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August 1960
SAFE HANDLING OF RADIOISOTOPES

MEDICAL ADDENDUM

by

Dr. F. HERČÍK and Dr. H. JAMMET

INTERNATIONAL ATOMIC ENERGY AGENCY
Kärntner Ring, Vienna I, Austria
1960
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SAFE HANDLING OF RADIOISOTOPES: MEDICAL ADDENDUM, IAEA, VIENNA, 1960

STL/PUB/11
The International Atomic Energy Agency published in 1958 a Manual entitled "Safe Handling of Radioisotopes" (Safety Series No. 1-STI/PUB/1), based on the work of an international panel convened by the Agency. As recommended by that panel and approved by the Agency's Board of Governors, this Addendum has now been prepared, primarily as a supplement to the Manual. It contains information necessary to medical officers concerned with the implementation of the controls given in the Manual. In addition, it is intended to serve as a brief introduction to the medical problems encountered in radiological protection work and to the methods of resolving them.

As in the case of the Manual itself, the information given in this Addendum is particularly relevant to the problems encountered by the small user of radioisotopes. Although the basic principles set forth in it apply to all work with radiation sources, the Addendum is not intended to serve as a radiological protection manual for use in reactor installations or large-scale nuclear industry, where more specialized techniques and information are required.

The Addendum has been prepared by the Secretariat with the assistance of two consultants appointed by the Agency, Dr. F. Hercík (Institute of Biophysics, Czechoslovak Academy of Sciences, Brno) and Dr. H. Jammert (Saclay Nuclear Research Centre, France) both of whom were among the experts forming the international panel mentioned above. The Agency believes that this Addendum will provide information of great value and publishes it for whatever use Member States and others may wish to make of it. However, it should not be regarded as representing the Agency's official judgment or policy on the matter.

August 1960.

Director General
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1. BASIC CONCEPTS

A. Radiobiology

I. ACTION OF IONIZING RADIATION

(a) Types of radiation. Primary events.

This handbook surveys some of the medical aspects of ionizing radiations and is mainly intended as a guide for the small user of ionizing radiation. The types of ionizing radiation which are likely to be encountered in a small user’s laboratory may be alpha, beta or gamma rays emitted from radioactive substances as well as X-rays from various types of X-ray machines. Protons and neutrons are not likely to be met with under these conditions but they do not differ basically in their action on the biological system. In the biological system, the absorbed energy from these kinds of radiation is dissipated in primary events, of which the most important are ionization and excitation. Such primary events last for an extremely short time, even less than $10^{-6}$ second, and give rise to chemical reactions; these in turn produce a biological reaction which may or may not be of significance to the organism as a whole. The absorption of radiant energy by matter is a quantum phenomenon, so that the maximum energy which may be imparted to a molecule is equivalent to the quantum energy of the radiation in question. For this reason quanta of light and of low-energy ultra-violet rays are unable to produce as strong an effect as, for example, X-rays or gamma rays, where the energy of the individual quantum is high and is sufficient to detach electrons from the atom. Thus, it may be stated in general that, as a result of ionizing radiation, matter is penetrated by electrons of various velocities and simultaneously a considerable number of atoms are excited, i.e. become more reactive with respect to other atoms or molecules.

(b) Direct and indirect action of radiation

The absorption of a quantum of radiation may result in a direct modification of the structure of a biologically important molecule, a process which may then lead to further changes that can become visible. The indirect effect takes the form of the decomposition of water or of organic molecules occurring in living matter, with the result that either short-lived radicals (e.g. OH, HO$_2$) or long-lived organic radicals, which may survive up to weeks or months, are produced. In both direct and indirect effects, a chain of chemical reactions is induced which may result in a visible biological effect.
(c) Biological effect of ionizing radiation

The biological effect depends on the size of the absorbed dose, its distribution in space and time, the sensitivity of the recipient organism, the length of the latent period, and the organism's powers of recovery. There is a marked difference in the space distribution of ions brought about by X-rays and by alpha-rays. In the former case the ions occur in widely-spaced clusters while in the latter they form a dense column of ionization. As a result of this uneven distribution and the influence of other factors, an alpha-ray dose of 1/10 rad may produce the same biological effect as an X-ray dose of 1 rad. In other words, the relative biological effectiveness (RBE) is different in each case.

The effect of radiation may be manifested immediately during irradiation or after a certain latent period, which in man may apparently be as long as several decades.

(i) Effects of ionizing radiations on biologically important macromolecules

A whole range of biologically important substances such as enzymes, proteins and nucleic acids, are also decomposed in vitro by relatively large doses of radiation. In certain cases direct action is exerted on the intra-molecular bonds; in others, however, the action is indirect through the medium of radicals. In this way some enzymes are inactivated. In the case of nucleic acids it has been observed that certain characteristics, viscosity for example, are modified even after the radiation has ceased. The majority of macromolecules forming important cellular constituents are, however, quite resistant in vivo. This is particularly true of proteins and of some enzymes, which at the same time are quite sensitive in dilute solution in vitro. On the other hand, the nucleo-protein metabolism in the cell seems to be modified even by small radiation doses. The end effect of radiation, it should be borne in mind, is a highly complex event, as changes in individual components interact and call forth new qualitative changes.

(ii) Morphological changes in the cell

After irradiation a characteristic change occurs both in the cell nucleus and in the cytoplasm. In the dividing nucleus, chromosome breaks may occur, and if these take place in gonadal cells, hereditary changes may ensue. In many cases the nucleus and cytoplasm increase in volume, vacuoles are formed and, after large doses of radiation, collapse of the entire cell structure ensues. The cell organelles, such as the mitochondria, appear to be markedly sensitive to
radiation. On the other hand, the cytoplasm may continue to perform its movements in plant cells even after doses of several hundreds of thousands of rads.

(iii) Cell division

A sensitive indicator of post-radiation changes is a delay in cell division. This is particularly the case when the cells are irradiated before division commences. This circumstance is of extreme importance, since, during cell division, reduplication of DNA (desoxyribonucleic acid) occurs. In some cases one or two further divisions occur after irradiation, before the complete cessation of activity and the death of the cell supervenes. It may be said that all rapidly dividing cells are much more sensitive to radiation than are non-dividing cells, with the exception of non-dividing lymphocytes and possibly ovarian cells, which do show enhanced sensitivity.

(iv) Occurrence of mutations

Irradiation of the nuclear structure of sexual cells induces mutations which manifest themselves in subsequent generations and are generally deleterious. In addition to these mutations of the germ cells, mutations of the somatic cells may also occur and subsequently become apparent as somatic lesions. The evidence at present available indicates that once a mutation has occurred it persists, the only possible way in which it might be eliminated being by reverse mutation, which is rare, or by the process of selection. The relationship between the radiation dose and the frequency of mutations is linear, although recent work on mice has tended to show some variation of effect with dose-rate. There is considered to be no threshold dose, which means that each individual elementary process (cluster of ions and excitations) has a low probability of causing mutation.

(v) Effect of radiation on embryonic development

Ionizing radiation has a deleterious effect on the development of the embryo, particularly in its early stages. During organogenesis, the effect of radiation may assert itself, with the result that malformations appear in the new-born child. In this respect the retina, brain, skeleton and a number of other parts of the body are particularly vulnerable.

(vi) Lethal effect

The individual parts of the human body are able to withstand comparatively high radiation doses, a circumstance of which advantage is taken in therapy. Such is not, however, the case with irradiation of the whole body, when even a dose of 500 to 600 r may be
lethal. The volume irradiated is most important. The various symp­
toms characteristic of radiation sickness occurring after less than
a lethal dose are described in section B: radiopathology.

(vii) Shortening of the life-span
Experiments with animals have convincingly shown that even
relatively low doses of radiation, which do not produce typical
radiation sickness, may lead to a reduced life expectancy.

(viii) Induction of tumours
It has been established beyond doubt that malignant tumours
may be induced by radiation doses much larger than those permitted
under the recommendations of the International Commission on
Radiological Protection (ICRP), after a latent period which in man
sometimes lasts for decades. With leukaemia, the maximum incidence
of cases is reached five to eight years after acute whole-body irradia­
tion. Among the malignant diseases most frequently occurring in
man after exposure to radiation, the most important are leukaemia
and bone tumours. In contra-distinction to genetic changes, it is not
entirely clear whether the occurrence of tumours is directly related
to the radiation dose received. Some experiments indicate that some
kind of threshold dose exists, below which tumours are not induced.

(ix) Relation between dose and effect
A certain relationship exists between the amount of the dose and
its biological effect, implying that small doses produce a smaller
biological effect than large ones. This dose-effect ratio is sometimes
linear in the case of somatic changes (for example, the lower weight
at birth of mice from embryos irradiated in utero). As already poin­
ted out, there is a linear correlation, in the case of genetic injury,
between the dose and the degree of injury. Here we are evidently
dealing with a general biological law, to the effects of which man
himself is not immune. In other words, this linear correlation signi­
fies that even smaller doses of radiation, an ion pair or an ion cluster,
have a slight chance of producing genetic consequences. This cir­
cumstance is of particular importance in the estimation of the genetic
implications of small doses of radiation. Not only mutations condi­
tioned by change in the germ cells occur in this way without there
being a threshold dose, but clearly somatic mutations as well, and
the possibility must not be excluded that leukaemia likewise is thus
induced.

Another factor as far as the genetic effect is concerned is that
the dose-rate is of comparatively small significance. In other words,
a large dose given over a short period has the same genetic effect as an identical dose received in small fractions over a longer period, though, as mentioned previously, the dose-rate has been recently shown in experiments with mice to have some significance. With acute somatic effects, on the other hand, a single dose may produce a greater effect than the same amount spread over a long period. This is due to repair processes. It is not yet clear whether the organism’s normal regenerative mechanism comes into play during recovery or whether specific post-irradiation repair processes exist.

II. FACTORS GOVERNING THE BIOLOGICAL EFFECT OF RADIATION

It has already been said that from the primary process occurring after the absorption of radiation a complicated reaction develops, which may finally emerge as a visible reaction to radiation. As might be expected, this chain of reactions can be influenced in various ways, particularly in more complex organisms. Among the agents which thus govern the final reaction to radiation are physico-chemical conditions, including temperature and degree of hydration, oxygen and the various so-called protective substances.

(a) Physico-chemical conditions (temperature, degree of hydration)

In general it may be said that a lowering of temperature reduces the effect of radiation. This should not be regarded as a fixed rule, because in some cases (bacteria) there exists a certain optimum temperature for the reduction of the radiation effect. In the case of some animals, it has, however, been ascertained that if they are kept at a low temperature after irradiation, the effect appears only when the temperature again rises to the normal level. The ultimate radiation injury however remains the same.

Similarly, it may be said that the level of hydration of the organism influences the effect of radiation, in the sense that the effect of radiation is increased under conditions of increased hydration. This is evidently connected with the production of radicals.

(b) Role of oxygen

If, during irradiation, the partial pressure of oxygen in the cells is lowered, the sensitivity of these cells to radiation and its effects is reduced, irrespective of whether we are dealing with chromosome breaks, biochemical changes or lethal events. It may thus be affirmed that a lowered oxygen concentration constitutes a protection against
radiation. However, in some cases the presence of oxygen assists in recovery and renders possible the reunion of the chromosome. The oxygen effect is not manifest in the presence of densely ionizing radiation such as alpha rays or slow electrons.

(c) Protective substances

The fact that it is possible to decrease the radiosensitivity of the organism by outside intervention led to a search for substances which would provide a measure of protection against radiation. In the majority of cases it has been shown that such a protective substance must be present during irradiation in order to be sufficiently effective. Among the best-known protective substances of this kind is cysteamin, which is effective both in vivo and in vitro. It has been shown that its presence reduces the major effects of radiation, whether they are biochemical or morphological changes or even certain types of mutation, and the survival rate of the cells and tissues accordingly shows a corresponding rise. The hypothesis usually advanced to explain this phenomenon is that the protective substances exercise a neutralizing influence on the free radicals, or that the partial pressure of oxygen within the cells is lowered.

(d) Recovery

It has been observed in numerous experiments that the effect of radiation, particularly on the mammalian organism, may be decreased or completely eliminated by the action of the organism itself. This follows from the fact that irradiation places the organism under a certain stress, to which it reacts by mobilizing its general adjustment mechanisms for dealing with stress phenomena.

When the cell is provided with a suitable energy source (e.g., by adding adenosine triphosphate), chromosome breaks can be helped to re-join. This points to the probability that irradiation damage can be reduced by prompt administration of energy sources.

A greater effect may be obtained in mammals by transplantation of tissue not injured by radiation. In particular, the grafting of bone marrow has given specific evidence of this in mammals. All transplantation operations of this kind pre-suppose, however, that the immune reaction obtained on grafting heterogeneous tissue is inhibited.

(e) Adaptation

There is at present no convincing evidence that organisms can adapt themselves to high levels of radiation. It is, however, not impossible that organisms so adapted will be found in geographic
regions where a high level of natural radioactivity exists. Certain densely populated areas of the globe (parts of India and Brazil) are known to have an unusually high content of radioactive substances in the environment. However, even if such adaptation occurs in the population, it is always necessary to bear in mind the influence of selection, in which the more resistant organism survives.

