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IONIZING RADIATION IN MEDICINE AND PUBLIC HEALTH

I INTRODUCTION

The rapid technical advance in the field of ionizing radiation has brought great advantages to man but, at the same time, has brought him great potential hazards. Living beings have always been exposed to ionizing radiation from natural sources (such as the cosmic rays), but the discovery of X-rays by Roentgen in 1895, in Wursburg, Germany, and of radioactivity in uranium salts by Becquerel in 1896 in Paris, created unforeseen dangers. The increase in the use of X-rays, during the first World War, had caused, by 1922, one hundred deaths among radiologists. The year 1921 marks the birth of national organizations for radiological protection and the publication of their first recommendations. International action was first taken during the Second International Congress of Radiology which met in Stockholm in 1928; there, the International Commission on Radiological Protection was established, members of which were elected according to their recognized ability in this field, independent of their nationality.

The discovery of nuclear fission in 1939 marked the beginning of the atomic epoch and was followed by a tremendous increase in potential radiation hazards, and consequently, protection problems. The atomic explosions in Hiroshima and Nagasaki caused tremendous devastation and a large number of deaths. The contamination of the environment by explosions of nuclear weapons, the discharge of radioactive wastes arising from nuclear reactors, and the increasing use of X-rays and of radioisotopes for medical and industrial purposes extend the problem to all populations and also raise new international questions. In 1955, the General Assembly of the United Nations established the Scientific Committee on the Effects of Atomic Radiations; that same year the programme of the World Health Organization in health aspects of ionizing radiation and the peaceful use of atomic energy went into active operation.

II IONIZING RADIATIONS

Ionizing radiation arises from natural and from man-made sources. Its effects, both on man and his environment, are fundamentally the same, whatever the source.

Our knowledge, concerning the effects of irradiation, in spite of the large amount of information collected during recent years, is still insufficient. This knowledge is in no way comparable to our knowledge of the physics of radiation nor, on the biological side, to our experience with many diseases. We possess some information regarding the biological effects caused by exposure to large doses of radiation, but the data so far available on the possible effects on man of intermittent small doses or of low levels of continuous irradiation, are very meagre.

The radiations with which we are concerned include X-rays, neutrons, protons, cosmic rays, and the radiations (alpha, beta and gamma rays) emitted by radioactive materials. All of these radiations produce biological effects by means of the same physical process, namely, energy transfer and consequent ionization. Radiation passing through matter without energy transfer produces no effect. The biological effect of a given type of radiation depends upon the energy absorbed in the tissue. "The ratio between the energy absorbed and the total ionization produced is almost independent of the kind and energy of particles producing the ionization; therefore, ionization is used as a measure of radiation exposure"⁽¹⁾. The types of radiation and their definition, together with certain important physical data are given in Annex A.

1. Somatic Effects of Radiation

The somatic effects of radiation depend on the dose rate, whether given as a single dose or fractionated, and on the area of the body exposed.

If a single dose of over 600 rem of penetrating radiation is delivered to the whole human body, or to a large part of it, in a matter of minutes, it will cause death in a matter of days or weeks. In the case of mice of a typical strain, there is a threshold dose of about 400 rem (whole-body exposure to X-rays) below which practically no acute deaths occur. The median lethal dose for man is considered to be approximately 300-500 rem. This dose will produce an acute illness, fatal within thirty to sixty days, to fifty per cent of the people thus exposed. The earliest symptoms are nausea and vomiting, and

(1) Report of the U.N. Scientific Committee on the Effects of Atomic Radiation, page 3 (II. Basic Physical Concepts, para. 5)

sometimes diarrhoea, accompanied by a feeling of great prostration and fatigue, and disturbances of the nervous system. An early and rapid fall occurs in the lymphocytes. The granulocytes, after a transient initial increase, fall, also rapidly, below normal levels. Reduction in the red cells causes progressive anaemia, and decrease in the number of blood platelets gives rise to bleeding. Anaemia and leucopenia may be severe at death. At the height of the illness, usually during the second or third week, there is sustained fever, severe exhaustion, loss of weight, erythema of the skin, loss of hair, haemorrhages in the skin, and ulceration of the mouth, throat and intestines. Damage to the protective power of the mucous membranes of the gastro-intestinal tract and impairment of the white cell production mechanism and immunological functions make the irradiated individual susceptible to infection with bacteria, otherwise harmless. Such infections have frequently been the cause of death.

