed to radiation from atom bomb explosions in Japan and from certain radiation accidents. These observations show that whole-body irradiation in the range between 400 and 600 rad does not have a permanent effect on fertility.

Longevity[D113-140, 332-339]

44. Animals having survived substantial or nearly lethal doses of radiation have an average lifetime shorter than controls, the life-shortening depending on the kind and amount of tissue irradiated (for partial body exposure) as well as on the dose. Under continuous irradiation at dose-rates as high as 0.5 rad per day, no difference in life-span between irradiated and control animals is, however, detectable with experiments of the size used so far.

45. Irradiated animals develop some of the diseases prevalent in their species earlier than non-irradiated ones and deteriorate sooner, showing physiological and histopathological changes suggestive of early senescence. The radiation-induced shortening of life-span is conditioned by several factors. Some species are more likely to show the effects than others; within a species, strains with different genetic constitutions have their life-span decreased in various amounts.

46. It is not yet clear how much of the reduction in longevity is due to an increased incidence of radiation-induced diseases and how much is accounted for by premature aging. The difficulty arises both from the lack of rigorous definitions of senescence and its progress, and from the necessity of observing animals for the duration of their lives.

47. Information on life-shortening effects in man is still inadequate. Mortality rates of United States radiologists are slightly higher than in the general male population, but the difference is not supported by the analysis of mortality of British radiologists. These differences may be due to different radiological practices. The survivors of Hiroshima and Nagasaki have so far shown no detectable shortening of the life-span, but it may be that not enough time has elapsed since the exposure as compared to the normal human lifetime.

48. Attempts to assess the risk of life-shortening by low doses in man meet the same difficulties and necessitate the same considerations as those entailed in the assessment of possible carcinogenic effects from low doses. The problem of extrapolation of animal life-shortening data to man is difficult because of the lack of data on life-shortening for large animals with life-spans intermediate between man and rodents. Life-shortening in man as a consequence of short-term irradiation of the whole body at doses higher than 200 rad would not be surprising, but the effects of long-term, low-level irradiation on the human life-span cannot be predicted.

Effects on embryos and foetuses[D170-191]

49. The effects of radiation on embryonic tissues are especially important because even a minor irreversible injury in an embryo may be amplified in the course of development and thus give rise to major anomalies. Susceptibility of embryonic tissue to radiation is high but probably not higher than that of actively dividing adult tissues. When mouse embryos are irradiated at a dose as low as 25 rad, 40 per cent of the embryos are killed. Irradiation of experimental animals may, at a later stage, be followed by the development of malformations. Similar observations have been reported in man; the most frequent defects involve the central nervous system, the eye and the skeleton.

50. The possibility of inducing somatic effects in foetuses at doses within the ranges of X-ray pelvic examinations (several rad) is shown by the recent observation of an increased incidence of anomalous distribution of pigment in the iris of children which had been irradiated *in utero* during such examinations of the mothers. This harmless anomaly may perhaps be attributed to a somatic mutation—either genic or chromosomal—occurring early in the embryonic development.

Conclusions

51. Since 1958, no new data have emerged which would warrant substantial modification of the views expressed in the last report. The new data have not disproved the assumed proportionality between dose and effect that was used for estimating risks at low doses, but they have in fact made it apparent that such a relationship may not hold at doses lower than those which have been investigated. It is also now more fully realized that somatic effects are less likely to occur at low dose-rates than at the high dose-rates employed in many experiments.

52. Short of obtaining adequate data on the frequency at low doses of such deleterious effects of radiation as leukaemia and other malignancies—and this will involve extensive human surveys and animal experiments—the use of any relationship to predict effects at low doses will, in fact, imply assumptions on the mechanisms through which specific radiation injuries are brought about.

53. In the present state of our knowledge, any such assumption would be largely speculative. The only justifications for applying to low doses relationships observed at higher doses, therefore assuming that there is no threshold for the induction of malignancies, are the expediency of the procedure and the consistency of the assumptions regarding mechanisms in both dose ranges. We do not know, however, whether in so doing the risk is underrated or overrated.

54. Although more information is required before firm conclusions can be drawn, there is evidence indicating that embryos are more susceptible to radiation injuries than adults and that even low doses may induce both developmental disorders and malignant changes in embryos. Further studies on the effects of radiation on foetuses exposed *in utero* are therefore crucial.

55. Search should be intensified for carcinogenic agents in the environment besides radiation. To assess the importance of radiation in carcinogenesis, radiation hazard must be placed in the perspective of agents that are understood at least as well as radiation.

56. Laborious though it may be to make observations on the effects of low doses on large human populations, such observations will be invaluable in complementing and confirming extensive animal experiments. Any large-scale investigation, however, especially in man, requires accurate planning to ensure that there is a reasonable likelihood of obtaining meaningful results. Both clinical, and vital and health statistical studies of sufficiently large populations living in areas of different radiation background, of the survivors of Hiroshima and Nagasaki, of persons receiving radiation for medical purposes and of occupationally exposed persons require continued support and prompt reporting.

CHAPTER IV

HEREDITARY EFFECTS

1. Genes are the determinants of the inheritable characteristics of organisms, and are characterized by an inherent stability which ensures that at each duplication two identical copies are produced. This stability is not absolute, however, and a sudden and fortuitous change of a gene, and therefore of the character which it determines, can occasionally occur. Such changes are called *gene mutations* and their frequency is increased by a number of chemical and physical agents. Of these, radiation is one of the best known.

2. It will be recalled from chapter II, paragraph 37, that cells of the germ line are diploid until they undergo reduction during meiosis and thus become haploid gametes. Depending on whether their diploid cells carry identical or different genes at a given site (locus) on a given chromosome pair, individuals are called *homozygotes* or *heterozygotes* for that locus, respectively—in other words, if A and A' are two different genes (i.e., alleles) which can occupy the same locus, then AA and A'A' individuals are said to be homozygous, whereas AA' individuals are said to be heterozygous. Heterozygous individuals may show the traits determined by either gene, or an intermediate trait. The gene which manifests itself more strongly in the heterozygote is called dominant, the other recessive.

3. The distinction between dominant and recessive genes is essential for an understanding of the hereditary effects of radiation. Mutations which give rise to dominant genes (dominant mutations) are expressed in the first generation offspring of the subject in whose germ cells the mutation has occurred. Recessive mutations, on the other hand, can become apparent in the offspring only if the offspring receives the same mutation from both parents, and this may take many generations to occur, unless the parents have one or more common ancestors, in which case it is likely to happen sooner.

4. Human diploid cells have forty-six chromosomes. Of these, twenty-two pairs (autosomes) are alike in both sexes. Another pair consists of the sex chromosomes which are alike in females but different in males. This is because all the eggs possess the same set of chromosomes, one of which is known as the X-chromosome. Sperms on the contrary are divided into two classes according to whether they possess an X-chromosome or, alternatively, a Y-chromosome, shorter than the X. Male gametes are called X- or Y-sperms depending on the sex chromosome which they carry, the two categories being produced in approximately equal numbers. Fertilization of an egg by an X-sperm will result in a zygote with two X-chromosomes which will develop into a female organism. Zygotes resulting from the union of an egg with a Y-sperm will develop into males.

5. In man and mouse, and possibly in all mammals, the Y-chromosome seems to have the principal role in determining sex, since it has recently been discovered that exceptional individuals carrying only one X-chromosome are predominantly female in their characteristics whereas other exceptional individuals who carry two X-chromosomes and one Y-chromosome are phenotypic males, contrary to what is observed in the fruit fly *Drosophila melanogaster*. Sex chromosomes also carry genes determining other traits, although at least in man no such gene is known beyond question to be carried by the Y-chromosome. On the other hand, some thirty loci have been identified in the X-chromosome, where specific mutations determine grossly harmful traits.

6. Characters controlled by genes located on a sex-chromosome are said to be sex-linked. The fact that females carry two X-chromosomes whereas males have only one accounts for the special mode of inheritance of sex-linked characters. Well-known examples are haemophilia and colour blindness.

Natural mutation frequencies

7. Mutations are said to occur naturally or spontaneously when their production results from conditions usually not under the direct control of man.[O62] The fact that mutations are rare events makes any estimation of their frequency of occurrence difficult and uncertain. Under ideal conditions dominant mutations would lend themselves to reasonably accurate estimations, since it would be sufficient to count the affected individuals born of unaffected parents.[C38] In practice, however, diagnostic difficulties and those of ruling out morbid conditions simulating a given hereditary trait may cast doubt on the reliability of the estimates. The situation is even more difficult with recessive gene mutations when most of the genes are hidden (carried by but not manifest) in heterozygotes. Indirect methods when used rest on assumptions which are often not easy to verify.[O63] The average frequency of occurrence of gene mutations per locus per generation—the mutation rate—may differ from one strain to another and within each species the mutation rate at individual loci also varies.[O63]

8. Various methods are available and have been used to estimate the frequency of occurrence of mutations affecting specific traits.[C33-44] The similarity of their results makes it reasonable to assume that the average mutation rate in main is about 1/100,000 per locus per generation. This frequency, however, may not be representative of all the mutations arising in man, but only of those which have been detected.

9. The causes of natural mutations are largely unknown. Various environmental factors, both chemical and physical, including natural radiation, might be responsible for their occurrence, but very little is known about their relative importance. It has been shown, however, that natural radiation cannot account for more than a small fraction of natural mutations in man.

Radiation-induced gene mutations

10. When the germ cells of an organism are exposed to radiation, mutations may arise which can be trans-

mitted to the offspring and their descendants. It is not possible, however, to say whether a given mutation occurring in an irradiated individual has been induced by radiation or has occurred spontaneously. The over-all frequency of mutations is always increased by irradiation, and their relative frequency at different loci may not be the same for those of spontaneous and induced origin.[O190]

11. Changes in frequency depend on such considerations as the stage of germ cells irradiated, the dose of radiation absorbed by the germ cells and the rate of delivery of the dose of radiation. However, for any single locus increases in frequencies are small, even with the highest doses possible in experimental animals. The study of radiation-induced mutations therefore necessitates the use of large numbers of animals observed over many generations. In man not only is experiment seldom possible but the intervals between generations are long.

12. Knowledge of the nature of the relationship between dose and mutation frequency is of crucial importance to understand the effect of radiation on hereditary material. From experiments on mature germ cells of animals, especially spermatozoa of *Drosophila melanogaster*, it appears that when they are exposed to radiation the mutation frequency is directly proportional to, and depends alone on, the total dose absorbed by the gonads.[O86] These results formed the basis of the assumptions on which the conclusions of the first comprehensive report rested. The proportionality factor was expressed in terms of doubling dose—namely the dose of radiation that is required to double the natural mutation frequency in a species.

13. Recent studies, while confirming that the assumptions were correct with regard to spermatozoa, have shown that the dose-effect relationship is more complex for other cellular stages in the germ-line. The new evidence comes mainly from observations on irradiated mice,[O88] but has also been confirmed in other animal material.[C84]

14. It appears from these observations that when immature germ cells (spermatogonia in males and oöcytes in females) are irradiated, the results are not inconsistent with the hypothesis of proportionality between dose and mutation frequency observed with irradiated spermatozoa in *Drosophila*. The proportionality factor, however—and therefore the doubling dose—varies both with the stage of the irradiated germ cells and with the rate of delivery of radiation. The same total dose induces fewer mutations when it is given at low dose-rate than at high dose-rate.

15. The effects of irradiation on spermatogonia and oöcytes are particularly important under conditions of continuous exposure at low dose-rates such as those delivered by sources to which human populations are exposed (e.g., natural sources and fall-out from nuclear explosions). The spermatogonia continue to multiply during the whole reproductive life, some of them giving rise, through meiosis, to mature sperms. Oöcytes, derived from oögonia in the course of embryonic life, remain in a particular stage of the meiotic process until just before ovulation. Sperms and ova survive only for a few weeks if they do not take part in fertilization. It is therefore apparent that, under continuous exposure, the total dose accumulated in sperms and ova is much lower than the total dose accumulated until the end of the reproductive life by both spermatogonia and oöcytes.

16. The mechanisms responsible for the dependence of the mutation rate on the dose-rate have not been elucidated. It has been suggested, however, that at low dose-rates part of the damage caused by radiation to the genetic material can undergo a process of repair.[O87] At higher dose-rates, the mechanisms leading to repair could be impaired or inhibited, thus making the exposure more effective in inducing mutations.

17. The evidence for the existence of repair processes has been considerably strengthened by recent investigations.[C88-92] These have shown that in lower organisms and in *Drosophila* a finite period of time elapses before radiation damage to the genetic material becomes irreversible. Treatment with various agents interfering with the metabolism of the irradiated cells during that period can prevent the fixation of at least part of the premutational damage.

18. It should be stressed, however, that none of the experiments carried out so far leaves any doubt as to the effectiveness of radiation in producing hereditary damage even at the lowest doses and dose-rates which have been investigated. At the time of the 1958 report, few experiments had been performed in the low ranges of doses and dose-rates. Since then, geneticists have consistently found both in mammals and other animals that the frequency of mutations is affected by radiation throughout the range of doses and dose-rates investigated.

Chromosomal aberrations

19. Like gene mutations, chromosomal aberrations may occur in cells either spontaneously or as a consequence of the action of the same agents which induce mutations. Whereas gene mutations may be considered as changes of the genes themselves, chromosomal aberrations may consist of duplications or deletions of part of, or of whole, chromosomes, transfer or exchange (translocations) of segments of chromosomes or even inversions of the sequence of genes along one or more chromosomes. Addition or loss of a whole chromosome usually arises through unequal distribution of the chromosomes during division.

20. Although chromosome aberrations have been known for a long time to occur spontaneously both in plant and in animal cells, very little attention was paid to them in the first report since no hereditary defects in man had yet been traced to chromosome aberrations. Progress in cytology and in the culture of human tissue cells[C67-70] has since made it possible to establish the normal human karyotype (chromosome number and form) and to detect abnormalities.

21. In 1959, some of the most important discoveries were made in human cytogenetics, which showed that Down's syndrome (mongolism), Turner's syndrome and Klinefelter's syndrome (both of which involve alterations of the sex characters) are due to chromosome aberrations. In Down's syndrome, one supernumerary autosomal chromosome is observed.[C21] In Turner's syndrome, the individual is an abnormal female who carries only a single sex chromosome, the X-chromosome;[O22] and in Klinefelter's syndrome the subject, an abnormal male, carries two X-chromosomes and one Y-chromosome.[C22]

22. The mode of inheritance of chromosomal aberrations in man is not essentially different from that of dominant gene mutations.[O67-70] Many of the chromosomal aberrations so far observed in man have been accompanied by complete sterility, which precludes transmission of the anomaly. However, individuals with Down's syndrome can be fertile and some with Turner's syndrome have had offspring. Furthermore, such aberrations as translocations are transmitted and can lead to the occurrence of abnormalities in the progeny of apparently normal and fertile individuals.[O24]

Frequency of chromosomal aberrations

23. Since 1956 technical advances have been made which permit a much more accurate study of human chromosomes. As yet, however, relatively few estimates of the over-all frequency of anomalies are available. Since, however, Down's and Klinefelter's syndromes are each known to have a frequency of about 1/500 at birth, it is considered as not unreasonable to estimate that 1/100 of all live-born children carry some chromosomal aberration.[C28 29]

Radiation-induced chromosomal aberrations

24. Aberrations involving deletions or duplications of whole chromosomes occur spontaneously and have also been observed as a consequence of irradiation in *Drosophila* and mice. In the mouse, it has been shown that the frequency of chromosome loss, and the mechanism through which it occurs—namely, chromosome breakage or unequal distribution of chromosomes during division—are markedly dependent on the irradiated cell stage.[C108-111]

25. When the anomalies concern sections of chromosomes only, the prerequisite for their occurrence is one or more breaks in one or more chromosomes. It has been shown that the frequency of detectable single breaks is proportional to the dose. As with gene mutations, their frequency is always rather low and here the possibility of restitution through rejoining of the free extremities of the broken chromosomes is well established. Furthermore, in order that complex chromosomal aberrations may be obtained—translocations, for instance—two chromosome breaks are required simultaneously and the probability that this occurs is much lower. In any case it leads us to expect a lack of simple proportionality between frequency and dose.[O106]

26. Some chromosome anomalies, unlike mutations, are often microscopically visible, and can be studied in the laboratory even on human material. By irradiating human and other cells grown in cell and tissue cultures, the effects of radiation on chromosomes as well as the dose-effect relationship can be studied.[C112-117] Dose-effect relationships for the occurrence of chromosomal anomalies as derived from study of somatic cells *in vitro* cannot at present be applied to germinal tissues *in vivo*.

27. Studies on *in vitro* production of chromosome anomalies are of great value in showing differences in sensitivity of different animal species to radiation-induced chromosomal damage. Preliminary results on mammalian cells, including human cells, have been obtained, but these do not yet make it possible to decide how human cells compare in this respect with cells from other species.

Effect of mutation in animal populations

28. When a new mutation is transmitted for a few generations, according to the laws governing heredity and in the absence of other factors which will be discussed later, there will be present in the population a fraction A of individuals homozygous for the mutant gene, a fraction B which is heterozygous for it and a fraction C which does not carry the gene. Depending on the dominance of the mutant gene, fractions A and B, or only fraction A, will show the character for which the gene is responsible.

29. When the mutant gene is incompatible with the survival of the individual there are several possible outcomes. If the gene is completely lethal, even in the heterozygotes B, then the condition will not be transmitted, because all who receive it will die. If it is not completely lethal in heterozygotes, then occasionally it will be transmitted through one or more generations. A good example is retinoblastoma, a dominant gene-determined tumour of the eye, which is usually fatal in childhood. Sometimes the tumour retrogresses, however, or may be removed by surgical treatment, thus allowing the individual to grow up and transmit the gene. Dominant mutations less severe in their effects may be transmitted through more generations, e.g. those determining dystrophia myotonica or acholuric jaundice.

30. When the mutant lethal gene is completely recessive, heterozygotes can live and reproduce, whereas homozygotes only are eliminated. The gene will therefore not be eliminated at once but will be maintained for a period of time in the population and its eventual elimination will be completed after a very large number of generations, unless the same mutation is continually produced, so that the frequency of the gene in the population will reach an equilibrium value determined by the mutation frequency. Many severe traits in man are caused by genes which fit the above description. Good examples are phenylketonuria and galactosaemia; both are disorders of metabolism which determine mental deficiencies and are usually lethal in the above-mentioned sense.

31. Recessive lethal mutations seem to be less frequent than mutations which only reduce the average number of the progeny of homozygous individuals by reducing their fertility or the probability of mating, or by making them more vulnerable to a given environment. In such cases the elimination of the mutants proceeds at an even slower pace. Various other situations may also arise when mutant genes are not completely recessive and heterozygotes show a certain degree of disadvantage as compared to individuals who do not carry the gene.

32. Some mutant genes cannot be appraised in absolute terms unless referred to a given environment. In man, a mutant gene is known which in the homozygote gives rise to a serious blood disease, sickle-cell anaemia.[O48] Most of the homozygotes die in the first decade of their life and very few reach the third decade, whereas heterozygotes, although clinically recognizable, live a normal life and show no impairment of fertility. With such a severe elimination of homozygotes it would, at first thought, seem necessary to assume that the trait is maintained in human populations by an unprecedentedly high frequency of mutation. It has, however, been observed that the mutant gene is present mainly in areas where the incidence of malaria is very high and there

is evidence that heterozygous individuals are more resistant to malaria than individuals which do not carry the gene. The loss of homozygotes may thus be more than compensated for by the increased survival, and therefore the more numerous progeny, of heterozygotes as compared to the normal population living in malarial areas.

Magnitude of the hereditary damage

33. Any estimate of the magnitude of the hereditary damage, as measured by the total number of harmful genes present in the germ cells of a population over one generation, must necessarily rest on the observation of the actual occurrence of hereditary defects and diseases. The possibility of estimating this amount in quantitative terms is hampered by our lack of precise knowledge about many harmful traits. It is admitted that genetic factors play an important role in the causation of these traits, but the extent to which they do so is unknown. The discovery of chromosomal aberrations in man enables us to give a more accurate picture of the total hereditary damage than was possible in the last report, since a whole new category of diseases can now be ascribed to known hereditary mechanisms.

34. It is convenient, if crude and oversimplified, to distinguish between visible damage and recessive (hidden) damage. The former is estimated to affect about 6 per cent of all live-born infants.[O18-37] One per cent are afflicted by known chromosomal aberrations, 1 per cent by defects due to known dominant or sex-linked genes, 1.5 per cent are destined to suffer later from serious mental or constitutional hereditary diseases and the rest have malformations which, although due to environmental factors, may also have some genetic component in their causation. A certain but unknown fraction of miscarriages and still births,[O38] as well as of total or partial sterility in both sexes is also probably due to dominant mutants or to chromosomal aberrations.

35. The recessive damage cannot be estimated directly, although an indirect method is available which has a very broad scope as it can be applied to very diverse situations and estimate even the recessive damage accounting for foetal deaths and sterility.[C39-41] Its potentialities have not yet been fully exploited owing mainly to lack of adequate data. The method is based on the principle that spouses who are related are more likely to be heterozygous for the same mutant gene than unrelated spouses. A greater fraction of recessive homozygous offspring, and thus of defects due to homozygosity, is therefore expected among consanguineous marriages than among the others and the size of that fraction is expected to be larger, the more closely related the spouses are.

36. The relationship between the degree of consanguinity and the frequency of traits due to recessive genes is, in fact, a very simple one. By comparing for instance the differential mortality at a certain age between unrelated and variously related individuals of the same population, it is possible to estimate the average number of variously harmful recessive genes per individual which, if present in homozygous conditions, would each, on the average, cause one death at the age which has been investigated. These indirectly observed genes (lethal equivalents) need not be 100 per cent lethal. Indeed, if two such genes each caused 50 per cent lethality when homozygous, they would achieve the same cumulative lethality as one single completely lethal gene.

37. The use of such an indirect method requires that accurate records of consanguinity and detailed data regarding fertility, morbidity and mortality of both consanguineous and non-consanguineous marriages should be available. The difficulty of securing that kind of information explains why the indirect method has not yet been extensively used. From the results obtained so far, however, it appears that each individual carries on the average from 2 to 4 lethal equivalents,[O41] the estimates being based on mortality before thirty years, including miscarriages and still births. The number of equivalents responsible for major malformations and hereditary diseases is not known with any certainty and those responsible for sterility have not so far been studied.

38. It should be pointed out that the visible damage, as estimated from its observable expression, and the recessive damage, as evaluated through the indirect approach, do not lend themselves to straightforward comparisons.[C140] On the one hand their magnitude is assessed through radically different methods, each affected by different sources of error; on the other hand they are expressed on different scales, the visible damage in terms of actual hardship, the recessive one in terms of potentially harmful factors.

39. Furthermore, as most of the manifestations of the visible damage are accompanied by either a total or severe reduction of fertility, the largest part of this damage is confined to the generation being investigated and only for minor detrimental characters can it be carried for a certain number of generations. The recessive damage, on the contrary, is spread over an unpredictable and always very large number of generations and the frequency of its manifestations largely depends on the frequency of consanguineous marriages.

Mutation and hereditary damage

40. Gene and chromosomal mutations obviously contribute to the hereditary damage, and it is important to know what fraction of these mutations occurred in immediately preceding generations. Dominant lethal traits are certainly due to new mutations having arisen in the germ cells of the parents of the affected individuals, since these mutations cannot be transmitted for more than one generation. The same is true for diseases such as Down's and Klinefelter's syndromes where the affected individuals are almost invariably infertile.[O70]

41. The role of mutation in maintaining the recessive damage in human populations is difficult to evaluate because completely recessive genes are detectable in homozygous individuals only. Moreover, when recessiveness is not complete, the heterozygous condition may result in reduced fertility and this adds further complexities to the problem of estimating mutation rates.[O44-46] The same is true of those cases in which the heterozygous condition for a lethal or quasi-lethal recessive gene results, at least in some environments, in an increased fertility.[C47-51] Data on the extent to which recessive heterozygotes are selected for or against are generally lacking.

42. If most recessive heterozygotes were favoured in their present environment to such an extent as to overcome the continual loss of genes due to the elimination of homozygotes from the population, then the role of mutation in the maintenance of the hereditary damage would be much less important.

43. The present consensus of opinion among geneticists is that most of the recessive damage is supported by mutation, but it should be stressed that such a view is still largely speculative.[C52]

Effect of irradiation on quantitative characters

44. Many hereditary characters can only be expressed in terms of measurements and are distributed more or less symmetrically around a mean.[O131-135] Examples are height, weight, birth weight and intelligence as measured by scores in intelligence tests. The effects of an increase of mutation rates on this type of character were considered rather fully in the 1958 report and there is no new information which would alter the conclusions.

45. One of the quantitative characters—viability—is known to be adversely affected by most mutations, so that an increase of mutation rates can be expected to give rise to a substantial reduction of viability even if the mutations produced are not responsible for visible harmful traits. It has in fact been shown in mice that the offspring of irradiated parents have a higher mortality than control animals during the early part of life. This effect on the viability of the offspring could be attributed to the over-all effect of many mutations and perhaps also to chromosomal changes, each with a small effect. It is difficult, however, to express this hereditary damage in terms that can be compared with other types of radiation-induced hereditary damage. It is hoped that much more work will be done to investigate its nature and extent, as it might prove the most important damage affecting the first generations of descendants of irradiated individuals.

Assessment of hereditary effects of radiation on man

Direct evidence of damage from radiation

46. Since 1958 very little new information has been added to our knowledge regarding hereditary effects induced by radiation in exposed human population.