(f) Individual sensitivity

It has been observed that the radioresistance of certain bacterial cells is substantially increased by mutation. Clinical experience in radiotherapy also indicates that there are probably certain individuals more resistant to radiation. However, since this experience is based largely on the effects of partial irradiation, the significance of the observation cannot be extended to the whole body. Thus in the meantime we can only say that there is a wide variation in the degree of sensitivity of various organisms, since a few rad are sufficient to kill lymphocytes, whereas some hundreds of thousands of rad are required to kill an adult insect, and over a million rad to destroy viruses and bacteria completely.

The various organs differ considerably in their radioresistance. Although it is not possible to construct an exact scale of radioresistance for the organs, it may be roughly concluded that the blood-forming organs, gonads and lenses of the eyes are among the most sensitive. Muscle, connective tissue and adult bone have a relatively high resistance to radiation. The skin, intestines and endocrine glands fall in an intermediate category. This classification cannot, however, be exact, because it depends on many factors (physiological state, oxygen content, temperature, etc.) and on the method of observation, i.e. whether morphological or physiological changes are registered.

III. Conclusions

It should be emphasized that today’s knowledge of the effects of radiation on living organisms is as yet incomplete, because the present knowledge of biology is not sufficient to establish sound criteria for distinguishing injury from the normal state of the organism. Nevertheless, our knowledge of radiation injury from both human experience and animal experiment is sufficient to make it possible to establish maximum permissible doses of radiation with a considerable degree of confidence.
B. Radiopathology

(a) Radiation sickness

After irradiation of the greater part of the body, a series of pathological symptoms ensue, which originally were described as “Röntgen sickness”. It was only after the experience gained as a result of the atom-bombing of Hiroshima and Nagasaki that these were shown to be the symptoms of typical radiation disease. Basically, this disease can occur either as acute sickness (acute radiation syndrome) resulting from whole-body irradiation by a single dose of over 100 rem, or as chronic sickness developing over a number of years after small repeated radiation doses. Radiation sickness is caused principally by irradiation with gamma-rays, X-rays and neutrons. Alpha and beta rays exercise an effect when radioisotopes have been taken into the organism and deposited there.

Acute radiation disease is characterized by a latent period, which supervenes after initial symptoms of malaise, loss of appetite and fatigue, during which the sufferer feels no other untoward symptoms, and the length of which is indirectly proportional to the radiation dose received. At the end of the latent period, the onset of the illness proper occurs; the degree of severity which it attains depends upon the radiation dose. In the course of radiation sickness and, naturally, as a result of strong local irradiation, characteristic changes in the individual organs develop.

Radiation sickness may be followed after a lapse of several years by late effects in the form of malignant changes (leukaemia, tumours of the skin, etc.).

(b) Lymphatic haematopoietic tissues

Lymphatic tissues are among the highly radiosensitive systems. It is here that the lymphocytes which pass into the blood and become part of the white corpuscle group are formed. Even after small radiation doses the number of lymphocytes temporarily falls in some cases. After high doses, the lymphatic tissue ceases to be active and the lymphocyte count in the peripheral blood falls immediately, the degree and duration of the drop depending upon the radiation dose received.

The bone marrow, where the red corpuscles and leukocytes are formed, is highly radiosensitive. Particularly liable to damage are the immature blood cells in the process of formation; the earlier their stage of development, the greater is their sensitivity. After
small radiation doses, a moderate multiplication of the young red and white cells occurs, but after large doses a crushing effect upon the marrow is observed, leading to the complete depopulation of the marrow tissue. The marrow begins to resume activity in the first or second week after irradiation and the duration of the process is governed directly by the radiation dose. During the process itself, recovery of white cell production is more rapid than erythrocytopoiesis.

It may be said, very broadly speaking, that reactions to radiation as manifested in the peripheral blood depend on the radiation dose, species specificity, the life span of the different corpuscular elements, their sensitivity and powers of renewal and the state of the organism at the time.

Immediately after irradiation a short period of leukocytosis ensues, occasioned by the release of leukocytes from the bone marrow. Then follows a drop of the total leukocyte count, the severity and duration of which are proportional to the degree and length of radiation exposure. A fall in the lymphocyte count is an early feature. Reduction of the neutrophil count is characteristic, and recovery from neutropenia may be taken as a good prognostic sign. The eosinophil count drops only after a larger dose. The number of reticulocytes is also reduced, and early reticulocytosis is a favourable indication of recovery. The red-corpuscle count drops only very slowly after irradiation. Marked anaemia does not occur until two to four weeks after a large radiation dose. In cases of severe damage this turns to aplastic anaemia.

After irradiation, the blood-platelet count also falls, the radiosensitivity of the platelets being greater than that of erythrocytes. The lack of blood platelets leads to a tendency to bleeding. The recovery of the blood-platelet count is generally very slow. The monocytes behave in the same manner as eosinophils, and an increase in their number is a favourable indication of recovery.

(c) Gastro-intestinal system

Small doses of ionizing radiation affect the motility of the intestine and enzyme secretion, whereas large doses lead to ulceration of the intestinal mucosa. The intestinal bacteria penetrate the damaged intestinal tract, enter the blood system and are carried throughout the body, causing serious septic conditions. Changes in the gastro-intestinal tract are frequently decisive in the outcome of radiation disease. Naturally, direct irradiation from considerable quantities of ingested radioactive substances may severely damage the intestinal wall in a similar manner.
(d) Skin

Since irradiation entering the body from external sources has almost invariably to pass first through the skin, the reaction of the skin to ionizing radiation has been studied in great detail. Before the development of accurate dosimeters, erythema of the skin following external irradiation by X-rays was for long taken as the basis of the biological unit of dose. After larger doses this erythema changes to pigmentation, and after still greater doses appear various types of radiodermatitis, which may lead to necrosis and ulcerations and may finally become malignant growths. This latter case applies particularly to the forms of dermatitis resulting from chronic low-dose X-ray irradiation.

Three degrees of acute radiodermatitis can be distinguished:

(i) Radiodermatitis erythematosa

This manifests itself in a reddening of the skin beginning on the fourth to the seventh day. Only in the third to fourth week does the skin regain its normal appearance. Hair from head and beard may fall from the areas of reddened skin within two or three weeks. The skin remains temporarily coloured, peels easily, and is dry;

(ii) Radiodermatitis bullosa

This occurs after larger doses, and between the second and fifth days after exposure the skin becomes dark violet in colour and water blisters, similar to second-degree burns, are formed. The skin itches, burns and is painful. Within two or three weeks, the hair falls out and the loss is largely permanent. Healing is slow, and the skin thereafter remains dry, whitish and crossed with bright-red blood vessels;

(iii) Radiodermatitis escharotica

The skin reddening appears as early as the second or third day after a high radiation dose. Deep and painful ulcers and also abscesses appear on the skin, healing is slow, and scars, interwoven with large blood vessels, remain on the damaged areas. The skin is dry, since the sebaceous and sweat glands have been completely destroyed.

Chronic dermatitis occurs after small doses (considerably more than those recommended by the health and safety regulations) when persons working with ionizing radiations receive damage to the skin, particularly of the hands, which becomes dry and of violet-red colour. Numerous telangiectatic areas are observed. Hair falls from the body, head and beard, the skin becomes thin, keratoses are sub-
sequently formed, together with warts, between which the skin easily cracks. In advanced stages ulcers occur and in some cases even epitheliomata.

(e) Skeleton

Bone-changes have for long been observed in human beings and in experimental animals as a result of ionizing radiations. In young individuals these changes range from cessation of the processes of ossification and growth (on exposure to doses of the order of 100 rem) to complete necrosis of the bone, observed after doses of several thousands of rem. The majority of these bone injuries occur as a result of incorrect radiotherapeutic treatment or of incorporation of radioactive substances into the bone. In both circumstances, an increased incidence of bone tumours has been observed. However, the only bone tumours recorded in man from the incorporation of radioactive substances into the bone have been from radium. In general it may be said that radioisotopes deposited in the bones display a particular tendency to become localized in the growing parts of the bone (epiphyses). With regard to malignant tumours, it has been shown that they most frequently develop in the metaphyses of the long bones and are frequently numerous in one and the same individual.

(f) Gonads and genetic effects

The sexual glands are highly radiosensitive, the male organs being considerably more sensitive than the female. With a dose as low as 30 rem with men and 300 rem with women, temporary changes in fertility may be caused. The dose to produce permanent sterility in men is approximately 600 rem and in women approximately 800 rem.

Irradiation of the germ tissues may cause mutations which appear in later generations. The following features are characteristic of mutations:

(i) Mutations having once occurred are permanent. The mutant genes may be restored only by a reverse mutation and this has only a slight probability of occurring. In the process of selection some of the mutant genes may be eliminated;

(ii) The great majority of observed mutations are deleterious;

(iii) It has not thus far been proved whether a threshold dose exists for mutations. This means that every ionizing radiation located in a germ cell has a small statistical probability of causing a mutation;
(iv) Small doses may be cumulative and the end result may not appear until many generations later;

(v) The genetic dose required to double the mutation rate in man is of the order of 10 to 100 rad. It cannot be less than 3 rad, since this level is attained in a human generation of 30 years as the result of natural radiation. However, recent work may indicate that at low dose-rates the dose required to double the mutation-rate in man may be larger than indicated here.

A whole range of characteristics may be influenced by genetic damage, including various morphological and biometrical characteristics (life-span, weight at birth, intelligence, fertility, lethal effects, etc.) Owing to the uncertainty of some of the genetic mechanisms involved, it is safest to assume that approximately 4% of children born are at present burdened with hereditary disturbances. An increase of the level of radiation could lead to an increase of this genetic load.

(g) Embryonic development

Developmental abnormalities may also occur when the embryo or foetus is irradiated during growth. Particularly in the early stages of embryonic development a dose of a few tens of rem may be sufficient to produce serious abnormalities. A number of cases of microcephaly with congenital implications have been observed among children who were irradiated in the uterus during the atom-bombings.

It may be mentioned that radioactive substances can reach the embryo and the developing foetus during the period of nourishment, via the placenta. Particularly in the early stages of embryonic development, radioisotopes absorbed in this manner constitute what is in effect a whole-body irradiation of the embryo.

(h) Nervous tissue

For a long time there was a general belief that nervous tissue is highly resistant to irradiation. This was due to the fact that after irradiation only morphological changes were sought, which require considerable doses to become apparent. Recently, functional changes were elicited with much smaller and often very low doses. Among these modifications, mention may be made of decrease in excitability and changes in conditioned reflexes. Irradiation of animals with 300—400 r produces changes in the electroencephalogram which may persist for about one week.
(i) Modification of the immune status

Disturbances of the immunological mechanism can be produced by external and internal irradiation. In the latter case, disturbances may occur when the cells of the reticulo-endothelial system have incorporated radioactive material which may inhibit their immunological function.

In experiments with monkeys a whole-body irradiation with 450 r showed a temporary suppression of the antibody response when the irradiation was performed twenty-four hours before the beginning of immunization. This effect did not develop fully after irradiation in previously immunized animals.

(j) Other organs

Modifications to the vascular system after irradiation take the form of changed permeability of the vessels, and also morphological changes in the walls with circulatory disturbances (necroses). These vascular changes are of particular significance for the skin.

Radiation affects the eye by inducing acute inflammation of the conjunctiva and the cornea. The most sensitive part of the eye is, however, the crystalline lens. The radiation dose from neutrons and other heavy ionizing particles which is required to produce cataracts, for example, is less than the gamma dose by a factor of perhaps 10.

Lung cancer may occur after the inhalation of radioactive materials as, for example, plutonium (in animal experiments) and, probably, radon. However, it is to be remembered that the type of radiation is more important than the particular radioisotope in which the radiation originates. The probability of such an occurrence is also, of course, related to the radiation dose involved.

Radiation can produce certain non-specific effects which are mediated through the adrenal gland and which are identical with those produced by other stresses. This emphasizes the non-specific character of some effects of radiation. Effects of this type can be obtained with a few hundred roentgens of X-rays, and it is possible that other endocrine processes also concerned with regulating functions in the body can likewise be affected by such doses.

Conclusions

From the foregoing it will be evident that the various forms of ionizing radiation essentially produce the same biological effects. On the other hand, it is not possible to say that the reaction to large doses is qualitatively identical with that to small doses. The subject of small doses of ionizing radiation, and particularly the question of their long-term effects, has not, however, been sufficiently studied.
After large radiation doses acute radiation syndrome occurs, the clinical symptoms of which have on the whole been thoroughly investigated. The haematopoietic organs, the gastro-intestinal tract and the gonads are the most highly radiosensitive. In certain cases it is possible to speak of a threshold dose, but it is considered that this does not apply to the genetic effects.

It is significant that embryonic development can be seriously affected by external and internal irradiation.

It is characteristic that the effect of small radiation doses makes itself felt only after a very long interval, which signifies that it is not always possible to decide whether or not there is a threshold. There appears to be a possibility that certain late pathological effects such as leukaemia, cancer and bone tumours may appear even many years after exposure to small radiation doses.

