Radiation risk assessment: the 1982 UNSCEAR report

Since its establishment in 1955 the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has reported yearly to the General Assembly and at irregular intervals has submitted more comprehensive reports with detailed scientific annexes. In 1982, the eighth in the series of such substantive reports was published*. It consists of a summary and a main text outlining the conclusions reached in the Committee's discussions and 12 scientific annexes reviewing in considerable detail the procedures and the scientific information on which such conclusions rest. The Summary of the main conclusions of the Committee is reprinted here.

In this report, as in previous ones, the Committee has systematically reviewed all the sources of ionizing radiation that give rise to human exposure, namely, natural sources, nuclear explosions, nuclear power production, use of radiation for medical, industrial and research purposes, and radiation-emitting consumer products. Both occupational exposures (that is, the exposures incurred during the course of work) and non-occupational exposures have been considered. For each source of ionizing radiation, the results are expressed in two ways. On the one hand, results are given in terms of individual doses, which from an individual point of view show the relative importance of the type of work, the place of residence, or particular habits. On the other hand, collective doses have also been used. As these are the sum of the individual doses resulting from a given source, they provide an index of the total health impact of that source. The use of collective doses permits comparison of the impact from a wide range of dissimilar sources or practices giving rise to ionizing radiation.

A basic assumption was adopted by the Committee for the purpose of dose assessments at the start of its activity and is still in use at present. This is the hypothesis of direct proportionality between doses and probability of occurrence of effects (cancers or genetic disease) for the relatively low levels of dose and dose rate that are generally considered in this report. The hypothesis is meant to apply to large populations comprising individuals of both sexes and of various ages, and not to a single individual. This hypothesis is not contradicted by the large body of experimental and epidemiological data. There are reasons to believe that it does not underestimate the risk at the low doses and dose rates of interest to the Committee, and it may in fact overestimate this risk.

* Ionizing Radiation: Sources and Biological Effects, Sales publication No. E.82.IX.8, United Nations, New York (1982).

This report differs from previous reports in one important aspect. Instead of estimating the absorbed doses to only a limited number of important tissues (for example, gonads, lungs, and bone marrow) the Committee now combines the doses in all organs and tissues in an expression of dose called the "effective dose-equivalent" which the Committee believes to better represent the whole risk incurred by the exposed populations. As a consequence, the present assessment of the relative importance of some radioactive substances has changed in certain cases in comparison with the previous reports of the Committee.

Natural sources

The major contribution to the annual average doses received by mankind comes from natural radiation sources, which include external sources, such as cosmic rays and radioactive substances in the ground and in building materials, and internal sources resulting from the inhalation and ingestion of naturally occurring radioactive substances in air and in diet. Inhalation is now recognized to be the most important pathway, followed by external irradiation and ingestion. Most of the effective dose-equivalent from inhalation is due to radon which is a radioactive noble gas often present in relatively high concentrations in indoor air.

Distinctive characteristics of natural irradiation are that it involves the whole population of the world and that it is and has been experienced at a relatively constant rate over a very long period of time. For these reasons, it may be used as a reference level for comparison with man-made sources of ionizing radiation.

The dose from natural sources of radiation received by a given individual depends upon a number of conditions, including the place of residence, the type of dwelling and the altitude. For most of the world's population, however, the range of individual doses from natural sources is considered to be rather narrow, as it probably extends only between one-half to two times the average value.

Nevertheless, when a separate component of the dose from natural sources is considered, it is generally found that some individuals are exposed to levels much higher than the average. Examples of such individuals are those who live in areas where the soils and rocks are rich in natural radioactive substances, those who live in buildings with high radon concentrations, those who live at high

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altitudes above sea level, and those who eat foodstuffs containing unusually high concentrations of radioactive substances.

The Committee has previously reviewed the exposure from natural sources of radiation in its 1958, 1962, 1966, 1972, and 1977 reports. Because of an increasing number of measurements, dose assessments have become increasingly accurate, particularly with respect to external irradiation. In the present report, expressing dose in terms of effective dose-equivalent emphasizes the importance of the inhalation pathway; on average, about one-half the effective dose-equivalent from natural sources of radiation is now calculated to be due to the presence of radon in the air inside buildings.