47. The largest group now available is still represented by the descendants of those exposed to radiation in Hiroshima and Nagasaki. The survey made in 1956 revealed no detectable effect on the frequency of prenatal or neonatal deaths nor on the frequency of malformations.[O121-123] It should be stressed again, however, that this does not mean that no visible hereditary effects were produced by the irradiation. The number of exposed parents and the dosage received by them was such that we should not have expected a detectable increase in the offspring of the exposed population.

48. A significant change in the ratio between males and females (sex ratio) among children born of irradiated parents in Hiroshima and Nagasaki has been reported.[O128] Other more limited and not strictly comparable surveys on the offspring of parents exposed to radiation for medical reasons also show changes of the sex ratio. Shifts in the sex ratio are expected on the basis of simple genetic theory which predicts a lowering in the frequency of males born of irradiated mothers and a lowering in the frequency of females born of irradiated fathers. Such an expectation, however, has not been borne out by investigations on the offspring of irradiated mice,[O130] and a detailed analysis of the human observations has revealed inconsistencies in the sex-ratio changes that cannot at present be explained.

49. The addition to the recessive damage occasioned by radiation has not been studied because recessive genes tend to appear among the offspring of consanguineous marriages. Since marriages between individuals more closely related than first cousins are not practised in most societies, at least three generations must elapse before any child is born to parents who have a common irradiated ancestor.

Other considerations

50. The scantiness of data on the hereditary effects of radiation in man does not preclude the possibility of assessing a part of the expected hereditary damage. For that purpose, the results of experimental studies on other species need to be applied to man. This requires careful biological judgement and is justified only for observations obtained in species for which it is known that the mechanisms of induction, transmission and manifestation of the effects considered are similar to those in man.

51. The possibility of inducing mutations in all the organisms that have been investigated, from bacteria to mice, makes it beyond doubt that radiation can cause the same types of damage in man. It is also reasonably certain that in man, as in other species, the overwhelming majority of newly arising mutations have detrimental consequences and that, if beneficial mutations arise at all, the frequency of their occurrence is so low as to be unlikely to offset the burden occasioned by the harmful ones.

52. In all organisms investigated, the frequency of induced hereditary changes has proved to be dose-dependent even at the lowest doses investigated and there is no reason to believe that this is not so in man.[O83] Animal species differ from each other, however, in their sensitivity to the mutagenic action of radiation.[O101] As far as the induction of chromosome anomalies is concerned, some observations of wide variations in sensitivity even between closely related species of rodents and between these and one species of monkey limit the possibility of straightforward quantitative extrapolation to man.

53. The effect of the dose-rate has so far been found in the mouse, in *Drosophila* and in silkworm,[C84-87] these species being sufficiently different to allow us to assume that other mammals, and in particular man, may show an analogous pattern of response. The quantitative picture may, however, differ in different species to an unknown extent if, as has been assumed, the dose-rate effect is accounted for by the intervention of metabolically conditioned recovery processes.[O87]

54. An increased exposure to radiation therefore adds to the hereditary damage affecting mankind. Of such additional damage, a fraction will become manifest during, and will be confined to, the first few generations following the exposure; another fraction, and perhaps the main one, will become apparent at a later stage in a less conspicuous way but will be sustained by mankind for an unpredictably large number of generations.[O144] It should be noted that some of the harm to human popu-

lations both from spontaneous and induced mutations may be spread over more generations because socio-medical care may relax selection against individuals with certain traits.

Conclusions

55. Any increase in the amount of ionizing radiation to which human populations are exposed is expected to bring about a proportional increase in the frequency of mutation. This expectation is based on the fact that ionizing radiation is known to induce mutations in experimental animals at all doses and dose-rates so far investigated. Experimental observations, however, are available only at single doses not lower than 5 rad[C88] and direct information on the dose-mutation relationship in man is presently lacking.

56. Much progress has been made in the field of radiation genetics during the last four years. Recent investigations have added to the information used in assessing the genetic hazards of ionizing radiations to human populations; they have also focused attention on the specific areas most in need of further research. It is now known that the frequency of radiation-induced mutation is not dependent solely on the accumulated dose but is also dependent on rate of delivery. Furthermore, factors such as sex and germ-cell stage are important influencing factors. Nevertheless, under some defined conditions it is possible to calculate a doubling dose for gene mutations in human populations. Calculations in the 1958 report, based on many considerations, including a lower limit estimated from the data from Hiroshima and Nagasaki, suggested that the representative doubling dose for man might well lie between 10 and 100 rad, with 30 rad as the most probable value. Recent information from mouse experiments now suggests that for acute irradiation, the probable combined value for both sexes is somewhat lower than 30 rad but not less than 15 rad.[C154] For chronic irradiation the most probable value is 100 rad or possibly higher. No better figures are available for estimates of doubling dose for gene mutation in man. A permanent doubling of the mutation rate would ultimately double the prevalence of those serious defects determined by unconditionally harmful genes which are estimated to affect about 1 per cent of those born alive.[C14-17] Present knowledge of dosage effects on the induction of chromosome anomalies is too scanty to predict a doubling dose.[C188] There are indications that monkey chromosomes and hence perhaps those of other primates are more radio-sensitive than those of mice. The Committee is of the opinion that ionizing radiation would increase the prevalence of developmental congenital malformations[C20-22] and of serious constitutional disorders,[C23-25] but no quantitative estimates can now be made.

57. Accurate and reliable estimates can only be obtained through further progress in both experimental and human genetics. Some fields of investigation will require particular encouragement and support, as those that are most likely to provide answers to the questions arising from exposure to radiation. Studies of the role of repair mechanisms in radiation-induced mutational processes, and of factors which may influence mutation frequencies, may help us understand better how radiation delivered at different rates induces mutations with varying effectiveness. Rigorous *in vitro* and *in vivo* methods of comparing susceptibilities to radiation of various species will provide a sounder basis for applying to man experimental results obtained in other species.

58. Careful, protracted study should be continued on those groups of individuals that are or have been exposed to higher doses of radiation, such as irradiated persons in Hiroshima and Nagasaki, populations living in areas where natural irradiation is high and individuals irradiated for medical reasons. Appropriate methods should be devised to extract from these studies all the relevant information on radiation-induced damage to the hereditary material that they are likely to yield.

59. An understanding of the hereditary effects of ionizing radiation cannot be obtained without a thorough knowledge of the factors which affect the maintenance of hereditary traits in the population—principal among them the pressures of mutation and selection and the genetic structure of the population. To ascertain the respective role of these factors, accurately planned and continued large-scale investigation on human populations living in different environmental, social and cultural conditions should be undertaken or pursued.

CHAPTER VII

EVALUATIONS AND CONCLUSIONS

1. In presenting its first comprehensive report to the General Assembly in 1958 the Committee emphasized that the conclusions of that report, as with any scientific assessment, must be subject to revision in the light of advancing knowledge. Since then, considerable progress has been made in the field of study of the Committee, so that much more information is now available and our understanding of the effects of radiation is much increased. Although this makes it possible in many instances to give a clearer account of radiation exposure and effects, the complexities of the subject that have been revealed by recent investigations have necessitated a qualification of some previous statements.

2. Earlier chapters of the present report outline the present status of our knowledge of radiation exposures and effects and provide the basis for an assessment of the significance of these exposures. The annexes contain detailed information on which this outline is based. The present chapter gives the conclusions arrived at in the report. The Committee wishes, however, to emphasize that the report should be regarded as a whole and that individual sentences or assessments may be misleading if taken out of their appropriate context.

3. The review and the evaluations made by the Committee are in no way final and will undoubtedly require continuing revision as scientific knowledge advances and new data become available, the present lack of which still limits our understanding of some problems.

4. The Committee hopes that this report, by pointing out subjects which require more investigation and sometimes a fresh approach, will stimulate research and discussion that will result in an improved understanding of the effects of ionizing radiation on man and his environment.

5. The main questions which the Committee has again attempted to answer are:

(*a*) What are the levels of radiation to which man is exposed from various external and internal sources (including those arising from radio-active contamination of the environment as a result of nuclear tests) and how is this exposure distributed in time, in different geographical areas and within different parts of his body? It has been important to specify in particular what doses and dose-rates of radiation from various sources are received by the gonads (testes and ovaries), in view of their genetic importance, and by those cells in which malignant change may be induced by radiation, such as the blood-forming cells of the bone marrow and those lining bone surfaces.

(*b*) What are the effects produced by radiation, both on the irradiated individuals and on their offspring, particularly at those levels to which populations are currently exposed?

Levels of radiation

6. The frequency with which harmful effects are caused by each form of exposure depends essentially upon the radiation dose received by human tissues from each source. A simple comparison of doses does not, however, indicate the likely frequencies of harmful effects if these doses have been delivered at widely different dose-rates. The following paragraphs discuss the sources of radiation to which man is exposed and the doses incurred.

Radiation from natural sources

7. The estimation of the radiation exposure from natural sources has considerable importance, particularly because part of the normal occurrence of hereditary, and perhaps some malignant, diseases may be due to natural radiations. Moreover, as man has always been exposed to such radiation, the dose received from natural sources forms a useful basis of reference with which the doses received from other sources may be compared.

8. Natural sources of radiation include cosmic rays and those radio-nuclides which occur naturally in the environment. The radiation that man receives from these sources is described either as "external" when it reaches the body from the exterior, as from cosmic rays or by gamma radiation from radio-nuclides in the earth's crust or atmosphere, or "internal" when it is derived from naturally occurring radio-nuclides which have become incorporated into the human body.

9. Investigations carried out during recent years have enabled us to achieve greater precision in estimating the radiation dose to which the world population is exposed from natural sources. In particular, the contribution to this dose from the neutron component of cosmic rays, which had been disregarded in the first comprehensive report, can now be taken into account despite uncertainties inherent in its evaluation. The inclusion of this contribution explains why the present estimates of doses from natural sources are higher than those given in the previous report. Accurate estimates of the doses from potassium-40 and carbon-14 have also become available. Combining the estimated average contribution from cosmic rays, that from external radiation from radio-nuclides in the environment, and that from internal radiation from radio-nuclides within the human body, the average yearly dose from all natural sources is now estimated for various tissue and is about 125 mrem to the gonads, 120 mrem to the blood-forming cells and 130 mrem to the cells lining bone surfaces.

10. Wide geographical variation has been observed in the dose from most natural sources of radiation, both internal and external. The exposure from cosmic rays varies mainly with altitude, showing an approximately twofold increase for each thousand metres rise in altitude. The external radiation from radio-active nuclides occurring in the environment also shows geographical variation, depending largely on the composition of underlying soil and rocks. While the average dose-rate from these sources is about 50 mrem per year in most inhabited regions of the world, areas are known, as in parts of the Kerala, and the adjoining, coast in India,

where the external dose-rates may be over twenty times as high. The exposure from internal sources also varies geographically owing to the variable intake of radium and of some other naturally occurring radio-nuclides. The contribution to internal radiation from carbon-14, tritium and potassium-40 on the other hand is fairly constant in different places.

Medical exposures

11. It is now possible to place greater reliance upon the estimates of the dose received from medical procedures. Data from a number of countries with extensive medical facilities and a total population of 200 million are now available. They indicate that for diagnostic radiology the annual genetically significant dose ranged from 6 to 60 mrem in the particular years studied. These countries may be considered as representative of other areas with comparable medical practice on which adequate data are not available in sufficient detail. However, only a small fraction of the world's population is covered and the estimates may not apply to larger areas of the world. The upper limit of the range does not exceed half of the dose received from natural sources, although no simple comparison is appropriate, owing to the much higher dose-rates at which the doses from medical procedures are delivered. A few types of examination, which comprise a small fraction of the total examinations carried out in each country, contribute about three-quarters of the genetically significant dose. One of the most important results of these investigations is the evidence that this dose can be very substantially reduced by the full use of appropriate techniques and equipment. The genetically significant dose due to therapeutic irradiation ranges from 2 to 13 mrem and that from the medical use of radio-isotopes is less than 1 mrem per year.

12. Limited data have been obtained for bone-marrow doses and these are insufficient to furnish accurate estimates of mean doses. They seem to confirm, however, the tentative estimates made by the Committee in its first comprehensive report, in which a range from 50 to 100 mrem was accepted for the yearly contribution to the bone-marrow dose, as averaged throughout the population, from diagnostic procedures, including fluoroscopy. No reliable estimates of the contribution from therapeutic irradiation is possible at the present time.

Occupational exposures

13. The available data obtained from five industrialized countries show that at the present time the number of workers who are directly engaged in radiation work does not exceed eight per ten thousand in the population. It has been observed that when proper radiation protection methods are used, the great majority of these workers receive very low doses of radiation. From information collected in four countries, the genetically significant dose to the general population resulting from occupational exposures is estimated to be less than 0.5 mrem per year.

Other types of radiation exposures

14. In some countries, individual members of the population may be exposed to various other sources of radiation such as X-ray shoe-fitting machines, luminous dials of clocks and watches, various devices incorporating radio-active materials, and television sets. Apart from those from shoe-fitting machines, the doses delivered are unlikely to present any significant hazard to individuals. The average exposure from any one of them is likely to be very small, although taken together they may make a small but significant contribution to the total genetically significant radiation dosage of populations in some countries. World average values of the total dose contribution to populations from these sources are not available at the present time.

15. It is important that the exposure of populations to radiation from such sources should be kept under continuing review, as regards both the exposure from each source and the aggregate exposure from them all. The introduction of any new source involving substantial exposure of individuals or of populations should be recognized and evaluated at an early stage. An example in the future might be the exposure of individuals to cosmic radiation in passenger aircraft flying at high altitudes.

Environmental contamination from nuclear explosions

16. The contamination of the environment and the radiation exposure of human beings from any nuclear explosion depends very much on the type and yield of the explosion, on its altitude and geographical location, on the construction of the device as well as on whether radio-active products are injected into the upper or lower atmosphere, deposited locally on the earth's surface or into water, or retained underground. The processes by which radio-active material from nuclear explosions causes radiation to human tissues are described in detail in chapter V and in annex F.

17. Since the 1958 report of the Committee, our understanding of the processes involved in fall-out from the stratosphere and the lower atmosphere has been increased considerably by information and continued investigation on these subjects and in consequence of the three-year period during which no significant stratospheric injections of nuclear debris took place. The resultant information has tended to confirm our views as to the way in which fission products are removed from the stratosphere and the mechanisms involved are discussed in detail in annex F.

18. However, it has become clear that owing to meteorological factors, the rate of fall-out tends to increase in the spring, and that the stratospheric half-residence time (or period in which half of any injection is removed from the stratosphere) is often considerably shorter than was estimated in 1958. Geographical as well as meteorological factors have resulted in higher deposition of fall-out in the northern temperate latitudes than in the rest of the world.

19. In our previous report the amount of radio-active debris present in the stratosphere (the so-called stratospheric reservoir) was estimated by calculation from the observed fall-out rate and from a half-residence time which was assumed to be as high as seven years. A high value was assumed as a precaution against underestimating the dose to which human tissues would be subjected from long-lived radio-nuclides. It is now known that the amount of strontium-90 present in the stratosphere was over-estimated in consequence. Direct measurements of the stratospheric reservoir have now been made by means of high-flying aircraft and balloons and the content of the reservoir in very recent years has been estimated by this means.

20. The half-residence time of strontium-90 in the stratosphere has proved to be critically dependent on a number of factors, including the time of year at which the explosion takes place, the latitude, and both the height of the explosion above the earth's surface and the altitude to which the fission products are carried into the atmosphere. Debris injected in polar latitudes appear to have a stratospheric half-residence time of between 6 and 12 months, whereas this time may be as long as 2 years for injections in the equatorial belt. A shorter half-residence time for injections is important because the resultant fall-out will contain short-lived radio-nuclides which will somewhat increase the radiation received by man from fall-out by adding to the exposure due to the longer-lived radio-nuclides.[FIII 23,50-68]

21. Much valuable information has become available on the transfer of radio-active materials from fall-out through the food chain, and our understanding of this process is greatly improved. Estimates of the amount of fall-out components, especially strontium-90, are now available from many more areas and we also have more information on the composition of the diet of many populations.

22. There is now much more detailed evidence concerning the importance of direct contamination of the leaves, inflorescences and stem bases of plants in introducing fall-out material into the food chain, in addition to that taken up by the plant from the soil. In some plants such as cereals this effect is of particular importance during the season when the flowers and ears are being formed. The new information has greatly helped our understanding of the transfer of strontium-90 from diets of various types to human beings, in whom it is deposited in bone.

23. Some data have become available on the rate at which strontium-90 may be removed in harvested crops, and also leached or washed down through the soil and so away from the rooting zone of plants. These data indicate that the contribution to human irradiation of an accumulated deposit of strontium-90 in soil is likely to be halved in a shorter period than the 28 years that was assumed for purposes of estimation in the previous report.

24. It has been possible to obtain information on the amount of strontium-90 taken daily in the diet in a number of different regions of the world, and on the ratio of strontium-90 to calcium in the diets of these regions. The ratio of strontium-90 to calcium in the whole diet usually is higher than that in the milk, the difference being less for diets containing a large component of milk and milk products. When the ratio for the diet as a whole is compared with the ratio in milk from the same region, it is found that the over-all value for this type of diet is usually about one and a half. But the value is higher if plant products are important components of the diet.

25. Even for the many regions for which complete dietary surveys are not available, therefore, it is possible to make some estimate of the likely dietary intake of strontium-90, provided that its concentration in milk samples from these regions is known. However, if milk is a minor component of diet, information on the strontium-90 content of other foods also is required. The levels of contamination of several components of diet show wide geographical variations connected with the different cumulative deposition of strontium-90 in the soil and the rate of fall-out. These differences and the characteristics of the diet in different areas combined with the geographical variations of fall-out lead to significant variation in the levels of contamination and in the quantity of strontium-90 received by man in food. The estimates made suggest that, over large areas in which the rates of deposition are similar, differences in the composition of the diet seldom result in more than twofold, or in certain types of diet at most fourfold, differences in strontium-90 intakes.

26. Our prediction of possible future concentrations of strontium-90 in dietary constituents continues to be based on the use of two factors, one depending on the rate of fall-out and the other on the accumulated deposition. Better values for such factors are now established for various food materials from survey data and from experimental methods, so that the dependence of dietary and hence of bone contamination on fall-out conditions can be adequately estimated.

27. The highest contamination of human bone with strontium-90 continues to be observed in the northern temperate latitudes. The average human bone concentrations in various parts of the world appear to be simply related to the observed or estimated amounts of strontium-90 present in the total diet, in the manner to be expected from experimental studies. The concentration of strontium-90 relative to calcium in new bone is about one-quarter of that in the diet consumed while the bone was being formed.

28. Caesium-137, unlike strontium-90, contributes to both external and internal irradiation. Caesium-137 differs from strontium-90 also in so far as it is not fixed in the human body but is retained there for a period of time, which is very short compared with that in which its activity is significantly reduced by radio-active decay. The rate of uptake of caesium-137, and therefore its contribution to internal contamination, depends principally on the rate of its deposition on vegetation since caesium contained in most soils is usually very poorly absorbed by plants, though there are some exceptions.[FII 124] The contribution of caesium-137 to external irradiation, however, depends on its accumulation on the ground. There is some evidence that the contribution of caesium-137 to external irradiation over undisturbed soil is reduced by about 50 per cent in ten years.[FIII 15]

29. Several years' data on mean concentration of caesium-137 directly determined in the human body are now available and apply to a large part of the world. Geographical variation seems to be rather small. The concentration of this nuclide, which showed a general upward trend from 1956 to 1959, decreased in 1960 and 1961.

30. The present report deals much more fully than was possible at the time of the previous report with the formation of carbon-14 in nuclear tests and its contribution to human irradiation. As a result of these tests, the concentration of carbon-14 in the atmosphere and in biological material had risen at the end of 1960 by 25 per cent above the concentration of the carbon-14 formed by natural processes, but the concentration of this carbon-14 will decrease considerably in forthcoming decades owing to the dilution of the nuclide in the oceans if tests are discontinued. Although the irradiation of future generations from this source will continue at a decreasing rate for thousands of years because of the long half-life of this nuclide, the dose-rate to human reproductive and other tissues will be small in any one generation.

Disposal of radio-active wastes

31. The operation of atomic plants for the production

of energy and isotopes and the use of the latter for medical and research purposes may involve the release of radio-active material into the air, ground or waters. At the present time the contribution from this source to human radiation exposure is certainly small in comparison with natural radiation and is restricted to local areas. However, with the increased utilization of atomic energy and radio-active substances for peaceful uses, releases into the environment are likely to become greater than they are now, and consequently suitable methods for safe disposal of radio-active wastes should be maintained so as to minimize the dose of radiation from these sources.

Effects of radiation

Fundamental radio-biology

32. The study of the effects of radiation on cellular and subcellular structures is a necessary prerequisite to the understanding of radiation effects on whole organisms, in so far as the basic radiation injury occurs at the lowest level of organization. Fundamental radiobiology has received new impetus from the dramatic advances made in the past few years by biochemistry and biophysics. Our knowledge of the structure and mode of replication of macromolecules and in particular of nucleic acids has greatly increased, so that new insight has been gained into the fundamental problem of how genes act in controlling cellular structures and functions and in ensuring that they are maintained in the products of cell division.

33. The nature of the initial disturbances caused by radiation at the molecular level has become better known, as are the factors which may alter them. The changes produced may be partly reversible, at least when studied at the cellular or at higher levels. This may be the case with gene mutation, which is believed to be due to a specific change in chemically identifiable constituents of nucleic acids.

34. The study of the relationship between dose and effect at cellular and subcellular levels does not give any indication of the existence of threshold doses and leads to the conclusion that certain biological effects can follow irradiation, however small the dose may be. When dose effect relationships are studied at higher levels of organization, however, it is now being increasingly realized that the situation may be much more complex, since many factors play a part between the occurrence of the primary event and the final manifestation of radiation damage.

Somatic effects

35. During the interval since the last report, our knowledge of the somatic effects of radiation on man (those effects which are produced on the individuals exposed) has increased substantially with the demonstration of the induction of certain transient somatic effects by low doses of a few rad of radiation, and with the confirmation that embryonic tissues are more sensitive than many adult ones to injury by radiation. Even low doses may induce developmental disorders or malignant changes in embryos. Recent work has emphasized the complexity of radiation effects, and the importance of the qualifications that we made in our earlier report with regard to the numerical estimates of the frequency of the effects that would be caused by various doses of radiation. The complexity of the dose effect relationships is due largely to the fact that in different dose ranges, different types of biological effect may be produced, and a simple mathematical relationship is unlikely to apply. The data that have been accumulated since 1958 have neither proved nor disproved the assumption made in the first report that at low doses proportionality can be used to estimate risks.

36. The early effects of large doses of radiation in man have become better known as a result of the close study of people who have been accidentally or therapeutically irradiated. It seems likely that, for short-term whole-body irradiation of man, the dose causing death in 50 per cent of the exposed individuals may be about 400 rad, but possibly as high as 500 rad and as low as 300 rad. Persistent damage from radiation is apparent after large doses approaching the lethal range. The predominant immediate changes after low doses are transitory ones, although persistent effects may be produced after a long period of time.

37. Various chemical, physical and biological treatments have some value in decreasing the effects of radiation exposure in animals, but no specific treatment has been established as having practical importance in man, except for the relief of symptoms that are induced by therapeutic irradiation of parts of the body. Several methods are, however, under investigation for the treatment of acute radiation injury, or to reduce the amounts of radio-nuclides which may have been taken into the body.

38. Radiation exposure of animals, continued for short or for long periods, causes a shortening of the life-span by an amount depending upon the dose received and the dose-rate. It is probable that a similar life-shortening occurs in man but the evidence on this point is inconclusive and no estimate can be given of the amount of any such effect.

39. Irradiation for short or long periods, either of animals or of man, may cause neoplastic changes, of which leukaemia appears to be the earliest to develop in man. There is good evidence that in the range of doses which it has been possible to explore (from 100 rad upwards), the frequency with which leukaemia is induced increases with the dose of radiation received, but no further evidence has been obtained as to the exact relationship between the dose and the frequency of this response. It does appear, however, that the annual incidence of leukaemia in the Japanese survivors of radiation at Hiroshima and Nagasaki, which had been rising after the nuclear explosions in 1945, though still elevated, has been decreasing since 1958. There is evidence to suggest that the incidence of some other forms of malignant disease may now have increased, but it is at present difficult to form a reliable estimate of the extent of any such increase.

Hereditary effects

40. Progress in human genetics has been very significant since 1958. An entirely new field of study has been opened owing to recent cytogenetic findings in man. The normal diploid number of chromosomes for the human species has been accepted as forty-six and certain serious diseases occurring in one per cent of all children born have come to be recognized as due to chromosomal changes. A new class of possible radiation-induced diseases, the importance of which was unrecognized at the time of the first report, has thus been demonstrated. The occurrence of chromosomal anomalies has been demonstrated in somatic cells of irradiated individuals.

41. The concept of mutation induction as an instantaneous process has been revised and evidence accumulates showing that for some mutations a finite period of time elapses between the absorption of radiation energy and the completion of the mutation process, during which, depending on the physiological state of the cell, at least partial repair of the damage may be possible. The effectiveness of the repair mechanisms may be altered by a variety of agents and conditions, and will also be dependent on the way in which the radiation is distributed in time.

42. The frequency of gene mutations produced by irradiation has been shown to be proportional to the total dose received by the germ-cells. The proportionality, however, has been shown, in mice, fruit flies and silkworms, to vary with certain factors including the dose-rate. The dose required to induce as many mutations as naturally occur, the so-called doubling dose, therefore also changes with the dose-rate. Doubling doses are higher for low than for high dose-rates, the observed difference in mice being fourfold for the male and possibly larger for the female.