It is not yet possible to affirm that any specific processes for the repair of radiation damage have been discovered. It appears, however, that after exposure to irradiation the organism mobilizes those defensive reactions of a non-specific character which it has at its general disposal.

C. Incorporation of radioisotopes

Radioisotopes can enter the human body by various paths and cause internal irradiation, the importance of which is particularly emphasized by the fact that certain radioisotopes are deposited more or less permanently in the body, leading to contamination which may have serious consequences for the affected individual. For this reason it is necessary to have a detailed knowledge of all the channels through which isotopes can be absorbed, of the factors which accelerate this absorption, of the manner and sites of deposition of isotopes in the body, and of the rate of their elimination.

(a) Absorption of radioisotopes into the body

Radioisotopes enter the body either through inhalation of radioactive aerosols, i.e. via the lungs, through the digestive tract or through the skin, either directly or as a result of a wound and its contamination by radioactive substances. The rate of absorption is governed by numerous factors. The most important of these is, naturally, the blood flow through the organ in question and the speed of exchange in the tissue. Foci of inflammation increase the absorption of radioisotopes 20 to 30 times. Young organisms absorb them more easily than older ones. Of importance also are the chemical properties of the isotopes or the chemical and physical form
in which they occur. It is important to remember that radioisotopes of elements normally present in the body (phosphorus, calcium, sulphur, iron, strontium) participate in the metabolic process and behave in the body like stable isotopes of the same elements. As a result of the development of atomic energy, however, radioisotopes not normally occurring in the body (plutonium, yttrium, caesium) may enter it and are then metabolized.

Radioisotopes which are inhaled may be quickly incorporated in the body, especially if the particles are small and soluble. It should be remembered, however, that a certain proportion of these isotopes is always trapped in the upper respiratory passages, whence it is removed by the movement of the bronchioles and ciliated epithelium, and by coughing. A certain proportion is also taken up by the phagocytes. The eliminated isotopes are thus returned to the oral cavity from where they may be swallowed and pass into the digestive tract.

The soluble isotopes pass rapidly from the lungs into the bloodstream and are deposited in the various organs (e.g. bones in the case of bone-seeking isotopes).

Intact skin resists the entry of most radioisotopes. Tritium, however, and some others can pass through. The permeability of skin which has been injured even by surface abrasions is very considerably increased. The presence of organic solvents on the surface of the skin also accelerates the penetration of radioactive materials.

(b) Deposition of radioisotopes in the body

Radioisotopes which enter the blood are retained there for a certain time until they are either eliminated or deposited. It may be approximately stated that after as little as 24 hours, only a small proportion of the quantity administered is retained in the blood. Radioisotopes sometimes form aggregates in the blood with the macromolecules present, and this has the effect of considerably slowing down their elimination.

The distribution of radioisotopes in the body is governed by their chemical characteristics. Some isotopes, for example those of sodium, phosphorus and caesium, are deposited roughly to the same extent in all regions of the body. However, the majority of dangerous radioisotopes accumulate only in certain organs. Thus, heavy metals and alkaline-earth metals accumulate in the bones, iodine in the thyroid gland and uranium in the kidneys. However, not even in the bones are the isotopes evenly distributed, because small foci of unusually high local concentration may be formed there (the so-
called “hot points”). Bone-seeking isotopes, for example strontium and radium, are deposited in the mineral part of the bone.

Other radioactive elements such as plutonium or yttrium are deposited largely in the organic part of the bone, independently of age and of calcium metabolism, and then remain more or less permanently fixed there.

(c) Elimination of radioactive isotopes from the body

Radioactive isotopes are eliminated from the body through various channels (kidneys, sweat glands, saliva, mammary glands, the glands of the stomach and intestinal mucous membrane, the bile and, in the case of gaseous elements, the lungs). The bowels eliminate isotopes which have been partly absorbed, and also those which have passed without absorption through the digestive tract owing to their low solubility. The urine eliminates only fully absorbed isotopes. Readily soluble isotopes are eliminated principally in the urine, whereas those which form complexes enter the liver, whence they are eliminated by the bile. Isotopes are most speedily removed from nerve and muscle tissue, much more slowly from the kidneys and the cells of the reticulo-endothelial system, and most slowly of all from the bones. In the lymph nodes radioactive isotopes are retained for a comparatively long period. Gaseous isotopes such as radon are eliminated most rapidly by the lungs. The elimination rate is naturally governed by the age of the organism, by its physiological condition and also by the quantity of isotopes in the whole body.

(d) Radiotoxicity of radioisotopes

The radiotoxic effect of radioisotopes on the human body is a complex function depending upon a variety of physical factors, one of the most important of which is the physical half-life of, and the strength and type of radiation emitted by, the isotope. With regard to the organism, too, a whole series of biological factors is involved, such as the mode of entry of the radioactive material, the site of its deposition and the rate of its elimination. Another important factor is the age and the assumed remaining life-span of the organism. In general it may be said that most poisonous of all are those radioisotopes with a long half-life, emitting alpha-rays. This statement is, however, only approximately correct, since some isotopes, e.g. uranium, although having a much longer physical half-life than plutonium, are considered much less poisonous than the latter. The toxicity of individual radioisotopes is very important in determining their maximum permissible dose.
Introduction

In the discussion in the previous chapter, it was seen that the exposure of persons to ionizing radiation may result in injuries manifesting themselves both in the exposed individual and in his descendants, i.e. somatic and genetic injuries respectively.

With the advent of the atomic energy industry, more and more people are liable to exposure to ionizing radiation. It is clear that man cannot entirely dispense with the use of ionizing radiation and therefore the problem in practice is to keep the radiation dose down to a level which involves a risk that is not unaccept able to the individual and to the population at large. This is called a “permissible dose”. The objectives of radiation protection are thus to ensure that nobody is over-exposed, and so to prevent or minimize somatic injuries and the genetic deterioration of the population.

To carry out this task of radiation protection of workers exposed to ionizing radiation, a strict system of supervision should be established. This system should comprise both individual physical monitoring of the absorbed dose and medical supervision of the workers’ state of health. Some authorities believe that medical methods are not sufficiently sensitive to detect the effects of low radiation doses, of the order of the maximum permissible doses to which workers may be occupationally exposed, and therefore conclude that medical supervision is of secondary importance only and may even be omitted if proper physical monitoring is carried out. In fact, however, medical inspection and physical monitoring are not only compatible but complementary: physical monitoring is essential for estimating radiation levels and for preventing over-exposure; medical examinations are essential for following trends in the individual’s state of health.

The requirements are governed by the particular nature of the radiation hazards to which personnel may be exposed. These hazards occur in two principal forms: one is exposure to radiation external to the body; and the other is internal contamination by radioactive substances. In either case the result is an irradiation of the organism.

It may be helpful to recall here the principal factors of the radiobiological phenomena occurring after irradiation. These factors comprise, firstly, the dose or quantity of radiation absorbed per unit mass of living organism, and secondly, the spatial distribution of
the energy absorbed by the tissues, together with its time distribution (i.e. the period during which it is absorbed). Identical total absorbed doses having different spatial and time distributions yield widely differing radiobiological effects. Next, the nature of the incident radiation and of the contaminating radionuclides is of great importance, particularly owing to the existence of differing spatial and time distributions. The relative biological effectiveness of the radiation and the relative toxicity of the radionuclides also play a decisive role, and, owing to the existence of great differences in radiosensitivity, the nature of the irradiated tissue has also to be taken into consideration. The more radiosensitive tissues constitute what are known as critical organs.

Consequently, working conditions and safety standards must take account of all the above factors, and in addition a distinction must be made, in planning safety standards, between whole-body and partial irradiation, and between prolonged and instantaneous irradiation.

Supervision will thus aim, in the first place, at determining the dose absorbed by each worker and expressing it in the unit adopted by the International Commission on Radiological Protection (ICRP), the rem. The dose is determined by adding together the individual readings obtained for each kind of irradiation. For the purposes of clearer exposition this chapter is divided into three Parts. In Part I an account is given of methods of measuring external radiation and internal radioactive contamination. In both cases, a study is made first of general methods of measurement, then of special methods applicable to particular forms of radiation or contamination and finally of the factors governing the choice of method or methods to be used. These remarks on methods of measuring external irradiation and radioactive contamination are followed by a description of the procedure for obtaining the total absorbed dose by adding together the figures for the various kinds of external and internal irradiations.

The last few pages of Part I are devoted to a summary and conclusions. Part II of the chapter deals with the medical care of radiation workers and is divided into two sections. Section A deals with the responsibilities of the medical services and section B with medical examinations. Finally, Part III of this chapter is devoted to the organization of radiological and medical archives and to the keeping of health records.

* See definition, p. 93 of the Manual. ("Safe Handling of Radioisotopes", IAEA, Vienna, 1958.)
Part I. Personnel monitoring in radiation work: Physical and radiochemical methods of estimating dose and radioactive contamination

As was stated earlier, the protection of workers against ionizing radiation requires both individual monitoring and medical examinations, the two types of supervision being complementary. In some countries responsibility for both types of supervision is assumed by the medical service; in others it is divided between physicists and physicians. When physicians are responsible for both individual monitoring and medical examinations, their qualifications should of course extend to all the methods involved. When the physicians are in charge of the medical examinations only, they should nevertheless take account of the data obtained from physical monitoring in the interpretation of their findings.

Therefore, as an aid to the physician, the methods of measuring external exposure or radioactive contamination to which personnel may be subjected are described in this Part.

A. Methods of measurement of external irradiation

(a) Measurement of gamma radiation

Personnel monitoring for gamma radiations may be done with films, pocket dosimeters, pocket ionization chambers or chemical dosimeters.

Films (film badges) have a range varying according to the emulsion used, but no single emulsion can cover all requirements. It is necessary sometimes to measure extremely low-level radiation of the order of 10 to 1,000 mr, and at other times, doses of the order of 1 to 1,000 r. Detectors containing several emulsions may therefore be used to record doses of interest for radiological protection purposes. The error of film badges is of the order of 20%, always in the direction of a high reading, which constitutes a safety factor.

The individual dose received may also be measured by means of small ionization chambers. Some types are equipped with electrometers and are known as pocket dosimeters (or pocket electrometers), while others are without electrometers and are termed pocket ionization chambers. The pocket dosimeters (pocket electrometers) allow direct self-reading since the detector and the electrometer are connected. They are useful for cases where it is of value to have an immediate reading of the dose at any given moment.

Pocket ionization chambers are intended for indirect reading, since the detector is separate from the electrometer. They have the ad-
vantage of being more economical but permit a reading of the dose only after a reasonably short time has elapsed. The range of pocket dosimeters (pocket electrometers) and pocket ionization chambers is comparable to that of the film badge; in some cases they are, however, more accurate.

Film badges have the advantage over pocket dosimeters or ionization chambers of being able to give some indication of the energy of the radiation and of leaving a permanent record for filing.

Generally, film badges should be worn continuously by radiation workers, while other dosimeters giving immediate readings are useful when it is imperative to know the dose being received at any moment during work.

Chemical dosimeters are sensitive only to high levels of radiation, are relatively inaccurate and hence are of very limited value for personnel monitoring. They are, however, useful for recording large doses.

(b) Measurement of beta radiation

The above-described monitoring apparatus used for gamma radiation may also be applied to the measurement of beta radiation. However, the windows of the detectors must be sufficiently thin to allow passage of the beta-rays to be measured. Beta-rays of low energy, less than 0.2 MeV for example, cannot be detected in current practice by means of personal monitors. This is, however, not a serious disadvantage, since such low-energy beta radiation cannot appreciably irradiate the human body from external sources.

With regard to film badges, the same types can be used as for gamma-radiation monitoring. The window is sufficiently thin to allow the beta-radiation to pass. There are cases — those of mixed irradiation — when it is desirable to distinguish between the respective contributions of beta and of gamma rays, and it is then necessary only to place a light-metal screen in front of a part of the film in order to shield off the whole of the beta-rays while allowing the gamma-radiation to pass. The difference in blackening between the unshielded and the shielded areas gives an approximate indication of the dose due to beta-rays.

Pocket electrometers and pocket ionization chambers normally used for gamma-rays can also serve as personal monitors for beta-radiation of energy greater than 0.5 MeV. There are available types of pocket electrometer and ionization chamber, with sufficiently thin walls and made of light material, capable of detecting beta-radiation of energies as low as 0.1 MeV.
(c) Measurement of neutron radiation

Although neutrons are not directly ionizing particles, they do produce nuclear reactions in the matter through which they pass; and these reactions in turn may give rise to ionizing radiation capable of detection by the methods previously described. These nuclear reactions may also lead to the formation of induced radio-isotopes, the radiation from which can likewise be measured. It is thus possible to detect neutrons either during or after irradiation.

For the detection of neutrons during irradiation, monitoring apparatus of the types described above can be used, equipped with certain accessories. Among these are cadmium screens able to capture thermal neutrons while re-emitting measurable gamma-radiation. Likewise, incorporation of boron-10 in the detectors makes it possible to measure the alpha-rays produced by the nuclear reactions between the neutrons and the boron.