**Man-made sources**

Exposures to natural sources of radiation vary little from year to year and involve the whole population of the world to about the same extent. On the contrary, man-made sources may vary significantly with time and the resulting exposures may differ substantially from one population group to another.

**Medical irradiation:** At present medical irradiation ranks first in amount among the man-made sources of human exposure. Radiation is used in medicine for diagnostic purposes (e.g., X-ray or nuclear medicine examinations) and for the treatment of diseases, mainly cancers. The doses received by patients are extremely variable: from very small, as in many diagnostic examinations, to very high, such as those delivered in clinical radiotherapy. As medical exposures usually involve irradiation of limited regions of the body, it has been difficult in the past to compare them with other types of exposure. The use in this report of the effective dose-equivalent is intended to diminish that difficulty.

Annual individual doses vary from zero, for the non-exposed patient receiving no diagnostic or therapeutic exposure, up to several tens of thousand times the annual average dose from natural sources, delivered to the treatment volume of patients undergoing radiotherapy. Under these conditions average doses are not very meaningful, although collective doses may give some indication of the impact of medical sources. In industrialized countries, the annual collective effective dose-equivalents from X-rays and nuclear medicine diagnostic irradiation may be in the region of one-half of the annual collective dose from natural sources. The contribution from exposure of patients for therapeutic purposes has not been estimated by the Committee. However, this component would need to be assessed differently, since it applies generally to people in later life who have a low probability of long-term or latent radiation-induced consequences due to their more limited life expectancy.

Data from developing countries are only now becoming available, in part as a result of collaboration with the World Health Organization. These data indicate an examination frequency about ten times lower than that in industrialized countries. Consequently, the annual collective effective dose-equivalent applying to medical exposure throughout the world may be about one-fifth of the annual collective effective dose-equivalent from natural sources of radiation. Although the individual doses received by workers involved with medical uses of radiation may be significant, the overall occupational contribution to the collective dose is insignificant compared with that from the irradiation of patients, because of the relatively small number of workers to be considered.

The Committee has previously presented data on medical irradiation in its reports issued in 1958, 1962, 1972, and 1977. However, in view of the limited information available and of the uncertainties attached to the dose estimates, trends in the collective dose over the years cannot be easily assessed. In industrialized countries an increasing number of examinations has taken place over the years; on the other hand, continuing improvement in the equipment that has occurred during this period should have resulted in a lower dose per examination. These two trends may have balanced out to some extent. For the purposes of the comparisons made in this report, the Committee has assumed a roughly constant annual collective dose from medical exposure.

**Nuclear explosions:** Artificial radioactive material from nuclear weapons tests in the atmosphere was the cause of widespread contamination of the environment. Much of this material was initially injected into the upper atmosphere, from which it transferred slowly to the lower atmosphere and then to earth in a process usually referred to as fallout. The radionuclides occurring in fallout give rise to exposure by inhalation while they are present in ground level air, or by external irradiation and ingestion when they are deposited onto plants or in the soil.

Nuclear explosions have been conducted since 1945. Intensive nuclear test programmes in the atmosphere took place during 1954–1958 and 1961–1962. Since 1964, additional atmospheric explosions have occurred, the latest one in October 1980. Underground nuclear explosions have been, and still are being, conducted but the resulting environmental contamination is relatively minor. As in all its previous reports, the Committee has assessed the exposures to which the population of the world has been subjected as a result of the atmospheric nuclear tests. Although several hundred radionuclides are produced by nuclear explosions, only a few contribute significantly to human exposure, since most of them decay within a short time or are produced in very small amounts. The Committee, in this report, has considered 21 radionuclides, including iodine-131, strontium-90, caesium-137 and carbon-14. Because of the wide range of decay times, the doses resulting from a nuclear test are delivered at a varying rate after the explosion. For example, the doses from iodine-131 are delivered in a matter of weeks, those from strontium-90 and caesium-137 are completed in a few decades, while doses from carbon-14 will be delivered over thousands of years.
At any given time, the doses depend also on the location being considered. There is a latitudinal variation in fallout which has caused the doses in the southern hemisphere to be generally lower than in the northern hemisphere by a factor of about four. In addition, local fallout (in the vicinity of a test site) has occasionally given rise to higher individual doses for small groups of population.