If, however, as mentioned previously, an otherwise lethal dose is divided into fractions administered over months or years, with exposure-free intervals, immediate death does not take place but, instead, certain chronic effects of irradiation may appear. Chronic irradiation may cause fibrotic and sclerotic changes in tissues, a diminished resistance to infection, shortening of life-span and malignant tumours. Examples of the local effect of prolonged external irradiation are late skin changes, including dermatitis, atrophy and skin cancer. The accidentally ingested small amounts of radium by dial painters, is an example of chronic irradiation, leading to severe diseases, including tumours of bones. Leukaemia or cancer may develop after a latent period of several months or years.

Irradiation on the skin may produce lesions ranging from transient erythema, changes in pigmentation, and temporary loss of hair, to severe necrosis and ulceration, and cancer. Contamination of the skin with radioactive material can also produce severe lesions in the skin, if the radiation dose is sufficiently great. The gastro-intestinal canal is relatively easily affected by radiations. Changes may range from interference with physiological functions such as intestinal mobility and secretion of digestive juices to denudation and ulceration. The passage of ingested radioactive materials through the intestinal tract might produce similar injury.

It was generally known that the central nervous system and the peripheral nerves were among the organs resistant to radiation, because a high dose had always been required before morphological changes were produced. It has, however, been shown recently that functional changes may be elicited with small doses, and that such changes may be of significance. Modifications of the

electro-encephalogram have been described at very low doses. Of the bone abnormalities reported the majority has resulted either from large doses used in radiotherapy or from deposits of radioactive materials, such as radium and mesothorium in the bone. With both types of exposure (external or internal) malignant tumours have been observed to develop either in the bone itself or in structures adjacent to the bone. Deposition of bone-seeking radioactive material is likely to occur chiefly in areas of most active bone growth (epithyses). Studies of bones, following large single or multiple doses of radio-strontium, in experimental animals, have shown that lesions and tumours are most likely to arise in these particular areas.

The effects of irradiation on the gonads are very significant. The ovaries and testes are more sensitive to damage by radiation than many other organs. Temporary sterility, in either sex, may be produced by single exposure of the order of 100 to 200 r, or through the cumulative effects of repeated smaller exposures. There is reason to believe that single doses of 25 or 30 r may cause changes in the total reproductive capacity. Eggs and sperm during development are more susceptible to damage than when mature. In the mouse, chronic irradiation, with multiple doses, is more effective in producing abnormalities, such as changes in the oestrus cycle, than is a single exposure. Neutrons are more effective in producing changes in the gonads than ~~X~~ or gamma rays. Various types of benign and malignant tumours have been observed in the ovaries of mice following single and repeated exposures to external irradiation. Such tumours are the result, not only of the local action of the radiations in the ovaries, but probably also of hormonal disturbances created in the animal as a whole.

Cataract formation in the lens of the eye may be induced by radiation exposure. In man, the minimal single dose required to produce cataract is estimated to be near 200 r of ~~X~~ and gamma rays. Neutrons are most effective in inducing cataracts, and several such instances have been observed among research physicists in recent years. Lenticular cataracts have been reported to be one of the late effects from exposure to atomic bomb radiation.

Pneumonitis, fibrosis and cancer of the lung have been described in miners of radioactive ores, presumably caused by radiation from radon and its decay products deposited in the lungs. Radiation pneumonitis and cancer of the lung have been produced in experimental animals by inhalation of radioactive materials such as plutonium and cerium.

The effects of ionizing radiation in relation to the endocrine glands have not been investigated extensively, yet certain non-specific effects which are mediated through the adrenal gland (lymphopenia, for instance) are

identical with those produced by other "stress" agents. Effects of this type can be obtained with moderate doses of X-rays, and it is possible that other endocrine processes, also concerned with regulatory functions in the body, can likewise be affected. On the other hand the direct tissue damage produced by the radiation given off from radioactive iodine is sometimes used therapeutically to suppress the function of the thyroid gland; by administering radio-iodine, which is selectively concentrated in the organ. Endocrinological studies have demonstrated that it is relatively easy to disturb certain sensitive hormonal equilibria existing in the body.

Radiation has long been known to be harmful to embryos. After low doses (25 to 50 r) only certain abnormalities may occur at given stages, whereas 400 r is so damaging that the embryo usually becomes extremely malformed or may be killed at once. The lowest dose of conventional X-rays (250 kv) that will produce visible destruction of embryonated cells in certain experimental animals is 30 r; doses of 25 r are capable of causing deviations of skeletal development in mice having certain predisposing genetic background.