When the nuclear reactions induce radioactive substances, it is possible to determine the degree of neutron irradiation subsequently. One method consists of utilizing certain metals which are rapidly activated by neutron radiation (e.g. indium, gold). It is even possible to use the human body as a monitor, since sodium-24 or phosphorus-32 are induced by neutron radiation. By gamma-spectrometry methods the amount of sodium-24 contained in the whole body, the blood or the urine can then be determined. It may be mentioned here that for fast-neutron monitoring the method of observing nuclear tracks in photographic emulsion is used.

(d) Factors governing the choice of method for measuring external irradiation

Individual external irradiation monitoring can and should be carried out in a completely systematic manner, and the available methods yield perfectly reliable data on the radiation levels to which personnel are exposed. However, the choice of method is governed by certain factors, the principal of which are the following:

(i) Spatial distribution

Irradiation of the body may be either whole or partial, and among cases of whole-body irradiation some may be practically homogeneous, such as exposure to gamma-rays, for example. In the case of neutron irradiation, on the other hand, distribution in the body is heterogeneous, depending on the orientation and energy of the neutron flux. With beta-rays, the extent of irradiation is limited to the surface layers of the organism. However, in all cases of whole-body exposure the monitoring apparatus is able to supply data to
estimate the resultant irradiation of the organism. In cases of partial exposure a distinction can be made between segmentary deep irradiation by gamma-rays or neutrons, and segmentary superficial irradiation by beta-ray beams. The demarcation of the part of the body irradiated is of great importance, but often it can be inferred only from the circumstances of the exposure. It is also helpful to have detectors judiciously placed in body regions particularly liable to exposure, as for example the wrists, fingers and front of the thorax. Such a procedure makes it possible to determine segmentary exposure in most cases, but certain instances of partial irradiation may nevertheless pass undetected.

(ii) Time distribution

Besides its space distribution, the time distribution of the dose is important. Therefore monitors have to be used which yield data on both the intensity of the incident radiation and the amount of radiation received during a given period. The instruments for measuring intensity are called dose-rate meters and the most usual type is the portable ionization chamber, used for area monitoring and warning purposes.

(iii) Types of radiation

The multiplicity of incident radiations also presents a problem for personnel monitoring and influences the choice of method for measuring external radiation. External radiation is often due to mixed gamma- and beta-rays, to which neutron radiation must sometimes be added. Workers must therefore be provided with dosimeters capable of recording these various types of radiation. Individual dosimeters at present available permit this, and sometimes also furnish data on the energy of the incident radiation.

(iv) Required range of personal dosimeters

The last important factor in this connexion is the range which personal dosimeters should have. For monitoring under normal working conditions, the measurement of small radiation doses of some tens or hundreds of milliroentgens is called for, and dosimeters with a range extending from 0 to 3 r are fully adequate for this work. However, if there is the risk of appreciable accidental exposure, it is essential for workers to be equipped also with dosimeters capable of recording doses up to 1,000 r at least; otherwise great difficulties may arise, after an accident, in evaluating the doses actually received. Such dosimeters are available and it is, in fact, already possible to obtain personal dosimeters capable of meeting the requirements both of routine and of emergency monitoring.
B. METHODS OF MEASUREMENT OF RADIOACTIVE CONTAMINATION

Radioactive contamination is the second form of irradiation to which workers handling radioisotopes may be subjected. Contamination may occur in various ways. It may be limited to the surface of the body, in which case it is termed skin contamination; or radio-nuclides may penetrate into the body through the skin, digestive tract or lungs, when it constitutes internal contamination. It is therefore necessary to evaluate skin contamination on the one hand and internal contamination on the other. Evaluation of the latter can be made either directly, as is possible in some cases, or indirectly, by measuring the amount of radioactive material liable to enter the body or the amount of such material eliminated from the body via the excreta.

(a) Evaluation of skin contamination

The evaluation of skin contamination is relatively easy. The contaminated area should first be demarcated by rough monitoring and a broad distinction made between the various possible contaminants. If it is known what kind of work was being performed, this usually provides an indication of what has occurred. In all cases it is easy, with the help of the available detectors, to make an immediate distinction between alpha-emitters on the one hand, and beta- or gamma-emitters on the other.

The detectors used are generally proportional counters, Geiger-Müller counters or scintillation counters. They are modified to suit requirements and the detecting surface is usually flat for use in relatively open areas, or in the form of a probe for work in places difficult of access.

The readings are expressed in counts per unit time. Account must first be taken of geometrical factors, and the shape and surface area of the detector must be known in order to derive the number of counts per unit time and per unit area from the number per unit time. It is then necessary to take account of physical factors, in order to derive a value in curies per unit area from the number of counts. For this purpose the disintegration scheme of the radionuclides, together with the efficiency of the counter with regard to the different types of radiation, must be known. Obviously, an exact determination of skin contamination is extremely laborious unless the nature of the contaminating nuclides is previously known. Skin contamination is therefore frequently evaluated only in terms of alpha or beta/gamma-emitting radionuclides. For this purpose maximum permissible limits have been established irrespective of
the nature of the contaminating radionuclide. Decontamination is regarded as necessary after accidental contamination above certain levels, the values of which, as established by a number of national organizations, are quoted in appendix II of the Manual.

(b) Evaluation of internal contamination

(i) Direct evaluation of internal contamination

In cases of internal contamination by radionuclides it would appear theoretically highly advantageous to make an overall measurement of the contamination and thus to determine the body-burden of the radionuclide. Direct measurement is possible only if the radionuclides emit radiations capable of detection outside the body, and at present this can be achieved, using spectrometry methods, only for gamma-emitters. Various instruments may be used to make such measurements in vivo; owing to their extreme sensitivity they require to be most carefully shielded from parasitic radiation in order to ensure accuracy of the results. For any given radionuclide the threshold of detection is improved with improved shielding. The materials most widely used for shielding such apparatus are water, iron and lead. The types of apparatus used include ionization chambers, liquid scintillators and crystal scintillators.

The most frequently used apparatus is, however, the crystal gamma spectrometer. In its most usual form it consists of a detecting crystal connected with a photomultiplier. The gamma-rays emitted in the organism are absorbed by the crystal and produce scintillations which in turn produce photoelectrons. The latter are then amplified by the photomultiplier, and converted into electric pulses. These pulses are then transmitted to a single or multi-channel pulse-height analyser. With this equipment the radioactivity of the whole or of a particular part of the organism can be measured.

An ionization chamber cannot achieve energy discrimination between gamma radiations, but this is to some extent possible if liquid scintillators are used and is an easy task with crystal scintillators. In all cases the readings should be carefully interpreted, taking into account physical factors connected with the nature of the contaminating radionuclides and geometrical factors connected with the equipment. Calibration with regard to sources or phantoms is still a delicate operation. However, the accuracy of the equipment is generally sufficient to allow a correct evaluation of the body-burden for certain radioisotopes, such as iron-59, cobalt-60, zinc-65, ruthenium-106, iodine-131, caesium-137 and radium-226.

Such apparatus is of value owing to the ease with which internal
contamination can be measured. They are particularly useful in cases of appreciable or suspected internal contamination of a worker. It is not necessary to take samples, and care must only be taken to ensure that there is no interfering skin contamination. The characteristic features of the spectrometry method are its high sensitivity, adequate reliability and precision, great flexibility and convenience of use. However, the equipment is expensive at present and can only be used by experts.

(ii) Indirect evaluation of internal contamination by monitoring of excreta

Since radionuclides are eliminated by excretion according to more or less well-known laws, it is possible to deduce from the quantity of nuclides in the excreta the quantity present in the organism at a given time. The mode of elimination depends on the nature of the radionuclide: uranium and plutonium are excreted in urine, strontium in faeces and urine, radon in breath, tritium in perspiration and urine. Radiochemical analyses are carried out generally on urine and occasionally on faeces and breath.

Radiochemical techniques generally consist of the following stages: preparation of samples; chemical isolation of radionuclides; quantitative determination of the latter by measurement of radioactivity after calibration with a control sample; exact identification of the radionuclides.

The sampling of excreta in reality requires more care than at first appears, if it is to give a true picture of the degree of elimination of the substance under consideration. The ideal procedure is to collect specimens over a period of 24 hours. However, in practice, quantities equivalent to those excreted in 24 hours are often used. This method is relatively easy for the sampling of urine but not so easy for that of faeces. Specimens of both urine and faeces are collected in flasks or polythene bags, and a check must be made that there has been no excessive absorption of the radionuclide on the walls of the receptacle used for collection. Breath is collected in large balloons having inlet and exhaust valves. This kind of sampling can be carried out only in specialized laboratories.

It is always useful to separate the contaminating radionuclides as far as possible, with a view to measuring the activity of each. Separation is effected by the physico-chemical methods of co-precipitation, adsorption, ion exchange, etc.

Quantitative determination of the radionuclides is effected by measuring the alpha-, beta- or gamma-activity, using counters of the
Geiger-Müller, proportional or scintillation type, carefully calibrated by means of control samples. Special precautions should be taken where there is a possibility of natural radioactivity (e.g. potassium-40) interfering with the artificial activity to be measured in the specimens.

Finally, steps must be taken to identify with absolute certainty the radionuclide or nuclides to be detected. This operation is carried out by the methods of radioactive decay (if the half-life is sufficiently short, i.e. a few hours or days), absorption (for beta-emitters), spectrometry (for gamma-emitters) and tracks in nuclear emulsions (for alpha-emitters).

Special radiochemical techniques have been developed to facilitate determination of the quantity of radionuclides present in the excreta, particularly the urine.

The method adopted for such examination must meet certain requirements: in particular it must be specific, sensitive, accurate and rapid. These conditions are, however, seldom fulfilled by any one technique.

Often variants exist for different radionuclides. Methods which are very highly sensitive but complex in application are used for occasional but extremely important examinations (e.g. following an accident). Other methods, less accurate and less sensitive but easy to apply, are suitable for routine examinations. A list of methods of particular importance for medical toxicological analyses has recently been prepared by the World Health Organization.\(^5\)

In the great majority of cases examinations are carried out on urine samples. The results can be used either to prove the existence of even a very slight degree of internal contamination resulting from normal working conditions or to determine the degree of internal contamination following an accident. It may be supposed that elimination takes place according to a simple exponential law and that contamination has occurred in a regular manner and finally reaches a certain equilibrium. Given such conditions, the body-burden of an individual for a particular radionuclide may be determined from the radioactivity of the excreta. Such conditions are, of course, ideal; the nearest approach to them is in cases where isotopes are absorbed in quantities that vary little from day to day and are eliminated very slowly. On the basis of the fraction excreted per unit time, the total body-burden of the organism may be estimated with some accuracy. In most cases, however, the nuclides are eliminated in a manner
which does not facilitate estimation of the total body-burden. In such cases the concentration may be expressed in terms of a range, indicating either that a small fraction of the maximum permissible quantity of radionuclides may have been retained in the organism and that investigations should therefore continue, or that a larger proportion has been retained and that urgent examinations and appropriate action are consequently required. When applying the method in cases of accidental contamination, interpretation of the results is easier, in so far as the time and conditions of the accident are generally sufficiently well known. It is usually possible, on the basis of several analyses made at definite times, to evaluate the initial body-burden for the contaminating radionuclides. However, the difficulties of furnishing a sufficiently accurate estimate of the body-burden on the basis of the quantities eliminated in the excreta should always be borne in mind.

(iii) Indirect evaluation of internal contamination based on environmental monitoring

It is also possible to evaluate internal contamination indirectly from the quantity of radionuclides assumed to have entered the organism with incorporated substances (water, air, etc.). The body-burden resulting from ingestion or inhalation of radioactive substances contaminating the environment may be calculated by reference to the contamination of the latter. This approach is particularly applicable in the case of atmospheric pollution, which is by far the most important for purposes of industrial hygiene. Two methods of evaluation may be used: the first is a rough method intended to give warning, and the second, which is more precise, is applied in case of persistent contamination.

The rough evaluation method consists of taking nasal swabs. Filter paper on holders is used for swabbing and is then unrolled for monitoring of the alpha or beta/gamma activity. What is being measured is in fact the easily removable part of the nasal contamination, and it is of course obvious that the results obtained are vitiated by a high degree of error. Furthermore, numerous factors, such as the physico-chemical form of the substances polluting the atmosphere, are ignored. However, if considerable levels of activity are found on the nasal swabs, it may be inferred that appreciable radioactive pollution has occurred, but not necessarily that it has been converted into internal contamination. A warning system of this kind makes it possible for any radiotoxicological or spectrometrical examinations that are necessary to be undertaken at a later stage.
A more precise evaluation of persistent internal contamination can be made entirely indirectly from the results of environmental monitoring. If the contamination of the atmosphere at any place and at any moment is sufficiently well known in respect of a given worker, the quantity of radionuclide absorbed by inhalation can be deduced from those data. An attempt is therefore made, by judicious frequent sampling, to obtain a sufficiently accurate picture of the atmosphere of the work place, a procedure which requires great skill and care. The method may be applied in uranium mines or radiochemical plants. For every worker, the type of work done and the time spent over each operation must be known, and as representative data as possible on the atmospheric pollution of the work place must be derived from samples in flasks or on filters and from continuous recording equipment. These data are weighted according to the type and duration of the work done by the individual concerned. By determining, for an average individual, the quantities of air inhaled and the modes of absorption, the body-burden at the end of a day, a week or a month may be deduced. These methods are undoubtedly capable of offering excellent cross-checks in determining the body-burden of radioactive substances difficult to measure directly and slow in elimination, as is the case with alpha-emitters such as radium or plutonium.