The annual collective doses expressed as percentage of the average exposure to natural background provide an illustration of the yearly trend of the exposure from nuclear tests. The long-term trend, derived from data contained in this report and in the previous reports of the Committee, is illustrated in Figure 1(a). There was a sharp increase of the annual collective doses in the early 1960s leading to a peak in 1963, corresponding to about 7% of the average exposure to natural sources. In 1966 the annual dose had decreased to approximately 2% of the annual average exposure to natural sources and it is at present less than 1%. Assuming no further atmospheric explosions, the future annual doses will become smaller and smaller until they vanish out completely.

The average annual collective doses received by the world population at any given time shown in Figure 1(a) are the result of all the explosions that have taken place up to that time. It is also of interest to study the trend of the collective doses that were committed until complete decay of the radionuclides released by each year of
testing. This is done in Figure 1(b) which shows that explosions in the years 1961–1962 were the major contributors to the total impact of fallout from weapons testing carried out so far.

In Figure 1(b) collective doses are expressed in terms of the number of days of exposure of the world population to natural radiation which would cause the same impact. If the doses received by the world's population could have been delivered at a constant rate equal to that of the average exposure to natural radiation sources, instead of at a low and irregular rate over more than thousands of years, then the total collective dose would equal that currently received from natural sources in about 4 years. It can thus be said that the impact from fallout corresponds to about 4 years of average natural background. The collective doses delivered so far can be derived from Figure 1(a) and amount to about 0.4 year of exposure to natural sources. The rest, that is, about 3.3 years of natural background, corresponds to doses from fallout which will be delivered until complete decay of the radionuclides released. Fifty per cent of the impact from fallout will be delivered at a small rate in the next 2000 to 3000 years.

**Nuclear power production:** The number of nuclear reactors in operation has increased since the previous report of the Committee to include, in 1979, 235 reactors with a total installed nuclear generating capacity of about 120 gigawatt (GW). The production of electrical energy by nuclear reactors presupposes the existence of a fuel cycle which involves many steps. They are: mining and milling of uranium ores; conversion to various chemical forms; enrichment of the isotopic content of uranium-235 (in some cases); fabrication of the fuel elements; production of power in nuclear reactors; reprocessing of irradiated fuel (in some cases); transportation of materials between the various installations and, finally, disposal of radioactive waste. For each major step of the nuclear fuel cycle the Committee has evaluated the doses to workers as well as the doses to members of the public.

Almost all the radioactive material associated with the nuclear industry remains in the reactor sites or in special storage facilities; but, at most steps of the operations, environmental releases of small quantities of radioactive material occur. Most of the radionuclides released are of local relevance only, because they decay rapidly. However some radionuclides, which have a longer life or are more rapidly dispersed, become globally distributed and contribute to the exposure of the entire population of the world, now and, in some cases, well into the future.

By rough approximations, the short-term annual collective effective dose-equivalents to members of the public from these sources can be calculated to have increased from 0.0001% of the corresponding values from natural sources in 1960 to about 0.01% in 1980. The increase in dose is directly related to the expansion of nuclear power production in the same time. The annual doses to individual members of the public vary widely around the average value, the highest doses usually being received by population groups living in the vicinity of nuclear installations. Typical values around nuclear reactors are reported between a fraction of one per cent to a few per cent of the average annual effective dose-equivalent from natural sources. In addition, radiation workers involved in the nuclear power industry receive annual effective dose-equivalents which are typically of the order of the corresponding average value from natural sources.

The long-term component of radiation impact arises from releases of long-lived radionuclides during the operation of the plant and from effluents from mill tailings or from high-level waste disposal. The long-term component corresponding to a period of 500 years following the release has been crudely assessed. For one year of nuclear power production at the 1980 level, the impact of this long-term component on members of the public may represent about 2 hours of exposure to natural background, whereas the radiation impact of the short-term component is estimated to amount to about 30 minutes of exposure to natural radiation sources. Most of the effective dose-equivalent from the long-term component stems from releases of mill tailings which may emanate radon over extremely long periods of time. The rate of emanation can be modified by improvements in management practices, which could result in decreases by orders of magnitude. In the far future (thousands to millions of years) the releases from mill tailings or from waste repositories will be influenced by geological and climatological changes, which are very difficult to predict. The dose-estimates from those releases also depend on living habits in the far future, which might be very different from present ones.