The retina of the eye and the brain of the foetus are particularly vulnerable to malformation. Among children who were exposed in utero to radiation from atomic bombs, some cases of microcephaly with mental retardation have been recorded.

Radioactive substances ingested by the mother, and which pass through the placental barrier, can become fixed in the foetal skeleton or in other organs and produce damages. In the very early stages of embryogenesis, radiation exposure of this type can involve all cells of the growing embryo and resemble whole-body exposure, whereas in later stages of development it will resemble partial body exposure through fixation of material in specific organs.

It is a very characteristic feature of radiation injury that delayed reaction may occur many months or years following exposure. The morphological and functional alterations which occur during the long periods of latency are poorly understood. Among the late effects, leukaemia, bone cancer and other malignant changes are especially worthy of mention. It has been demonstrated that whole-body exposure can shorten the average life-span of experimental animals, and it is possible that the same may be true for man.

Within a decade following the discovery of X-rays, it became apparent that exposure to radiation carried with it the risk of malignant disease. Clinical and experimental evidence seems to indicate that where the total body is irradiated, leukaemia is the most probable end-result among the various

forms of malignant diseases. When the skeleton is selectively irradiated by radioelements, such as radium, an increase in bone tumours is a prominent result. From experiments with animals, it is clear that other radioelements which are deposited in the skeleton, e.g. plutonium, strontium-89 and -90, and various rare earth radioisotopes can likewise produce bone tumours and other tissue changes which have been observed in radium poisoning in man.

2. Genetic Effects

It is accepted that radiation-induced mutations are, in general, harmful, and until very recently, it was thought that they would increase in direct proportion to the amount of radiation exposure, even at very low dose levels. Recent studies on mice, however, indicate that radiation given by chronic low level exposure is not as effective in producing genetic mutations as the same amount of radiation given in acute doses. It is thought that a dose of between ten and one hundred rads per generation would probably be required to double the natural mutation rate in human populations. About four per cent of all births are affected with hereditary disorders, some one-quarter of which appear to be at least determined by single gene differences. On this basis, an increase in the mutation rate would eventually result in a directly proportional increase in a part of this four per cent, amounting to more than one-quarter, but less than the whole. In addition, there would be some changes in other hereditary characteristics of a less sharply defined nature, but the probable extent of these and their importance cannot be assessed at the present time. The United Nations Scientific Committee on the Effects of Atomic Radiation concludes from the foregoing genetic facts that exposures to ionizing radiation should be reduced wherever possible, and that medical and industrial procedures tending to increase radiation levels to which human population might be exposed, should be carefully weighed as to such benefits or hazards as each may have.

The chief uncertainties associated with an attempt to assess the consequences of a given increase in radiation centre around the following :

(a) The dose required to double the mutation rate is, for the present, believed to be reliable only within a tenfold range.

(b) Any assessment of the present extent of hereditary defects in the population simply in terms of affected people is admittedly an incomplete measure of "social consequences", which can in any case vary from country to country with the social environment.

(c) The proportion of the hereditary defects which is maintained by recurrent mutation is not at all certain. In the absence of adequate and appropriate observations on the workings of selection pressures in man, present opinions have had to be based on essentially crude criteria.

(d) The possible extent to which irradiation would affect human biometrical characters (life-span, birth weight, stature and intelligence), their range and mode of variation, is at present largely a matter of speculation.

(e) The effect of a future environment on the magnitude of the "social burden" is not known. Improvement in social, medical, and biological procedures which can be brought to bear on human populations might lessen the effects of some of the deleterious changes. However, such influences could also operate in the opposite direction. Therefore, we cannot predict how future changes in environment will interact with any hereditary alterations so as to influence the general and the individual states of health in future human populations.

3. Sources of Ionizing Radiation

The sources of ionizing radiation may be classified into two categories :

(a) Natural

Man is exposed to radiation from :

(1) external sources, namely cosmic rays and terrestrial radiations from natural radioactivity in the ground, air, and building construction materials, etc., and

(2) internal sources such as the radioisotopes potassium-40 and carbon-14 which are normal body constituents, radium and thorium deposited in bone, and radon, thoron and their disintegration products in the blood and tissues.