(c) Factors governing the choice of methods for measuring radioactive contamination

The measurement of the radioactive contamination of an individual still remains one of the basic problems facing radiological protection. While it is relatively easy to evaluate skin contamination, it is a more complex operation to estimate internal contamination by either direct or indirect methods. In addition, the methods used call for highly specialized material and personnel. Whereas continuous individual monitoring of the external irradiation of each worker should be insisted upon, only occasional individual monitoring for radioactive contamination can be regarded as a practical possibility. There should be two aspects to the latter: on the one hand, any normal work with unsealed radioactive sources should be accompanied by periodical measurements of external or internal contamination, the results of which should be compared with those obtained from area monitoring at the work place; and on the other hand, personnel monitoring should be carried out whenever an incident or an accident involving the risk of radioactive contamination has occurred. The results then determine to what extent, if any, contamination has affected the workers present.
(i) Spatial distribution

As with external irradiation, it is important, in any case of radioactive contamination, to know the spatial distribution of the dose. This can be determined relatively easily for skin contamination, but the spatial distribution of internal contamination is governed by the physico-chemical properties and the metabolism of the radionuclide. Acquaintance with the nature of the contaminating nuclide is therefore a prerequisite for determining the degree of irradiation of the different organs of the body.

(ii) Time distribution

Various factors affect the time distribution of the dose. These include the physico-chemical form in which the contaminating substance occurs, and the radioactive properties, particularly the half-life, of the radionuclides. Thus, in the case of skin contamination, a distinction must be made between the initial contamination and the residual contamination after treatment. In that of internal contamination, the radioactive substances move in the organism in accordance with their metabolism. The biological half-life may be defined as the time necessary for half of the radionuclide to be eliminated from a given organ or from the whole organism. The contaminating nuclides have also a radioactive half-life which is the time necessary for their radioactivity to fall to half of its original value. It is the combination of these two half-lives which represents the time necessary for the radioactivity in the organ or organism concerned to fall to half of its original amount and which is termed the effective half-life. It is therefore logical that particular attention should be devoted to evaluating contamination by radioactive substances which become fixed in the organism for a considerable length of time and have a long radioactive half-life. Irradiation extending over several years or even over the life-time of the individual may indeed occur, as is the case with the most toxic radioisotopes, such as those of strontium, plutonium, radium, etc.

(iii) Nature of radionuclide and extent of contamination

Sometimes the contamination is due to one radionuclide only, but it is very often multiple. A correct appraisal of the degree of irradiation of the organism and an accurate deduction of the probable consequences are possible only if the nature of the contaminating radionuclides is known. In dealing with skin contamination this is less important and it is often thought sufficient to estimate the contamination in terms of alpha and beta/gamma-emitting substances. This simplified procedure can also be adopted with internal contami-
nation, but here there is every advantage to be gained from determining the respective contribution of each of the contaminating nuclides.

From the foregoing remarks it will be apparent that the measurement of radioactive contamination remains an extremely intractable problem. The interpretation of readings depends on a number of arbitrary hypotheses regarding the geometrical conditions in the case of direct measurement of internal contamination, and regarding the basic laws of metabolism in that of indirect measurement from the excreta. Moreover, the radioactivity levels to be detected under normal working conditions are extremely low; while it is relatively easy to detect accidental contamination, it is very difficult correctly to assess regular contamination lower than the maximum permissible quantities of radionuclides in the organism.

C. ESTIMATION OF THE TOTAL ABSORBED DOSE

(a) Summation of external and internal irradiation

In the preceding paragraphs a description has been given of methods of evaluating irradiation, both from external radiation and from radioactive contamination. It is not an easy process to add together the dose values due to various types of irradiation, but an attempt to do so should be made whenever practicable, as there is a great difference between the readings for external radiation and those for radioactive contamination. It is relatively easy, with the help of continuously operating dosimeters, to obtain approximate estimates of the total radiation dose due to external exposure. Data on radioactive contamination, on the other hand, are highly incomplete, and indicate only the body-burden of radionuclides at a given moment. In theory, therefore, considerable interpretation work is needed in connexion with internal irradiation, although in practice such work is undertaken only if the exposure exceeds about 10% of the permissible concentration. However, the various types of irradiation should be added together as far as possible, and the results expressed in units valid for all types. These units are the unit of absorbed dose, the rad, and, when taking account of the relative biological effectiveness, the rem. It will therefore be necessary to convert to rem units results obtained in roentgen units or curies or in terms of particle flux.

(b) Effect of spatial distribution of the dose

Besides the problems involved in merely adding together the different types of irradiation, there are those of obtaining satis-
factory data on the spatial distribution of the dose. These latter can be obtained only by precise identification of the radiation and the radionuclides. This approach cannot be avoided, as the maximum permissible doses recommended by the International Commission on Radiological Protection (ICRP) have been established differently for whole-body exposure and for partial exposure affecting the skin or different organs. In practice, therefore, all types of radiation likely to result in a relatively homogeneous distribution of the dose within the body will be added together. Thus, the doses due to gamma and neutron radiation and to radionuclides considered as diffusing fairly uniformly in the organism (sodium, potassium, tritium, etc.) will together form one total. Separate totals will have to be made for the exposure of particular organs. To take as an example one of the most important cases, that of the bones and the bone marrow, it will be necessary to add together all the doses received by incorporation of bone-seeking radionuclides, such as radium, plutonium, strontium, etc., and by irradiation of the skeleton from generally diffused radionuclides (sodium, potassium, tritium, etc.). It is thus possible to determine by this method the doses actually received by the most important organs — skeleton, thyroid, skin, digestive tract, lungs, etc. Separate totals should also be obtained for exposure of the extremities, especially the hands, comprising the general exposure of the body and the particular additional exposure of the members in question. The concept of spatial distribution of the dose therefore leads us to consider different kinds of exposure, either of the organism as a whole or of some part of it. Although it might appear advantageous to evaluate the integral absorbed dose, this is in reality of limited importance, as no maximum permissible level has yet been established for the integral dose delivered to the whole body.

(c) Effect of time distribution of the dose

It is fully sufficient for dose-readings to be taken at intervals of some weeks or months, since the period quoted by the ICRP is 13 weeks. Measurements covering shorter periods are of value only for purposes of administrative convenience. As mentioned above, it is relatively easy to obtain adequate information on the circumstances of an external exposure. The wearing of direct-reading dosimeters and the use of personal or portable dose-rate meters make it possible to evaluate the fluctuation of radiation in the course of time. The procedure is more complex in the case of radioactive contamination and it is often difficult to deduce the irradiation received over a
period from a given degree of radioactive contamination. The hypothesis normally adopted is that there is an exponential decrease of the dose in time; this is expressed in terms of effective half-life. It will thus be seen that the precise determination of the time distribution of the absorbed dose is not simple.

(d) Influence of the type of radiation and radionuclide

In addition to the spatial and time distribution of the absorbed dose, the type of radiation also has its part to play in the origin of radiobiological effects. It is therefore necessary to use relative biological effectiveness (RBE) factors for alpha, beta, gamma and neutron radiations; only thus is it possible to determine the sum of the doses in rem. It must not be forgotten, however, that the RBE factors depend on a very large number of variables besides the type of radiation, including the circumstances of the exposure, the nature of the effects produced, etc.

D. Summary and conclusions

Personnel monitoring should be carried out to determine the levels of external radiation and of radioactive contamination to which the worker has been subjected. The methods described in earlier paragraphs are to be applied for this purpose.

(a) Monitoring of external exposure

Individual dosimeters yield adequate data; they should be worn continuously, and the exposure checked at appropriate intervals. Measurement of total beta, gamma and neutron-activity should be systematically performed and the results should also distinguish between the gamma, beta and neutron fractions. Doses expressed in roentgen units or in terms of particle flux should be converted into rem units to indicate accumulation. Film dosimeters can be developed at intervals of from one to thirteen weeks, depending on the nature of the hazard and on administrative conditions. The current practice is to carry out weekly readings, but there is no objection to making them on a monthly or quarterly basis only, since these readings in fact indicate only the dose accumulated during a relatively short period, a week or a month for example.

If a worker is exposed to a significant irradiation hazard in connexion with which the limitation of working time is used as a method of controlling exposures, it is then advisable to use direct-reading monitors such as pocket electrometers. Readings can then be made daily, hourly or at any required moment, after a particular operation.
The data yielded by this second category of dosimeter should normally be collated with those derived from the type mentioned previously. Comparison of the two kinds of data normally gives excellent results.

In the external exposure record of each worker all doses are entered and added together so as to give the accumulated dose-time curve. From this curve it can be decided whether the exposures received are compatible with the maximum permissible dose formula recommended by the ICRP.

The above data on whole-body exposure should be supplemented by information regarding partial exposures. For this purpose monitors should be worn in the region of the hands or the fingers whenever a predominant exposure of the extremities may occur. The results are recorded separately.

(b) Monitoring of radioactive contamination

As regards skin contamination, the work is relatively easy, and the detectors already described are capable of registering contamination by both alpha and beta/gamma-emitters. The frequency of this monitoring should be governed by the extent of the contamination hazard. Wherever unsealed radioactive sources liable to produce an appreciable amount of surface contamination are handled, monitoring should be carried out daily or even twice daily, after each half-day's work. Workers should normally wash before using the monitoring instruments in order to safeguard the latter from contamination, and the measurement made is therefore of residual contamination after washing. When normal washing procedures are ineffective in removing the contamination, and decontamination under medical supervision has been resorted to, the exposure readings obtained must be entered in the records. Maximum permissible levels have not been definitively established by the ICRP; however, the tables appearing in Appendix II of the Manual may be referred to as an indication.

For internal contamination, monitoring should be carried out periodically, the frequency again depending on the extent of the hazard. Thus, for work with radioisotopes used as tracers, annual monitoring is sufficient, while for operations involving substantial quantities of isotopes twice-yearly, quarterly or even more frequent surveys should be undertaken. Finally, any accident or occurrence as a result of which appreciable radioactive contamination is suspected must be followed by obligatory monitoring. As has already

* "Safe Handling of Radioisotopes", IAEA, Vienna, 1958, pp. 95 ff.
been seen, various direct or indirect methods may be used. Gamma-spectrometry should make it possible to carry out periodical surveys fairly easily so as to evaluate the body-burden of gamma-emitting nuclides. It should, however, be noted that this is a highly advanced and expensive method which will become generally applicable only in the course of time. Radiochemical analyses of the excreta, particularly the urine, are therefore preferred. A knowledge of the radionuclides with which the given individual is working makes it possible to determine the kind of examination required. However, these examinations need only be made at present in respect of persons exposed to considerable internal contamination hazards. In certain cases, as has been described above, it is possible to determine the quantities of radionuclides likely to have been inhaled on the basis of the contamination of the atmosphere and the conditions of work. All these readings for internal contamination of the worker should permit the calculation of total annual figures, indicating the dose received by the individual as a whole and by particular organs. Obviously this can be done only if the number of contaminating radionuclides and the contribution of each to the dose is known.

(c) Monitoring of whole-body irradiation

By recording the external radiation doses and the quantities of internally-deposited radionuclides it should be possible, by addition, to arrive at the total dose. However, this can be no more than an approximation, because, although relatively accurate data are obtainable on total or partial external exposure, it is a more complex operation to derive precise figures on total internal contamination or the dose delivered to a particular organ from internal deposition. Therefore, when the level of internal contamination is not too high, it is usually thought sufficient to obtain exact data regarding external exposure and summary indications concerning internal radioactive contamination. However, in cases where considerable radioactive contamination has occurred, or where the hazards associated with the work are sufficiently great, the utmost should be done to establish such total doses, since they alone make possible a full evaluation of the risks incurred by a worker through exposure. As radiochemical analysis and spectrometry methods develop, progressively better results may be expected.
A. Responsibility and Duties of the Medical Service

The medical service is responsible for the medical aspects of the radiological health programme. This includes the proper selection of personnel for work involving actual or potential exposure to ionizing radiation (pre-employment medical examination), medical examinations during employment and, preferably, thereafter, special laboratory and other medical tests for persons exposed at or above maximum permissible levels, and diagnosis and treatment of radiation injury in cases of accident. Finally, an additional reason for health surveillance is to demonstrate over a long period the normality of the incidence of disease in groups of people exposed to radiation within the permissible limits.

