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

GENERAL ASSEMBLY

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REPORT OF THE

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SCIENTIFIC COMMITTEE

ON THE

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UNITED NATIONS

New York, 1972

NOTE

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

CONTENTS

INTRODUCTION

1. This is the sixth substantive report of the United Nations Scientific Committee on the Effects of Atomic Radiation 1/ to the General Assembly. It reviews the levels of radiation received from all sources to which man is exposed and, among the effects of ionizing radiation, it considers the genetic effects, the effects on the immune response and the induction of malignancies in animals and man. These are not the only effects of ionizing radiation. The acute consequences of massive amounts of radiation that may be received accidentally or during nuclear warfare are not reviewed here (the short discussion of this subject in the 1962 report is still largely valid, at least as an introduction), nor are the effects on the nervous system and the induction of chromosome anomalies in somatic cells, which were both considered by the Committee in its 1969 report.

2. Unlike previous reports of the Committee, the present report is submitted to the General Assembly without the technical annexes in which the evidence considered by the Committee is discussed in detail and in which the bases for the Committee's conclusions, which are stated in the report, are fully documented. However, the annexes are being made available at the same time as the report in a separate publication, issued in two volumes 2/ and the Committee wishes to draw the attention of the General Assembly to the fact that the separation of the report from the annexes is for convenience only and that major importance attaches to the scientific evidence given in the annexes.

3. The preparation of the report took place at the twentieth, twenty-first and twenty-second sessions of the Committee. 3/ Most of the work was done in meetings

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1/ The Scientific Committee was established by the General Assembly at its tenth session in 1955. Its terms of reference are set out in resolution 913 (X). It is composed of the following Member States: Argentina, Australia, Belgium, Brazil, Canada, Czechoslovakia, Egypt, France, India, Japan, Mexico, Sweden, Union of Soviet Socialist Republics, United Kingdom of Great Britain and Northern Ireland and United States of America. For the previous substantive reports of the Committee, see Official Records of the General Assembly, Thirteenth Session, Supplement No. 17 (A/3838; ibid., Seventeenth Session, Supplement No. 16 (A/5216); ibid., Nineteenth Session, Supplement No. 14 (A/5814); ibid., Twenty-first Session, Supplement No. 14 (A/6314); and ibid., Twenty-fourth Session, Supplement No. 13 (A/7613). They will be referred to as the 1958, 1962, 1964, 1966 and 1969 reports, respectively.

2/ Ionizing Radiation: Levels and Effects, Volume I: Levels (United Nations publication, Sales No.: E.72.IX.17) and Volume II: Effects (United Nations publication, Sales No.: E.72.IX.18). Volume I contains the appendices and annexes A to D; volume II contains annexes E to H.

3/ The twentieth session was held at the United Nations Office at Geneva from 21 to 25 September 1970, the twenty-first and twenty-second sessions at Headquarters from 14 to 25 June 1971 and 13 to 24 March 1972, respectively.

of groups of specialists which considered working papers prepared by the Secretariat and modified as the drafting proceeded, on the basis of the Committee's requests. The report itself was drafted at the twenty-second session. Professor B. Lindell (Sweden), Dr. V. Zeleny (Czechoslovakia) and Professor L. R. Caldas (Brazil) served as Chairman, Vice-Chairman and Rapporteur, respectively, at the twentieth session. Professor B. Lindell (Sweden), Professor F. H. Sobels (Belgium) and Professor L. R. Caldas (Brazil) served as Chairman, Vice-Chairman and Rapporteur, respectively, at the twenty-first session; and Professor L. R. Caldas (Brazil), Professor F. H. Sobels (Belgium) and Dr. A. Nelson (Sweden) served in the same capacity, respectively, at the twenty-second session. The names of those experts who attended the twentieth, twenty-first or twenty-second sessions of the Committee as members of national delegations are listed in appendix I.*

4.   The Committee wishes to recall that in 1971 it submitted to the Secretariat of the United Nations Conference on the Human Environment a basic paper on the assessment and control of environmental contamination based on the Committee's experience with artificial radio-activity. The Committee recognizes that, under its present terms of reference as laid down in General Assembly resolution 913 (X), the Committee and its resources can become an element of value in the environmental strategy of the United Nations which may evolve as a result of the Conference on the Human Environment, and it is prepared to play such a role. The Committee further recognizes that, in the present state of affairs, it can continue to discharge its current responsibilities while reporting to the General Assembly less frequently than heretofore. The Committee therefore requests to be relieved from the obligation to report to the General Assembly before the twenty-ninth session and, subject to the acceptance of that request by the Assembly, is not planning to meet before the end of 1973, unless it is asked to undertake new tasks in the context of the environmental strategy of the United Nations or to respond to any other special demand.

5.   The Committee was assisted in the preparation of the present report by a small scientific staff and by consultants appointed by the Secretary-General. The scientific staff and consultants were responsible for preliminary review and evaluation of the technical information received by the Committee or published in the scientific literature. Although the Committee itself assumes full responsibility for the report, it wishes to acknowledge the help and advice given by those scientists whose names are listed in appendix II.* The Committee owes much to their co-operation and scientific expertise.

6.   Representatives of the International Labour Organisation (ILO), the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), and of the International Atomic Energy Agency (IAEA), as well as of the International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU), attended sessions of the Committee held during the period under review. The Committee wishes to acknowledge with appreciation their contribution to the discussion.

7.   The reports received by the Committee from States Members of the United Nations, and members of the specialized agencies and the International Atomic

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    * Not reproduced in the present document, but included in Ionizing Radiation: Levels and Effects, Volume I: Levels (United Nations publication, Sales No.: E.72.IX.17).

Energy Agency, as well as from these agencies themselves, between 17 May 1969 and 24 March 1972, are listed in appendix III* of this report. Reports received before 17 May 1969 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 communications of individual scientists.

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* Not reproduced in the present document, but included in <u>Ionizing Radiation:</u> <u>Levels and Effects, Volume I: Levels</u> (United Nations publication, Sales No.: E.72.IX.17).

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 kilometeres 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

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4/   For details, see annex A.

on the nature of the ground and the 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 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 to 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.

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 tons of millirads and the highest annual doses remained markedly lower than those reported in the nothern 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 ($\sim$0.1 rad) to 50 times as high. Radiation treatments, on the other hand, may involve individual doses thousands of times higher then 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 delivered 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 become 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.

5/   For details, see annex B.

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

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6/   For details, see annex C.

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.

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 E.

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_

10/   For details, see annex F.

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.

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 radio-therapy 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. Leukaemia is the best known of the radiation-induced malignancies. All evidence indicates that the incidence of certain types of leukaemia 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 leukaemic are destroyed by radiation. Radiation-induced leukaemias 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 leukaemias 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 yeild. For thyroid

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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.

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 leukaemia 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 leukaemias 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 continously 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 over-estimates 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 continously 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.