On the assumption that the production of nuclear power by fission reactors may continue for 500 years at the present rate, the Committee estimates that the maximum annual collective effective dose-equivalent may amount to a fraction of one per cent of the corresponding dose received annually from natural sources of radiation. It must be emphasized that this long-term forecast is based on existing technologies and is therefore subject to change. It is likely that changes in present technologies such as the introduction of fast reactors or other advanced fuel cycle technology, or the containment of long-lived radionuclides may further reduce the long-term impact of future practices.

The contribution of occupational exposures to the impact from nuclear power production is much easier to assess as most radiation workers are individually monitored. At the present level of nuclear power production, the annual collective effective dose-equivalent resulting from occupational exposure amounts to about 0.03% of the corresponding value from natural radiation sources.
New developments in radiobiology

Radiation induces biological effects essentially through the deposition of energy in the cells of the irradiated individual. Two classes of cells may be visualized in this respect: the somatic cells, which do not survive beyond the life-span of the individual; and the germinal cells, whose function is to transmit genetic information to new individuals. The somatic effects of irradiation take place in the somatic cells and they must become apparent, by definition, within the life of the irradiated person. On the other hand, hereditary effects occurring in the second class of cells become apparent in the descendants of the irradiated persons within the first, or in some later, generation.

In general terms, the radiobiologically important effects interfere with the division of somatic cells in one of two possible ways: they may either cause the irradiated cell to stop dividing and eventually to die; or they may confer upon the cell a capacity for unrestrained division which is characteristic of cancer. A distinction is usually made between early and late effects of irradiation, according to the time at which such effects become manifest: a few hours to a few weeks in the first case; many months to many years in the latter.

It has been past policy of the Committee not to attempt to cover all biological effects in animals and man in any one report, but rather to review selected areas, depending on the amount of information accumulating and on the need to survey all fields at some interval of time. This report was compiled in the light of the same general policy. Among somatic effects, some non-cancerous consequences of irradiation administered to the whole body or to selected tissues are considered.

Information on genetic effects is updated and assessed for the purpose of risk estimation.

Genetic effects

In the field of genetic effects, important conclusions were reached on the basis of recent publications. These have increased the Committee's confidence that earlier assumptions and risk estimates remain essentially valid. These estimates have been compared with spontaneously-arising hereditary defects which affect, with different grades of severity, roughly 10% of all liveborn children. Physical agents such as ionizing radiation, as well as some noxious chemicals, may interact with the genetic material of the germinal cells in the testes or in the ovary by altering the genes, the elementary units of heredity (thus causing gene mutations), or with the structure or number of chromosomes on which the genes are carried (thus causing chromosomal aberrations). Changes in the genetic material may be associated with a variety of hereditary defects, some of which have severe clinical consequences.

Using gene mutations and chromosomal aberrations as end-points of experimental observations, data on dose-effect relationships have been compared in a variety of organisms. These comparisons have strengthened the assumption that one may expect a proportionality between the rates of spontaneous and of induced mutations of particular genes. This basic assumption has been applied in the indirect method of risk estimation.

Using the indirect method, the Committee estimated in 1977 that when a population is continuously exposed to low doses of low-LET radiation at a rate of 0.01 Gy per generation (1 generation = 30 years), 63 new cases of hereditary diseases per million first generation progeny would be expected. A substantial part of the hereditary diseases included in this estimate is related to those arising from numerical anomalies of chromosomes. However, data on experimental animals and man point to the possibility that the estimate for diseases falling under the category of chromosomal diseases may be lower than previously estimated. In view of this, the Committee has now estimated that when a population is exposed under the conditions specified above, the increment in genetic diseases is likely to be of the order of 20 (instead of 63) cases per million births in the first generation and about 150 (instead of 185) cases per million births at equilibrium (or about 2000 and 15 000 cases in the first generation and at equilibrium, respectively, when the exposure is at a rate of 1 Gy per generation).