Medical officers should therefore be acquainted with the duties of workers and with the radiological hazards to which the latter may be exposed. They should ascertain that levels of exposure to these hazards are in accordance with the standards and regulations in force, and should keep, or at least have access to, all records of workers' overall exposure and radioactive contamination. In addition, they should carry out general and special medical examinations in order to detect any disorder or affection which might be due to ionizing radiation. With the aid of adequately kept health records, comparative studies should be made of the results of personnel monitoring and medical examinations, with a view to establishing causal relationships whenever pathological disturbances appear.

In cases of accident, the responsible medical officer must take the necessary decisions. If there are no detectable clinical symptoms and the total irradiation of the body is less than 3 rem, a simple warning may be sufficient. If the total irradiation has exceeded 3 rem, the removal of the worker from exposure to any irradiation hazard for a time sufficient to meet the requirements of the general formula recommended by the ICRP should be arranged. If detectable clinical symptoms are found, arrangements should exist to permit the individual to spend the necessary period for recovery outside the range of any radiation source, either by transfer to another post or by temporary or permanent suspension from work. In addition, first aid and other treatment should be given where necessary, as set forth in chapter 3.

The medical service should take part in instructing workers during
employment, with a view to ensuring a continuous increase in their knowledge of radiological protection.

The duties of the medical service can be adequately fulfilled only provided extremely close collaboration is established with the service responsible for physical monitoring of radiation. The medical service should indicate the general rules to be observed and request that the necessary physical surveys be carried out. It should be provided with all personnel monitoring data and should also be given such information about the general working conditions as will enable it to determine the extent to which work places are subject to exposure and contamination. The closest liaison must also be established between the medical service and the management of the establishment.

In general, the activities of the medical service should be regarded as confidential, concerning as they do data of a personal nature. This confidential character must, however, in no way form an obstacle to the improvement of working conditions. The importance of health records, standardized in such a manner as to permit their use for statistical purposes, should consequently be stressed.

Furthermore, the confidential character of the activities of the medical service should not have the effect of obstructing exchange of information on the irradiation to which workers have been subjected or on their state of health. In particular, if a worker changes his employment, provision should be made to communicate useful data. The formulae recommended by the ICRP apply continuously to the worker's entire occupational activity. The fact, also, that the latent period between the exposure and its pathological effects may extend over several years requires that medical records be preserved for an adequate period after cessation of employment, and that the medical service have access to them.

B. Medical examination

As was suggested under A above, radiation workers should undergo medical examinations before, during and, preferably, after employment. These examinations do not differ basically from those adopted in good industrial medicine, but reflect certain medical requirements specific to radiation work. A general review of the different types of examination is given below, preceding the sections on their use at the various pre-employment, employment and post-employment stages.
(a) History

Every medical examination should begin by careful questioning regarding the family, personal and occupational history of the worker.

(i) Family history

Family history is of importance because genetic disturbances are a significant part of the possible effects of irradiation. Particular attention should therefore be given to any history of hereditary, family and congenital diseases, and it is also useful to know the incidence of cancer and leukaemias. The investigations should relate to ascendants (parents and grandparents), collaterals (brothers, sisters and cousins), descendants (children) and also the spouse and his or her direct ascendants.

(ii) Personal history

Accurate data on the worker's personal history are important, facilitating as they do an evaluation of his state of health before employment. Care should be taken to investigate all disorders which may have affected organs or organic functions that are particularly radiosensitive or liable to damage as a result of work with radiation. The investigations should therefore be made to bear on haematological diseases (anaemia, granulopenia, haemorrhagic diathesis), skin diseases (dermatitis, dermatoses), diseases of the digestive tract (acute, chronic), diseases of the lungs (infectious, allergic) and diseases of the eyes (cataract, conjunctivitis).

(iii) Occupational history

Finally, the worker's occupational history should be carefully noted. Injuries at work and previous occupational diseases should be recorded. However, the history of any work done with radiation or with radiomimetic substances presents the greatest interest, and any occupation involving radiation exposure and, in particular, any cases of over-exposure or of radioactive contamination should therefore be faithfully recorded. Previous work with benzene, other hydrocarbons and all other carcinogens or mutagens must also be carefully noted.

(b) Clinical examinations

General examinations should be such as to give a proper picture of the worker's state of health. A detailed description of such examinations is unnecessary here, since the investigations usually made in good industrial medical practice should be sufficient. Thus, anthropometrical data (weight, size, morphology) and the results of examin-
ation of the main organs and functions (cardiovascular system, digestive system, respiratory system, nervous system and endocrine glands, blood and haematopoietic organs, liver and kidneys, locomotor system, skin and sense organs, genital system) should be recorded.

These examinations should be supplemented by radiological examinations and biochemical tests of the main blood constants and urine characteristics. The fact that the workers in question are exposed to irradiation hazards is no reason for neglecting to make the necessary radiological examinations (lungs and other).

In the medical care of radiation workers, it is of course the most radiosensitive organs and their functional and morphological condition which present the greatest interest. It will therefore be necessary to give particular attention to the blood and blood-forming organs, the skin, lungs, digestive tract, sense organs and genital system, as described below.

(i) Haematological examination

It should be remembered that the sensitivity of ordinary haematological methods of examination is grossly insufficient for the detection of radiation effects at levels at or moderately above maximum permissible levels. However, the purpose of these examinations is on the one hand to provide a general picture, and on the other to detect the smallest anomalies of the blood possibly due to radiation. Investigations should cover both the peripheral blood and the blood-forming organs, but for all regular inspections before or during employment it is, of course, recommended that examination be confined to the peripheral blood only. Examination of the blood-forming organs proper should be considered only in cases of over-exposure or of considerable radioactive contamination.

Examinations of the peripheral blood include blood counts and also the study of morphological or functional changes in the blood cells. The blood counts should give the number per cubic millimetre of erythrocytes, reticulocytes, total leucocytes (neutrophils, basophils, acidophils, lymphocytes, monocytes) and thrombocytes. In addition, Arneth's formulae for overall leucocytes and for granulocytes should be established. However, in calculating the effect of radiation on numerical change in the white blood count, account must be taken of the fact that the day-to-day variation of an individual's white blood count has been estimated at about 15% and the technical error in an average case is about 10% even with carefully standardized techniques. Blood changes only become manifest with relatively
high doses, and consequently cannot be used as a sensitive test to evaluate the effects of moderate or low-level irradiation. Attention should also be given to morphological changes such as anisocytosis and poikilocytosis in erythrocytes, abnormal cytoplasmic granulation in granulocytes, bi-lobed nuclei and chromophile granulation in lymphocytes, and changes of size or structure in thrombocytes. A careful watch should also be kept for immature forms of the red or white series. These examinations may be supplemented by tests of the functional capacity of the circulating blood. It is of especial value to determine the haemoglobin-concentration, haematocrit-reading and blood-coagulation factors. These haematological examinations should be made before employment and at sufficiently regular intervals during employment to follow trends in a given haematological condition. However, some of these examinations, such as those regarding morphological changes, can only be carried out in research laboratories and are not indicated as routine measures.

The same holds true for examination of the blood-forming organs, which should be carried out only in cases of over-exposure. It is advisable in this case to perform a sternal puncture to obtain a myelogram, including count and formula. This test is of particular interest if a prognosis has to be made, or therapeutical indications given for an over-exposed worker. Occasionally, and much more rarely, adenograms may be made in addition.

(ii) Examination of the skin

Dermatological examinations are of value in that they provide information on the state of an organ which, generally speaking, is sensitive to radiation and, moreover, runs the greatest risk of exposure. In all cases of exposure to soft radiation, such as beta-rays, the skin in fact absorbs almost the entire amount. Also, in handling radioactive substances, the skin of the hands is exclusively or at least primarily exposed. It is therefore advisable to make a survey of the condition of the skin, especially with a view to detecting the chronic dermatoses which increase its radiosensitivity. In addition, particularly careful examination should be made of the hands and fingers in order to evaluate the functional or morphological changes possibly occurring as a result of chronic irradiation. Thus, the regular taking of fingerprints provides an indication of progressive deterioration of the contour of the skin and of affection of the epidermis as shown by flattening. A study of the capillary circulation also provides valuable data on subjacent affection of the dermis and of the conjunctive tissue. Finally, a precise tactile examination may usefully supplement the two previous examinations.
(iii) Examinations of the eyes

The eye is generally regarded as a critical organ. The crystalline lens is indeed particularly sensitive to external radiation consisting of relatively heavy particles, such as neutrons, protons, etc., the lesion to be sought in this case being a progressively developing cataract. It is therefore indispensible to determine the condition of the lens in all workers who may be subjected to considerable external irradiation by neutrons or heavy particles. In the case of over-exposure to such radiation, a careful watch on the condition of the lens must be kept.

The eye may also be exposed to radioactive dust and consequently show changes of the conjunctiva or of the cornea. It is therefore also necessary to make a careful examination of the protective coating of the eye.

Finally, an examination of the vitreous body and the fundus should be made, although this is of lesser importance.

(iv) Mouth, ear, nose and throat examinations

Where workers are exposed to the risk of radioactive contamination, in particular by pollution of the atmosphere, the upper respiratory and digestive tracts are the first to be contaminated. Radioactive particles may remain for some period in contact with the mucous membranes of the mouth, the nose and the pharyngolaryngeal region. This may lead to local irradiation and disorders of the epithelium which can be detected by regular examination. Therefore a mouth and ENT inspection should be made periodically, and an immediate examination effected in case of an accident involving significant radioactive contamination.

(v) Examination of the lungs

Examinations of the lungs are generally carried out on a regular basis in industrial medicine in view of the high incidence of diseases of the respiratory system. They are particularly necessary whenever work is done in a polluted atmosphere, whether or not the pollution is radioactive, and they should therefore be carried out on persons engaged in work involving risk of contamination from that source. The information sought should indicate the morphological and functional condition of the lungs; particular attention should be devoted to detecting conditions of fibrosis or of emphysema, and the vital capacity and other lung functions should be tested.

(vi) Examination of the digestive tract

The digestive tract is recognized as one of the critical organs, as it is often heavily irradiated during inhalation or ingestion of radio-
active substances. It should, however, be recognized that, unlike the preceding case, the digestive tract does not lend itself readily to examinations likely to reveal small changes in its structure or functions.

(vii) Examination of the liver and kidneys

The important role played by the liver and kidneys as organs of excretion in general and of elimination of radioactive substances in particular is well known. It is therefore useful to have information on the functional status of these organs in a case of regular or accidental radioactive contamination. Liver and kidney, however, cannot be expected to reveal the effects of even a significant degree of irradiation, as their radiosensitivity is too low as compared with that of other organs.

(viii) Examination of the genital system

The study of the gonads has a double significance — both genetic and somatic. The genetic effects of irradiation can of course only be evaluated in the descendants, but in the somatic field it is possible to point to immediate consequences. The spermatogenic function is extremely radiosensitive in the male, so much so that its study is a particularly valuable test for evaluating the radiation dose absorbed. However, for various reasons, such examinations cannot be carried out systematically. They should, however, be made in all cases of significant over-exposure, when a count of the spermatozoa and a study of their morphological and functional changes are called for. Particular care should be given to the detection of abnormal forms, abnormal nuclei, caudal bifidity and motility disturbances, and also increased fragility.

In the female, however, the effects of irradiation are much more difficult to detect and disturbances of the menstrual cycle become evident only at very high doses.

(ix) Neurological examination

The effects of radiation on the nervous system at relatively low levels are mainly functional. Low-level irradiation may, according to some authors, lead to certain disturbances, the transitory nature of which, however, makes the practical application of functional tests impossible. In the case of a whole-body exposure, it is, nevertheless, of undoubted value to study the electro-encephalogram etc. for neurological changes.

(x) Biochemical examination

The purpose of biochemical examination is to study general or particular changes of metabolism and especially those more or less
specifically connected with an instance of irradiation. The determination of the main blood or urine constants is of relatively secondary interest, with the exception of urea excretion, but even here after very high radiation doses only. However, the urinary excretion of aminoacids is highly important, any significant irradiation being followed by an increase of aminoaciduria, and it is particularly recommended that the nature and quantity of excreted aminoacids be determined by chromatographic analysis. In cases of over-exposure additional aminoacids appear and the quantities eliminated increase significantly. For certain aminoacids, such as aminoisobutyric acid, the quantities eliminated are proportionally related to the dose received and determination of them is, therefore, of the greatest value. This examination should be carried out for every worker liable to significant over-exposure, with the aim of establishing a base-line of aminoacid excretion; the excretion rate should then be checked regularly. Since aminoaciduria can be a constitutional abnormal condition, it is not possible to draw any precise conclusions from aminoaciduria discovered following an over-exposure unless the preceding levels of aminoacid excretion are known.

Useful blood examinations may also be made, particularly enzymological examinations, but they still belong to the field of research. However, immuno-electrophoretic examination of the plasma may have real value in cases of over-exposure.

(c) Pre-employment examination

Before any worker liable to exposure to radiation is engaged, a report should be established to serve two purposes; firstly, to serve as a basis for determining to what extent the past history and the present condition of the worker render him fit for the type of work involving exposure to radiation for which he is being considered; and secondly, if he proves fit for such work, to serve as a reference point for any subsequent changes due to the hazards of that work. Every worker should therefore undergo a pre-employment interview and medical examination.