43. More data, however, are needed before the possible magnitude of this effect in man can be evaluated so as to enable us to make better comparisons between different conditions of irradiation. In any event the recent findings, while confirming the validity of the concept of doubling dose in particular circumstances for a given dose-rate, have shown that it is not possible to estimate with confidence a representative doubling dose for man.

44. In spite of the preceding reservations there should be no misunderstanding about the reality of genetic damage from radiation. Although individual mutations vary greatly in their effect, there is no doubt that any increase in mutation is harmful. Further, we know that mutations accumulate in germ-cells and we have no evidence from any experimental work for a threshold dose, or rate of delivery below which mutations are not induced. In fact, it has recently been shown that a single dose as low as 5 r increases significantly the number of mutations in the fruit fly. As regards man, the total dose received by the average individual in the population is still the most important indicator that we have of the amount of damage induced.

45. It is likely that the great majority of gene mutations induced by radiation are identical with those which occur "spontaneously". There is some evidence, however, from lower organisms that radiation determines a different proportion of certain harmful mutations than that occurring naturally.

46. The most extensive study is still the investigation of the offspring of parents exposed to the atomic explosions of Hiroshima and Nagasaki. The investigators detected no significant increase in the frequency of malformations or early deaths in the children of irradiated parents. Both this survey and a number of other more limited investigations have, however, consistently shown that in the progeny of irradiated mothers there is a significant excess of females over males. This has been attributed to the radiation-induced (sex-linked) mutations which would reduce the number of males born of those mothers. In the progeny of irradiated fathers a more complex situation obtains which has not yet been fully understood.

Conclusions

47. The review that we have made of the effects of ionizing radiation and of the present exposure of mankind to radiation affords a basis for general comments concerning this source of hazard.

48. It is clearly established that exposure to radiation, even in doses substantially lower than those producing acute effects, may occasionally give rise to a wide variety of harmful effects including cancer, leukaemia and inherited abnormalities which in some cases may not be easily distinguishable from naturally occurring conditions or identifiable as due to radiation. Because of the available evidence that genetic damage occurs at the lowest levels as yet experimentally tested, it is prudent to assume that some genetic damage may follow any dose of radiation, however small.

49. It must be recognized that the human species has in fact always been exposed to small amounts of radiation from a variety of natural sources and that the present additional average exposure of mankind from all artificial sources is still smaller than that from natural sources.

50. At present even the wide use of radiation in medical diagnosis and treatment in countries with extensive medical facilities does not usually involve more than about a 50 per cent increase in the genetically significant exposure to radiation of their populations, and there is evidence that simple and inexpensive modifications of techniques could reduce the figure considerably without loss of medically important information. Advances in nuclear science and industry are being achieved with only slight resultant increases in the average radiation levels to which populations are exposed, and with only very occasional accidental over-exposure of individuals.

51. At the same time, the exposure of mankind to radiation from increasing numbers of artificial sources, including the world-wide contamination of the environment with short- and long-lived radio-nuclides from weapons tests, calls for the closest attention, particularly because the effects of any increase in radiation exposure may not be fully manifested for several decades in the case of somatic disease, and for many generations in the case of genetic damage.

52. The Committee therefore emphasizes the need that all forms of unnecessary radiation exposure should be minimized or avoided entirely, particularly when the exposure of large populations is entailed; and that every procedure involving the peaceful uses of ionizing radiation should be subject to appropriate immediate and continuing scrutiny in order to ensure that the resulting exposure is kept to the minimum practicable level and that this level is consistent with the necessity or the value of the procedure. As there are no effective measures to prevent the occurrence of harmful effects of global radio-active contamination from nuclear explosions, the achievement of a final cessation of nuclear tests would benefit present and future generations of mankind.

53. The urgent need for research into many aspects of radiation and its biological effects has been emphasized repeatedly in this report. Although we have extensive and increasing information about the levels of radiation to which man is exposed from various sources and about the types of harmful effect which may result, we still know very little about the frequency with which such effects are likely to occur, particularly following small doses of radiation received at low dose-rates. It is of the utmost importance that investigation of this central problem should be actively pursued by all relevant means, including not only studies of the ways in which radiation may induce malignant and other delayed changes in tissues but also well planned surveys of the frequency with which such late effects occur in human populations following any accidental, medical or other relevant type of exposure to radiation or in areas of high natural radiation.

Annex 5

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

(*GA*, *OR*, 19th Session, Supplement No. 14 (A/5814), 1964)

CHAPTER II

RADIO-ACTIVE CONTAMINATION OF THE ENVIRONMENT BY NUCLEAR TESTS

1. The nuclear explosions carried out between September 1961 and December 1962 sharply increased the radio-active contamination of the environment and consequently the doses of radiation that human populations will receive. However, the Committee notes that after the cessation of nuclear test explosions in the atmosphere, in outer space and under water, and in view of the propitious circumstances prevailing, further contribution from these sources to the radio-active contamination of the environment has ceased. Information on the amounts of various radio-nuclides and on the rates at which they deposit on the earth's surface and enter the food chain is necessary in order to compute the doses to human tissues. Since the cessation of atmospheric tests in December 1962, the Committee has been able to collect sufficient information to enable it to up-date adequately the estimates of the resulting radiation doses.

2. Almost all of the fission products from the 1961-1962 explosions have been introduced into the stratosphere. The strontium-90 from these tests increased the stratospheric inventory at the end of 1962 by about 5 megacuries over the level in mid-1961 (A32-34).[4]

3. The rate of transfer from the stratosphere to ground level depends upon the altitude to which the products rise in the atmosphere and the latitude at which the explosions occur. For example, the mean residence time of material in the stratosphere above 100 km exceeds five years while in the lower stratosphere it is less than one year (A16-19). Assessment of the experimental data has led the Committee to adopt an over-all mean residence time for the composite stratospheric fission products of two years (A20). While this time is shorter than that used in the 1962 report, the predicted deposition of strontium-90 and caesium-137 is not appreciably altered by the change in the mean residence time.

4. The fall-out rate of long-lived radio-activity in 1962 was three times that for the period 1960-1961 and during the year 1963 the fall-out exceeded that in any previous year (A36-38). The Committee envisages that in 1964 the fall-out rate may be some two-thirds of that during 1963 and will continue to decrease progressively in future years.

5. Short-lived fission products have decayed to negligible levels during 1963 so that no further dose will be incurred from them after 1964 (A56-59).

6. Radio-active materials which have been deposited on the surface of the earth constitute sources of both external and internal radiation to the population. Whereas their contribution to the external dose depends on the gamma radiation which they emit, the magnitude of the internal dose is determined mainly by the extent to which different nuclides are transferred through food chains to man.

7. Strontium-90 and caesium-137 are the most important fission products from nuclear explosions that contaminate man's diet. The mechanisms which control the transfer of strontium-90 through food chains into man's diet were discussed extensively in the 1962 report.[5] Information which has been obtained since that time does not necessitate the modification of the basis for assessment. During 1962 dietary contamination in the northern hemisphere was somewhat greater than in 1959, which, up to that time, had been the year when highest levels were observed. In 1963, dietary levels in the northern hemisphere were at least twice those in 1962 (A80). In the southern hemisphere, dietary contamination increased in 1962 and 1963, though to a smaller extent, and the levels remained considerably lower than those in the northern hemisphere (A81).

8. Recent evidence on the transfer of caesium-137 through food chains has led to an improved basis for evaluating radiation doses from caesium-137 within the human body (A134, 135, 178-180). It is now apparent that doses from caesium-137 were somewhat over-estimated in the 1962 report. Between 1961 and 1963, the changes in levels of caesium-137 in diet were broadly similar to those in levels of strontium-90 (A117).

9. It has been found that, under certain local ecological conditions, the transfer of caesium-137 to man is enhanced, leading to the highest body contents yet measured. Thus, in arctic regions, the levels of caesium-137 in the flesh of reindeer and caribou are high on account of the accumulation of this nuclide in the vegetation on which the animals graze (A118). The body content of caesium-137 in small groups of local inhabitants who live almost exclusively on the meat of reindeer and caribou has on occasions exceeded the world average by a factor of more than 100 (A128).

10. Short-lived radio-nuclides have been measured in the environment, in food and in the human body more consistently since the end of 1961 than during earlier series of tests. As a consequence, doses delivered by those nuclides are now more accurately known. Iodine-131 has received particular attention (A136-146) because its absorption by infants from fresh milk leads to the irradiation of their thyroid glands. Adults receive much lower doses owing to the larger size of their thyroid glands, and their lower consumption of fresh milk.

11. In most areas of the temperate zone in the northern hemisphere, the average dose to the thyroid glands of children who were brought up on fresh milk was about 0.1 rad in 1961 (A, table XXX); similar doses were received in 1962, whereas in 1963 the doses were negligible (A182, 183). In the southern hemisphere, doses were considerably lower. In 1962, the concentration of iodine-131 in milk produced in some limited areas within a few hundred kilometres of testing grounds were ten times higher than the average; doses to the thyroid were correspondingly higher (A138).

[4] Throughout the present report, references to the annexes are indicated by a letter immediately followed by a number. Thus A32-34 refers to paragraphs 32 to 34 of annex A.

[5] *Official Records of the General Assembly, Seventeenth Session, Supplement No. 16* (A/5216), chapter V, paragraphs 60-69.

12. The Committee has again reviewed the problem of the doses due to carbon-14, a radio-nuclide with a half-life of about 5,700 years, which is formed from atmospheric nitrogen both naturally, by the continuous interaction of cosmic rays, and artificially, by neutrons released from nuclear explosions. The atmospheric content of artificial carbon-14 has been increased about threefold by testing in 1961-1962. By July 1963, the artificial carbon-14 concentration in ground level air rose to 90 per cent of the natural carbon-14 concentration in the northern hemisphere (A, table XV). With time, artificial carbon-14 will tend to become uniform throughout the atmosphere and to be progressively absorbed by the oceans. Thus, by the year 2000, the artificial carbon-14 concentration in the atmosphere will fall to some 3 per cent of the natural carbon-14 concentration (A71).

13. As in its 1962 report,[6] the Committee has based its evaluation of comparative risks due to past nuclear explosions on dose commitments to the gonads, to the cells lining bone surfaces and to the bone marrow—those tissues whose irradiation may give rise to hereditary defects, bone tumours and leukaemias, respectively. The dose commitment is the total dose that will be delivered, as an average for the world population, to the relevant tissues during the complete decay of radio-active material introduced into the environment. Doses included in the dose commitments may be delivered over a very long period of time. The dose commitments due to all tests before January 1963 are summarized in table I.

14. In the present report dose commitments are expressed in rads.[7] For radiations resulting from nuclear explosions, rads, as used here, and rems, as defined in the 1962 report,[8] are numerically equivalent. In this report, doses from natural radiation also are expressed in rads and therefore are numerically slightly smaller than in the 1962 report where they were expressed in rems. They are 99, 96 and 95 millirads per year to gonads, cells lining bone surfaces and bone marrow, respectively.

15. Comparative risk estimates can be made by reference to doses from natural sources of radiation. One inherent difficulty in such comparisons arises from the arbitrary period over which the natural radiation dose must be integrated. In principle, several alternatives are possible:

(1) The dose commitment could be compared with the natural radiation dose delivered over a period of time equal to that over which a substantial part of the dose commitment is delivered. This comparison could be misleading in the sense that exposure from future nuclear tests might overlap this period

[6] A/5216, chapter VI.

[7] The rad is the unit of absorbed dose; A/5216, chapter II paragraph 23.

[8] A/5216, chapter II, paragraph 26; the rem has recently been given a new definition by the International Commission on Radiological Units and Measurements.

TABLE I. DOSE COMMITMENTS FROM NUCLEAR EXPLOSIONS [a]

Tissue	Source of radiation	Dose commitments (mrad): For period of testing 1954-1960 (estimates from 1962 report)	Dose commitments (mrad): For period of testing 1954-1962 (new estimates)	Paragraph of annex A
Gonads	External, short-lived [b]	11	21	163
	Cs^{137}	16	29	165
	Internal, Cs^{137} [b]	8	13	179
	C^{14}	5[c]	13[c]	187
	TOTAL	40	76	
Cells lining bone surfaces	External, short-lived [b]	11	21	163
	Cs^{137}	16	29	165
	Internal, Sr^{90}	67	174	173
	Cs^{137} [b]	14	13	179
	C^{14}	8[c]	20[c]	187
	Sr^{89}	0.15	0.30	176
	TOTAL	116	257	
Bone marrow	External, short-lived [b]	11	21	163
	Cs^{137}	16	29	165
	Internal, Sr^{90}	33	87	174
	Cs^{137} [b]	10	13	179
	C^{14}	5[c]	13[c]	187
	Sr^{89}	0.07	0.15	176
	TOTAL	75	163	

[a] In the 1962 report, these doses were reported in mrems. As explained in paragraph 191 of annex A, the doses in the present report are all given in mrads.

[b] The dose commitments from short-lived nuclides and from internal Cs^{137} have been calculated on a slightly different basis in this report (paragraphs 162, 178 of annex A) as compared to the 1962 report.

[c] For C^{14} it seems to be appropriate to include only the dose which is accumulated up to the year 2000, at which time the doses from the other nuclides will have essentially been delivered in full. The *total* dose commitments from C^{14} from tests up to 1960 for the gonads, cells lining bone surfaces and bone marrow are 48, 80 and 48 mrads, respectively. For all tests up to the end of 1962, the dose commitments from C^{14} are 180, 290 and 180 mrads, respectively.

(2) As in the 1962 report,[9] a comparison could also be made with the natural radiation dose delivered during the period of testing, with the justification that it is the commitment incurred during this period which is relevant, irrespective of the radiation source. However, the latter comparison may also be considered unsatisfactory because the period is not easy to define.

(3) A direct comparison between dose commitments (millirads) and annual dose rates from natural radiation (millirad/year) is hardly justified.

(4) An alternative approach that was also used in the 1962 report[10] and is followed here is to express the dose commitments in terms of the period of time during which natural radiation would have to be doubled to give a dose increase equal to the dose commitment.

[9] A/5216, chapter VI.
[10] A/5216, chapter VI, paragraph 17.

16. For all tests carried out before January 1963, these periods amount to approximately 9 months for the gonads, 32 months for cells lining bone surfaces and 20 months for the bone marrow. These periods are not directly comparable with the periods given in the 1962 report because they only take into account that part of the dose commitment from carbon-14 which is delivered before the year A.D. 2000. In addition, the periods given in the 1962 report related to tests during the years 1954-1961 and involved an assumption of testing practice for the year 1961.

CHAPTER III

RADIATION CARCINOGENESIS IN MAN

1. Among the major problems discussed in the 1958 and 1962 reports was that of obtaining estimates of absolute risk of induction of a number of effects by irradiation at doses and dose rates such as those delivered by natural sources and by fall-out from nuclear testing. In the 1958 report, the estimates of absolute risks that were presented in terms of expected frequencies of given effects per unit dose were tentative and largely hypothetical, and in many cases involved hardly justifiable assumptions in applying the observed results of high doses and dose rates to low doses and dose rates and to different conditions of exposure. For these reasons, in the 1962 report the Committee confined itself to estimating comparative risks. Having again reviewed the available information relating radiation to cancer induction in man, the Committee sees no possibility of changing this procedure at the present time.

2. Data published since 1962 have, however, led the Committee to believe that it is possible, for a few tissues only and mainly in the high dose range, to make estimates of risk (B20)[11] (expressed for example as number of cases per year per rad per million exposed individuals) that are valid within the observed range of doses and the given conditions of irradiation. Furthermore, and especially when the doses studied lie within the range over which the frequency of the effect increases rapidly with rising dose, it is unlikely that the risk per unit dose at very low doses will be any greater than that at high doses and it is likely to be much less. Thus, the estimated risk per unit dose will in most cases represent an upper limit for effects at very low doses (B18, 19).

3. New possibilities of analysing the increased incidence of leukaemias as a function of dose among the survivors of the explosions at Hiroshima and Nagasaki have been offered by a study of a sample of survivors who had been divided in groups according to the estimated doses that they had received. The estimate was made according to distance from the hypocentre and extent of shielding from radiation (B25-30). The accuracy of the dose estimates is difficult to assess, as they might well be affected by some systematic error, in particular that due to our limited knowledge of the relative importance of neutrons and gamma rays delivered during the explosions. The estimates of the doses are, however, almost certainly not in error by a factor greater than two or three.

4. Taking the dose estimates at face value, the average yearly incidence of radiation-induced leukaemia, as determined over a period of nine years, from 1950 to 1958, shows approximate proportionality with the dose in the range from about 100 rads to 900 rads. The rate of increase with dose is between 1 and 2 cases per year per rad per million exposed individuals (B30). It is not known for how long a period of time the increased incidence of leukaemia among survivors will last. There is some indication that the excess has been slightly subsiding during the 1960's.

[11] Throughout the present report, references to the annexes are indicated by a letter immediately followed by a number. Thus B20 refers to paragraph 20 of annex B.

5. This estimate of absolute risk can only be applied with caution to the population at large. The surviving population has been heavily selected by the lethal effect of the irradiation itself so that the survivors may not necessarily be representative of the irradiated population with respect to sensitivity to radiation carcinogenesis.

6. The estimate obtained from the A-bomb survivors is consistent with that determined, between 300 and 1,500 rads, from a completely different survey of subjects irradiated therapeutically for ankylosing spondylitis (B40-55). In this survey doses were fractionated and are known with greater accuracy, but the number of cases of leukaemia that were observed is very small. Besides, there is no way of knowing to what extent the disease itself for which the patients had been treated, or other means of therapy to which they had been exposed, might have been responsible for the increased incidence of leukaemia. An estimate obtained from this survey alone would therefore only apply to spondylitic patients.

7. The 1962 report dealt briefly with data on induction of malignancies in children irradiated *in utero* The data were at that time considered as controversial. More recent reports have confirmed a higher incidence of malignancies, including leukaemias, in children irradiated *in utero* (diagnostic irradiation, sometimes repeated) (B62-73). Though precise dose estimates are not available, there is reason to believe that the doses were of the order of a few rads. Risk estimates based on this assumption suggest that the risk of leukaemia per unit dose might be several times higher in children irradiated *in utero* than in adults (B72). These surveys have provided the important suggestion that under certain conditions low radiation doses, of the order of a few rads, can induce malignancy. As in the case of ankylosing spondylitis, there is the possibility that the sample of irradiated children may not be representative of the whole population of children (B73).

8. The 1962 report also discussed data from the Hiroshima tumour registry on the relationship between distance from the hypocentre and over-all incidence of tumours. Further data from the Hiroshima and also from the Nagasaki tumour registry have now been reviewed by the Committee. While these data still indicate a diminishing incidence with distance from the hypocentre, this relationship is now less clear-cut than that derived from earlier reports and does not lend itself to quantitative analysis. Another recent study among Japanese survivors, based on a restricted but more precisely defined population sample, though showing the increased mortality from leukaemia, gave no clear evidence that radiation affected mortality from any other cause of death between 5 and 14 years after the irradiation, though

there was some indication of an increased incidence of other malignancies (B175-180).

9. The Committee has reviewed recent surveys on the induction of thyroid carcinoma as a result of irradiation of the thyroid region for therapeutic purposes during childhood (B105-119). The irradiation was often fractionated. As in all instances of therapeutic irradiation, it is not possible to distinguish between the effect of the irradiation and the effect of the conditions for which radiation was administered. The accuracy of the estimates of doses of radiation to the thyroid is not high, but is sufficient to allow some conclusions to be drawn about the relationship between dose and incidence of thyroid carcinoma.

10. As in the case of leukaemia, the incidence of thyroid cancer shows approximate proportionality in a range of doses between 100 and 300 rads, and leads to a risk estimate of about one case per year per rad per million exposed individuals, averaged over a period of approximately sixteen years following irradiation (B117). The period of risk may, however, be somewhat longer. Higher incidence of thyroid tumours has also been reported among adult survivors of atomic explosions (B90-100). The incidence is related to distance from the hypocentre but information is not adequate to provide quantitative assessments of risk.

11. The Committee has reviewed evidence bearing on risk estimates for certain other malignancies; namely, bone tumours in persons contaminated with radium (B130-145), liver tumours in persons who had received thorium compounds for diagnostic purposes (B146-151), skin cancer from external irradiation (B126-129), and lung tumours in miners exposed to radio-active dusts (B152-174). Inadequacies of sampling and dosimetry, longer latent periods and possibly lower likelihood of induction, make unreliable the quantitative assessments based on the information now available. However, the Committee considers that for some tumours, besides leukaemias and thyroid tumours, it might be possible in time to collect enough information to make additional estimates of risk practicable, and that investigations aimed at recording significant quantitative relationships between doses and observed incidence of any specific malignancy in man should be strongly encouraged and supported.

12. It is not to be expected, however, that such estimates will become available for all, or even for many, types of human tissue. The only data suitable for determination of over-all risks of radiation-induced malignancy are those derived from whole body exposure with substantial doses, as in Hiroshima and Nagasaki. The continuation of the latter studies is therefore of great importance. It is still too soon after the exposure of these populations for all possible malignancies to have developed, but present data suggest that leukaemia may well be the predominant type of malignancy produced and that the over-all risk of all malignancies is unlikely to exceed by any large factor that given above for leukaemia (B179, 180).

13. It is important that no opportunity should be lost of exploring the possibilities for undertaking significant studies in exposed human population groups and of pursuing such studies when sound epidemiological techniques can be applied. On the other hand, the usefulness of such data in estimating the effects of very low doses must depend on progress in our understanding of the fundamental mechanisms of carcinogenesis, the mode of action of radiation, and its interaction with other carcinogenic agents in the environment.

Annex 6

EXTRACT FROM REPORT OF THE UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION
(*GA*, *OR*, 21st Session, Supplement No. 14 (A/6314), 1966)

Chapter II
ENVIRONMENTAL RADIATION

Radiation from natural sources

1. The interest of the Committee in radiation from natural sources arises from the fact that living beings have been exposed to it for a very long time at a relatively constant rate. Because of this constancy of the average dose rate from natural radiation to which human populations have been exposed, these dose rates are used by the Committee as a standard against which population doses from other sources are compared for the purpose of risk estimation. It is of importance, therefore, that the estimates of dose rates from natural radiation should be kept under review.

2. Natural radiation owes its origin to interactions of primary cosmic rays from outer space with the atmosphere, and to the radio-active decay of naturally-occurring radio-isotopes.

COSMIC RAYS

3. The interactions of primary cosmic rays with the atmosphere give rise to secondary rays which contribute about one-third of the external natural radiation reaching the human body. Higher contributions from both primary and secondary cosmic rays apply at very high altitudes; the resulting dose rates have been studied in connexion with the planning of supersonic transport and of space flights, but they will not be considered in the present report.

4. The major advances in the study of cosmic rays as contributors to the natural radiation to which man is exposed have been made with regard to their neutron component. Recent data on cosmic-ray neutron flux densities show that the dose-rate estimate of about two millirads per year to the world population made in the 1962 report needs revision. The Committee now believes the dose rate due to neutrons at sea level to lie between 0.3 and 1.1 millirads per year. This range reflects the uncertainties involved in measurements and the variation of neutron flux densities with latitude.

5. No change is called for in the estimate of the dose rates due to the other (so-called ionizing) components of cosmic rays—28 millirads per year—that was accepted in the 1962 report. As was mentioned in that report, dose rates approximately double every 1,500-metre increase in altitude for the first few kilometres.

6. It must be mentioned that neutron doses are more effective than doses of ionizing radiation in bringing about biological effects. To obtain estimates of risk from cosmic-ray neutrons, allowance must be made for their relative biological effectiveness. However, the necessary weighting factors applying to neutrons as compared to the other components are not known at low dose rates, although they are frequently assumed to have a value of ten. Even with such a high weighting factor, the contribution from neutrons would still be small compared to the total dose rate from natural sources.

RADIATION FROM THE EARTH'S CRUST

7. Terrestrial radio-activity contributes both to natural radiation reaching the human body from outside, owing to the emission of penetrating gamma radiation, and to that arising internally from radio-active nuclides which decay within the organism with the emission of alpha, beta or gamma rays.

EXTERNAL IRRADIATION

8. The Committee has reviewed the dose rates from naturally-occurring external radiation and considers that there is no reason to change its view as expressed in the 1962 report, namely that, subject to wide geographical variations, the average external dose rate from naturally-occurring radio-active nuclides to which the world population is exposed is about 50 millirads per year, allowing for the fraction of time spent indoors and outdoors.

9. In some areas, however, the soil and the underlying rocks contain abnormally high amounts of radio-active material. In some high radiation areas where sizable populations live, external dose rates up to twenty times higher than average have been reported.

INTERNAL IRRADIATION

10. Radio-active material in soil may either be absorbed by plants or leached into water, and so may enter the human food chain and eventually be ingested by man. Radon, a radio-active gas resulting from the radio-active disintegration of nuclides of the uranium and thorium series, escapes from soils and rocks into the atmosphere, and can thus be inhaled together with its radio-active daughters.

11. The major natural sources of internal radiation are potassium-40, which delivers relatively uniform dose rates to the whole body, and members of the uranium and thorium series which predominantly irradiate the bone and bone marrow. Carbon-14 and rubidium-87 are among other nuclides which deliver much smaller dose rates.

12. The estimates of dose rates to gonads and to bone and blood-forming cells from internally deposited radio-nuclides, expressed in millirads per year, are essentially the same as in the 1962 report. In that report, however, dose rates were expressed in different units to take into account the higher efficiency of alpha particles in producing biological effects when compared to gamma rays. As in the case of cosmic-ray neutrons, it seems more appropriate to express dose rates in millirads per year, since allowing for the relative biological effectiveness of alpha particles would require information that is not available now and would therefore involve largely arbitrary assumptions.