(b) Man-made

At the present time, radiation exposures from man-made sources (excluding environmental contamination) arise principally from :

(1) medical uses of X-rays and radioactive materials;

(2) industrial and research uses of X-rays and radioactive materials; and

(3) other sources such as luminous dials of watches, television sets and shoe-fitting fluoroscopes.

The medical uses of X-rays and radioactive materials are:

- (1) diagnostic uses of X-rays;
- (2) use of X-rays and external radioactive sources for radiotherapy;
- (3) use of radioactive isotopes as internal sources for diagnosis and therapy.

Medical uses of radiation provide the major source of radiation exposure to human populations, aside from natural background radiation.

Estimations of the contribution to the annual genetically significant dose from diagnostic X-ray procedures have been made for some countries in which the use of X-rays is extensive. (The per capita gonad dose has been found to differ but little from the genetically significant dose in countries for which both have been estimated.) In some of these countries, this contribution seems to be about equal to that from natural sources.

For countries with an extensive use of X-rays, the average annual marrow dose of the population can be estimated to be of the order of one hundred mrem per person. This figure is very close to the per capita marrow dose from natural radiation. The exposed marrow may in individual extreme cases receive very high doses, especially in the case of fluoroscopy where the dose-rate in the irradiated marrow may be several rem per minute. It is frequently possible to reduce the diagnostic exposure considerably by careful attention to techniques. Valuable precautions are described in the current recommendations of the International Commission on Radiological Protection (ICRP)⁽¹⁾ and are collected and further elaborated in the report of the Joint Study Group of that Commission and the International Commission on Radiological Units (ICRU)⁽²⁾. The annual genetically significant dose that may be achieved with good practice without detriment to diagnostic information has been estimated to be fifteen mrem for Sweden. The contribution from radiotherapy in England and Wales has been estimated to be appreciably less than that from diagnostic procedures but greater than that from any other man-made contributions. In the United States, the annual genetically significant gonad dose from radiotherapy has been estimated at roughly ten mrem.

(1) Recommendations, revised December 1, 1954
Brit. J. Radiol. suppl. 6(1955).

(2) Report of the ICRU, 1956. U.S. National
Bureau of Standards, Handbook 62, Washington 1957.

4. Medical Uses of Radioactive Isotopes (internal administration)

The principal contribution to the population dose from the medical use of radioisotopes arises from the use of iodine-131 and phosphorus-32, which are most widely employed. While considerable quantities of gold-198 are used, the biological significance of exposure from this source is negligible since gold-198 is generally limited to palliative treatment of incurable conditions. Other radioisotopes are used in very small quantities and almost entirely for diagnostic purposes.

Estimates of the average gonad dose resulting from the use of iodine-131 and phosphorus-32 can be based upon information about either treatments or radioisotope shipments, the first approach being more accurate and preferable. From the report of the ICRP/ICRU Joint Study Group and other information available to the United Nations Scientific Committee on the Effects of Atomic Radiation (UN SCEAR) it seems likely that the genetically significant dose is lower than one mrem per year, even in the countries for which the highest figures can be expected.

Occupational Exposure ⁽¹⁾

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

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

(1) Report of the United Nations Scientific Committee
on the Effects of Atomic Radiation. General Assembly,
Official Records: Thirteenth Session, Supplement No.17 (A/3838)

Radioactive Wastes⁽¹⁾

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

III NUCLEAR ENERGY AND PUBLIC HEALTH

1. Nuclear Energy and Medical Studies

The medical student will require from now on a sound knowledge of nuclear physics. In many countries, a much more thorough training in mathematics will have to be given, and in the first years of medical studies, the physics course must lay particular stress on the study of electrical and nuclear phenomena.

The organization of theoretical courses in these subjects should not in general raise any particular problem. On the other hand, the organization of practical experiments and demonstrations in nuclear physics calls for a new approach. In the past, a regrettable isolation has often separated medical students from their contemporaries in the other scientific departments of the University. This has sometimes resulted in the underrating of the abilities of medical students by senior men engaged in research and teaching in the more advanced fields of physics and chemistry, and these have relegated the medical students to tuition by junior colleagues. But it is only through collaboration by those in charge of larger physics laboratories that such apparatus as that effecting particle acceleration, isotope preparation and micro-wave emission can be seen in operation.