(i) Pre-employment interview and assessment of the worker’s health

As explained above, the interview has the purpose of determining the candidate’s hereditary, personal and occupational history. It is of particular importance that all previous irradiations be noted, for which purpose an account should be kept of external radiation doses received, and an attempt made to obtain as much data as possible
on any radioactive contamination. A gamma-spectrometrical exami-
nation may be useful for evaluating the present body burden of
gamma-emitting nuclides. In the analysis of previous exposures, a
distinction should be made between those due to work with radiation
and those due to radiological examinations or treatments. The former
must be taken into account later, during employment, for the assign-
ment of maximum permissible limits. The latter, however, should
be ignored when determining the accumulated dose, although they
should still be carefully noted. In some cases, especially after exten-
sive radiotherapy, an additional occupational exposure may seem
inadvisable. Only the medical officer, however, is qualified to deter-
mine to what extent such previous therapeutic irradiations are com-
patible with subsequent work involving radiation hazards. All pos-
sible occurrences of earlier poisoning by radiomimetic substances
must also be recorded. Although it is difficult to establish a suffi-
ciently precise relationship between the effect of radiomimetic sub-
stances and that of radiation, there is no doubt that previous in-
toxication, especially by hydrocarbons, may be a factor in not allow-
ing a worker to engage in work connected with radiation. In this
respect again, each case must be considered individually, and it is
for the medical officer to decide to what extent disturbances due to
chemical radiomimetic agents may contra-indicate subsequent work
involving exposure to radiation.

(ii) Medical examination

A complete medical examination should be carried out, preferably
not more than two months before engagement, and should comprise,
as explained above, a general examination comparable to those made
in industrial medicine and special examinations of the most radio-
sensitive organs. The former indicate the candidate’s general fitness
for employment, and the latter aim at determining to what extent he
is fit for the special work, involving risk of external irradiation or
radioactive contamination, upon which he is to be engaged. The
special examinations should therefore be exactly adapted to the kind
of work for which the candidate is intended. The following remarks
may be taken as a guide. If there is to be any risk of whole-body
exposure or general contamination, a detailed haematological exami-
nation should be made. If there is any likelihood of exposure to
soft (beta) radiation, of skin contamination (alpha and beta-emitters)
or of manipulation of radioactive substances by hand, a dermato-
logical survey should be made, supplemented by a careful exami-
nation of the hands and fingers. The risk of atmospheric pollution
is extremely high if unsealed sources are handled, and in this case, particularly if pollution by radioactive dust is involved, an examination of the lungs should be carried out to reveal any morphological changes and to check the vital capacity of the respiratory system. If the work involves exposure to neutron radiation or heavy particles, the condition of the crystalline lens should be determined by ophthalmological examination. Further instances could be given of how the special medical examinations should be adapted to particular exposure or contamination risks. It is therefore advisable for the medical officer to have at his disposal an occupational hazard record, as described below.

(iii) Conclusions and decisions

The interview and the general and special medical examinations should yield conclusions regarding the candidate's fitness for a given type of work. Candidates are classified on the basis of a number of criteria, the choice of which is an extremely delicate matter. Clear-cut standards for judging a candidate's fitness are highly desirable, and in some fields such standards now exist. Blood-count values are those that have been most generally fixed, but they vary from country to country depending on geographical, physiological and biological conditions and on the techniques used.

In addition, the amount of subsequent irradiation which the worker may be allowed to receive can be estimated from the total dose received during previous occupational exposure, using the formula $D = 5(N - 18)$, as recommended by the ICRP. It should, however, be recognized that the medical officer will normally be responsible for determining the fitness or unfitness of the worker. Poisoning by radiomimetic substances or excessive therapeutic irradiation may give grounds for hesitation regarding an individual's fitness. As far as medical examinations are concerned, it is impossible to define quantitatively the limits beyond which skin disorders, morphological or functional changes of the lungs, slight abnormalities of the lens, etc. should contra-indicate work involving the risk of skin contamination, atmospheric pollution or neutron irradiation respectively.

In all cases decisions must be based on both the case history and the results of the medical examinations. Candidates are, as a rule, classified in three categories: individuals placed in the first category are considered fit for work involving the risk of external exposure or radioactive contamination; those in the second are considered temporarily unfit for such work; candidates in the third category are declared permanently unfit. Persons placed in the second category
should remain under medical observation for a certain period, during which further examinations are carried out to determine whether an improvement in their condition will render them fit for the employment intended. It should be stressed that a final decision of unfitness should only be taken after several confirmatory examinations. Conclusions and decisions should be recorded in the worker’s medical file, as described below.

(d) Supervision during employment

As already stated, the supervision of workers during employment should consist of personnel monitoring and medical examinations.

(i) Personnel monitoring

This should be carried out in the manner described in Part I of this chapter (see in particular the summary and conclusions, pp. 40 — 42).

(ii) Medical examinations

During employment medical examinations should be carried out at regular intervals. Exposure or contamination may in fact sometimes easily remain unnoticed, and consequently efforts must be made to detect them. On the other hand, changes in an individual’s state of health may occur and may be ascribed to ionizing radiation, while they are in reality due to other causes. Even so, they provide a reason for taking the individual off any work involving considerable exposure and contamination hazards. All these factors therefore point to the advisability of regular medical examinations during employment, their nature and frequency of course depending on the occupational hazards involved. It has already been fully explained in preceding paragraphs that these examinations should comprise general investigations supplemented by special inspections of the organs likely to be most affected by external exposure or radioactive contamination. The frequency of these examinations will naturally vary: the minimum should be one examination per year, and the optimum frequency depends on two factors. Firstly, the occupational hazards have to be taken into account, as regards both their nature and their extent. In this respect, the occupational hazard sheets referred to below play an essential role. The extent of the hazards may be judged from the results of area monitoring of radiation and radioactive contamination levels at the work place. Secondly, the frequency of examination should be governed by the state of health of the worker concerned. In the case of workers in whom a particular organ shows morphological changes or signs of functional disorders, the examinations should, of course, be carried out at more frequent intervals.
(e) Post-employment follow-up

The effects of ionizing radiation always become manifest after a certain latent period. In the case of acute irradiation, and for certain disturbances, this latent period may be as little as a few hours or days. However, in exposures spread over a period of time, and in most cases of radioactive contamination, the effects only become apparent at the end of several weeks, months or years. Even in the case of acute exposure, accidental for example, certain disorders, such as secondary cancer formation or the induction of leukaemias, may appear only after several years have elapsed. It is therefore important to provide follow-up care of workers after employment has ceased.

This follow-up care will not, of course, include physical monitoring, except possible gamma-spectrometrical measurements in cases of an abnormal body-burden of gamma-emitting nuclides. It is theoretically desirable that it should include some type of medical examination intended to detect late effects of ionizing radiation: in this connexion a special watch should be kept for long-term changes of the skin, eyes and blood in particular. Furthermore, the detection of neoplasms should be an important preoccupation in all cases where excessive irradiation may have occurred.

This post-employment follow-up care raises, of course, the question of occupational diseases due to ionizing radiation. As stated in connexion with accidents, it is in most cases extremely difficult or even impossible to establish a causal relationship between occupational irradiation and the detected change. Only statistical methods applied to groups of workers subject to ionizing radiations offer prospects of obtaining significant data on possible increases in the incidence of given disorders.

Part III. Health Records

The well-organized supervision of workers exposed to ionizing radiation is inconceivable without systematic and accurate records of all the data yielded by physical monitoring and medical examinations. The data in question are of course those relating to the individual worker himself. Consequently, readings obtained from environmental monitoring (environmental radiation, contamination of air and water) should not be recorded, but all data on exposure of the individual (film badge and electrometer readings, skin conta-
mination, internal contamination) should be included in the worker's file together with the results of the medical examinations undergone. These data constitute individual health records which must be kept under conditions of medical secrecy as defined by the competent authorities of each country.

The health records consist of: job assignment and occupational hazard sheets, from which can be inferred, in respect of each worker, the working conditions to be established and the radiation and contamination hazards to which he may be exposed; health files containing all data yielded by physical monitoring and medical examination before, during and after employment; and, preferably, a separate register of accidents or occupational diseases due to ionizing radiation.

A. JOB ASSIGNMENT AND OCCUPATIONAL HAZARD SHEETS

Each worker's file should contain a record of the posts held by him, and it is therefore useful to introduce what may be termed a job assignment sheet. This document is started when the worker is recruited for the first post held, and should indicate all changes of post. Such information is basic, and if it is desired to determine a worker’s contamination level by the indirect method of calculation from the pollution level of the work place, the time spent at each job must also be indicated. From the administrative point of view this may entail a considerable amount of work, and a compromise solution must sometimes be adopted. However, it is the only relatively accurate means of evaluating internal contamination by deduction from the working conditions.

This job assignment sheet should be supplemented by an occupational hazard sheet providing information on the hazards of external exposure or radioactive contamination involved in each operation. These records should be kept with great accuracy, as they represent the only possibility of establishing a causal relationship between occupational activity, radiation levels and the workers' state of health. The occupational hazard sheets should be suitably amended whenever the working conditions change.

B. HEALTH FILES

Health files should include all available evidence for evaluating workers' radiation exposure or contamination on the one hand and their state of health on the other.
Before actual recruitment the file should include:

(a) the results of the interview;

(b) data on previous occupational exposure and, as appropriate, on other considerable non-occupational irradiation or exposure to radiomimetic substances, together with a statement of the level of internal contamination where this is thought to be advisable;

(c) the results of the pre-employment medical examination to determine fitness for work involving exposure to radiation.

During employment, the individual file should contain, in the first place, a record of the physical monitoring results. They should be entered in such a way as to facilitate summation of the doses received from external exposure and radioactive contamination. It should be possible to determine in this manner the dose accumulated after three months, six months or a year. The record should also make it possible to determine at any moment, by means of a graph, whether the dose received in the course of the preceding quarter has remained within the maximum permissible level (3 rem in the case of a whole-body irradiation). The individual file should also contain an account of the worker’s medical supervision, particularly the special examinations. Only significant and positive facts revealed by the examination should of course be recorded. Comparison of the two sets of data will be made with a view to establishing possible causal relationships between health disorders and occupational exposure. It may be pointed out that for most radio-pathological effects where a threshold dose exists, it is possible to establish such a causal relationship: e. g. skin disorders can be easily related to radiation exposures of known level. For individual cases it is, however, impossible to establish a causal relationship between a disturbance where a threshold dose does not exist and a given exposure; thus one cannot, in an individual case, relate with certainty an occurrence of leukaemia to previous exposures.

After cessation of employment, the file should present on the one hand a record of the exposure and contamination to which the worker has been subjected during employment and on the other a record of his health. The doses received from external exposure or radioactive contamination should be added together year by year and a grand total found. If an accident has occurred, the circumstances should be recorded together with the doses received. A summary of the results of the medical examinations, both general and special, should be included. Special mention must be made of any abnormalities that may be related to occupational irradiation. Finally, an in-
dication should be given of the worker's state of health on cessation of employment. This should be determined by a complete medical examination supplemented where possible by a gamma-spectrometry test to evaluate the body-burden of gamma-emitting nuclides.

If a worker is transferred to another establishment, it may be of value to prepare an employment termination sheet containing a very brief summary of the preceding data for the use of the medical service of the new establishment.

C. RECORDING OF ACCIDENTS

Any accidents which have occurred in the course of work should be recorded. It is often useful to classify them in special files. All cases of over-exposure, or skin or internal contamination exceeding certain limits, should be noted in this way. While it is of course difficult to assign these limits, it may be considered that, in the case of external irradiation, an over-exposure has occurred when the dose received by the whole body in one calendar quarter exceeds 3 rem, or 20 rem for the extremities. As regards radioactive contamination, it may be assumed that all cases where the resulting irradiation may exceed 3 rem in one calendar quarter for the whole organism or 4 rem for a particular organ should be noted.

It is often useful to include in accident records both the physical monitoring data and the findings of medical examinations. In particular, all medical examinations made following an accident, together with their results and the decisions taken, should be mentioned.

D. SUMMARY AND CONCLUSIONS

The individual files make it possible to trace the radiation exposure and the state of health of each worker. They should be prepared in a manner sufficiently logical and clear to permit use of the data derived from them as a basis for statistical studies. It is therefore strongly recommended that an attempt at harmonization or even standardization in this field be made. It would indeed be extremely helpful if these individual records were to assume a comparable or identical form making for easy use as statistical material. In particular, all useful evidence with regard to both physical monitoring and medical examinations should be included. This is the only means of estimating the contribution of the doses received by the working population to the genetic dose for the population as a whole.
3. RADIATION ACCIDENTS

A. General principles

It is highly advisable to plan in advance all work with radioactive isotopes and to establish correct modes of procedure by rehearsal or preliminary conduct of the entire operation without the use of the radioactive substance.

If external or internal contamination of persons occurs, it is the duty of workers to bring the accident to the notice of the radiological health and safety officer (see Manual), who will then summon the physician or health and safety team (see below), who will in turn immediately proceed to take the necessary measures in cooperation with him.