As in the 1977 report, an estimate of risk for hereditary disorders has also been made using the direct method. The estimated values using these two different methods (i.e. indirect and direct methods) are in reasonable agreement.

The risk from the induction of a particular type of chromosomal effect of radiation (reciprocal translocations) has been re-evaluated on the basis of results from studies in marmosets, rhesus monkeys, and man. However, the health consequences to the individuals carrying such translocations cannot be reliably assessed at present.

Further advances have been made in our knowledge of the dose-response relationships and other aspects of some of the more important types of genetic changes which can be induced by radiation in experimental mammals. Extensive use of experimental data for genetic risk assessment is still considered essential in the absence of significant results with respect to hereditary effects after human exposures. Suggestions have also been formulated for more detailed analyses of genetic effects with respect to detriment.

Somatic effects

One of the conclusions of the present report is that at low doses and dose rates the induction of non-neoplastic effects is not observed. This conclusion holds true for both whole-body and specific organ irradiation. At comparable doses and dose rates cancer induction may be the only somatic consequence of irradiation in animals and man.
Radiological protection

In its 1977 report the Committee discussed factors which make any accurate assessment of risk of cancer induction in man very difficult. In spite of such difficulties, the Committee provided at that time an analysis of the human data and of the risk estimates to be derived therefrom, to be used as a necessary starting point for decisions of practical value, particularly as scientific criteria for radiation protection policies.

In view of the limited amount of new epidemiological evidence, there would have been no merit in repeating the same analysis in a short-time interval. The Committee undertook instead to review whatever information might be of interest, in experimental animals and in man, in the light of some basic models of tumour induction. The scope was to assess the possible errors that might affect the estimates if one or another model of radiation action applied. Such a study might be regarded as an indirect way of estimating risk ranges at the low doses and dose rates where direct evidence is not available.

The Committee decided, however, to postpone the publication of a document based on this study when it became known that revisions had been proposed to the dosimetric estimates for the survivors of the atomic bombs at Hiroshima and Nagasaki on which some of the Committee's analyses had been based. Not only the total doses received by the exposed populations, but also the relative contributions of the neutron and gamma-ray components in the presently used T65D (Tentative 1965 Dose) were called into question. The effect of the proposed revisions is to reduce the neutron dose component at both cities and to increase the gamma component at Hiroshima substantially, while reducing the gamma component at Nagasaki slightly. In addition, many more factors must be examined and taken into account before reliable revised estimates of individual organ doses can be determined for the survivors. This matter is technically complex, and it appears unlikely that the proposed revisions can be thoroughly investigated and agreed upon within a short time.

The Committee awaits with interest the results of further studies in this field, as they would form one of the bases on which radiation risk estimates in man must be founded. In the meantime the Committee wishes to emphasize that it does not expect a significant impact of these revisions on the risk estimates contained in the 1977 report of the Committee, namely, that the risks of fatal cancer induction for X- and gamma-rays is of the order of 2 \times 10^{-5} for an effective dose-equivalent corresponding to one year of natural background, as an average for both sexes and all ages. This is so for two reasons. First, while it is impossible yet to say exactly what influence the revisions, if accepted, will have on the risk estimates, it is unlikely that this influence will exceed a factor of 2. Indeed, improved agreement between data from Hiroshima and Nagasaki may tend ultimately to strengthen confidence in the estimates. Secondly, the information derived from the survivors of the atomic bombs in the two cities is only one of the sources of human exposure that the Committee has used in arriving at its estimates.

While little change is therefore expected to result in regard to estimates for cancer induction in man by X- and gamma-rays, an important presumed source of information for whole-body neutron irradiation will no longer be available if these dose revisions are indeed substantiated. The calculation of the doses to the atomic bomb survivors of Hiroshima and Nagasaki will be kept under close scrutiny and the Committee will continue to study dose-effect relationships.

A large amount of information has been available on the effects in man of irradiating selected organs and tissues for radiotherapy of various types of disease, mostly cancer. There was a need to review these data and to verify their consistency with information obtained for different purposes in experimental animals. The Committee's study considered: the nature of the early and late non-stochastic damage induced by radiation on normal tissues; the dose thresholds at which specific forms of early damage may become apparent in various animal species, and particularly in man; the effect of some important variables of exposure (radiation quality, fractionation of treatment) on these thresholds.