If instruction in nuclear physics is to be effective, study courses must also provide for revision and amplification of the basic knowledge already acquired, and ensure that the student has a clear idea of the biophysical properties of radiations. In the study of ionizing radiations - which are by far the most important in pathology - special attention should be paid to the ionization density they produce along their paths, and the depth to which they penetrate various kinds of tissues. In this connection, the study of

(1) ibid. ref.(1) page 9

alpha, beta and gamma rays, and X-rays is of particular importance, since it is to these that living tissues are most likely to be exposed at the present time. Nevertheless, since proton and neutron radiations may also possibly come into more general therapeutic use, these too must be dealt with.

When the student becomes familiar with the various types of radiation, he will have to learn to distinguish the units which are generally used for measuring their intensities and their biological effects.

In addition to measurement, the question of dosage must also be dealt with - total-body dose, depth dose, etc.

Although rapid progress has been made in nuclear physics, there are still gaps in our knowledge of the biological effects of radiations. Nevertheless, students must know the essential characteristics of the tissue changes brought about by ionizing radiations. In addition to possible sequelae after local irradiation and whole body irradiation, it is necessary to know the hazards of internal contamination by radioactive substances - hazards which are increasing with the growing use of radioactive elements in research, diagnosis and therapy, and also with the accumulation of radioactive waste from nuclear fission.

This instruction on radiation pathology will be given during the clinical period and it would seem desirable to organize a special course on radiation medicine within the radiological services.

Of all the scientific problems which the use of nuclear radiation raises, the most serious and alarming is undoubtedly that of its genetic effects. During the clinical period, a short time should be devoted to a fresh study of genetics, from the point of view of the relationship between disease and acquired mutations in human population groups. The role of heredity as an etiological agent should be dealt with, wherever appropriate, by all teachers giving clinical instructions. During the medical course great emphasis should be placed on genetic hazards, and in this connection diagnostic and therapeutic radiology services will bear a heavy responsibility.

2. Nuclear Energy and Public Health

Sources of atomic energy constitute a risk not only to those engaged in the production of such energy but also to people living near these sources. This risk is too small, however, to justify relinquishing one of the most powerful means of improving human well-being. Nevertheless, it raises new public health problems. Sources of atomic energy, the utilization of ionizing radiations and radioactive isotopes, and the accumulation of large quantities of radioactive waste, are all factors calling for preventive action for which public health workers as a whole must be trained.

Members of the public health services will have to be responsible for many tasks, such as the detection and assessment of radioactive contamination of soil, air and foodstuffs, protection of personnel, the control of the radioactive substances themselves, etc.

Health personnel may be required to engage in educational activities so as to inform the general public, who sometimes react strongly to questions of atomic energy. In fact, the public information side of atomic energy is of paramount importance since the only way of reassuring people is to provide them with objective information.

It is obvious, therefore, that health personnel must have some knowledge of nuclear energy matters. Naturally, the nurse will not be expected to have the same knowledge as that demanded of a medical officer of health, but at least elementary training courses for certain categories of staff will be just as necessary as more advanced or specialized training.

Governments, ministerial departments, educational authorities and the general public must be made to understand that there can be no effective protection against the dangers of atomic energy, unless medical and health workers receive appropriate training.

IV WHO ACTIVITIES IN THE FIELD OF IONIZING RADIATION

1. Education and Training

In 1957, two expert committees on professional and technical education were held on the subject of graduate and undergraduate training in radiation medicine and the public health aspects of atomic energy.

An international course on radiation protection (health physics) was arranged through the Regional Office for Europe at Mol (Belgium) in October 1957. This course involved a good deal of mathematics and physics. Twenty-four participants from nineteen different European and Eastern Mediterranean countries took part in the course.

In March 1958, a course was arranged through the Regional Office for Europe on the public health aspects of radiation protection. This was an introductory course for medical officers and sanitary engineers. Twenty-seven participants from various European countries took part in this course. Seventeen health officers from sixteen countries in the European and Eastern Mediterranean Regions attended as WHO fellows at a four-week course in radiation protection at the Centre d'Etudes nucléaires, Saclay (France).

A further activity at the end of 1957 was the visit of a short term consultant to India and Ceylon, to advise and lecture on hospital physics at various centres, with particular reference to radiation protection.

2. Genetic Effects of Radiation

Three consultants on human genetics made a preliminary survey in Kerala State, India, in preparation for the Expert Committee on the effects of radiation on human heredity, held in 1958.

3. Mental Health

A study group on the mental health aspects of the peaceful uses of atomic energy met at the end of 1957.

4. Consultants

In view of the importance of the health aspects of atomic energy, it was proposed to increase the provision of consultants to sixteen consultant-months in 1959.