13. The Committee has re-evaluated the dose rates from naturally-occurring radio-active material to the

lung tissues. Such material reaches the lungs mainly through inhalation of the daughter products of radon. These daughter products are inhaled in particulate form and therefore tend to be deposited on the walls of alveoli and bronchi and to remain there long enough for significant doses to be delivered. The dose rates to the cells lining these cavities seem to be of the order of some hundreds of millirads per year, although no exact figure can, at present, be given. These are the highest tissue dose rates received from natural radiation. Any biological significance that these dose rates may have, however, is still unknown.

Dose-rate estimates

14. Dose rates from natural radiation are summarized in table I. They have been computed for the gonads, irradiation of which gives rise to genetic effects, for cells lining the inner surface of bone from which bone tumours may arise, and for blood-forming cells, the irradiation of which may result in leukaemias. The average dose rate in the whole body is taken as equal to that to the gonads.

15. The figures in the table must be considered as average dose rates received by the world population. It has not been possible to assess accurately the variability of the dose rates received by different population groups. Those limited populations, however, which live in subarctic regions and consume large amounts of caribou and reindeer meat or of fresh-water fish may receive somewhat higher doses to blood-forming cells and to cells lining the internal surface of bone. Similarly, populations living in the high-radiation areas of Brazil and India receive higher dose rates of external radiation from the soil.

Radiation from man-made sources

16. Nuclear tests are the main source of present world-wide radio-active contamination of the environment. Low activity wastes released from facilities using nuclear technologies for industrial, medical and research purposes contribute a negligible fraction of the doses received by human populations from artificial sources, though their significance may increase in the future as a consequence of the increased use of nuclear energy in human activity. Accidents at nuclear establishments have been only of local importance.

17. The unplanned re-entry into the atmosphere in April 1964 of a spacecraft carrying a power source containing plutonium-238 resulted in the dispersion of this radio-active material. This material is slowly descending towards the ground and has now been detected in surface air at some sampling stations in the southern hemisphere. It is expected that the average amounts of plutonium from this source that may be inhaled in the coming years will remain exceedingly small, and will give rise to negligible radiation exposures.

18. The atmospheric tests that were carried out in central Asia in 1964 and 1965, and those underground tests from which leakage of radio-active material into the atmosphere has taken place, have not contributed significantly to world-wide mean doses. A further atmospheric test took place in May 1966; although no detailed evaluation is yet possible, it appears that the quantity of fission products released was very small compared with the total quantity produced by all previous tests.

19. Results of measurements of radio-activity in the stratosphere, which constitutes the main reservoir of radio-active debris still available for world-wide deposition, and estimates of the total amount of artificial radio-activity so far deposited over the surface of the globe lead to estimates of current and expected contamination of land areas which are the same as, or only slightly lower than, those made by the Committee in its 1964 report.

20. Increasing but conflicting evidence indicates that higher amounts of radio-active debris fall into the oceans than were assumed in the past. However, this does not influence greatly the prediction of future land deposition, since only relatively small amounts of radio-active material still remain in the stratosphere. The estimate of sea deposition relative to land deposition is, in fact, mainly of interest for predictions of the fate of material located in the stratosphere. The somewhat higher radio-activity deposition over the oceans does not affect the estimates of doses due to intake of seafood, since the previous estimates were based upon direct measurements of radio-activity in food.

21. The Committee has reviewed the current information on body contents of strontium-90 and caesium-137 in the world population and on dietary levels of these radio-active nuclides, and has concluded that no change in the method of calculation of dose commitments from strontium-90 appears warranted at this time. There are, of course, still considerable uncertainties in the numerical factors used in the calculation of dose commitments.

22. New evidence indicates that the factors used to calculate the long-term contamination of diets by strontium-90 contained in the soil are probably too high and hence the dose commitments from strontium-90 listed in table II may be over-estimates. The numerical factors used in the calculation of the internal dose commitments from caesium-137 have been somewhat increased taking into account new information. As a consequence, these dose commitments are slightly higher than those given in the 1964 report.

23. With regard to external doses from artificial radio-activity deposited on to the ground, the Committee has modified its methods of calculating the external dose commitment from gamma emitters. There is no significant change in the numerical values obtained, but the new methods follow the actual processes more closely.

24. Estimates of the average dose commitments already received and to be received by the world population by the year 2000 from all tests carried out to the end of 1965 are summarized in table II. These estimates differ little from those made in 1964. The fraction of the total dose commitment which is attributable to external sources ranges from about two-thirds for gonads to one-fifth for cells lining bone surfaces.

25. Appreciable variations of dose are found in different parts of the world. A particular situation is that prevailing in the arctic and subarctic regions of Alaska (United States), Canada, the Scandinavian countries and the Soviet Union, where sizable populations consume large amounts of caribou and reindeer meat. As these animals graze over land areas and feed on lichens that derive their nutrients mainly from atmospheric dusts, their meat contains high concentrations of radio-active nuclides, particularly caesium-137. As mentioned

in paragraph 15, a similar food chain mechanism explains that these same populations are also exposed to higher levels of internal natural radiation.

Conclusions

26. The Committee has re-evaluated the contributions to the exposure of human populations from natural radiation (annex A) and from radio-active contamination of the environment by past nuclear weapon tests (annex B). Estimates of comparative risks have also been reviewed. Comparative risks are expressed, as in the 1964 report, in terms of the periods of time during which natural radiation would have to be doubled to give a dose increase equal to the total doses expecte by the year 2000 from the current contamination of tl environment due to past nuclear weapon tests.

27. These periods do not differ appreciably fro those given in the 1964 report. Present estimates a approximately three-quarters of a year for the gonad two and a half years for the cells lining bone surfac and one year and a half for the bone marrow. The values present a certain degree of approximation sin they are based on assumptions and measurements whi may not be entirely representative of the whole wor situation. They are more likely to be over- rather th under-estimates.

Table I. Dose rates due to external and internal irradiation from natural sources in "normal" areas

Source of irradiation	*Dose rates (mrad/y)* Gonads	Cells lining bone surfaces[a]	Bone marrow	*Paragraphs in annex A*
External irradiation				
Cosmic rays				
Ionizing component	28	28	28	48
Neutrons	0.7	0.7	0.7	49
Terrestrial radiation (including air)	50	50	50	58
Internal irradiation				
K^{40}	20	15	15	136
Rb^{87}	0.3	< 0.3	< 0.3	136
C^{14}	0.7	1.6	1.6	136
Ra^{226}	—	0.6	0.03	135–139
Ra^{228}	—	0.7	0.03	135–139
Po^{210}	0.3	2.1	0.3	135–139
Rn^{222} (dissolved in tissues)	0.3	0.3	0.3	135–139
Total[b]	100	99	96	
Percentages from alpha particles and neutrons	1.3	4.4	1.4	

[a] The dose rates under this heading were actually calculated for the Haversian canals of bone. Doses to cells lining bone surfaces may be somewhat lower than those quoted here.

[b] Totals have been rounded off to two significant figures.

Table II. Dose commitments from nuclear explosions

Tissue	*Source of radiation*	*Dose commitments (mrad) for period of testing 1954-1965*[a]	*Paragraphs in annex B*
Gonads	External, short-lived	23	137
	Cs^{137}	25	135
	Internal, Cs^{137}	15	145
	C^{14} [b]	13	147
	Total[c]	76	
Cells lining bone surfaces	External, short-lived	23	137
	Cs^{137}	25	135
	Internal, Sr^{90}	156	143
	Cs^{137}	15	145
	C^{14} [b]	20	147
	Sr^{89}	0.3	146
	Total[e]	240	

TABLE II. DOSE COMMITMENTS FROM NUCLEAR EXPLOSIONS (*continued*)

Tissue	*Source of radiation*	*Dose commitments (mrad) for period of testing 1954-1965*[a]	*Paragraphs in annex B*
Bone marrow	External, short-lived	23	137
	Cs^{137}	25	135
	Internal, Sr^{90}	78	143
	Cs^{137}	15	145
	C^{14}[b]	13	147
	Sr^{89}	0.15	146
	TOTAL[c]	150	

[a] As in its 1962 and 1964 reports, the Committee has based its evaluation of comparative risks due to past nuclear tests on dose commitments to the gonads, to the cells lining bone surfaces and to the bone marrow. The dose commitment is the total dose that will be delivered, as a world population average, to the relevant tissues during the complete decay of radioactive material introduced into the environment. Some of the doses included in the dose commitments may be delivered over a very long period of time.

[b] As in the 1964 report, only the doses accumulated up to the year 2000 are given for carbon-14; at that time, the doses from the other nuclides will have essentially been delivered in full. The *total* dose commitment to the gonads due to carbon-14 from tests up to the end of 1965 is about 180 millirads.

[c] Totals have been rounded off to two significant figures.

Chapter III

THE GENETIC RISKS OF IONIZING RADIATION

1. Radiation damage to the genetic material may take two forms: gene mutations and chromosome anomalies. Gene mutations result in an alteration of the elementary units of information that make up the genetic message received by the progeny from their parents, whereas chromosome anomalies involve the loss, duplication or rearrangement of minor or major parts of the same message. It will be recalled from the 1962 report that the elementary units of genetic information are called genes and that they are linearly arrayed along nuclear structures called chromosomes.

2. Both gene mutations and chromosome anomalies occur for reasons usually not ascertainable in populations not unduly exposed to radiation. As in the past, the Committee has reviewed information on both the spontaneous incidence of genetic changes in the general population and on the induction of those changes by radiation. The advances in genetics and cytology made in the last few years have made it possible for the Committee not only to review its earlier estimates of the risk of induction of gene mutations, but also to reconsider the risk of induction of a few chromosome anomalies.

Natural incidence of mutations in man

GENE MUTATIONS

3. Gene mutations are believed to occur at a rate of approximately one in seven gametes (mature germ cells) per generation in males and possibly at a lower rate in females (C23).[2] The great majority of these continually arising mutations are harmful in various degrees and, by failing sooner or later to be transmitted to the following generations, are eliminated from the population at a rate related to their harmfulness. Failure of transmission may occur through death of the cell carrying the mutation, through lack of fertilization, or lack of implantation of the fertilized egg in the maternal organism, all events that pass practically unnoticed. It may also occur through processes involving hardship, such as miscarriages or peri-natal mortality, as well as reduction of fertility associated with physical or mental defects of all shades of severity. There is no way to tell at present whether the elimination of mutants occurs predominantly through events of limited social consequence or by processes associated with major sufferings.

4. It is, however, possible to estimate the frequency of those mutations that give rise to various severe and well-known disabilities and which, being dominant, become manifest in the generation immediately following the one in which they have arisen. The total rate of mutations responsible for these disabilities appears to be between one and two mutations per 10,000 gametes per generation (C9). Therefore, of all the spontaneous mutations, only one in 1,000 is a dominant mutation associated with a clearly identified hereditary disability recognizable at birth. Many more, not necessarily dominant, mutations are probably associated with disabilities less easily identifiable as genetic in origin.

CHROMOSOME ANOMALIES

5. Chromosome anomalies consist of changes in the number or in the structure of chromosomes. Two categories of chromosomes are recognized—autosomes and sex-chromosomes. With the exception of mature germ cells, human cells contain twenty-two pairs of autosomes and one pair of sex-chromosomes. The two members of each of the twenty-two autosomal pairs are morphologically identical regardless of the sex of the subject to which the cell belongs; the sex-chromosomes in each pair, on the other hand, are identical in females but not in males.

6. The first anomaly that was described in man involved the presence of a specific extra autosome. This anomaly is associated with a severe clinical condition called Down's syndrome (mongolism). Other extra chromosomes were described subsequently. These anomalies have always been associated with grave disabilities. The frequency of children with extra autosomes is about two per 1,000 live-born children (C42).

7. Changes in the number of sex-chromosomes, including loss of a chromosome, are also known. The syndromes associated with these changes are detected in about three per 1,000 live-born children (C51). Though less severe in their effects than extra autosomes, changes in the number of sex-chromosomes are responsible for serious clinical syndromes and are usually associated with sterility.

8. Alterations of structure and numbers of chromosomes appear to occur with equal frequency, but small structural rearrangements probably escape detection because they may affect the individual only slightly and may be difficult to recognize cytologically. Two types of structural rearrangements can be easily detected in man—translocations and deletions. Both autosomes and sex-chromosomes can be affected.

9. Translocations consist of exchanges of fragments between non-identical chromosomes. One survey gave a frequency of translocations of five per 1,000 adults (C46). When the whole of the chromosomal material is present in the cell, even though arranged in a different order as a consequence of a translocation, the anomaly is called balanced, and the individual that carries it is usually normal. During the reshuffling of the chromosomes that takes place in the course of the maturation of germ cells, unbalanced translocations, characterized by deficiency or excess of chomosome material, may arise. Individuals with unbalanced translocations may live, but only with severe handicaps.

10. Deletions are losses of part of a chromosome. Those that have been identified are associated with

[2] Throughout this chapter, references to paragraphs of annex C are indicated by the letter C followed by the corresponding number.

severe syndromes. Their total frequency in the population cannot yet be estimated. One type of deletion appears to occur with frequency of at least two per 10,000 live-born children (C45).

Summary

11. Between 2 and 3 per cent of all live-born children are affected by one of the disabilities mentioned in paragraph 4 or by detectable chromosome anomalies. In addition, about 4 per cent of all pregnancies terminate in miscarriage associated with a chromosome anomaly (C53). Genetic changes occurring naturally must also be responsible for a number of other detrimental consequences, but, in the present state of our knowledge, we are unable to identify them as being genetic in origin, and their frequency is therefore difficult to estimate.

Risk of induction of genetic changes by radiation

12. Gene mutations can be induced by ionizing radiation. This has been shown experimentally in so many animal and plant species that there is no reason to doubt that they can be induced in man. On the other hand, chromosome changes have been proved to arise following irradiation in human somatic cells. The great majority of the radiation-induced genetic changes are harmful, but the damage that they entail extends over a wide range of severity. Some changes have scarcely noticeable consequences; others may be incompatible with reproduction or survival.

13. Clear evidence of genetic damage in the offspring of irradiated human subjects is, however, meagre. The only effect that has been reported is a change of the sex-ratio in the offspring of irradiated individuals. Such an effect, though probably genetic in origin, is difficult to interpret, and the observations are of little use in predicting other genetic consequences of radiation damage.

14. There is no alternative therefore to using results obtained with experimental animals in estimating rates of induction in man. The limitations of such a procedure are obvious when it is realized that animal species differ from each other in their susceptibility to the induction of genetic changes by radiation and that there is no evidence indicating whether the genetic material of man is more or less sensitive to radiation than that of other animal species. The only mammal which has been studied in some detail with respect to radiation genetics is the mouse. Results of mouse experiments must therefore form the main basis for the assessment of genetic risks in man.

15. Most of the experimental data were obtained with immature germ cells, which are also the cells that accumulate most of the genetic damage induced in germ cells. The estimates given in paragraphs 16-23 apply to acute single doses of x or gamma rays. For each of them it will be indicated whether the numerical values refer to mature germ cells (gametes) or to immature ones.

Risk of gene mutations

16. The over-all risk of induction of gene mutations, as based on rates of induction in the mouse at acute high doses, is estimated by the Committee to be two mutations per 1,000 male gametes per rad (C256). As discussed later, the rate of induction of mutations is much less when radiation is delivered at a lower dose rate. It may be recalled from chapter II that man receives from natural sources about one-tenth of a rad per year to the gonads or about three rads in a reproductive lifetime.

17. Induced mutations are similar in nature to those discussed in paragraph 3. Generally harmful, they are eliminated from the population at a rate depending upon their harmfulness, but we are unable at present to determine to what extent the elimination takes place through practically unnoticed events rather than through events that involve individual or collective hardship.

18. It would be desirable to know the risk of induction of that part of the total induced damage that is expressed through those disabilities which are easily detected and are known to occur spontaneously with a measurable frequency in human populations (paragraph 4). To obtain such an estimate it is necessary to make certain assumptions. Depending on the assumptions made, the resulting estimates differ by several orders of magnitude (C264). Observations in mice show that a number of serious skeletal abnormalities can be induced in the offspring of animals irradiated at high doses. The yield of abnormalities is not known at low doses, but the observations may in the future give a clue to a more precise estimation of risks of induction of dominant traits in man.

19. The particular importance of dominant mutations lies in the fact that, once induced, they become apparent in the offspring of the irradiated individuals, and each of these mutations will persist for a number of generations depending on the detriment to which it gives rise. It must be emphasized, however, that this category of induced mutations represents only part of the total damage due to induced gene mutations and that the elimination of perhaps a large fraction of the rest may also involve considerable hardship.

Risk of chromosome anomalies

20. Data on the induction of chromosome anomalies in mice are scantier than on the induction of gene mutations but can be supplemented by data obtained from the irradiation of human somatic cells grown outside the organism. The limitations of this latter material as a basis for estimating rates of induction in man arise from the fact that the anomalies induced in these cells may not be transmitted at cell division in the same way as if they had been induced in immature germ cells within the body.

21. Loss of a sex-chromosome can be induced in the mouse at a rate of one to four losses for 100,000 immature male germ cells per rad (C278). In man, loss of a sex-chromosome is known to be one of the most frequent among the chromosome anomalies that are associated with spontaneous miscarriages. There is no way to assess at present the rate of induction of extra sex-chromosomes or autosomes. Preliminary information indicating an increased incidence of Down's syndrome in the offspring of irradiated individuals needs to be confirmed.

22. Estimates of rates of induction of translocations in man can be obtained on the basis of experiments both with mice and with human somatic cells grown *in vitro*. The rise of the frequency of translocations is not expected to be proportional to the dose but to depend on it in a complicated manner that do not permit a simple expression of risks. It may, however, be said that the rate of induction after one rad is of the order of one translocation in every 200,000 im-

mature male germ cells (C286). At higher doses, the number of translocations induced is higher than would be expected if the frequency of induction was linearly related to the dose increase.

23. The rate of induction of those deletions that have so far been observed to occur spontaneously in man can be estimated on the basis of *in vitro* experiments on human somatic cells. The estimates, however, depend so much on the assumptions about the mechanism that brings about deletions that the figures obtained differ widely according to the particular theory which is adopted (C293, 294).

Conclusions

24. The Committee has considered genetic effects of radiation, with particular regard to recent data, and has tried to derive from them information as to the importance of genetic effects of irradiation of man.

25. A new estimate has been obtained for the spontaneous frequency of gene mutations over the whole of the hereditary material of man. An estimate has also been made of the rate of induction of gene mutations per unit of radiation dose. From these it would appear that a dose of one rad per generation would add something like one-seventieth to the total number of mutations arising spontaneously in a generation. Taking into account the various uncertainties, the range of that estimate would be very wide, but it is probably not in disagreement with the limits set in the 1962 report of between one-tenth and one one-hundredth. It is known that the great majority of all harmful mutations are expressed as small reductions of viability over intra-uterine and post-natal life, and their effects on health are detectable with difficulty in man. However, it is known that the cumulative effect of these small changes causes the major part of the damage from induced mutations. Furthermore, these changes will be expressed over many generations.

26. The proportion of one-seventieth above might also apply to hereditary diseases of man which are known to be important and which can be transmitted directly from parent to offspring, but it should be emphasized once more that these diseases contribute only a small proportion of the damage from gene mutations. There is evidence that complexly inherited characteristics, such as stature and intelligence, may be affected by induced gene mutations and that the effects would probably be adverse.

27. One-quarter of all abortions are caused by, and 1 per cent of all live-born infants suffer from, severe effects of chromosomal anomalies which arise spontaneously. It is, in our present state of knowledge, only possible to give estimates of rates of induction by high doses of radiation of chromosomal damage of types which include not more than a small proportion of the anomalies that occur naturally. The number of these that would arise after exposure to high doses can be estimated, but it is not known how many would occur following low doses, although the yield per unit dose would be much less than that expected if the yield were directly proportional to the dose. It should be noted that a large part of this type of genetic damage is not expected to persist in a population for more than one generation.

28. Part of the total impairment in the first generation offspring of irradiated parents has been studied in mice, namely, certain skeletal defects. From experiments using high doses, it is known that malformations of the skeleton do occur fairly frequently in these offspring. Whether proportional numbers of such defects would result from low doses to parents is not known.

29. The estimates arrived at in this report relate to the genetic effects of acute exposures, at high doses, of male reproductive cells in the stage (spermatogonia) that is most important in human hazards. Lower numbers of these mutations per unit dose will occur where the radiation dose is low or is spread out over a long time. It is also known that the reproductive cells of the two sexes differ in sensitivity; fewer mutations, on the average, will occur when the reproductive cells of females (oöcytes) are exposed to radiation.

30. The Committee is of the opinion that these estimates, because they are subject to many uncertainties should not be applied in a simple and direct fashion to radiation protection. Any practical application of these numerical estimates must be made with full recognition of the qualifications set out in the above paragraphs and discussed in detail in annex C.

31. Although there are insufficient data for making satisfactory estimates of risk, it is clear that, with any increase of radiation levels on earth, the amount of genetic damage will increase with the accumulated dose. While any irradiation of the human population is genetically undesirable because of its implications for future generations, it should be pointed out that the proper use of radiation in medicine and in industry is important for the health of the individual and for the welfare of the community.

32. The limited number of estimates made, the many uncertainties as to their accuracy and the reservations which have to be attached to each of them may seem disappointing. The reasons will be clear to readers of annex C where the complications of establishing meaningful estimates are fully discussed. Although absolute measures of risk are still very uncertain and will probably remain so for some time, major advances have been made in our knowledge of the relative risks under various conditions of radiation exposure and for different biological variables such as the reproductive-cell stage. These findings are of considerable practical value. Thus, it is useful to know that the genetic hazard will be less per unit dose of radiation when the exposure is spread out in time, is delivered in small dosage, or when a long interval occurs between irradiation of the female germ cell and conception. These factors must be clearly borne in mind when making comparative risk estimates.

Annex 7

Extract from Report of the United Nations Scientific Committee on the Effects of Atomic Radiation

(*GA*, *OR*, 24th Session, Supplement No. 13 (A/7613), 1969)

Chapter II

RADIO-ACTIVE CONTAMINATION OF THE ENVIRONMENT BY NUCLEAR TESTS

1. Debris from atmospheric nuclear tests continues to be the most important man-made radio-active contaminant of the environment. A number of tests have been carried out since the Committee's 1966 report; these have, however, added about 2 per cent to the amounts of long-lived radio-active nuclides still in the environment as a result of tests carried out in the early 1960s, although they have about doubled the current low content of the stratosphere and have thus contributed substantially to the deposition observed since the middle of 1967.

2. Small amounts of radio-active material have leaked from a few underground tests, and the crash of an aeroplane carrying nuclear weapons resulted in a localized contamination by plutonium-239 off the coast of northern Greenland in January 1968. These events have contributed only minutely to the global inventory.

3. Since the 1966 report, levels of long-lived nuclides in food-stuffs and human tissues have continued to decline except in the second half of 1968, when a slight increase in levels of caesium-137 due to recent tests was observed in food-stuffs in some countries of the northern hemisphere.

4. Most of the amount of long-lived nuclides injected into the stratosphere by earlier tests had been deposited by the middle of 1967. However, substantial fractions of the total doses to which the population is committed remain to be received from present body burdens and from the deposit in soil which will continue to be transferred to food-stuffs. This is particularly true in the case of strontium-90 which remains available for absorption by plant roots and is retained for long periods in the human skeleton. Present estimates indicate that roughly one-eighth of the total expected population dose due to strontium-90 had been delivered by the end of 1967, compared with between two-thirds and three-quarters of that due to the total amount of caesium-137 available for deposition in the body. On the other hand, only a small fraction of the expected population dose due to carbon-14, the radio-active half-life of which is much longer, has so far been delivered, and somewhat less than one-tenth of it will have been delivered by the year 2000. By contrast, more than half of the contribution to the dose commitment from external sources has already been delivered.

5. As in its earlier reports, the Committee has evaluated comparative risks of biological damage to the whole world population by means of "dose commitments" derived from the sum of radiation doses received and expected to be received by the world's population as a result of the nuclear explosions which have already taken place. As previously, dose commitments have been estimated for the gonads, for cells lining bone surfaces and for the bone marrow, as these are the tissues whose irradiation may give rise to hereditary effects, to bone tumours and to leukæmias, respectively. The Committee has not made special dose commitment estimates applicable to limited populations, such as those in individual countries, except in a few cases of populations with much higher than average exposures.

6. In the present report, for the purpose of estimating dose commitments, the Committee has used more extensively than heretofore actually measured levels of long-lived radio-nuclides in human tissues. This is particularly so in the case of strontium-90, which poses special problems because of its long retention in soil and bone and because of its complex metabolism in human tissues. By making use of measured levels in tissues, the Committee has been able to avoid some of the assumptions previously needed. Though a large number of other assumptions are still necessary and are common to all methods of calculation, the method now used will enable the Committee to use more efficiently the results of future measurements to verify and, if necessary, modify those assumptions in the future.

7. As far as the world-wide dose commitment is concerned, the major source of uncertainty continues to be the lack of information concerning the levels of any of the radio-active nuclides in the food and tissues of nearly two-thirds of the world population. In its previous reports, the Committee assumed that the numerical constants that describe the transfer of long-lived radio-nuclides were the same as those determined for areas from which measured data had been consistently available.

