



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

GENERAL ASSEMBLY

OFFICIAL RECORDS : TWENTY-FIRST SESSION

SUPPLEMENT No. 14 (A/6314)

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Chapter I

INTRODUCTION

Constitution and terms of reference of the Committee

1. The Scientific Committee on the Effects of Atomic Radiation was established by the General Assembly at its tenth session on 3 December 1955, under resolution 913 (X), as a result of debates held in the First Committee from 31 October to 10 November 1955. The terms of reference of the Committee were set out in paragraph 2 of the above-mentioned resolution by which the General Assembly requested 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.”

2. The Committee is composed of Argentina, Australia, Belgium, Brazil, Canada, Czechoslovakia, France, India, Japan, Mexico, Sweden, the Union of Soviet Socialist Republics, the United Arab Republic, the United Kingdom of Great Britain and Northern Ireland and the United States of America.

Activities of the Committee

3. Since its establishment, the Committee has held sixteen sessions. Its activities during the first fourteen sessions were surveyed in the introductions to the reports that the Committee submitted to the General Assembly in 1958, 1962 and 1964.¹

4. The Committee held its fifteenth session at the European Office of the United Nations in Geneva from 15 to 23 November 1965. During that session the Committee discussed new information on natural radiation sources and on radio-active contamination of the environment as well as on certain biological effects of ionizing radiation on the basis of reviews prepared in the Secretariat.

5. The Committee also adopted its annual progress report to the General Assembly (A/6123). In that report the Committee expressed its intention of preparing for submission to the General Assembly at its twenty-first session a substantive report dealing with such estimates of risk as might result from consideration of the subjects mentioned in paragraph 4 of this chapter.

6. The General Assembly considered both the 1964 and 1965 reports of the Committee during its twentieth session. By resolution 2078 (XX) of 18 December 1965, the General Assembly: (1) took note of the reports of the United Nations Scientific Committee on the Effects of Atomic Radiation on the work of its thirteenth, fourteenth and fifteenth sessions; (2) commended the Scientific Committee for its valuable contributions to wider knowledge and understanding of the effects and levels of atomic radiation during the ten years of the Committee's existence; (3) requested the Scientific Committee to continue its programme, including its co-ordinating activities, to increase the knowledge of the levels and effects of atomic radiation from all sources; (4) commended the World Meteorological Organization for its work in carrying forward the scheme for monitoring and reporting levels of atmospheric radio-activity; (5) acknowledged with appreciation the assistance rendered to the Scientific Committee by the World Meteorological Organization, the Food and Agriculture Organization of the United Nations and the International Atomic Energy Agency; (6) recommended that all parties concerned continue their co-operation with the Scientific Committee; (7) noted the intention of the Scientific Committee to submit a report to the General Assembly at its twenty-first session; (8) requested the Secretary-General to continue to provide the Scientific Committee with the assistance necessary for the conduct of its work and the dissemination of its findings to the public.

¹ *Official Records of the General Assembly, Thirteenth Session, Supplement No. 17 (A/3838); ibid., Seventeenth Session, Supplement No. 16 (A/5216); ibid., Nineteenth Session, Supplement No. 14 (A/5814)*. Hereafter these documents will be referred to as the 1958, 1962 and 1964 reports, respectively.

Scientific assistance

7. The sixteenth session of the Committee was held at Headquarters from 6 to 17 June 1966. At that session the Committee adopted the present report to the General Assembly. It also considered the problem of the effects of ionizing radiation on the central nervous system. The Committee decided that it should at its future meetings consider in detail the effects of ionizing radiation on the nervous system, biological indicators of irradiation of man, and the principles, procedures and parameters used by it in estimating doses to the population from global radio-active contamination of the environment. In its consideration of the last topic, the Committee proposed to review the requests it had made in the past to States Members of the United Nations or members of the specialized agencies and of the IAEA for data on levels of environmental contamination. The above subjects, together with a further review of reported levels of environmental global contamination, might form the substance of a report or reports to the General Assembly. The Committee also decided to request that arrangements be made for a session to be held in 1967.