During 1958, a WHO short term consultant, visited Iran, Israel, Lebanon and the United Arab Republic (Province of Egypt), and reported on the medical uses of radioisotopes. Another consultant, to be provided in 1959 for three months, will follow up his recommendations and give advice to hospitals and institutions. It is planned that a training course will be organized by the consultant in one of the medical schools of Beirut, Lebanon.

5. Fellowships

From 1949 to 1957 forty fellowships have been awarded on some aspects of radiation and health. Of these, twenty-five were awarded during 1957.

6. Radiation Protection

A joint WHO/FAO Expert Committee on Radiochemical Methods of Analysis met in 1958 and is proposed to meet again in 1960.

The objective of the Expert Committee is to consider available analytical methods which may be used in the identification of specific radionuclides in water, in soils or bottom muds, in flora and fauna, and in body fluids and tissues. Such analyses are used for the control of radioactive waste disposal or in the medical supervision of those working with radioisotopes.

A second Expert Committee has been proposed for 1959, to discuss the protection of patients from the adverse effects of ionizing radiation used in medicine.

7. Proposed Programme for 1959

The WHO Regional Offices are developing programmes for the use of atomic energy for peaceful purposes. Training courses and seminars are being arranged and fellowships awarded.

RELATIONSHIP OF WHO WITH OTHER INTERNATIONAL ORGANIZATIONS

1. United Nations Scientific Committee on the Effects of Atomic Radiation

The Organization has actively cooperated with this Committee in its task of collecting and collating information on radiation effects on man and his environment. A report of the WHO Study Group on the Effect of Radiation on Human Heredity was presented to the Committee, and the rapporteur of the Study Group took an active part in the drafting of the genetics section of the Committee's comprehensive 1958 report. At its meeting in 1959 the Committee made a number of requests for assistance from WHO in studying groups of the population exposed to radiation, the adaptation and use of vital and health statistics for genetic purposes, human radiation genetics, accidental exposures, and related questions in the field. It is visualized that there will be an increasingly close cooperation between WHO and UNSCEAR in this work.

2. United Nations Educational, Scientific and Cultural Organization

In matters of fundamental science WHO also works closely with UNESCO. Radiobiology, for example, is of interest to both organizations, and is basic to the field of radiation health. Four evening lectures on different health aspects of radiation were given by WHO consultants at the UNESCO International Conference on Radioisotopes in Scientific Research held in September 1957.

3. International Labour Organization

The ILO is interested in the question of radiation protection of workers, so that there is a significant field of mutual interest to the two organizations. A meeting of Experts on Radiation Protection was held by ILO in 1957. This was attended and assisted by WHO. Recommendations were made on provisions for protection against ionizing radiation.

4. Food and Agriculture Organization of the United Nations

Cooperation with FAO in this field has been close, because of joint interest in questions such as health aspects of radioactive contamination of food sources and food products. In 1958, the Joint WHO/FAO Expert Committee on Radiochemical Methods of Analysis was convened. A second meeting of this Committee is planned for 1960.

5. International Atomic Energy Agency

The International Atomic Energy Agency came into operation in 1957. Its objective to accelerate and enlarge the contribution of atomic energy to man's welfare involves interests in certain health aspects of radiation arising from the peaceful uses of atomic energy. WHO works closely with the Agency in this field.

6. International Commission on Radiological Protection and International Commission on Radiological Units and Measurements

These two non-governmental bodies are in official relationship with WHO. Cooperation between them and WHO has been very close because of mutual concern with recommendations for health protection against radiation questions of maximum permissible exposures, and measurements of radiation.

VI WHO, EMRO Fellowships

Twenty fellowships on Radiation Medicine have been awarded since 1952: 1 in 1952; 1 in 1954; 8 in 1957; 4 in 1958; 6 in 1959.

VII REPORT OF THE JOINT WHO/FAO EXPERT COMMITTEE RADIOCHEMICAL METHODS OF ANALYSIS⁽¹⁾

Radiochemical analysis is an essential part of many health control measures related to the use of radioactive materials and atomic energy. These methods are used in the control of radioactive waste disposal and environmental contamination; they are of importance to agriculture, especially with respect to possible contamination of food-producing resources and food supplies; and they are a necessary part of the control and evaluation of internal contamination in man.