8. In the present report, the Committee has confined itself to estimating the dose commitment specifically for those populations from which sufficient measurements have been reported. For the rest of the world population, an upper limit to the dose commitment has been estimated.

9. The Committee feels that the uncertainty regarding the estimate applying to a large part of the world population, though unlikely to have caused a serious under-estimate of the global dose commitment, is undesirable, and it recognizes that, because of the very slow turnover of strontium-90 in adult bone, it will be possible, by sampling human bone from those areas of the world from which no data have yet been available, to estimate dose commitments to the population of these areas. The Committee notes with appreciation that the World Health Organization, in response to a recommendation made by the Committee at its eighteenth session, is now undertaking a limited programme of bone sampling, the results of which will be available in the near future.

10. Short-lived radio-nuclides are a source of radiation exposure of the population for a comparatively short time following their release into the environment, and external doses from short-lived nuclides due to tests carried out in 1966, 1967 and 1968 have not significantly increased the global dose commitment. Measurable iodine-131 levels in milk have been reported mainly from the southern hemisphere following the tests carried out in that area.

11. Since the last report, there has been a continuing interest in the doses received by populations in the subarctic regions where, because of special ecological conditions, there is an enhanced transfer of caesium-137 from deposit to the body, mainly through consumption of reindeer or caribou meat. In these regions, individual doses from internal caesium-137 are of the order of one hundred times greater than the average for the northern hemisphere. There are also indications that, in these regions, levels of strontium-90 in food and tissues may be significantly greater, though not by as much as caesium-137 levels, than the average for the northern hemisphere.

12. There are several other limited regions of the world where levels of caesium-137 in food-stuffs and in humans have been found to exceed by many times the average for the corresponding latitudinal band. This has been attributed to high precipitation and to special soil conditions resulting in increased availability of caesium-137 to plants.

13. The estimated dose commitments are summarized in table I. The table includes estimates for the temperate zones of the northern and southern hemispheres. A third column shows values applicable to the whole world population. Although the Committee has used new and less indirect methods of estimating dose commitments, the present estimates differ little from those given in the previous report.

14. Comparative risks are, as in the 1964 and 1966 reports, expressed as the periods of time during which the natural background would have to be doubled in order to deliver an additional dose equal to the fraction of the dose commitments that will be received by the year 2000. These periods derived from the dose commitment estimates applicable to the whole world population are approximately 11, 26 and 18 months for gonads, cells lining bone surfaces and bone marrow, respectively.

15. The Committee now has increased confidence that its estimates are representative of the doses to which humans have been committed, particularly for those populations in the countries and areas from which measurements are available.

TABLE I. DOSE COMMITMENTS FROM NUCLEAR TESTS CARRIED OUT BEFORE 1968

Tissue	*Source of radiation*			*Dose commitments (mrad)* North temperate zone	South temperate zone	Whole world
Gonads	External	Short-lived		36	8	23
		^{137}Cs		36	8	23
	Internal	^{137}Cs		21	4	21[a]
		^{14}C[b]		13	13	13
			Total[c]	110	33	80
Cells lining bone surfaces	External	Short-lived		36	8	23
		^{137}Cs		36	8	23
	Internal	^{90}Sr		130	28	130[a]
		^{137}Cs		21	4	21[a]
		^{14}C[b]		16	16	16
		^{89}Sr		< 1	< 1	< 1
			Total[c]	240	66	220
Bone marrow	External	Short-lived		36	8	23
		^{137}Cs		36	8	23
	Internal	^{90}Sr		64	14	64[a]
		^{137}Cs		21	4	21[a]
		^{14}C[b]		13	13	13
		^{89}Sr		< 1	< 1	< 1
			Total[c]	170	51	140

[a] The dose commitments due to internally deposited ^{90}SR and ^{137}Cs given for the north temperate zone are considered to represent upper limits of the corresponding dose commitments to the world population.

[b] As in the 1964 and 1966 reports, only the doses accumulated up to year 2000 are given for ^{14}C; at that time, the doses from the other nuclides will have essentially been delivered in full. The total dose commitment to the gonads and bone marrow due to the ^{14}C from tests up to the end of 1967 is about 180 millirads and that to cell lining bone surface is about 230 millirads.

[c] Totals have be[illegible] off to two significant figures.

Chapter III

EFFECTS OF IONIZING RADIATION ON THE NERVOUS SYSTEM

1. The nervous system performs various functions in the organism. In the first place, it provides the means for relating the organism to the external environment by means of perception through the sense organs and of control of the skeletal muscles. The nervous system is also the instrument by which immediate or delayed behaviour is expressed, and in man it is responsible for the most complex intellectual functions.

2. With regard to such functions as digestion, respiration, blood circulation and excretion, the nervous system, often in conjunction with the endocrine glands, plays an essential regulatory role by adapting these functions to the changing needs of the organism and thus contributes to maintaining the constancy of the internal environment. This task is largely performed by the autonomic nervous system whose control centres are located in the spinal cord and in certain brain structures.

3. Reflex activity usually involves an orderly progression of events, namely, an initiation of activity at sensory receptors, a relay of impulses to a neural centre and final transmission to a muscle or other effector. While reflex activities are readily analysed, the nervous activity concerned with the highest integrative functions of the organism, such as complex behaviour, are much more difficult to assess.

4. The importance and diversity of these functions emphasize the need for the study of the effects of ionizing radiation on the nervous system. Although ultimately it is the functional effects that may be more important, both structural and functional effects need to be studied. Investigations of functions and structures have been mostly carried out by different researchers, and relatively few attempts at integrating the two approaches have been made. Because the response of the nervous system is so different depending on whether irradiation takes place during its development or afterwards, it is customary and convenient to consider the effects during these two periods in sequence.

Irradiation of the nervous system during its development

5. Observations on experimental animals indicate that pre-natal irradiation can produce severe developmental anomalies. Those of the nervous system are prominent among them. When they are serious enough, further development of the foetus is prevented and death ensues. Anomalies of the nervous system are produced only if irradiation occurs in the period when the nervous system and its various parts are differentiating. Specific anomalies such as microcephaly, encephalocele and hydrocephalus occur in this period only after irradiation at certain so-called critical times.

6. The frequency and severity of anomalies of any given type depend on the radiation dose, but information is insufficient to establish dose-effect relationships for any of the malformations affecting the nervous system. It is likely that the induction of gross malformations of the nervous system requires doses higher than a threshold which, for mice and rats, is probably around 100 rads.

7. Disorganization of the cellular layers of the brain cortex has been observed, however, after an x-ray dose of 20 rads administered to rats on the sixteenth day of pre-natal life and are still apparent when the animals reach maturity. Less pronounced changes also occur in rats after 10 rads given on the first day after birth, but evidence of damage disappears progressively as the animal grows. Such changes have been observed by means of painstaking studies which need to be systematically pursued at various doses and various times of irradiation and observation, and attempts should be made to correlate them with the functional effects that have also been reported after pre-natal irradiation.

8. The functional impairment of animals irradiated pre-natally has been studied by various methods, particularly in rodents. Electro-encephalographic changes seem to reflect disturbances in the inhibitory function of the cortex on lower centres. Visual, olfactory and distance discrimination and other learning processes are also affected. These changes have been observed in adult rats which have received doses of the order of 100 rads or more during the second and third week of their intra-uterine life.

9. Some studies of conditioned reflexes, however, have been reported to reflect changes of learning processes at much lower doses. Slight changes in conditioned reflex performance have been observed in the adult after as little as 1 rad on the eighteenth day of pre-natal life. The assessment of the relevance of these and other behavioural changes for the problem of risk estimation in man requires better knowledge on the comparability of results of studies on animals and on man.

10. That severe damage to the nervous system can be induced in man also is shown by a number of observations of children born of mothers irradiated for medical reasons during pregnancy. Doses are unknown but are believed to have been high. A number of cases of reduction of head size, often accompanied by severe mental retardation, have been reported among these children as a result of irradiation from the second through the sixth month of intra-uterine life. However, contrary to what animal experiments would lead one to expect, major structural changes of the nervous system have seldom been observed, perhaps because these would be incompatible with sufficiently long survival of the human embryo for the damage to be detected at birth.

11. Similar observations have been made among the offspring of women exposed during pregnancy to the Hiroshima and Nagasaki explosions. Reduced average head size and increased incidence of mental retardation are clearly observed among those exposed within 1.5 kilometres of the hypocentre between the second and the sixth month of intra-uterine life, and the frequency of mental retardation may also be above normal at greater distances, where doses were of the order of a few rads.

12. The value of this latter observation is limited by the fact that the number of cases among the offspring of women irradiated at low doses is extremely small and that the role of other factors cannot be entirely excluded. Where the opportunity exists, any additional investigations on pre-natally irradiated subjects are very desirable in order to establish further the degree of radio-sensitivity of the foetus.

13. Surveys of children whose mothers were irradiated for medical reasons during pregnancy have shown an associated increase (40 per cent) of malignancies, including malignancies of the nervous tissue. The excess was noticeable after doses assumed to be of the order of a few rads, but it cannot be entirely excluded that it may have been associated with the condition in the mother that prompted the irradiation rather than with the irradiation itself. Such an increase has not been reported among survivors of *in utero* exposure to the Hiroshima and Nagasaki bombings, but the expected number of induced cases in that population was very low.

14. An increased incidence of tumours of the nervous tissue has also been observed in a number of surveys of children irradiated for medical reasons in infancy or early childhood. One of these surveys suggests that, at the doses absorbed by the relevant tissues, the incidence of these malignancies is increased by the same order of magnitude as the incidence of leukæmias. The same survey has also shown an increased incidence of serious mental disturbances associated with previous irradiation of the brain around the age of seven years. Most of the brain was estimated to have received doses of approximately 140 rads. However, as the role of a number of variables that may themselves have contributed to that excess cannot at present be assessed, the results of further analysis of these results are required before the relationship between radiation and mental disorders can be considered as proved. Other surveys of brain-irradiated children that are currently in progress should be vigorously pursued.

15. The evidence available induces the Committee to draw attention to the particular hazards that may result from irradiation of the fœtus and of children.

Irradiation of the nervous system in the adult

16. In the adult, the radiation dose required to induce severe structural changes in the nervous system under conditions of whole-body irradiation is higher than the dose needed to cause gross alterations of other systems such as the gastro-intestinal tract and of the hæmopoietic system. Under conditions of short-term irradiation, the median lethal dose for man lies around 400 rads, and death when it occurs is mainly due to the involvement of both of these. Sudden death primarily due to the involvement of the nervous system, on the other hand, occurs after doses of the order of several thousands of rads.

17. Only isolated cases of malignant intracranial tumours of the nervous tissue have been reported after irradiation of adult subjects. It seems, therefore, that the induction of malignancies is unlikely to be a substantial hazard of irradiation of the adult nervous system in man.

18. Functional and behavioural effects are observed in experimental animals after high doses (above 50 rad). These effects include some electro-encephalographic changes and some disturbances of certain conditioned reflexes. The accomplishment of many tasks involving learning and performance is little if at all affected. Such changes as have been induced by radiation disappear with time, but repeated irradiations with the same dose tend to produce greater disturbances. There are both positive and negative reports on the induction of similar, but milder, functional changes by low-dose radiation.

19. It is not clear to what extent such functional effects as have been observed after whole-body doses of 50 rads and above are the primary consequence of damage to the nervous system or whether they result from different stimuli originating in, or from toxic products released by, other damaged tissues and systems such as the cardio-vascular, gastro-intestinal and endocrine systems. Nevertheless, whether primary or secondary, these effects on the nervous system may play a role at the doses at which the acute radiation syndrome may occur.

20. Observations are available on radiation workers exposed in the past for a number of years to average levels of radiation estimated as being higher than current maximum dose levels for radiation protection. Subjective complaints, such as headaches and sleep disturbances accompanied by mild and reversible neurological and cardio-vascular changes, have been reported. No changes of consequence were observed among workers exposed, even for a number of years, within the currently accepted dose limits.

21. Even at very low doses, ionizing radiation may act as a non-specific stimulus. Evidence of this is found in the possibility of using radiation as a conditioning stimulus, the ability of radiation to awaken an animal, the avoidance of a radiation source by an animal, and in the fact that radiation can serve as a visual or olfactory stimulus. Under certain circumstances, ionizing radiation can be perceived by the human retina at doses as low as a few millirads. There is no evidence that these doses induce any injury to the sense organs involved.

22. It seems, in summary, that the most significant fact emerging from a review of the effects of ionizing radiation on the nervous system is the striking dependence of the type and intensity of effects on the age at irradiation. In the adult, except at extremely high doses, the effects that have been observed, whether structural or functional, appear to be of secondary importance compared to those that may arise in other tissues and systems. Functional reactions of the nervous system may also appear at very low doses (10 rad or less). However, they are of a physiological nature, and no damage of the nervous system has been observed. In children, on the other hand, the evidence suggests that, at least with regard to the induction of malignancies, the nervous tissue might be about as susceptible as other tissues such as the thyroid and

blood-forming tissues. It is, however, in the pre-natal period that the vulnerability of the nervous system is highest. There is clear evidence that, from the second to the sixth month of pre-natal life, doses from 50 rads onwards are associated with increases in mental retardation and microcephaly. Evidence on the effects of lower doses during this same period of pre-natal life is still extremely tenuous and does not permit exclusion of the possibility that increased incidence of the same effects may be a result of exposure in this lower range. Available data suggest that even low doses given to the fœtus later in pregnancy may increase the incidence of tumours of the nervous system as well as of other malignancies.

Chapter IV

RADIATION-INDUCED CHROMOSOME ABERRATIONS IN HUMAN CELLS

1. The cells of any given species have a characteristic number of chromosomes, and each chromosome has a characteristic structure and size. Chromosomal changes visible by some form of light microscopy are called chromosome aberrations. These can be separated into aberrations involving changes in structure—the chromosome structural aberrations—and those involving changes in the number of chromosomes. Since chromosomes contain genetic material, the various types of chromosome aberrations may result in genetic effects.

2. In man, as in all other animal and plant species, chromosome aberrations are to be found with low frequencies in both somatic and germ cells of individuals in populations that have not been exposed to radiation over and above natural background levels. Such spontaneous aberrations are changes that may, in some cases, be transmitted to descendant cells. In other cases, the changes are so gross that they result in the death of the cells containing them. Clearly there are differences between the relative importance of such changes in somatic as opposed to germ cells.

3. Chromosome aberrations in human germ cells are associated with and may be responsible for a considerable proportion of spontaneous abortions and, where they are compatible with viability, for a variety of congenital abnormalities. Indeed, as discussed in the 1966 report, it has been estimated that one child out of every 200 live-born has a constitutional chromosome anomaly responsible for a gross physical or mental abnormality. The importance of chromosome aberrations in somatic cells is less clear, although there is evidence that one particular kind of chromosome anomaly may be causally related to the development of human chronic granulocytic leukæmia. On the other hand, in normal healthy individuals peripheral blood lymphocytes may occasionally contain a chromosome aberration (less than one in 2,000 for one specific type of aberration). In itself the presence of such aberrations appears to be of no consequence to the well-being of the individual.

4. Exposure to radiation may result in an increase in the number, but not in the variety, of chromosomal aberrations. These aberrations are clearly of genetic importance and they may, in fact, comprise the major component of the genetic damage resulting from radiation exposure. Thus, a considerable amount of work has been carried out on the mechanisms whereby such aberrations are induced by radiation, on the behaviour of the aberrant chromosomes at cell division and on the genetic consequences of the aberrations.

5. Until relatively recently, most of this work had been carried out on organisms that were particularly well suited for cytological study, because they possessed small numbers of rather large chromosomes. However, in the last decade, and particularly over the last four or five years, a considerable amount of study has been devoted to the induction of aberrations in man. These studies have been made possible through the development of simple and reliable techniques for culturing human cells *in vitro* and through the application and refinement of cytological techniques previously utilized by plant cytogeneticists.

6. As a result of the developments in human cytogenetics, it has become possible to make observations on chromosome aberrations induced in human cells both *in vivo* and *in vitro*. Studies have been carried out on individuals exposed to radiation in the course of their work or for diagnostic or therapeutic purposes, as well as on individuals who had been exposed accidentally or as a consequence of nuclear explosions. In addition, a considerable amount of work has been undertaken on the responses of human chromosomes in cells exposed to radiation *in vitro*. These studies have shown that the human chromosome complement is sensitive to radiation and that it is possible to detect effects following x-ray doses as low as 10 rads delivered to substantial proportions of the body in a short period of time.

In vitro studies

7. The blood leucocyte culture system offers a means of experimenting on freshly obtained human cells which can be easily and painlessly collected in large numbers without any adverse effect on the donor and are amenable to short-term culture, using relatively simple techniques. The obvious advantages offered by this system for studies on the *in vitro* response of human cells to radiation exposure have been exploited by a number of groups of workers, and a considerable amount of data on radiation-induced chromosome aberrations in such cells has been obtained.

8. A variety of studies have been carried out on the influence of various factors, including radiation quality, dose, dose rate and time of sampling, on the yield of radiation-induced chromosome aberrations in human peripheral blood cells. In general, it has been found that, for any given set of factors, there exists a quantitative relationship between the yield of aberrations and dose, as has been observed in all other mammalian and non-mammalian cell systems that have been studied.

9. Although studies in various laboratories on the relationship between aberration yield and dose have shown that separate experiments yield consistent results, significant differences have been observed between laboratories. However, it is now clear that the main factors contributing to the quantitative differences between these results are (*a*) differences in the quality of the radiations employed; (*b*) the use of irradiated cultures as opposed to the irradiation of blood cells *in vitro* prior to culture and (*c*) the use of different durations of culture. When these factors are taken into account, close agreement between different laboratories

is evident. However, further standardization of methods is highly desirable to ensure better comparability.

10. This work has great importance because of the possible use of dose-yield relationships established *in vitro* in attempts to estimate radiation doses absorbed *in vivo* and as an indication of their likely biological importance. In theory, dose estimates can be obtained with this technique through the study of chromosome-aberration yields in the exposed individuals and extrapolation to equivalent yields obtained *in vitro* under defined conditions of exposure. A number of laboratories have had a good measure of success in estimating radiation doses in accidentally exposed individuals by the use of this "chromosome-aberration dosimetry" approach. However, there are a number of important problems, particularly in relation to problems of non-homogeneous exposures of the body. At the present time, it seems clear that the use of chromosome aberrations in biological dosimetry may have considerable potential, but much work remains to be done.

In vivo studies

11. Studies on peripheral blood lymphocytes from patients exposed to diagnostic x rays and from radiation workers receiving long-term irradiation have, in some cases, clearly revealed significant increases in aberration yields after doses of the order of a few rads. The ability to detect such effects at low doses is a consequence of the relatively high sensitivity of the human chromosome complement, of the high quality of cytological preparations from lymphocytes and of the very low frequency of spontaneous chromosome aberrations in such cells.

12. To relate aberration yield to radiation dose *in vivo*, data obtained over a range of exposures, preferably under standardized conditions, are desirable but rarely obtainable. A number of studies, however, have been carried out on individuals irradiated at various dose levels and under various conditions either as a result of accident or for therapeutic purposes. The integral absorbed dose has been estimated from aberration yields in some of the studies on individuals accidentally exposed, sometimes with good agreement with measurements obtained by physical means.

13. Evaluation of the dose under these conditions is fraught with uncertainty since, although the cells (small lymphocytes) that are sampled for studying aberration yields are widely distributed throughout the body, they tend to migrate so that only a small proportion is to be found in the peripheral blood at any one time. Thus, in the case of short-term partial-body exposure by radiation of a given quality, the aberration yield observed in the cells sampled will depend upon a variety of factors, including the volume irradiated, the proportion of small lymphocytes in the exposed volume and, since there is considerable mixing between lymphocytes in different tissues, the time at which blood is sampled after exposure. Similar difficulties arise in cases where limited areas of the body have been exposed to radiation for medical purposes, and blood samples are taken at short defined intervals after exposure.

14. Because at least some of the cells sampled for aberration yields are long-lived, it has recently been possible to obtain dose estimates from blood cells of survivors of Hiroshima who had been exposed to radiation from the nuclear explosion twenty-two years previously. These estimates are in reasonable agreement with indirect estimates of exposures obtained by physical methods.

15. It may be concluded that studies to date indicate that scoring of chromosome aberrations in the lymphocytes of circulating blood is a potentially important biological adjunct to physical dosimetry. Special difficulties, however, arise in the irradiations restricted to parts of the body because of the mixing of lymphocytes from irradiated and unirradiated parts of the body. Thus, this method only reflects an average effect upon lymphocytes irradiated in different parts of the body. Further data are urgently required to improve the validity and broaden the field of application of this method.

Possible biological significance of the aberrations

16. The possible biological significance of chromosome aberrations present in germ cells has been the subject of continued review by the Committee, and the views expressed in the 1966 report are still largely valid. There are no direct observations yet on the genetic consequences of radiation-induced chromosome aberrations in the germ cells of man, although information on the genetic consequences of radiation-induced chromosome anomalies in laboratory mammals is available and was reviewed in detail in the 1966 report. Further study on human meiotic cells is clearly necessary, particularly in order to provide better estimates of the spontaneous frequency of translocations in man and a better understanding of their genetic consequences.

17. At the somatic level, the interest of chromosome anomalies results mainly from their possible role in the causation of malignant changes, with which they are frequently associated. Such a role is, however, still unclear. Only in the case of chronic myeloid leukæmia does the evidence strongly implicate a specific chromosome aberration (the Ph[1] chromosome) as playing a significant role in the initiation of the disease if cells with this aberration are present in the bone marrow. Although it is possible that other specific chromosome abnormalities could be associated with other types of neoplastic change, the evidence is tenuous, whereas the presence of a wide variety of chromosome aberrations in most tumours and their complete absence in some others argues against a simple causal relationship. Chromosome aberrations may well be phenomena that are secondary to, and could be independent of, the neoplastic change, although it is clear that most agents and conditions that produce chromosome aberrations also cause tumours.

18. The incidence of chromosome aberrations and that of tumours both increase with increasing dose, but the relationship between the two effects is complex. Although there is some correlation between radiation-induced chromosome aberrations and malignancies, it is a matter of observation that, of the individuals exposed to low levels of radiation and who have aberrations in many of their cells, very few manifest malignant disease.

19. The considerable interest in the possibility that radiation-induced chromosome aberrations may contribute to life shortening and to immunological deficiency has not so far resulted in any clear conclusions regarding the relationship between chromosome aberrations and these effects. Although life shortening and acute immunological deficiency may be induced by radiation, the part played by chromosome aberrations, other than by contributing to cell killing in the case of immunological deficiency, is by no means clear.

20. Information on the yields and types of chromosome aberrations in somatic cells does not as yet provide us with a new approach to, or better estimates of, risks except in the one specific case of the Ph[1] chromosome change which correlates with chronic granulocytic leukæmia. Knowledge of an increased frequency of chromosome aberrations in the peripheral blood lymphocytes of an irradiated individual does not enable us to make any quantitative statement regarding the risk of developing neoplastic diseases, immunological defects or other clinical conditions. For the time being, estimates of risk of somatic diseases must, therefore, remain largely based on empirical relationships between doses and observed incidences in groups of irradiated people, as were the estimates earlier obtained by the Committee.

Annex 8

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

(*GA*, *OR*, 27th Session, Supplement No. 25 (A/8725), 1972)

Chapter I

SOURCES AND DOSES OF RADIATION

A. ENVIRONMENTAL RADIATION[4]

1. *Natural radiation*

8. Man has been continuously exposed to natural radiation since his appearance on earth and, until less than a century ago, was exposed to natural radiation only. Even now, despite the widening use of radiation-producing devices, the widespread radio-active contamination from nuclear weapon tests and the increasing applications of nuclear energy and radio-isotopes, natural sources are the main contributors to the radiation exposure of most of the human population and are likely to remain so in the foreseeable future.

9. Natural radiation is of two origins, extraterrestrial and terrestrial. Extraterrestrial radiation originates in outer space as primary cosmic rays and reaches the atmosphere, with which the incoming energy and particles interact, giving rise to secondary cosmic rays—those to which living beings on the earth's surface are exposed. The rate at which doses from cosmic rays are delivered is fairly constant at any one point on the earth's surface but varies with latitude and, to a greater extent, with altitude. Typical values at sea level in temperate latitudes are of the order of 30 millirads per year. As the altitude increases, dose rates approximately double every 1,500 metres up to a few kilometres above earth.

10. Special problems arise with aircraft flying at high altitudes. In that case, not only is the cosmic-ray dose rate consistently higher than at lower altitudes but it may also, on rare occasions, suddenly rise as a consequence of the emission of high-energy particles from solar flares. The dose rates may, on occasion, be sufficiently high to require the aircraft to descend into the lower protective layers of the atmosphere in order to prevent unacceptable exposures of crew and passengers. The crews of supersonic transports airborne for more than 500 hours per year at high altitudes and latitudes will probably receive exposures somewhat higher than those received by the crews of current subsonic jets. Passenger doses per kilometre flown are likely to be about the same in supersonic transport as in conventional jet aircraft owing to the shorter flight time of the supersonic transports.

11. Terrestrial radiation is emitted from radio-active nuclides present in varying amounts in all soils and rocks, the atmosphere and the hydrosphere, and from those radio-nuclides that, transferred to man through food chains or by inhalation, are deposited in his tissues. Terrestrial radio-activity, therefore, leads to both external and internal exposure. External dose rates vary depending on the nature of the ground and of building materials, whereas internal dose rates are relatively constant. The largest part of the world population receives dose rates of the order of 50 and 20 millirads per year from external and internal terrestrial radiation, respectively. Dose rates higher by an order of magnitude are received by populations (a few hundred thousand people) living in areas where soils have a high content of uranium and thorium.