Organization of the work of the Committee

8. As in the past, most of the technical discussions were held during informal meetings of groups of specialists whose conclusions were eventually reviewed by the full Committee. According to the Committee's established practice, no detailed record of its technical deliberations was taken.

9. Mr. D. J. Stevens of Australia and Dr. A. R. Gopal-Ayengar of India served as Chairman and Vice-Chairman, respectively, during the fifteenth session of the Committee. At the fifteenth session, Dr. A. R. Gopal-Ayengar of India and Dr. G. C. Butler of Canada were elected Chairman and Vice-Chairman, respectively, to serve during the sixteenth and seventeenth sessions. The names of those scientists who attended the fifteenth and/or the sixteenth sessions of the Committee as members of national delegations are listed in appendix I.

Sources of information

10. The reports received by the Committee from States Members of the United Nations and members of the specialized agencies and of the International Atomic Energy Agency, as well as from these agencies themselves, between 15 June 1964 and 7 June 1966, are listed in annex D. Reports received prior to 15 June 1964 were listed in earlier reports of the Committee to the General Assembly. The information received officially by the Committee was supplemented by, and interpreted in the light of, information available in the current scientific literature or obtained from unpublished private communications from individual scientists.

11. As in the past, the Committee was assisted by a small scientific staff and by consultants appointed by the Secretary-General. Scientific staff and consultants were responsible for preliminary review and evaluation of the scientific information received by the Committee or published in the technical literature.

12. While the responsibility for the report rests entirely with the Committee, the Committee wishes to acknowledge the help and advice received from those scientists whose names are listed in appendix II. The Committee owes much to their co-operation and goodwill.

Relations with United Nations agencies and other organizations

13. Sessions of the Committee were attended by observers from the International Labour Organisation (ILO), the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), the World Meteorological Organization (WMO), and from the International Atomic Energy Agency (IAEA), as well as from the International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU). The Committee wishes to record its appreciation for their contribution to the discussions.

Scope and purpose of the report

14. Like the 1964 report, the present report is not intended to cover comprehensively the whole field of interest of the Committee; in particular, the report will not deal with medical irradiation nor with somatic radiation effects. The report is limited to a discussion of environmental radiation, both natural and artificial, and of the genetic risks arising from exposure to ionizing radiation. The Committee has surveyed especially those aspects of both subjects in which new advances may require a revision of its earlier assessments of radiation risks. The present report, being neither comprehensive nor self-contained, must be read in the context of the earlier reviews made by the Committee in its 1962 and 1964 reports.

15. The main text of the report is followed by technical annexes where the scientific information on which the Committee rests its conclusions is discussed in detail. The Committee wishes to emphasize, as it did in the past, that its conclusions, being based on the scientific evidence presently available, cannot be considered as final and will require revision as scientific knowledge progresses.

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 expected by the year 2000 from the current contamination of the environment due to past nuclear weapon tests.

27. These periods do not differ appreciably from those given in the 1964 report. Present estimates are approximately three-quarters of a year for the gonads, two and a half years for the cells lining bone surfaces and one year and a half for the bone marrow. These values present a certain degree of approximation since they are based on assumptions and measurements which may not be entirely representative of the whole world situation. They are more likely to be over- rather than 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)			Paragraphs in annex A
	Gonads	Cells lining bone surfaces ^a	Bone marrow	
<i>External irradiation</i>				
Cosmic rays				
Ionizing component	28	28	28	48
Neutrons	0.7	0.7	0.7	49
Terrestrial radiation (including air)	50	50	50	58
<i>Internal irradiation</i>				
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 ^c	240	

TABLE II. DOSE COMMITMENTS FROM NUCLEAR EXPLOSIONS (continued)

<i>Tissue</i>	<i>Source of radiation</i>	<i>Dose commitments (mrad) for period of testing 1954-1965^a</i>	<i>Paragraphs in annex B</i>
Bone marrow	External, short-lived	23	137
	Cs ¹³⁷	25	135
	Internal, Sr ⁹⁰	78	143
	Cs ¹³⁷	15	145
	C ^{14b}	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

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

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 chromosome 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

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 re-

ceives 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 does 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 (oocytes) 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.