Two unifying concepts emerged. First, tissue damage depends primarily on the loss of reproductive capacity of some of the constituent cells; second, the structure and function of each tissue determines to a large extent the time and magnitude of its observed response. It was necessary to derive, from experience collated mostly at high doses and dose rates, information applicable at low doses and dose rates, which are the irradiation conditions of most interest in practice. Finally, it was necessary to rely on experience derived from exposure of normal human tissues during radiotherapy.

The study was useful for the great amount of information it provided in respect to each particular issue. The most general conclusions to be drawn from such a complex analysis are that non-stochastic tissue effects are generally characterized by non-linear relationships with dose and apparent thresholds at low doses. These conditions are of paramount importance for any consideration of non-stochastic tissue damage. Although the magnitude of the threshold may vary for each tissue and for each specific effect, the mechanisms producing the effects make it unlikely that thresholds will be abolished at low doses and dose rates. Thus, if a non-threshold response applies or is assumed to apply for induction of cancer, it follows that this latter might be induced at the low doses where the threshold would prevent expression of the non-stochastic damage to be seen. In this respect the induction of cancer may in general be regarded as the most important effect at low doses and dose rates for planning of radiation protection.

In cases of partial-body irradiation it is, in principle, easier to attribute the resulting damage to target cells in organs and tissues than in the case of whole-body
irradiation, where effects and symptoms may be of doubtful significance and of uncertain pathogenesis.

A typical example is to be found in an effect of whole-body irradiation which is commonly, and incorrectly, referred to as "aging" or "non-specific life-span shortening". The Committee has carried out an analysis of the experimental findings regarding radiation-induced aging in animals and man. Since the biological mechanisms of natural aging are essentially unknown, there appears to be insufficient ground to postulate a possible effect of irradiation in the absence of convincing experimental data; this possibility may not, however, definitely be ruled out. The study was therefore limited to the radiation-induced shortening of life.

Although the length of the life-span is usually taken as a measure of aging, it represents simply the actuarial aspect of it, and ignores the complex interplay of factors leading to death. It is well known that, on the average, the life-span of irradiated animal and human populations tends to be shorter than the life-span of suitably matched controls. However, to ascertain the causes of death may be an exceedingly difficult task, though the only reasonable means to attribute death to specific causes and thus to decide on the reality of possible non-specific mechanisms. An overwhelming body of literature shows that at low doses and dose rates life shortening is essentially caused by the occurrence of cancers at above the spontaneous rate. When the contribution to life shortening by these cancers is subtracted from the total life shortening effect, there is no evidence of other non-specific mechanisms being responsible for additional shortening. This conclusion is well documented and it applies in humans and in other mammals. There is indeed some conflicting evidence but this does not, in the Committee's opinion, carry sufficient weight to invalidate the conclusion. Further study on this point may be required.

It is essential that risk estimates be formulated with a wide perspective of possible applications. In this connection it is important to ascertain if the effects of ionizing radiation, a ubiquitous agent in nature, could be modified by the interaction with other agents (physical, chemical or biological) having a widespread distribution in the environment and therefore apt to affect large numbers of people and, possibly, to cause changes of the risk estimates.

Although the possibility of such interactions has often been suggested, the amount of positive information, particularly regarding effects that are significant for risk estimates in humans (induction of cancer, hereditary effects, developmental abnormalities), is rather scanty and inconsistent. The analysis of the Committee was therefore of necessity mostly theoretical, with illustrations drawn from published work. It has, however, demonstrated the complexities of a thorough scientific treatment of this matter because the nature of the interacting agents, the variable mechanisms of action, the doses, the order and the schedules of administration allow a variety of possible interactions.

The study reviewed some agents which are important under specific conditions, mostly occupational, among which the best documented is the interaction of tobacco smoke and alpha-irradiation by radon daughters for lung tumour induction in uranium miners. Although this finding is certainly applicable to specific occupational situations (and may be relevant to actions by local authorities) the review of the Committee indicates that it does not decrease the general validity of the broad use of radiation risk estimates. There is a need for more research to be directed towards these problems, with coherent strategies and sensible choices of the agents to be investigated. The Committee has made recommendations in this respect.