2. *Man-made environmental radiation*

(a) *Atmospheric and surface nuclear weapon tests*

12. Tests of nuclear weapons have been carried out in the last few years at a much lower rate than during earlier periods. Those carried out before 1963 still represent by far the largest series of events leading to global radio-active contamination. However, the debris that these tests had injected into the stratosphere has been almost entirely deposited on the earth's surface so that most of the residual, undecayed, radio-activity from earlier tests is now present in soil, crops and animal tissues, from which it is steadily removed by a number of physical and biological mechanisms. As in the past, the Committee has reviewed the contribution made by the radio-nuclides produced by nuclear tests to the total average doses that will accrue to certain tissues by the year 2000.

13. The intake of strontium-90, a nuclide that is deposited in bone, is now lower than in the past because comparatively small amounts of it are absorbed from the soil by plants used as food-stuffs or animal feed, whereas direct deposition on vegetation, which was the main mechanism of contamination when fall-out rates were high, now contributes very little to the intake. As a result, levels of strontium-90 have considerably decreased both in children and in adults. The fact that rates of deposition of strontium-90 are now so much lower than a few years ago has made it possible to evaluate more realistically the rates at which this nuclide is taken up from soils and is eliminated from the human body. These values differ from those that the Committee, in the absence of direct estimates, had so far assumed, and lead to estimates of dose commitments smaller than those accepted by the Committee in its last report. Conversely, the estimates of external doses to all tissues from fall-out deposited on the ground have now been revised upwards. As a result, although the total inventory of long-lived nuclides produced by nuclear tests has changed only slightly, the relative importance of strontium-90 as a contributor [illegible] the total dose to be received by the year 2000 is less than in the past, the main contribution being now from those nuclides, in particular caesium-137, that give rise to external irradiation. The total *per caput* dose to be received between 1955 and 2000 by the whole world population from tests carried out between 1955 and the end of 1970 is equivalent to about two years of exposure to natural sources. However, since nuclear weapons tests have not ceased in 1971, it cannot be excluded that a further dose commitment must be added.

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[4] For details, see annex A.

14. Iodine-131 is a radio-nuclide that poses special problems because it is concentrated in the thyroid and irradiates that gland more than any other tissue, the doses per unit intake (mostly through milk) being highest in infants. The presence of iodine-131 in milk has been reported in a number of countries of the southern hemisphere after each of the 1970 and 1971 series of tests in the southern hemisphere. The annual average doses to the thyroids of infants were of the order of several tens of millirads and the highest annual doses remained markedly lower than those reported in the northern hemisphere before 1963.

(b) *Power production from nuclear fission*

15. Large-scale production of electric power by nuclear fission presupposes a cycle of complex operations, most of which involve some discharges of radio-active material to the environment and a corresponding radiation exposure of the population at large. The exposures that have resulted so far and may result in the future from operational discharges throughout the world have been considered by the Committee on the basis of published information or of information directly submitted to the Committee. While such information was available from only a few of the countries in which power reactors are in operation, there is no reason to believe that the population exposure associated with the power production cycle differs markedly in other countries. The Committee has not reviewed the contamination that may result from future accidental releases of radio-activity.

16. In the full production cycle—from mining and milling of ore to fuel fabrication and enrichment, to power production in reactors and finally to reprocessing of spent fuel—the last two operations are at present the main contributors to the total population dose resulting from nuclear power production, largely because of occupational exposure of workers in these two parts of the cycle.

17. The exposure of the population is both local, to limited populations living in the proximity of nuclear installations, and global. Most of the population exposure is external, from gaseous discharges through the stacks, whereas a lesser contribution is made by discharges through liquid effluents. Global doses to be received annually by the general public as a result of the continued operation of the energy production cycle at the 1970 production rate are estimated to be one hundred thousandth of the average dose received annually by the world population from natural sources. Local doses can be several times higher than global ones.

18. According to estimates provided by the International Atomic Energy Agency, the world generating capacity will increase more than two hundredfold by the year 2000. With current technology and operational practice, if the nuclear power production were to stabilize at the estimated level reached by the year 2000, annual global radiation doses from the power-production cycle might be as high as two thousandths of those received annually from natural sources. The magnitude of the average increase in the local doses is more difficult to predict for these depend on the population density as well as on the output of the installations, but doses to be received annually as a result of continued power production at the level estimated for the year 2000 are unlikely to exceed greatly the annual global doses received from these sources. Technological advances may make it possible to reduce these expected doses considerably.

(c) *Peaceful nuclear explosions*

19. Nuclear explosives have a virtually unused potential for peaceful applications. Those that have some prospects of being developed in the near future are the recovery of underground natural resources (particularly natural gas and oil) or the provision of underground storage cavities by contained explosions, and the construction of reservoirs, harbours, canals, etc. by exploiting the earth-moving effect of subsurface cratering explosions. Both types of explosions potentially involve population exposure, associated mostly with the radio-activity of the resources recovered in one case, and with the release of radio-active material to the environment in the other. Their practical applications will probably require international agreements to ensure the protection of the public.

20. A detailed evaluation of artificial radio-activity in the natural gas recovered from the first experimental contained explosion has indicated that, if the gas had been introduced into the distribution network that supplies gas to the 7 million inhabitants of the Los Angeles, California (USA) area, they would have received a dose of the order of a few ten thousandths of that received annually from natural sources. The explosive used in this experiment had not been designed for gas stimulation, however, and it is to be expected that the new explosives that are now being developed will make it possible to keep gas contamination to such low levels that distribution of gas for industrial and even domestic consumption may become justifiable.

21. Cratering explosions, by their very nature, always involve at least some venting of radio-activity into the atmosphere. Few have been carried out experimentally so far, but one has been used in the Soviet Union for the creation of a water reservoir. Current technology may make it permissible to use cratering explosions for small projects in isolated areas. For bigger ones, the safety of the populations living near the site of the project, as well as long-range contamination, are powerful limiting factors, and will restrict the use of these projects unless they are overcome by major technological advances.

B. MEDICAL EXPOSURE[5]

22. Radiation is used in medicine for diagnostic purposes and for the treatment of diseases, particularly cancer. The local doses received by individual patients in the course of diagnostic investigations may vary from being about equal to the average doses received annually from natural sources (~ 0.1 rad) to 50 times as high. Radiation treatments, on the other hand, may involve individual doses thousands of times higher than those received for diagnostic purposes and are usually delivered over several weeks to part of the body only. Both for diagnosis and for therapy, irradiation is mostly external, but an increasing number of radiological procedures now involves the administration of radio-active materials which result in internal irradiation.

23. The mean doses received by the population are determined by a combination of the doses deliv-

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[5] For details, see annex B.

ered by the individual procedures and the number of cases in which these procedures are applied. In the 10 years since the Committee last reported on this topic the frequency of diagnostic radiological examinations has increased by a few per cent per year in a number of technologically advanced countries, as more facilities for medical care became available and new developments in techniques and instrumentation have been introduced. The aim of medical radiology is to provide maximum benefit to the population served, and therefore an increase in frequency of examinations is likely to be fully justified, particularly in the developing countries. Since it is probable that a large proportion of the world population does not have easy access to modern x-ray facilities, the number of such facilities must increase greatly if local health standards are to improve substantially.

24. Most surveys of medical exposure have been concerned with doses to the reproductive cells. Because such doses, when received after completion of a person's reproductive life, will make no contribution to genetic effects in subsequent generations, individual dose estimates are weighted by the child expectancy of the patient so as to obtain an estimate of the "genetically-significant dose". The estimates so obtained vary for different countries by a factor of almost 10 and range from less than one tenth to more than one half of the annual dose from natural sources. Therapeutic irradiation being most frequently carried out on patients unlikely to have any more children, most of the genetically-significant dose is due to diagnostic irradiation, and different types of examination contribute to different extents to the mean dose. It is very important to note that some of the lowest doses have been reported from countries with the highest health standards, indicating that, with the use of modern radiological techniques and equipment (in particular strict control of field size), the best medical care need not at present involve genetically-significant doses higher than one fifth of the annual dose from natural sources.

25. Only three surveys of doses to blood-forming cells in the bone marrow have been carried out so far. Their results indicate mean annual *per caput* doses from medical procedures ranging from one third to two times the annual dose from natural sources.

26. There is sufficient agreement between the surveys carried out in the various countries to assess the magnitude of the average doses for particular examinations within an order of magnitude. However, surveys have additional value in indicating where changes in radiological practice or technical advances may achieve significant reductions of the population exposure, and can help in identifying those groups of patients that, having received high doses of radiation, may need continuing surveillance to detect possible increases in late radiation effects. But it is questionable whether emphasis should continue to be placed on the conduct of dose surveys alone or whether more attention should not be given to the other means of achieving the minimum practicable dose to the patient commensurate with the needs of diagnostic radiology.

27. Three basic approaches can contribute variously to this improvement, depending, in any particular case, on the availability of funds and trained staff—educational programmes, surveys of the frequency of examination and of the doses received, and administrative control measures. Educational programmes can be aimed at (*a*) the radiation staff and the conduct of their day-to-day work, (*b*) the clinical staff that prescribe investigations involving radiation and (*c*) the general public and the development of an awareness of the need for radiation protection. The provision of educational training programmes and the establishment of some administrative control may be much more important than dose surveys, particularly where resources are limited.

C. Occupational exposure[6]

28. Individuals may be exposed to radiation in the course of their occupation. In industrially developed countries the number of persons liable to receive radiation exposures in the course of their work is reported to be between one and two per thousand of population. Close adherence to the recommendations of such bodies as the International Commission on Radiological Protection, the International Labour Organisation, the World Health Organization and the International Atomic Energy Agency ensures that most workers receive very low exposures, and that very few workers exceed the recommended maximum permissible doses. The maximum permissible annual dose to the whole body is about 50 times that received from natural sources.

29. The mean radiation dose received annually by workers in most types of work involving radiation exposure is reported to be less than six times that received from natural sources, although some types of workers (including industrial radiographers and medical radium workers) tend to receive doses several times higher. The yearly contribution of occupational exposure to the genetically-significant dose of the whole population has been estimated in various countries to be less than one hundredth of the annual dose received from natural sources.

30. Radiation injuries are now very rare and, when they happen, can usually be attributed to carelessness. Most of the reported injuries occur in industrial radiographers, in research workers using x-ray crystallographic machines, and in medical workers using hand-held fluoroscopes. Such injuries can be prevented by adherence to recommended practice. Underground miners, not only in uranium mines but in some other types of mines as well, are exposed to radio-active materials in the air they breathe. Considerable efforts are being made to improve conditions in mines so as to reduce this form of radiation exposure, which, at sufficiently high levels, has been shown to be associated with an increased incidence of lung cancer.

D. Miscellaneous sources[7]

31. The general public may be exposed to ionizing radiation from a wide variety of miscellaneous sources. The most widespread are consumer products containing radio-active materials and electronic tubes emitting x rays but not designed for that purpose. Until a few years ago, appreciable doses could be received from self-luminous wrist watches and from colour television sets. Owing to international recommendations and national regulations, the exposure from these sources has rapidly decreased. Although no recent study of the annual genetically-significant dose has been published, it is estimated to be less than 1 per cent of the annual dose from natural sources.

[6] For details, see annex C.
[7] For details, see annex D.

Chapter II

GENETIC EFFECTS OF RADIATION[8]

32. The genetic material consists of chromosomes—microscopically visible structures within cell nuclei—and genes—the functional units of which the chromosomes are composed and which cannot be distinguished microscopically. Although these structures are present in all body cells, only those in the reproductive cells are transmitted to the fertilized ovum (the zygote) and hence from one generation of individuals into the next. When the reproductive cells are irradiated, changes may be produced in the genes or in the chromosomes of these cells and subsequently transmitted to the descendants of the irradiated individual. These genetic changes are of different kinds: (*a*) gene mutations i.e., alterations in the function of individual genes; (*b*) chromosome aberrations resulting from breakage and reorganization of the chromosomes and (*c*) changes in the number of chromosomes. Some of these changes result in offspring suffering abnormalities which may range from mildly detrimental to severely disabling or lethal disorders.

33. Since adequate human data are not available, the estimates of genetic risks ensuing from radiation exposure of the human reproductive cells are based on results obtained with other species, notably mice.

A. Gene mutation

34. The two reproductive cell stages most important for the assessment of genetic risks are spermatogonia in the male and oöcytes in the female. At high acute doses of radiation the rate of induction in spermatogonial cells is estimated to range between 100-5,000 recessive mutations per rad[9] per million. Human populations, however, predominantly receive low doses of radiation under acute (short-term at high dose rate) or chronic (protracted at low dose rate) conditions of exposure. On the basis of experimental studies, it is estimated that under these conditions the rate of mutation induction is about one third of the above figure. Consequently, for males, a rate of induction of 30-1,500 mutations per million per rad seems a more realistic approximation. At high acute doses of radiation the risk of mutation in females conceiving shortly after radiation exposure will be about twice as high as in males, whereas at low doses the risk will be reduced to at least one third and with chronic exposure to about one twentieth of that expected after acute exposure to high doses. If the human ovary responds to irradiation as does that of the mouse, which is by no means certain, it can be expected that, if conception occurs after a sufficient interval following irradiation, the resulting frequency of mutations in the descendants of irradiated females might approach zero.

[8] For details see annex F.
[9] 1 rad ~ 10 times the annual dose received from natural sources.

35. Dominant gene mutations are expressed in the first-generation descendants of an irradiated population. There is evidence suggesting that in man about 1,000 genes may contribute to this category. The estimated rate of induction of dominant visible mutations in the human male exposed to low doses of irradiation is two per rad per million descendants.

B. Chromosome aberrations

36. Spontaneously occurring chromosome aberrations are a source of considerable human hardship, since they are responsible for a large fraction of all spontaneous miscarriages, congenital malformations and mental and physical defects. For instance, the possession of an additional small chromosome (number 21) leads to Down's syndrome, which is associated with severe mental retardation. Extensive data have been collected recently in the mouse on another type of aberration, known as translocation. This involves the exchange of parts between two different chromosomes. It is known that in man it may lead to malformations similar to those associated with the presence of additional chromosomes, or may lead to early pre-natal death. These effects are associated with the presence of translocations in an unbalanced form, in which there may be loss of one of the exchanged segments and gain of the other. In its balanced form, a translocation usually has no detrimental effect for the person carrying it, but half of his or her offspring are likely to have the translocation in unbalanced form.

37. In male mice, the yield of balanced translocations in the generation after exposure is more or less proportional to dose for acute x-irradiation at moderate to high doses, about 30 being induced per million offspring per rad. It is probably similar in female mice, but information is still meagre. The expected yield of unbalanced translocations (causing early death or detectable abnormality) will be 60 per million zygotes per rad after exposure of males and 180 per million per rad after exposure of females.

38. In attempting to deduce from these figures the probable risk for man under usual exposure conditions, a number of different factors have to be considered. First, there is evidence from work on chromosome aberrations in blood cells that man may be twice as radio-sensitive as the mouse in this respect. Second, chronic gamma-irradiation is only one third as effective as acute x-irradiation in inducing translocations in male mice, while acute x-irradiation at very low doses (as used in medical diagnosis) may be only about one quarter as effective per rad as at higher doses. Therefore the probable yield of balanced translocations in the offspring of exposed males is about 7 per million per rad with chronic gamma-irradiation and about 15 per million per rad with low-dose acute x-irradiation. The expected yields of unbalanced translocation products will be about twice these.

39. Information from both man and the mouse suggests that many of these unbalanced zygotes will die at such an early stage in pregnancy that they will lead, at most, to a missed menstrual period. The proportion surviving to produce abnormal new-born babies is difficult to estimate at present, but is likely to be less than 6 per cent. Therefore one to two additional abnormal babies per million would be expected per rad of paternal exposure at low doses or dose rates. Although a similar estimate cannot yet be made with confidence for maternal exposure, it seems unlikely that risks will be much higher.

40. Translocations are only one category of chromosomal aberration. Those occurring spontaneously (in balanced or unbalanced form) represent about one third of all the chromosome aberrations observed in new-born babies. Information from the mouse suggests that very few of the other aberrations (e.g. gains or losses of chromosomes) are likely to be transmitted to the next generation after irradiation of the male because the reproductive cells carrying them will be eliminated before they mature. In the female, however, some are transmitted. Thus evidence from the mouse suggests that irradiation of females at low dose rates results in eight additional zygotes with the XO constitution per million (i.e. with a missing sex chromosome).

41. Most of these cases will die before birth; those surviving will be sterile and will have certain other symptoms (Turner's syndrome). No doubt loss of other chromosomes will also occur, but these are likely to be associated with such early embryonic death that they may not constitute a significant risk to live-born children. Gains of chromosomes form an important component of the human genetic burden. They may be induced by irradiation, especially of females, but positive evidence is lacking so far.

42. Thus in summary, gene mutations are induced at higher frequencies than chromosome aberrations; furthermore chromosome aberrations will be eliminated after a few generations, whereas gene mutations may persist through many more generations thereby affecting a larger number of individuals.

C. Estimates of genetic damage in relation to the spontaneous incidence of genetic disease

43. While the above estimates provide assessments of the risk of induction of mutations, they do not necessarily provide a useful method of evaluating the harm which is experienced by society. The Committee feels that it can also present an estimate of risk of mutation per unit of radiation dose in relation to the natural incidence of genetic disorders observed in man. This was first attempted in the Committee's 1958 report, but confidence in the methodology was not sufficiently great to justify its continued use. Recently, however, experimental work with the mouse has suggested that in males five major indices of mutation are increased, under conditions of acute irradiation, by about 3 per cent per rad. For low-dose or chronic irradiation, the expected increase will be about 1 per cent per rad. Because *all* these indices of induced mutation have approximately the same rate of increase relative to the spontaneous rate, the Committee feels it may revive this method of assessment with renewed confidence, although it still recognizes that numerous qualifications are necessary.

44. It has been estimated that about 4 per cent of all live-born children suffer from various forms of genetically determined diseases, of which about 2 per cent appear to follow simple rules of inheritance. The other 2 per cent have a more complex mode of transmission. For computational purposes a figure of 3 per cent will be used. Therefore the natural incidence of hereditary diseases maintained by receiving mutation is estimated at 30,000 per million live births.

45. The mutations responsible for that incidence would increase by about 300 per rad under conditions of chronic exposure of males in a parental generation. Up to 20 of these new mutations would contribute to the incidence of hereditary diseases among the immediate descendants of the irradiated males, while the contribution of the remaining new mutations would be distributed over many subsequent generations of descendants.

Chapter III

EFFECTS OF RADIATION ON THE IMMUNE RESPONSE[10]

46. The immune system provides the main defence mechanisms of the body against infectious agents or their products. The system recognizes what is foreign to the body, and responds by destroying or neutralizing it: it does not distinguish between "foreign-good" and "foreign-bad". Sometimes, therefore, it stands in the way of medically desirable objectives, such as the acceptance of needed tissue or organ transplants. Sometimes, too, the net effects of the immune reaction are themselves undesirable, as in allergies and other immunopathological disorders. Sometimes the system goes awry and reacts to the body's own components, producing auto-immune disease.

47. Because of the many values, "good" and "bad", associated with the immune system, affecting it by irradiation has great human significance in numerous contexts. For example, depressing immune responsiveness by irradiation reduces the ability to acquire resistance to bacterial, rickettsial and parasitic infections or to neutralize bacterial toxins, and is therefore an undesirable effect of radiation. But depressing immune responsiveness by some means is desirable, even necessary, if organ transplants are to be accomplished. Suppressing or controlling allergy, hypersensitivity, immunopathological disorder, and auto-immune disease are other important medical objectives.

48. The concept that the immune system evolved only to protect the body against administered foreign agents has been questioned. There is a growing body of data from both experimental animal, and human clinical, studies which indicates that in cancer the malignant cells are recognized as foreign by the individual's own immune system, and that lymphocytes in the host may be directed against tumour cells. The existence of specific serum factors which react with cancer cells has also been recognized, and in some instances these may protect cancer cells from the action of potentially lethal lymphocytes. Most of the recent data in this field have considered the immune response as reacting against an already existing cancer, and in at least some situations it is clear that radiation-induced immune depression permits an increased rate of growth of the cancer. The more critical unanswered question is whether immuno-suppression may be an important factor in the radiation-induction of cancer.

49. There have been extensive studies of the effects of radiation on the immune response in experimental animals, but relatively few observations have been made on the radio-sensitivity of the cells involved in the immune response in man. Limited data are available from Hiroshima and Nagasaki and from patients given extensive radio-therapy for malignancy. Comparative studies among many animal species indicate that the radio-sensitivity of a given cell type in the immune system is similar for most species studied. The results of many of these studies can probably be applied directly to man. The relatively recent availability of *in vitro* techniques for analysing the immune response may now permit direct dose-effect studies to be made with human lymphocytes and other cell types involved in the human response. However, even if it were determined that similar radio-sensitivities of cell types existed for man and animals, it still could not be safely concluded that the immune response will show a similar dose-effect relationship in animals and man, because many factors are involved that cannot be accounted for at the cellular level alone. These include the extent of previous antigenic exposure of the individual (the secondary response as a whole being relatively more radio-resistant *in vivo*), the type and dose of antigen, and the interval between antigenic challenge and irradiation.

50. The immune system appears to have large built-in factors of safety, so that it can withstand substantial injury and recover from damage. Although effects on human lymphocytes in culture have been noted even at doses of 10 rads,[11] the observable damage to the immune system such as changes in antibody formation resulting from whole-body doses of the order of tens of rads is unlikely to be the effect causing the greatest concern. At doses in the range of 100 rads to the whole body, damage to the immune system leads to an increase in susceptibility to infection, and when whole-body doses approach and exceed 200 rads, damage to the immune system is a very important effect of irradiation as expressed, for example, in increased risk of mortality from infection.

[10] For details, see annex F.

[11] 1 rad ~ 10 times the annual dose received from natural sources.

Chapter IV

RADIATION CARCINOGENESIS[12]

51. While experiments with animals suggest that malignant transformations may occur in most mammalian tissues if they are exposed to sufficient radiation doses, the number of people exposed to substantial doses is so small that the relationship between dose and incidence of malignancies in man can only be studied for the most radio-sensitive tissues. By far the largest and most informative groups of irradiated subjects continue to be the survivors of the atomic bombings at Hiroshima and Nagasaki. To these must be added several groups of patients treated by radiotherapy and followed up for several decades, and a few groups of workers exposed to radiation in the course of their occupation—especially underground uranium miners. Children exposed while *in utero*, in the course of radiological examinations of their pregnant mothers, form a special category.

52. Leukæmia is the best known of the radiation-induced malignancies. All evidence indicates that the incidence of certain types of leukæmia increases with dose as a result of post-natal irradiation at high dose rate in the 50-500 rad interval.[13] At higher doses the rise in frequency decreases, possibly because an increasingly large fraction of cells that would otherwise become leukæmic are destroyed by radiation. Radiation-induced leukæmias tend to occur most frequently within a few years after exposure and, after 25 years, the frequency tends to return to the levels expected in the absence of irradiation. By that time some 15-40 cases of leukæmias per rad[14] per million exposed have been observed.

53. Lung cancers appear to have been induced at Hiroshima by doses estimated on the basis of crude assumptions to be equivalent to some 30 rads of external gamma radiation delivered at high dose rate, and to have increased with dose up to a dose of about 100 rads. The higher incidence of this type of cancer among irradiated people has been revealed by other surveys also but it is not yet known whether the increase, which starts some 15 years after irradiation, will be sustained for a long time or will eventually subside. Taken at face value, however, the data indicate that from 10 (at 250 rad) to 40 (at 30 rad) cases of cancer per rad per million exposed develop during the first 25 years after exposure to high-dose-rate gamma radiation.

54. Information is available also on the induction of thyroid and breast cancers. Because those affected by these cancers have long survival times, only in the very long run do mortality data reflect the incidence of these tumours. Thus, while breast cancer mortality at Hiroshima suggests a risk of 6-20 cases per million per rad in the first 25 years after irradiation among women exposed to between 60 and 400 rads, this is probably an underestimate of the total yield. For thyroid cancers, an average figure of about 40 cases per million per rad in the same range of doses over the same period of time is obtained from more reliable morbidity data, but the estimate has large uncertainties due to the small number of cases observed. As for lung tumours, there is no information as to whether the increased annual incidence of tumours in the irradiated populations will subside and when.

55. Many surveys of externally irradiated people confirm an increase in other types of cancer taken together, although it is not possible at this stage to identify the specific types whose frequency is enhanced. Among the survivors of the atomic bombing at Hiroshima there is a clear trend for mortality from malignancies other than leukæmia and lung and breast cancers to increase with increasing dose, but quantitative estimates of the rate of increase are hampered by our ignorance of the doses to the tissues concerned. Only a tentative estimate of 40 cases of cancers (other than leukæmias and breast and lung cancer) per rad per million occurring during the first 25 years after exposure to 250 rads can be advanced on the basis of crude assumptions about tissue doses. Here also it is not known how many additional cases may develop at times later than 25 years.

56. In considering these estimates it must be clearly borne in mind that they are based on observations made after doses of at least tens of rads delivered at high dose rates. These dose rates, and occasionally these doses, are of the order of those that can be received in the course of certain radiological procedures carried out on medical indications, but much higher than those at which we are irradiated by environmental sources, both natural and man-made. It is a matter of speculation whether doses of the order of those received continuously from natural sources may have similar effects. Animal experiments suggest that the yield of tumours per unit dose should be lower at very low doses, except when the target tissue has a susceptibility to radiation induction of malignancies much higher than has been observed in man. Animal experiments also indicate that radiation given continuously or in several fractions is usually less carcinogenic than if administered in a single dose within a short period of time. The figures given in the preceding paragraphs are therefore likely to be overestimates of the risk of doses and dose rates such as are received from environmental sources.