The Expert Committee was convened to consider the analytical methods available for the various radionuclides and types of sample which are of interest to health and public health workers, to make recommendations regarding them, and to make a selection of basic recommended methods and those thought to be most practical for laboratories new to radiochemical work.

The report deals with methods for determining radioactive materials in the environment in certain biological materials and foods and in the human body. In the first three sections are discussed, in general terms, the sources of radioactive contamination, the evaluation of environmental contamination, and the evaluation of internal contamination of the human body. The final section contains a selection of radiochemical (and physical) methods for the determination of important radioactive elements in various types of sample together with a description of sampling methods and a discussion of the instruments used to measure radioactive materials.

(1) WHO/RAD/7, 18 December 1958

VIII NATIONAL LAWS AND REGULATIONS ON RADIATION PROTECTION⁽¹⁾

In August 1954, a circular letter was sent to all Member States of the World Health Organization requesting them to send information on the following points :

1. Regulations, if any, for the protection of technical workers against roentgen and isotopic radiations.
2. Whether these regulations cover the general public as well.

This enquiry was undertaken in accordance with the Executive Board resolution (EB13.R54) which noted the suggestion of the Government of Austria concerning the preparation of international regulations covering the following points :

- (a) permissible dose for external radiation;
- (b) permissible dose for international radiation;
- (c) protection against X-rays generated at potentials up to 2,000,000 volts,
- (d) protection against X-rays above 2,000,000 volts and against beta and gamma rays;
- (e) protection against heavy particles, including neutrons and protons;
- (f) disposal of radioactive wastes, handling of radioisotopes.

(1) See Document WHO/RAD/1, 8 July 1955 for information of particular interest to countries desiring to amend or enact laws and regulations on radiological protection.

ANNEX IDEFINITIONS OF QUANTITIES, UNITS AND SYMBOLS

1. The 1956 report of the International Commission on Radiological Units and Measurements⁽¹⁾ gives the following definitions of quantities and units used in radiological physics.

"1.1 Absorbed dose of any ionizing radiation is the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest.

"1.2 The unit of absorbed dose is the rad. One rad is 100 ergs/g.

"1.3 Integral absorbed dose in a certain region is the energy imparted to matter by ionizing particles in that region.

"1.4 The unit of integral absorbed dose is the gram rad. One gram rad is 100 ergs

"1.5 Absorbed dose rate is the absorbed dose per unit time.

"1.6 The unit of absorbed dose rate is the rad per unit time.

"1.7 Exposure dose of X- or gamma radiation at a certain place is a measure of the radiation that is based upon its ability to produce ionization.

"1.8 The unit of exposure dose of X- or gamma radiation is the roentgen (r). One roentgen is an exposure dose of X- or gamma radiation such that the associated corpuscular emission per 0.001293 g of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign.

"1.9 Exposure dose rate is the exposure dose per unit time.

"1.10 The unit of exposure dose rate is the roentgen per unit time.

"1.11 Intensity of radiation (radiant energy flux density) at a given place is the energy per unit time entering a small sphere of unit cross-sectional area centred at that place.

"1.12 The unit of intensity of radiation may be erg per square centimeter second, or watt per square centimeter.

(1) International Commission on Radiological Units and Measurements (ICRU): Report of the ICRU, 1956.
U.S. National Bureau of Standards, Handbook 62,
Washington 1957.

"1.13 The unit of quantity of radioactive material, evaluated according to its radioactivity, is the curie (c). One curie is a quantity of radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10} .

"1.14 Specific gamma-ray emission (specific gamma-ray output) of a radioactive nuclide is the exposure dose rate produced by the unfiltered gamma rays from a point source of a defined quantity of that nuclide at a defined distance.

"1.15 The unit of specific gamma-ray emission is the roentgen per millicurie hour (r/mch) at 1 cm.

"1.16 Linear energy transfer (LET) is the linear rate of loss of energy (locally absorbed) by an ionizing particle traversing a material medium.

"1.17 Linear energy transfer may be conveniently expressed in kilo electron volts per micron (kev/ μ).

"1.18 Mass stopping power is the loss of energy per unit mass per unit area by an ionizing particle traversing a material medium.

"1.19 Mass stopping power may be conveniently expressed in kilo electron volts per milligram per square centimeter (kev cm²/mg)."

2. The RBE symbol is described in the I.C.R.U. report, in the following way:

"2.1 RBE (relative biological effectiveness) is used to compare the effectiveness of absorbed dose of radiation delivered in different ways. It has been commonly represented by the symbol γ . It signifies that m rads delivered by a particular irradiation procedure produces a biological response identical with that produced by m γ rads delivered by a different procedure.