57. Studies of people exposed to internal irradiation at substantial doses are few. They concern workers and patients contaminated with radium isotopes and miners exposed to radon gas. Radium-226 is deposited in bones, irradiates bone-forming cells continuously at a decreasing rate for decades after being absorbed into the body and gives rise to bone tumours. Radium-224 causes similar effects after a shorter period of irradiation.

58. Miners exposed to high levels of radon and its radio-active daughters show a very high incidence of lung cancers. The frequency appears to rise in proportion to the level and duration of exposure. The range of exposures within which the increased incidence has been reported corresponds to doses of at least a few hundred rads of alpha radiation. However, dosimetry is difficult and the role of other carcinogenic factors such as smoking habits has not yet been fully assessed.

59. The effects of pre-natal irradiation have been the subject of much research. A number of large surveys of children that were exposed to radiation for medical reasons before birth, and that must have received thereby doses of at most a few rads at high dose rate, indicate that pre-natal irradiation is associated with a significant increase of the risk of malignancies in the first 10 years of life. The extent to which the increased risk of malignancies in the medically irradiated is due to radiation rather than to an association with the cause that prompted the irradiation must still be considered as open.

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[12] For details, see annexes G and H.

[13] 1 rad ~ 10 times the annual dose received from natural sources.

[14] The estimate applies to doses between 60 and 400 rads of gamma rays.

Annex 9

UNITED NATIONS GENERAL ASSEMBLY RESOLUTION 1762 A (XVII) OF 6 NOVEMBER 1962 ON "THE URGENT NEED FOR SUSPENSION OF NUCLEAR AND THERMONUCLEAR TESTS"

The General Assembly,

Deeply concerned with the continuation of nuclear weapon tests,

Fully conscious that world opinion demands the immediate cessation of all nuclear tests,

Viewing with the utmost apprehension the data contained in the report of the United Nations Scientific Committee on the Effects of Atomic Radiation,

Considering that the continuation of nuclear weapon tests is an important factor in the acceleration of the arms race and that the conclusion of an agreement prohibiting such tests would greatly contribute to paving the way towards general and complete disarmament,

Recalling its resolution 1648 (XVI) of 6 November 1961, whereby the States concerned were urged to refrain from further nuclear weapon test explosions pending the conclusion of necessary internationally binding agreements with regard to the cessation of tests,

Noting with regret that the States concerned have not responded to the appeal contained in the aforementioned and in other relevant resolutions and that, despite its efforts, the Conference of the Eighteen-Nation Committee on Disarmament, referred to in General Assembly resolution 1722 (XVI) of 20 December 1961, is not yet in a position to report agreement on this vitally important issue,

Recalling that, in resolution 1649 (XVI) of 8 November 1961, the General Assembly reaffirmed that an agreement prohibiting all nuclear weapon tests would inhibit the spread of nuclear weapons to other countries and would contribute to the reduction of international tensions,

Noting that, among the States represented in the Sub-Committee on a Treaty for the Discontinuance of Nuclear Weapon Tests of the Eighteen-Nation Committee, basic agreement now prevails as regards the question of control of tests in the atmosphere, in outer space and under water,

Noting further that the proceedings of the Eighteen-Nation Committee indicate a somewhat enlarged area of agreement on the question of effective control of underground tests,

Considering that the memorandum of 16 April 1962, submitted to the Eighteen-Nation Committee by the delegations of Brazil, Burma, Ethiopia, India, Mexico, Nigeria, Sweden and the United Arab Republic, represents a sound, adequate and fair basis for the conduct of negotiations towards removing the outstanding differences on the question of effective control of underground tests,

Welcoming the intention to find a speedy settlement of the remaining differences on the question of the cessation of nuclear tests, declared in the letter dated 27 October 1962 from Mr. Khrushchev, Chairman of the Council of Ministers of the Union of Soviet Socialist Republics, to Mr. Kennedy, President of the United States of America, in the letter dated 28 October 1962 from Mr. Kennedy to Mr. Khrushchev, and in the letter dated 28 October 1962 from

Mr. Macmillan, Prime Minister of the United Kingdom of Great Britain and Northern Ireland, to Mr. Khrushchev,

Convinced that no efforts should be spared to achieve prompt agreement on the cessation of all nuclear tests in all environments,

1. *Condemns* all nuclear weapon tests;

2. *Asks* that such tests should cease immediately and not later than 1 January 1963;

3. *Urges* the Governments of the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland and the United States of America to settle the remaining differences between them in order to achieve agreement on the cessation of nuclear testing by 1 January 1963, and to issue instructions to their representatives on the Sub-Committee on a Treaty for the Discontinuance of Nuclear Weapon Tests to achieve this end;

4. *Endorses* the eight-nation memorandum of 16 April 1962 as a basis for negotiation;

5. *Calls upon* the parties concerned, taking as a basis the above-mentioned memorandum and having regard to the discussions on this item at the seventeenth session of the General Assembly, to negotiate in a spirit of mutual understanding and concession in order to reach agreement urgently, bearing in mind the vital interests of mankind;

6. *Recommends* that if, against all hope, the parties concerned do not reach agreement on the cessation of all tests by 1 January 1963, they should enter into an immediate agreement prohibiting nuclear weapon tests in the atmosphere, in outer space and under water, accompanied by an interim arrangement suspending all underground tests, taking as a basis, the eight-nation memorandum and taking into consideration other proposals presented at the seventeenth session of the General Assembly, such interim agreement to include adequate assurances for effective detection and identification of seismic events by an international scientific commission;

7. *Requests* the Conference of the Eighteen-Nation Committee on Disarmament to reconvene not later than 12 November 1962, to resume negotiations on the cessation of nuclear testing and on general and complete disarmament, and to report to the General Assembly by 10 December 1962 on the results achieved with regard to the cessation of nuclear weapon tests.

Annex 10

Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water

The Governments of the United States of America, the United Kingdom of Great Britain and Northern Ireland, and the Union of Soviet Socialist Republics, hereinafter referred to as the "original parties",

Proclaiming as their principal aim the speediest possible achievement of an agreement on general and complete disarmament under strict international control in accordance with the objectives of the United Nations which would put an end to the armaments race and eliminate the incentive to the production and testing of all kinds of weapons, including nuclear weapons,

Seeking to achieve the discontinuance of all test explosions of nuclear weapons for all time, determined to continue negotiations to this end, and desiring to put an end to the contamination of man's environment by radioactive substances,

Have agreed as follows:

Article I

1. Each of the parties to this treaty undertakes to prohibit, to prevent, and not to carry out any nuclear weapon test explosion, or any other nuclear explosion, at any place under its jurisdiction or control:

(a) in the atmosphere; beyond its limits, including outer space; or under water, including territorial waters or high seas; or

(b) in any other environment if such explosion causes radioactive debris to be present outside the territorial limits of the State under whose jurisdiction or control such explosion is conducted. It is understood in this connection that the provisions of this subparagraph are without prejudice to the conclusion of a treaty resulting in the permanent banning of all nuclear test explosions, including all such explosions underground, the conclusion of which, as the Parties have stated in the Preamble to this Treaty, they seek to achieve.

2. Each of the Parties to this Treaty undertakes furthermore to refrain from causing, encouraging, or in any way participating in, the carrying out of any nuclear weapon test explosion, or any other nuclear explosion, anywhere which would take place in any of the environments described, or have the effect referred to, in paragraph 1 of this Article.

Article II

1. Any Party may propose amendments to this Treaty. The text of any proposed amendment shall be submitted to the Depositary Governments which shall circulate it to all Parties of this Treaty. Thereafter, if requested to do so by one-third or more of the Parties, the Depositary Governments shall convene a conference, to which they shall invite all the Parties, to consider such amendment.

2. Any amendment to this Treaty must be approved by a majority of the votes of all the Parties to this Treaty, including the votes of all the Original Parties. The amendment shall enter into force for all Parties upon the deposit of instruments of ratification by a majority of all the Parties, including the instruments of ratification of all the Original Parties.

Article III

1. This Treaty shall be open to all States for signature. Any State which does not sign this Treaty before its entry into force in accordance with paragraph 3 of this Article may accede to it at any time.

2. This Treaty shall be subject to ratification by signatory States. Instruments of ratification and instruments of accession shall be deposited with the Governments of the Original Parties—the United States of America, the United Kingdom of Great Britain and Northern Ireland, and the Union of Soviet Socialist Republics—which are hereby designated the Depositary Governments.

3. This Treaty shall enter into force after its ratification by all the Original Parties and the deposit of their instruments of ratification.

4. For States whose instruments of ratification or accession are deposited subsequent to the entry into force of this Treaty, it shall enter into force on the date of the deposit of their instruments of ratification or accession.

5. The Depositary Governments shall promptly inform all signatory and acceding States of the date of each signature, the date of deposit of each instrument of ratification of and accession to this Treaty, the date of its entry into force, and the date of receipt of any requests for conferences or other notices.

6. This Treaty shall be registered by the Depositary Governments pursuant to Article 102 of the Charter of the United Nations.

Article IV

This Treaty shall be of unlimited duration.

Each Party shall in exercising its national sovereignty have the right to withdraw from the Treaty if it decides that extraordinary events, related to the subject-matter of this Treaty, have jeopardized the supreme interests of its country. It shall give notice of such withdrawal to all other Parties to the Treaty three months in advance.

Article V

This treaty, of which the English and Russian texts are equally authentic, shall be deposited in the archives of the Depositary Governments. Duly certified copies of this Treaty shall be transmitted by the Depositary Governments to the Governments of the signatory and acceding States.

In witness whereof the undersigned, duly authorized, have signed this Treaty.

Done in triplicate at the city of Moscow the fifth day of August, one thousand nine hundred and sixty-three.

Annex 11

United Nations General Assembly Resolution 1910 (XVIII) of 27 November 1963 on the "Urgent Need for Suspension of Nuclear and Thermonuclear Tests"

The General Assembly,

Fully aware of its responsibility with regard to the question of nuclear weapon testing and of the views of world public opinion on this matter,

Noting with approval the Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water, signed on 5 August 1963 by the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland and the United States of America, and subsequently by a great number of other countries,

Noting further with satisfaction that in the preamble of that Treaty the parties state that they are seeking to achieve the discontinuance of all test explosions of nuclear weapons for all time and are determined to continue negotiations to this end,

1. *Calls upon* all States to become parties to the Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water, and to abide by its spirit and provisions;
2. *Requests* the Conference of the Eighteen-Nation Committee on Disarmament to continue with a sense of urgency its negotiations to achieve the objectives set forth in the preamble of the Treaty;
3. *Requests* the Eighteen-Nation Committee to report to the General Assembly at the earliest possible date and, in any event, not later than at the nineteenth session;
4. *Requests* the Secretary-General to make available to the Eighteen-Nation Committee the documents and records of the plenary meetings of the General Assembly and the meetings of the First Committee at which the item relating to nuclear testing was discussed.

Annex 12

United Nations General Assembly Resolution 2032 (XX) of 3 December 1965 on the "Urgent Need for Suspension of Nuclear and Thermonuclear Tests"

The General Assembly,

Having considered the question of the cessation of nuclear and thermonuclear weapon tests and the relevant sections of the reports of the Conference of the Eighteen-Nation Committee on Disarmament,

Recalling its resolutions 1762 (XVII) of 6 November 1962 and 1910 (XVIII) of 27 November 1963 on the cessation of all test explosions of nuclear weapons,

Noting with regret that notwithstanding these resolutions nuclear weapon tests have taken place,

Recalling the undertaking given by the original signatories to the Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water, signed at Moscow on 5 August 1963, to continue negotiations for the discontinuance of all test explosions of nuclear weapons for all time,

Recognizing the mounting concern of world opinion for the fulfilment of this undertaking,

Mindful of the crucial importance of a comprehensive test ban to the issue of non-proliferation of nuclear weapons,

Noting with satisfaction the joint memorandum on a comprehensive test ban treaty submitted by Brazil, Burma, Ethiopia, India, Mexico, Nigeria, Sweden and the United Arab Republic and annexed to the report of the Conference of the Eighteen-Nation Committee on Disarmament,

Convinced that agreement in regard to taking this further step towards nuclear disarmament would be facilitated, *inter alia*, by the important improvements made in detection and identification techniques,

1. *Urges* that all nuclear weapon tests be suspended;
2. *Calls upon* all countries to respect the spirit and provisions of the Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water;
3. *Requests* the Conference of the Eighteen-Nation Committee on Disarmament to continue with a sense of urgency its work on a comprehensive test ban treaty and on arrangements to ban effectively all nuclear weapons tests in all environments, taking into account the improved possibilities for international co-operation in the field of seismic detection, and to report to the General Assembly.

Annex 13

UNITED NATIONS GENERAL ASSEMBLY RESOLUTION 2163 (XXI) OF 5 DECEMBER 1966 ON THE "URGENT NEED FOR SUSPENSION OF NUCLEAR AND THERMONUCLEAR TESTS"

The General Assembly,

Having considered the question of the cessation of nuclear and thermonuclear weapon tests and the report of the Conference of the Eighteen-Nation Committee on Disarmament,

Recalling its resolutions 1762 (XVII) of 6 November 1962, 1910 (XVII) of 27 November 1963 and 2032 (XX) of 3 December 1965,

Recalling further the joint memorandum on a comprehensive test ban treaty submitted by Brazil, Burma, Ethiopia, India, Mexico, Nigeria, Sweden and the United Arab Republic and annexed to the report of the Conference of the Eighteen-Nation Committee on Disarmament, and in particular the concrete suggestions contained therein,

Noting with great concern the fact that all States have not yet adhered to the Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water, signed in Moscow on 5 August 1963,

Noting also with great concern that nuclear weapon tests in the atmosphere and underground are continuing,

Taking into account the possibilities of establishing, through international co-operation, an exchange of seismic data so as to create a better scientific basis for national evaluation of seismic events,

Recognizing the importance of seismology in the verification of the observance of a treaty banning underground nuclear weapon tests,

Realizing that such a treaty would also constitute an effective measure to prevent proliferation of nuclear weapons,

1. *Urges* all States which have not done so to adhere to the Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water;

2. *Calls upon* all nuclear-weapon States to suspend nuclear weapon tests in all environments;

3. *Expresses the hope* that States will contribute to an effective international exchange of seismic data;

4. *Requests* the Conference of the Eighteen-Nation Committee on Disarmament to elaborate without any further delay a treaty banning underground nuclear weapon tests.

Annex 14

UNITED NATIONS GENERAL ASSEMBLY RESOLUTION 2343 (XXII) OF 19 DECEMBER 1967 ON THE "URGENT NEED FOR SUSPENSION OF NUCLEAR AND THERMONUCLEAR TESTS"

The General Assembly,

Having considered the question of the urgent need for suspension of nuclear and thermonuclear tests and the interim report of the Conference of the Eighteen-Nation Committee on Disarmament,

Recalling its resolutions 1762 (XVII) of 6 November 1962, 1910 (XVIII) of 27 November 1963, 2032 (XX) of 3 December 1965 and 2163 (XXI) of 5 December 1966,

Noting with regret the fact that all States have not yet adhered to the Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water, signed in Moscow on 5 August 1963,

Noting with increasing concern that nuclear weapon tests in the atmosphere and underground are continuing,

Taking into account the existing possibilities of establishing, through international co-operation, an exchange of seismic data, so as to create a better scientific basis for national evaluation of seismic events,

Recognizing the importance of seismology in the verification of the observance of a treaty banning underground nuclear weapon tests,

Realizing that such a treaty would also constitute an effective measure to prevent the proliferation of nuclear weapons,

1. *Urges* all States which have not done so to adhere without further delay to the Treaty banning nuclear weapon tests in the atmosphere, in outer space and under water;

2. *Calls upon* all nuclear-weapon States to suspend nuclear weapon tests in all environments;

3. *Expresses the hope* that States will contribute to an effective international exchange of seismic data;

4. *Requests* the Conference of the Eighteen-Nation Committee on Disarmament to take up as a matter of urgency the elaboration of a treaty banning underground nuclear weapon tests and to report to the General Assembly on this matter at its twenty-third session.

Annex 15

UNITED NATIONS GENERAL ASSEMBLY RESOLUTION 2455 (XXIII) OF 20 DECEMBER 1968 ON THE "URGENT NEED FOR SUSPENSION OF NUCLEAR AND THERMONUCLEAR TESTS"

The General Assembly,

Having considered the question of the urgent need for suspension of nuclear and thermonuclear tests and the report of the Conference of the Eighteen-Nation Committee on Disarmament,

Recalling its resolutions 1762 (XVII) of 6 November 1962, 1910 (XVIII) of 27 November 1963, 2032 (XX) of 3 December 1965, 2163 (XXI) of 5 December 1966 and 2343 (XXII) of 19 December 1967,

Recalling further the joint memorandum on a comprehensive test ban treaty submitted on 26 August 1968 by Brazil, Burma, Ethiopia, India, Mexico, Nigeria, Sweden and the United Arab Republic and annexed to the report of the Conference of the Eighteen-Nation Committee on Disarmament,

Noting with regret the fact that all States have not yet adhered to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, signed in Moscow on 5 August 1963,

Noting with increasing concern that nuclear weapon tests in the atmosphere and underground are continuing,

Taking into account the existing possibilities of establishing, through international co-operation, a voluntary exchange of seismic data so as to create a better scientific basis for a national evaluation of seismic events,

Recognizing the importance of seismology in the verification of the observance of a treaty banning underground nuclear weapon tests,

Noting in this connection that experts from various countries, including four nuclear-weapon States, have recently met unofficially to exchange views and hold discussions in regard to the adequacy of seismic methods for monitoring underground explosions, and the hope expressed that such discussions would be continued,

1. *Urges* all States which have not done so to adhere without further delay to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water;
2. *Calls upon* all nuclear-weapon States to suspend nuclear weapon tests in all environments;
3. *Expresses the hope* that States will contribute to an effective international exchange of seismic data;
4. *Requests* the Conference of the Eighteen-Nation Committee on Disarmament to take up as a matter of urgency the elaboration of a treaty banning underground nuclear weapon tests and to report to the General Assembly on this matter at its twenty-fourth session.

Annex 16

UNITED NATIONS GENERAL ASSEMBLY RESOLUTION 2604 B (XXIV) OF 16 DECEMBER 1969 ON THE "URGENT NEED FOR SUSPENSION OF NUCLEAR AND THERMONUCLEAR TESTS"

The General Assembly,

Having considered the question of the urgent need for suspension of nuclear and thermonuclear tests and the report of the Conference of the Committee on Disarmament,

Recalling its resolutions 1762 (XVII) of 6 November 1962, 1910 (XVIII) of 27 November 1963, 2032 (XX) of 3 December 1965, 2163 (XXI) of 5 December 1966, 2343 (XXII) of 19 December 1967 and 2455 (XXIII) of 20 December 1968,

Noting with regret the fact that all States have not yet adhered to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, signed in Moscow on 5 August 1963,

Noting with increasing concern that nuclear weapon tests in the atmosphere and underground are continuing,

Taking into account that several concrete suggestions have recently been set forth in the Conference of the Committee on Disarmament as to possible provisions for a treaty banning underground nuclear weapon tests,

1. *Urges* all States which have not done so to adhere without further delay to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water;
2. *Calls upon* all nuclear-weapon States to suspend nuclear weapon tests in all environments;
3. *Requests* the Conference of the Committee on Disarmament to continue, as a matter of urgency, its deliberations on a treaty banning underground nuclear weapon tests, taking into account the proposals already made in the Conference as to the contents of such a treaty, as well as the views expressed at the current session of the General Assembly, and to submit a special report to the Assembly on the results of its deliberations.

Annex 17

United Nations General Assembly Resolution 2663 B (XXV) of 7 December 1970 on the "Urgent Need for Suspension of Nuclear and Thermonuclear Tests"

The General Assembly,

Having considered the question of the urgent need for suspension of nuclear and thermonuclear tests and the report of the Conference of the Committee on Disarmament,

Recalling its resolutions 1762 (XVII) of 6 November 1962, 1910 (XVIII) of 27 November 1963, 2032 (XX) of 3 December 1965, 2163 (XXI) of 5 December 1966, 2343 (XXII) of 19 December 1967, 2455 (XXIII) of 20 December 1968 and 2604 B (XXIV) of 16 December 1969,

Noting with regret that all States have not yet adhered to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, signed in Moscow on 5 August 1963,

Noting with increasing concern that nuclear weapon tests in the atmosphere and underground are continuing,

Taking into account that several concrete suggestions have been set forth in the Conference of the Committee on Disarmament as to possible provisions in a treaty banning underground nuclear weapon tests,

1. *Urges* all States that have not yet done so to adhere without further delay to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water;
2. *Calls upon* all nuclear-weapon States to suspend nuclear weapon tests in all environments;
3. *Requests* the Conference of the Committee on Disarmament to continue, as a matter of urgency, its deliberations on a treaty banning underground nuclear weapon tests, taking into account the proposals already made in the Conference as well as the views expressed at the current session of the General Assembly, and to submit to the Assembly at its twenty-sixth session a special report on the results of its deliberations.

Annex 18

United Nations General Assembly Resolution 2828 (XXVI) of 16 December 1971 on the "Urgent Need for Suspension of Nuclear and Thermonuclear Tests"

A

The General Assembly,

Viewing with the utmost apprehension the harmful consequences of nuclear weapon tests for the acceleration of the arms race and for the health of present and future generations of mankind,

Fully conscious that world opinion has, over the years, demanded the immediate and complete cessation of all nuclear weapon tests in all environments,

Recalling that the item on the question of a comprehensive test ban has been included in the agenda of the General Assembly every year since 1957,

Deploring the fact that the General Assembly has not yet succeeded in its aim of achieving a comprehensive test ban, despite 18 successive resolutions on the subject,

Noting with regret that all States have not yet adhered to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, signed in Moscow on 5 August 1963,

Deploring the fact that the determination expressed by the original parties to that Treaty to continue negotiations to achieve the discontinuance of all test explosions of nuclear weapons for all time has not so far produced the desired results,

Noting with special concern that the continuation of nuclear weapon tests in the atmosphere is a source of growing pollution and that the number and magnitude of underground tests have increased at an alarming rate since 1963,

Having considered the special report submitted by the Conference of the Committee on Disarmament in response to General Assembly resolution 2663 B (XXV) of 7 December 1970,

Recalling its resolution 1762 A (XVII) of 6 November 1962, whereby all nuclear weapon tests, without exception, were condemned,

Convinced that, whatever may be the differences on the question of verification, there is no valid reason for delaying the conclusion of a comprehensive test ban of the nature contemplated in the preamble to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water,

1. *Reiterates solemnly and most emphatically* its condemnation of all nuclear weapon tests;
2. *Urges* the Governments of nuclear-weapon States to bring to a halt all nuclear weapon tests at the earliest possible date and, in any case, not later than 5 August 1973;
3. *Requests* the Secretary-General to transmit the present resolution to the nuclear-weapon States and to inform the General Assembly at its twenty-seventh session of any measures they have taken to implement it.

B

The General Assembly,

Noting that one of the first steps in the strengthening of international security is to dissipate world-wide fears that nuclear, thermonuclear and other weapons of mass destruction may be used by miscalculation in what could appear to be a desperate situation,

Considering that for the last few years the United Nations has been preoccupied with finding ways and means of diminishing the pollution of the earth's atmosphere,

Noting that scientists have been unanimous in the conclusion that the fall-out from nuclear tests is injurious to human and animal life and that such fall-out may poison the earth's atmosphere for many decades to come,

Taking into account that underground nuclear and thermonuclear tests may not only create serious health hazards but may also cause as yet undetermined injury to humans and animals of the region where such tests are conducted,

Recognizing that there already exist sufficient nuclear, thermonuclear and other lethal weapons of mass destruction in the arsenals of certain Powers to decimate the world's population and possibly render the earth uninhabitable,

1. *Appeals* to the nuclear Powers to desist from carrying out further nuclear and thermonuclear tests, whether underground, under water or in the earth's atmosphere;

2. *Urges* the nuclear Powers to reach an agreement without delay on the cessation of all nuclear and thermonuclear tests;

3. *Reassures* the peoples of the world that the United Nations will continue to raise its voice against nuclear and thermonuclear tests of any kind and earnestly requests the nuclear Powers not to deploy such weapons of mass destruction.

C

The General Assembly,

Recognizing the urgent need for the cessation of nuclear and thermonuclear weapon tests, including those carried out underground,

Recalling that this subject has been included in the agenda of the General Assembly every year since 1957,

Recalling in particular its resolutions 914 (X) of 16 December 1955, 1762 (XVII) of 6 November 1962, 1910 (XVIII) of 27 November 1963, 2032 (XX) of 3 December 1965, 2163 (XXI) of 5 December 1966, 2343 (XXII) of 19 December 1967, 2455 (XXIII) of 20 December 1968, 2604 (XXIV) of 16 December 1969 and 2663 (XXV) of 7 December 1970,

Expressing serious concern that the objectives of those resolutions have not been fulfilled,

Noting with regret that all States have not yet adhered to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, signed in Moscow on 5 August 1963, and that some continue to test in the atmosphere,

Taking into account the determination expressed by the parties to that Treaty to continue negotiations to achieve the discontinuance of all test explosions of nuclear weapons for all time,

Noting the appeal for progress on this issue, made by the Secretary-General in the introduction to his report on the work of the Organization,

Noting with special concern that nuclear weapon tests in the atmosphere and underground are continuing,

Having considered the special report submitted by the Conference of the Committee on Disarmament in response to General Assembly resolution 2663 B (XXV),

1. *Stresses anew* the urgency of bringing to a halt all nuclear weapon testing in all environments by all States;

2. *Urges* all States that have not yet done so to adhere without further delay to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water and meanwhile to refrain from testing in the environments covered by that Treaty;

3. *Calls upon* all Governments that have been conducting nuclear weapon tests, particularly those parties to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, immediately to undertake unilateral or negotiated measures of restraint that would suspend nuclear weapon testing or limit or reduce the size and number of nuclear weapon tests, pending the early entry into force of a comprehensive ban on all nuclear weapon tests in all environments by all States;

4. *Urges* Governments to take all possible measures to develop further, and to use more effectively, existing capabilities for the seismological identification of underground nuclear tests, in order to facilitate the monitoring of a comprehensive test ban;

5. *Requests* the Conference of the Committee on Disarmament to continue, as a matter of high priority, its deliberations on a treaty banning underground nuclear weapon tests, taking into account the suggestions already made in the Conference as well as the views expressed at the current session of the General Assembly;

6. *Requests particularly* governments that have been carrying out nuclear tests to take an active and constructive part in developing in the Conference of the Committee on Disarmament, or in any successor body, specific proposals for an underground test ban treaty;

7. *Expresses the hope* that these efforts will enable all States to sign, in the near future, a treaty banning underground nuclear weapon tests.

Annex 19

Resolution 3 (I) Adopted by the United Nations Conference on the Human Environment, Stockholm, 5 to 16 June 1972

Considering that there is radio-active contamination of the environment from nuclear weapons tests,

Taking into account the reports of the United Nations Scientific Committee on the Effects of Atomic Radiation,

Believing that all exposures of mankind to radiation should be kept to the minimum possible and should be justified by benefits that would otherwise not be obtained,

Considering that the United Nations has endorsed world treaties such as the Partial Test Ban Treaty and the Seabed Denuclearization Treaty and regional treaties such as the Tlatelolco Treaty for the Denuclearization of Latin America, and has repeatedly called for the cessation of nuclear weapons tests,

Resolves:

(a) to condemn nuclear weapons tests, especially those carried out in the atmosphere;

(b) to call upon those States intending to carry out nuclear weapons tests to abandon their plans to carry out such tests since they may lead to further contamination of the environment.

Annex 20

Declaration of the United Nations Conference on the Human Environment

The United Nations Conference on the Human Environment,

Having met at Stockholm from 5 to 16 June 1972,

Having considered the need for a common outlook and for common principles to inspire and guide the peoples of the world in the preservation and enhancement of the human environment,

I

Proclaims that:

1. Man is both creature and moulder of his environment, which gives him physical sustenance and affords him the opportunity for intellectual, moral, social and spiritual growth. In the long and tortuous evolution of the human race on this planet a stage has been reached when, through the rapid acceleration of science and technology, man has acquired the power to transform his environment in countless ways on an unprecedented scale. Both aspects of man's environment, the natural and the man-made, are essential to his well-being and to the enjoyment of basic human rights— even the right to life itself.

2. The protection and improvement of the human environment is a major issue which affects the well-being of peoples and economic development throughout the world; it is the urgent desire of the people of the whole world and the duty of all governments.

3. Man has constantly to sum up experience and go on discovering, inventing, creating and advancing. In our time, man's capability to transform his surroundings, if used wisely, can bring to all peoples the benefits of development and the opportunity to enhance the quality of life. Wrongly or heedlessly applied, the same power can do incalculable harm to human beings and the human environment. We see around us growing evidence of man-made harm in many regions of the earth: dangerous levels of pollution in water, air, earth and living beings; major and undesirable disturbances to the ecological balance of the biosphere; destruction and depletion of irreplaceable resources; and gross deficiencies harmful to the physical, mental and social health of man, in the man-made environment, particularly in the living and working environment.

4. In the developing countries most of the environmental problems are caused by under-development. Millions continue to live far below the minimum levels required for a decent human existence, deprived of adequate food and clothing, shelter and education, health and sanitation. Therefore, the developing countries must direct their efforts to development, bearing in mind their priorities and the need to safeguard and improve the environment. For the same purpose, the industrialized countries should make efforts to reduce the gap between themselves and the developing countries. In the industrialized countries, environmental problems are generally related to industrialization and technological development.

5. The natural growth of population continuously presents problems on the preservation of the environment, and adequate policies and measures should be adopted, as appropriate, to face these problems. Of all things in the world,

people are the most precious. It is the people that propel social progress, create social wealth, develop science and technology and, through their hard work, continuously transform the human environment. Along with social progress and the advance of production, science and technology, the capability of man to improve the environment increases with each passing day.

6. A point has been reached in history when we must shape our actions throughout the world with a more prudent care for their environmental consequences. Through ignorance or indifference we can do massive and irreversible harm to the earthly environment on which our life and well-being depend. Conversely, through fuller knowledge and wiser action, we can achieve for ourselves and our posterity a better life in an environment more in keeping with human needs and hopes. There are broad vistas for the enhancement of environmental quality and the creation of a good life. What is needed is an enthusiastic but calm state of mind and intense but orderly work. For the purpose of attaining freedom in the world of nature, man must use knowledge to build, in collaboration with nature, a better environment. To defend and improve the human environment for present and future generations has become an imperative goal for mankind – a goal to be pursued together with, and in harmony with, the established and fundamental goals of peace and of world-wide economic and social development.

7. To achieve this environmental goal will demand the acceptance of responsibility by citizens and communities and by enterprises and institutions at every level, all sharing equitably in common efforts. Individuals in all walks of life as well as organizations in many fields, by their values and the sum of their actions, will shape the world environment of the future. Local and national governments will bear the greatest burden for large-scale environmental policy and action within their jurisdictions. International co-operation is also needed in order to raise resources to support the developing countries in carrying out their responsibilities in this field. A growing class of environmental problems, because they are regional or global in extent or because they affect the common international realm, will require extensive co-operation among nations and action by international organizations in the common interest. The Conference calls upon Governments and peoples to exert common efforts for the preservation and improvement of the human environment, for the benefit of all the people and for their posterity.

II

PRINCIPLES

States the common conviction that:

Principle 1

Man has the fundamental right to freedom, equality and adequate conditions of life, in an environment of a quality that permits a life of dignity and well-being and he bears a solemn responsibility to protect and improve the environment for present and future generations. In this respect, policies promoting or perpetuating *apartheid*, racial segregation, discrimination, colonial and other forms of oppression and foreign domination stand condemned and must be eliminated.

Principle 2

The natural resources of the earth including the air, water, land, flora and fauna and especially representative samples of natural ecosystems must be safeguarded for the benefit of present and future generations through careful planning or management, as appropriate.

Principle 3

The capacity of the earth to produce vital renewable resources must be maintained and, wherever practicable, restored or improved.

Principle 4

Man has a special responsibility to safeguard and wisely manage the heritage of wildlife and its habitats which are now gravely imperilled by a combination of adverse factors. Nature conservation including wildlife must therefore receive importance in planning for economic development.

Principle 5

The non-renewable resources of the earth must be employed in such a way as to guard against the danger of their future exhaustion and to ensure that benefits from such employment are shared by all mankind.

Principle 6

The discharge of toxic substances or of other substances and the release of heat, in such quantities or concentrations as to exceed the capacity of the environment to render them harmless, must be halted in order to ensure that serious or irreversible damage is not inflicted upon ecosystems. The just struggle of the peoples of all countries against pollution should be supported.

Principle 7

States shall take all possible steps to prevent pollution of the seas by substances that are liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea.

Principle 8

Economic and social development is essential for ensuring a favourable living and working environment for man and for creating conditions on earth that are necessary for the improvement of the quality of life.

Principle 9

Environmental deficiencies generated by the conditions of underdevelopment and natural disasters pose grave problems and can best be remedied by accelerated development through the transfer of substantial quantities of financial and technological assistance as a supplement to the domestic effort of the developing countries and such timely assistance as may be required.

Principle 10

For the developing countries, stability of prices and adequate earnings for primary commodities and raw material are essential to environmental management since economic factors as well as ecological processes must be taken into account.

Principle 11

The environmental policies of all States should enhance and not adversely affect the present or future development potential of developing countries, nor should they hamper the attainment of better living conditions for all, and appropriate steps should be taken by States and international organizations with a view to reaching agreement on meeting the possible national and international economic consequences resulting from the application of environmental measures.

Principle 12

Resources should be made available to preserve and improve the environment, taking into account the circumstances and particular requirements of developing countries and any costs which may emanate from their incorporating environmental safeguards into their development planning and the need for making available to them, upon their request, additional international technical and financial assistance for this purpose.

Principle 13

In order to achieve a more rational management of resources and thus to improve the environment, States should adopt an integrated and co-ordinated approach to their development planning so as to ensure that development is compatible with the need to protect and improve the human environment for the benefit of their population.

Principle 14

Rational planning constitutes an essential tool for reconciling any conflict between the needs of development and the need to protect and improve the environment.

Principle 15

Planning must be applied to human settlements and urbanization with a view to avoiding adverse effects on the environment and obtaining maximum social, economic and environmental benefits for all. In this respect projects which are designed for colonialist and racist domination must be abandoned.

Principle 16

Demographic policies, which are without prejudice to basic human rights and which are deemed appropriate by governments concerned, should be applied in those regions where the rate of population growth or excessive population concentrations are likely to have adverse effects on the environment or development, or where low population density may prevent improvement of the human environment and impede development.

Principle 17

Appropriate national institutions must be entrusted with the task of planning, managing or controlling the environmental resources of States with the view to enhancing environmental quality.

Principle 18

Science and technology, as part of their contribution to economic and social development, must be applied to the identification, avoidance and control of environmental risks and the solution of environmental problems and for the common good of mankind.

Principle 19

Education in environmental matters, for the younger generation as well as adults, giving due consideration to the underprivileged, is essential in order to

broaden the basis for an enlightened opinion and responsible conduct by individuals, enterprises and communities in protecting and improving the environment in its full human dimension. It is also essential that mass media of communications avoid contributing to the deterioration of the environment, but, on the contrary, disseminate information of an educational nature, on the need to protect and improve the environment in order to enable man to develop in every respect.

Principle 20

Scientific research and development in the context of environmental problems, both national and multinational, must be promoted in all countries, especially the developing countries. In this connection, the free flow of up-to-date scientific information and transfer of experience must be supported and assisted, to facilitate the solution of environmental problems; environmental technologies should be made available to developing countries on terms which would encourage their wide dissemination without constituting an economic burden on the developing countries.

Principle 21

States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.

Principle 22

States shall co-operate to develop further the international law regarding liability and compensation for the victims of pollution and other environmental damage caused by activities within the jurisdiction or control of such States to areas beyond their jurisdiction.

Principle 23

Without prejudice to such criteria as may be agreed upon by the international community, or to standards which will have to be determined nationally, it will be essential in all cases to consider the systems of values prevailing in each country, and the extent of the applicability of standards which are valid for the most advanced countries but which may be inappropriate and of unwarranted social cost for the developing countries.

Principle 24

International matters concerning the protection and improvement of the environment should be handled in a co-operative spirit by all countries, big or small, on an equal footing. Co-operation through multilateral or bilateral arrangements or other appropriate means is essential to effectively control, prevent, reduce and eliminate adverse environmental effects resulting from activities conducted in all spheres, in such a way that due account is taken of the sovereignty and interests of all States.

Principle 25

States shall ensure that international organizations play a co-ordinated, efficient and dynamic role for the protection and improvement of the environment.

Principle 26

Man and his environment must be spared the effects of nuclear weapons and all other means of mass destruction. States must strive to reach prompt agreement, in the relevant international organs, on the elimination and complete destruction of such weapons.

Annex 21

United Nations General Assembly Resolution 2934 A-C (XXVII) of 29 November 1972 on the "Urgent Need for Suspension of Nuclear and Thermonuclear Tests"

A

The General Assembly,

Recognizing the urgent need for the cessation of nuclear and thermonuclear weapon tests,

Recalling its resolution 2602 E (XXIV) of 16 December 1969, by which it declared the decade of the 1970s as a Disarmament Decade, and its resolution 2734 (XXV) of 16 December 1970, which contains the Declaration on the Strengthening of International Security,

Recalling also its resolutions 914 (X) of 16 December 1955, 1762 (XVII) of 6 November 1962, 1910 (XVIII) of 27 November 1963, 2032 (XX) of 3 December 1965, 2163 (XXI) of 5 December 1966, 2343 (XXII) of 19 December 1967, 2455 (XXIII) of 20 December 1968, 2604 (XXIV) of 16 December 1969, 2663 (XXV) of 7 December 1970 and 2828 (XXVI) of 16 December 1971.

I

Noting with regret that all States have not yet adhered to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, signed in Moscow on 5 August 1963,

Expressing serious concern that testing of nuclear weapons in the atmosphere has continued in some parts of the world, including the Pacific area, in disregard of the spirit of that Treaty and of world opinion,

Noting in this connection the statements made by the governments of various countries in and around the Pacific area, expressing strong opposition to those tests and urging that they be halted,

1. *Stresses anew* the urgency of bringing to a halt all atmospheric testing of nuclear weapons in the Pacific or anywhere else in the world;

2. *Urges* all States that have not yet done so to adhere without further delay to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water and, meanwhile, to refrain from testing in the environments covered by that Treaty;

II

Noting that no less than nine years have elapsed since the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water came into force,

Taking into account the determination expressed by the parties to that Treaty to continue negotiations to conclude a treaty resulting in the permanent banning of all nuclear weapon test explosions,

1. *Declares* that a treaty banning all nuclear weapon tests is an important element in the consolidation of the progress towards disarmament and arms control made thus far and that it would greatly facilitate future progress in these fields;

2. *Calls upon* all nuclear-weapon States to suspend nuclear weapon tests in all environments;

3. *Calls upon* the Conference of the Committee on Disarmament to give urgent consideration to the question of a treaty banning all nuclear weapon tests, taking into account the views already expressed in the Conference, the opinions stated at the current session of the General Assembly and, above all, the pressing need for the early conclusion of such a treaty.

B

The General Assembly,

Conscious of the dangers to mankind presented by a continuation of the nuclear arms race,

Believing that a cessation of all nuclear and thermonuclear weapon tests, including those carried out underground, would contribute to a deceleration of the nuclear arms race, to the promotion of further arms control and disarmament measures, and to a reduction in world tension,

Believing further that a cessation of all nuclear weapon testing would inhibit the wider dissemination of nuclear weapons,

Noting with regret that not all States have yet adhered to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, signed in Moscow on 5 August 1963,

Noting with regret that despite the determination expressed by parties to that Treaty to achieve the discontinuance of all test explosions of nuclear weapons for all time, parties to the Treaty continue to test nuclear weapons underground, and no specific proposals for an underground test ban agreement are under negotiation,

Recalling that the General Assembly has repeatedly expressed its concern regarding the continuation of nuclear and thermonuclear weapon testing, in particular in its resolutions 914 (X) of 16 December 1955, 1762 (XVII) of 6 November 1962, 1910 (XVIII) of 27 November 1963, 2032 (XX) of 3 December 1965, 2163 (XXI) of 5 December 1966, 2343 (XXII) of 19 December 1967, 2455 (XXIII) of 20 December 1968, 2604 (XXIV) of 16 December 1969, 2663 (XXV) of 7 December 1970 and 2828 (XXVI) of 15 December 1971,

Having considered the report submitted on 26 September 1972 by the Conference of the Committee on Disarmament, and in particular the sections thereof concerned with achieving a comprehensive test ban,

Noting with satisfaction the completion of a first set of bilateral agreements on the limitation of strategic arms and expressing the hope that the progress so far achieved will lead to further agreed limitation on nuclear arms and be conducive to the negotiation of a ban on underground nuclear weapon testing,

1. *Stresses again* the urgency of halting all nuclear weapon testing in all environments by all States;

2. *Urges* all States that have not yet done so to adhere without further delay to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, and meanwhile to refrain from testing in environments covered by that Treaty;

3. *Calls upon* all governments conducting underground nuclear weapon tests, particularly those parties to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, immediately to undertake unilateral or negotiated measures that would suspend or reduce such testing, pending the early entry into force of a ban on all nuclear weapon tests in all environments;

4. *Urges* governments that have been carrying out nuclear weapon tests to take an active and constructive part in presenting and developing in the Conference of the Committee on Disarmament, or in any other appropriate body, specific proposals for a comprehensive test ban;

5. *Requests* the Conference of the Committee on Disarmament to give first priority to its deliberations on a treaty banning underground nuclear weapon tests, taking full account of views of experts and of technical developments bearing on the verification of such a treaty, and further requests the Conference to submit a special report to the General Assembly at its twenty-eighth session on the results of its deliberations on this matter;

6. *Urges* governments to take all appropriate measures further to develop existing capabilities for detection and identification of underground nuclear tests through seismological and other technical means, and to increase international co-operation in the elaboration of relevant techniques and evaluation of seismographic data, in order to facilitate an underground nuclear weapon test ban;

7. *Calls upon* governments to seek as a matter of urgency a halt to all nuclear weapon testing, and to endeavour to achieve at the earliest possible date a comprehensive test ban and to obtain universal adherence to such a ban.

C

The General Assembly,

Reaffirming its deep apprehension concerning the harmful consequences of nuclear weapon tests for the acceleration of the arms race and for the health of present and future generations of mankind,

Deploring that the General Assembly has not yet succeeded in its aim of achieving a comprehensive test ban, despite 21 successive resolutions on the subject,

Deploring further that the determination expressed by the original parties to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, signed in Moscow on 5 August 1963, to pursue negotiations to achieve the discontinuance of all test explosions of nuclear weapons for all time has not so far produced the desired results,

Recalling its resolutions 1762 A (XVII) of 6 November 1962 and 2828 A (XXVI) of 16 December 1971, whereby all nuclear weapon tests, without exception, were condemned,

1. *Reiterates once again with the utmost vigour* its condemnation of all nuclear weapon tests;

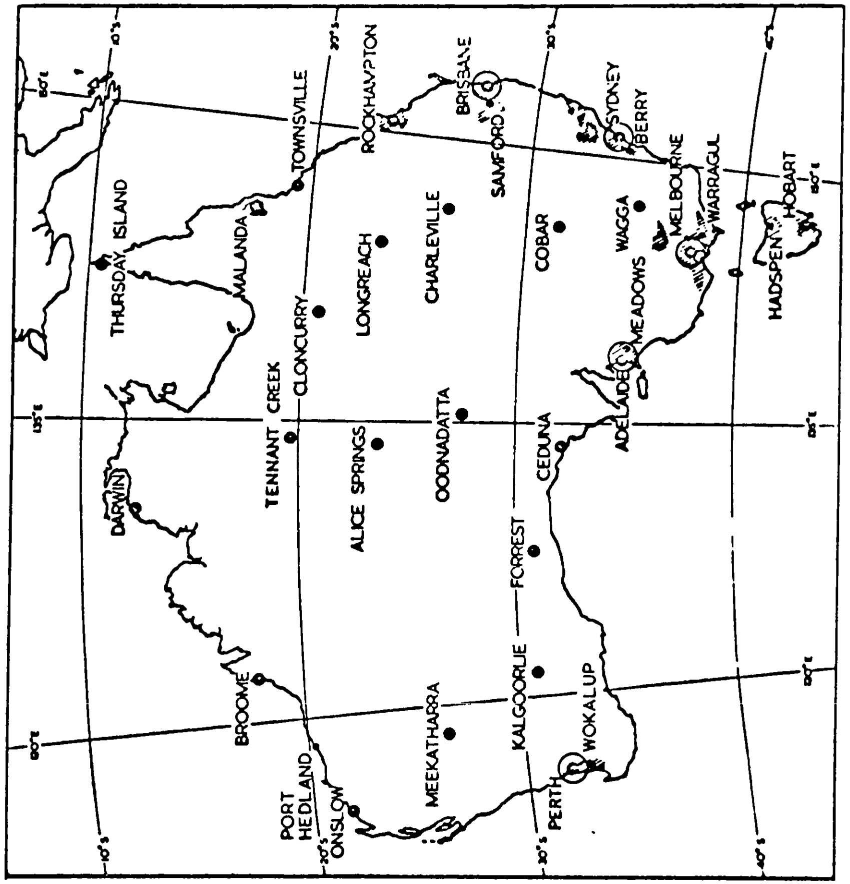
2. *Reaffirms its conviction* that, whatever may be the differences on the question of verification, there is no valid reason for delaying the conclusion of a comprehensive test ban of the nature contemplated in the preamble to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water;

3. *Urges once more* the governments of nuclear-weapon States to bring to a halt all nuclear weapon tests at the earliest possible date, and in any case not later than 5 August 1973, either through a permanent agreement or through unilateral or agreed moratoria;

4. *Requests* the Secretary-General to transmit the present resolution to the nuclear-weapon States and to inform the General Assembly at its twenty-eighth session of any measures they have taken to implement it.

Annex 22

Map Showing Geographical Coverage of Monitoring Programme



Annex 23

Main Fission Products Present in Fall-out over Australia Following French Nuclear Tests in Polynesia

Those predominating, and to which specific attention is given in the fall-out monitoring, are indicated *.

antimony 125	* cerium 144	neodymium 147	ruthenium 106	tellurium 129m
antimony 126	europium 155	praseodymium 143	silver 111	tellurium 129
antimony 127	europium 156	praseodymium 144	* strontium 89	tellurium 132
* barium 137m	* iodine 131	promethium 147	* strontium 90	tin 119m
* barium 140	iodine 132	promethium 149	technetium 99m	tin 125
caesium 136	* lanthanum 140	* rhodium 103m	tellurium 125m	* yttrium 90
* caesium 137	molybdenum 99	rhodium 106	tellurium 127m	yttrium 91
* cerium 141	* niobium 95	* ruthenium 103	tellurium 127	* zirconium 95

Annex 24

INTEGRATED CONCENTRATIONS OF IODINE-131 IN MILK SUPPLIES FOLLOWING FRENCH NUCLEAR TESTS IN POLYNESIA, 1966 TO 1972

Picocurie-days per litre

Centre	*1966*	*1967*	*1968*	*1970*	*1971*	*1972*
Adelaide	6300	820	2120	1870	1460	90
Brisbane	4600	940	2250	1320	1360	60
Hobart and Launceston	1500	380	790	860	350	0
Malanda	11000	10360	4540	5790	5390	170
Melbourne	2400	410	830	1000	500	0
Perth	7200	1410	1970	3000	2990	50
Rockhampton	4700	1140	2780	1850	1320	70
Sydney	2800	580	890	920	830	0

Annex 25

STRONTIUM-90 AND CAESIUM-137 FALLOUT DEPOSITION IN AUSTRALIA FROM NUCLEAR TESTS IN THE ATMOSPHERE BY USSR AND USA UP TO 1962 AND BY FRANCE AND CHINA FROM 1966

Centre	*Strontium-90 millicuries per square kilometre*						*Caesium-137 millicuries per square kilometre*					
	1966	*1967*	*1968*	*1969*	*1970*	*1971*	*1966*	*1967*	*1968*	*1969*	*1970*	*1971*
Adelaide	1.26	0.49	0.48	0.61	0.56	0.87	1.29	0.62	0.53	0.84	0.75	1.23
Alice Springs	0.63	0.10	0.43	0.27	0.20	0.37	1.16	0.29	0.41	0.43	0.31	0.40
Berry	1.36	0.72	0.53	1.60	1.36	1.86	2.17	1.29	0.63	2.10	1.44	2.32
Brisbane	1.08	0.61	0.42	0.79	0.79	1.24	1.47	1.12	0.55	1.16	1.51	1.63
Darwin	0.91	0.31	0.41	0.46	0.36	0.36	1.29	0.48	0.55	0.85	0.52	0.64
Hadspen	0.73	0.38	0.47	0.68	0.65	0.88	0.98	0.54	0.52	0.78	0.92	1.04
Hobart	0.94	0.41	0.28	0.53	0.57	0.69	0.86	0.52	0.31	0.63	0.85	0.96
Meadows	1.26	0.41	0.67	0.71	0.79	1.39	1.42	0.76	0.75	0.77	0.87	1.69
Melbourne	1.06	0.38	0.37	0.85	0.96	0.77	1.22	0.44	0.39	0.95	1.05	0.76
Perth	1.18	0.64	0.50	0.52	0.74	0.90	1.35	0.90	0.58	0.64	1.06	1.14
Port Hedland	0.48	0.22	0.12	0.06	0.11	0.09	0.41	0.18	0.10	0.24	0.12	0.12
Samford	0.98	0.61	0.54	0.82	1.13	1.06	1.46	1.06	0.54	1.10	1.26	1.34
Sydney	1.50	0.82	0.33	1.01	0.86	0.93	1.63	1.36	0.23	1.39	1.03	1.21
Townsville	0.71	0.40	0.27	0.20	0.31	0.41	0.87	0.43	0.32	0.31	0.39	0.49
Warragul	1.03	0.45	0.75	1.12	0.97	1.12	1.40	0.73	0.71	1.26	1.22	1.22
Wokalup	0.85	0.52	0.44	0.40	0.56	0.87	1.25	0.90	0.49	0.66	0.89	1.13
Population-weighted mean for Australia	1.18	0.58	0.48	0.96	0.93	1.12	1.52	0.95	0.50	1.24	1.12	1.38
Component due to French nuclear tests	0.24	0.06	0.19	0.67	0.70	0.90	0.30	0.10	0.20	0.87	0.84	1.10

Annex 26

DEPICTION OF STRONTIUM-90 AND CAESIUM-137 FALL-OUT IN AUSTRALIA