The statement that 'the RBE of α radiation relative to γ radiation is 10' signifies that m rads of α radiation produces a particular biological response in the same degree as 10m rads of γ radiation. This statement may be further summarized as $\gamma \overset{\alpha}{\gamma} = 10$.

The concept of RBE has a limited usefulness because the biological effectiveness of any radiation depends on many factors. Thus the RBE of two radiations cannot in general be expressed by a single factor but varies with many subsidiary factors, such as the type and degree of biological damage (and hence with the absorbed dose), the absorbed dose rate, the fractionation, the oxygen tension, the pH, and the temperature.

"2.2 RBE dose is equal numerically to the product of the dose in rads and an agreed conventional value of the RBE with respect to a particular form of radiation effect. The standard of comparison is X- or gamma radiation having a LET in water of 3 kev/ μ delivered at a rate of about 10 rad/min.

"2.3 The unit of RBE is the rem. It has the same inherent looseness as the RBE and in addition assumes conventional and not necessarily measured values of RBE. It is therefore recommended that its use be restricted to statements relating to radiation protection. For example the statement might be made :

The permissible weekly whole body RBE dose is 0.3 rem regardless of the type of radiation to which a person is exposed.

Should occasion arise when results have been evaluated with other than agreed conventional values of RBE, the values used should be clearly stated.

In the case of mixed radiations the RBE dose is assumed to be equal to the sum of the products of the absorbed dose of each radiation and its RBE:

$$\text{RBE dose in rems} = \sum [(\text{absorbed dose in rads}) \times \text{RBE}]$$

ANNEX IIFALL-OUT OF RADIOACTIVE MATERIALS⁽¹⁾Radiation from Fall-out

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

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

Fall-out Adjacent to Tests

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

Fall-out from the Troposphere

Radioactive materials injected into the atmosphere below the tropopause (at about 11 km) are brought down to the earth's surface by rainfall and sedimentation. This process takes a few months during which they are carried

(1) Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, General Assembly, Official Records: Thirteenth Session, Supplement No. 17 (A/3838)

several times around the world. This tropospheric fall-out consists of a mixture of radioactive materials, most of which are short-lived isotopes. At the present time, the tropospheric fall-out is deposited intermittently during the year and a certain deposit of short-lived activities is built up and maintained. When appropriate factors for shielding and weathering effects are included, the gonad and average marrow dose from this deposit, as an external source, is calculated to be about 0.5 mrem per year.

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

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

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

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

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

World-wide Fall-out from the Stratosphere

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

Owing to the relatively gradual fall-out from the stratosphere, most of the subsequent radiation is due to two radioactive isotopes of slow decay, other fission products already having largely undergone decay. These two radioactive isotopes are caesium-137 and strontium-90. The physical properties and chemical behaviour of the two differ.

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

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

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

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

Agricultural conditions may also affect the content of strontium-90 in the diet, since the available calcium of the soil will, within certain limits, influence the ratio of strontium-90 to calcium in crops derived from the soil. The distribution of soils which are highly deficient in calcium and their utilization require further study. More work is also needed to understand the distribution of strontium-90 in the soil, its chemical availability to plants and uptake through their roots, its behaviour under ploughing and the leaching of it from soil by the action of water.

Bone marrow exposures from fall-out are based on observations in the United States of America and the United Kingdom, where milk is the main source both of dietary calcium and of strontium-90, and where soil calcium contents are commonly high; also upon data from Japan where milk products are much less used and where rice and other vegetable products form the main source of dietary calcium and strontium-90, and where low calcium soils are frequent.

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

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

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

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

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IONIZING RADIATION IN MEDICINE AND PUBLIC HEALTH

NUCLEAR ENERGY AND PUBLIC HEALTH

In addition to the information contained in Document EM/RC9/8 on this subject (see page 10) reference may be made to: Expert Committee Reports Nos.154 and 155 for instruction to 1) postgraduates, 2) students.

WHO ACTIVITIES IN THE FIELD OF IONIZING RADIATION

The attention of the Committee is drawn to the Education and Training section of the main document, (page 12, third paragraph), where a course on the public health aspects of radiation protection is mentioned. A Seminar to discuss the public health aspects of waste disposal is now being planned to take place at Saclay, France, in November 1959.