Depending upon the nature of the accident and/or the degree of contamination, the radiation dose should be estimated in cooperation with a physicist, and decontamination measures put into operation as soon as possible. Much depends upon action being taken as soon as possible, e.g. within the first half-hour following the contamination, whether external or internal, since within that time it is still possible to take sufficiently effective preventive measures against internal contamination or contamination from wounds.

In most cases decontamination measures ought to be taken on the spot. Immediate hospitalization is appropriate only in cases of whole-body irradiation from external sources or when large wounds or other damage to extended areas of tissue occur.

The actual treatment of internal contamination or of radiation sickness needs great skill and care. The degree of success of such treatment is closely dependent on the time elapsing between the accident and the rendering of first aid and initial therapy. It is always to be borne in mind that medical procedures, particularly with the decontamination of persons exposed to bone-seeking isotopes (radium, strontium, etc.), have not so far been very successful.

In co-operation with the radiological health and safety officer, a team should be established at every work site, consisting of a physician and two health and safety workers, to provide first aid in case of accidents with radioactive materials. This team should be well instructed and trained for immediate action, and ought to have a knowledge of the principles of first aid in working with radioactive substances. Small laboratories which have no medical officer on the staff should enter into association with a physician or medical clinic.
where the availability of health and safety staff capable of rendering first aid in cases of radiological contamination and radiation sickness would be guaranteed.

The actual organization of first aid will necessarily be governed by the size of the work site and the type of isotope constituting a potential source of danger.

All workers handling radioactive substances must from time to time be given detailed instructions on the following points:

(a) The routine to follow in case of accidents with isotopes (i.e. summon the radiological health and safety officer and take all the other measures enumerated in the Manual);
(b) the first-aid measures which they should take pending the arrival of the physician or health and safety team; and
(c) the action to be avoided in order not to interfere with subsequent decontamination measures.

B. First aid measures

All immediate medical decontamination measures should preferably be performed by the physician or by a member of the health and safety team. In their absence the following action may be taken by laymen.

Radioactive substances should be removed as quickly as possible by washing or wiping with filter paper, absorbent paper, towels or cloths. The latter objects will then be regarded as radioactive waste.

Internal decontamination

In the event of ingestion of radioactive substances, the mouth must be rinsed out immediately after the accident, care being taken not to swallow the water used for this purpose, and vomiting may be mechanically induced. In cases of inhalation of a radioactive aerosol, first aid can be given by inducing coughing and blowing the nose.

Radiation from external sources

The immediate action should be to remove the victim outside the range of the radioactive source causing the injury.

It should be emphasized that any other first-aid action taken by laymen may interfere with subsequent medical action and must therefore be avoided.
C. Medical action in case of accidents

(a) Estimation of the dose or the degree of contamination

Evaluation of the radiation dose to which an accident victim has been exposed is generally difficult. It is easier in cases of external irradiation, where a reconstruction of the conditions of irradiation is possible, less easy in cases of external contamination and still more difficult in cases of internal contamination. It should be borne in mind that prompt evaluation of the dose received during external or internal contamination is most important, whereas evaluation of the dose from external irradiation may be postponed to a more convenient time.

It may be necessary in some cases to reconstruct the accident by placing a suitable dosimeter in the position of the victim under the same conditions of geometry and dose rate, for the purpose of making a reasonable estimate of the absorbed radiation dose.

Neutron dosimetry is effected by special methods based on induced radioactivity (e.g. Sodium-24 in the body). However, this procedure requires specially equipped laboratories. In a criticality accident, any metal objects present on the irradiated person should be retained with a view to calculation of the dose by the health physics staff.

In all cases of accidental external contamination, decontamination of the skin and removal of the contaminated clothing must be effected as quickly as possible. It would be an incorrect procedure to delay actual decontamination pending an exact evaluation of the dose received. After preliminary decontamination, it is desirable to search for further contaminated areas by means of suitable monitoring equipment. It will be understood from the foregoing that in the majority of cases of external contamination it is impossible accurately to determine the original degree of contamination.

Internal contamination may occur through inhalation, through ingestion or through wounds. In every case the nature and the approximate amount of the absorbed radioisotope must be estimated, and for this purpose the monitoring of nasal swabs and of the skin of the face may be of value.

Appropriate steps must be taken as quickly as possible for the decontamination of the respiratory and digestive tracts. The first half-hour may have a decisive bearing on whether it will be possible to restrict the passage of radioactive substances into the blood. De-contamination of the digestive tract offers some prospects of success. Once the more urgent therapeutic measures have been taken, the
concentration of radioactive substances in the urine, faeces and breath, etc. should then be determined.

Entirely different circumstances arise when the presence of external or internal contamination is confirmed after the lapse of a certain time. In such cases radioactive substances may have been transferred by the hands to various other parts of the body; it is then necessary to effect a careful monitoring of contaminated persons and of other persons who may have been in contact with them.

(b) Limitation of contaminated area

If there is a danger of the radioactive substances spreading from the contaminated area, the local contamination must be removed by means of absorbent material (filter paper, paper wadding, laboratory cloths, which are then to be treated as radioactive waste). If possible, the adjacent skin should be covered in order to avoid spreading the contamination. In all cases an uncontaminated open wound must be suitably covered. When decontaminating the face, care must be exercised to prevent the entry of radioactive substances into the mouth, nose, eyes or ears.

(c) Isolation of contaminated persons

Contaminated persons should not be allowed to come into contact with others if there is a danger of spreading the contamination.

It has always to be borne in mind that any movement of externally contaminated persons inevitably results in a considerable spread of contamination. The basic principle must always be to effect decontamination as far as possible on the spot or in adjoining premises. Only when immediate decontamination is impossible should the patient be conveyed to a more suitable area for further decontamination. Plastic sheets may be used to prevent contamination of the stretcher, ambulance, etc.

(d) Decontamination

(i) Handling of contaminated clothing

It is taken for granted that all workers handling radioactive substances wear the appropriate clothing. For low-level work, laboratory coats may be used. In work with higher levels of activity or with more toxic radioactive materials, the use of coveralls is recommended. The legs of these coveralls are closed and fit well into high rubber boots. Where there is serious risk of accidents, the use is recommended of clothing manufactured of plastic, which is easily decontaminated, and of a respirator suitable for use with supplied air.
Gloves of rubber or plastic materials should be worn for radiochemical operations. However, it is to be borne in mind that plastic gloves become electrostatically charged, and this may have undesirable consequences in work with dry radioactive powders, etc.

Work clothing must be monitored for the presence of radioactive substances at the end of every operation. If a high degree of contamination is recorded, the clothing must be removed and left until the acquired activity sinks to a safe level.

The radiological health and safety officer is to be regarded as a worker in a highly dangerous area. Consequently, throughout the decontamination procedure he must be careful not to become contaminated himself.

(ii) Decontamination of the skin

A prerequisite for effective decontamination of the skin is the observance of all rules governing work with radioactive materials. As a corollary, it is naturally essential to observe the basic rules of personal cleanliness, particularly cleanliness of the hands, which are the parts most frequently contaminated.

It must be remembered that rubber gloves are only an apparent safeguard against contamination, since they are easily torn. After considerable periods of work in rubber gloves, particularly in hot atmospheres, the skin of the hands may become considerably swollen, with the result that, if the gloves are damaged, radioactive substances gain easier access to the deeper skin strata. It is recommended that light cotton gloves, which absorb perspiration, be worn under the rubber gloves.

Persons suffering from even the smallest wound or abrasion on the hands, rhagade in the area of the nail-bed, or any other lesion of the skin, should be extremely careful in work with radioactive substances, even when wearing gloves.

The value may be pointed out in this connexion of water-proof dressings to protect very minor cuts and abrasions on the hands and forearms. It should be emphasized, however, that this procedure should be carefully supervised so that persons with cuts of any depth do not continue working.

In case of an accident, the contaminated gloves should be stored for subsequent monitoring to determine the degree of contamination. Decontamination of the hands themselves may be effected in accordance with the following procedures:

1. The contaminated region, particularly in the case of a small area of surface contamination, is first washed under a gentle
stream of water, to remove the surface layer of contaminating substances;
2. The hands are then washed with a good foaming soap and warm water for approximately three minutes. Care should be taken that contamination is not transferred to unaffected parts by the washing operation. The hands are then rinsed with clean water and dried with a paper towel, which is immediately discarded as radioactive waste. The hands are then monitored and the washing operation repeated if necessary;
3. If the result is still unsatisfactory, the hands should be scrubbed with a very soft brush and a large quantity of foaming soap, during which operation care must be taken not to abrade the skin. The hands are rinsed and monitored. In place of soap a detergent may be used.

It should be remembered that soap and water are at present the most practical means for the decontamination of hands;
4. Only when washing has proved insufficiently effective should recourse be had to chemical decontamination. A moderate degree of chemical decontamination can be obtained by application of titanium dioxide paste, which is prepared by mixing precipitated titanium dioxide (a very thick slurry never permitted to dry) with a small amount of lanolin. The paste is applied to the contaminated hand (after the more simple decontamination procedure has been carried out) and is left for approximately two minutes. The paste is then washed off with soap and water, if necessary with the assistance of a brush. (Epinephrine locally applied arrests skin absorption);
5. A further method is the use of ethylene-diamine-tetra-acetic acid (EDTAA), which is applied together with soap. The hands should be well rinsed with water after the application;
6. As a drastic remedy, recourse may be had to the use of potassium permanganate. A saturated solution of potassium permanganate is prepared, mixed with 0.2 N sulphuric acid. This mixture is applied to the hand, which is carefully scrubbed with a soft brush for not more than two minutes. This period should not be exceeded, as there is otherwise a danger of damaging the upper skin strata. The hands are then thoroughly rinsed with warm water, after which lanolin or cream is rubbed into the skin. Instead of the above procedure it is possible to use a simple solution of potassium permanganate, into which the hands are dipped and then rinsed in water. Should permanganate staining occur, this can be removed by a 5%
solution of sodium sulphite, which, however, should not be left in contact with the skin for longer than two minutes. It is also possible to apply the permanganate method to restricted areas for the removal of local contamination. In such cases it is recommended that a pad be used, dipped in the solution and, after use, regarded as radioactive waste;

7. The method of isotopic dilution may also be used for decontamination of the hands; e.g. in the case of contamination with radioactive iodine, radiostable potassium iodide solution is used. When there exists a stable isotope, this method is preferable to those listed under 4 to 6 above;

8. In no case should organic solvents be used for decontamination purposes, since they remove fat from the skin and facilitate the penetration of radioisotopes into the deeper strata of the skin.

In connexion with this subject, it is highly desirable to note that residual radioactivity somewhat higher than the conventional maximum permissible limits may be less hazardous than drastic means of removal.

(iii) Decontamination of wounds

Liquid isotopes are rapidly absorbed into the organism from a contaminated wound, in particular via the blood and lymphatics. With some isotopes, the contamination remains for a short time only at the site of the wound, and internal contamination of the body as a whole may ensue rapidly. On the other hand, in the case of isotopes in the form of insoluble particles, the radiation has a predominantly local effect and, where the isotopes are retained in the body for a long time, may give rise to inflammation or necroses in the area surrounding the wound and render the latter more liable to infection.

If, in spite of all precautions, an injury is received, the wound must be washed as quickly as possible with running water and should, as far as possible, be kept open, debrided and allowed to bleed. The debrided material should be kept for subsequent monitoring. Copious bleeding may help the elimination of the radioactive substances, particularly from punctured wounds, whence they are with difficulty removed by normal washing. The hair should be cut short with scissors only, as there is a danger that the minute abrasions caused by shaving will allow the isotope to enter the body. In the case of more serious extremity wounds, a vein tourniquet may be applied before decontamination. If the nature of the isotope is known, the principle of isotopic dilution may be applied.
After initial decontamination, the wound is monitored, and decontamination is continued thereafter until the activity drops to a safe level. Decontamination should be carried out as rapidly as possible; immediate surgical intervention makes possible a substantial decontamination of the wound. With many contaminating isotopes only a part of the radioactive substances can be removed one hour after the injury, and two hours after injury the proportion drops to only a few per cent of the total. Care should be taken in the case of alpha-emitters, since they may sometimes form local deposits which may be overlooked by monitoring.

In certain cases the degree of decontamination of the wound may be tested by monitoring a drop of blood taken directly from the wound.

After decontamination the wound is treated in the normal manner.

(iv) Decontamination of the eyes

Careless handling of radioactive isotopes may result in a spray of radioactive fluid directly entering the eyes, or, for example, the bursting of an ampoule containing radioactive salt may throw radioactive material in powder form into the eye. In each case immediate intervention is essential. The conjunctiva must be copiously irrigated with plain water. There is a danger that radioactive material may penetrate into the nose along the lachrymal passages and thence into the respiratory system or the stomach.

(v) Decontamination of the respiratory tract

Radioisotopes can enter the organism very rapidly via the lungs. In the case of soluble substances the spread of active material is similar to that from intravenous injection. Hence, the most dangerous radioisotopes are those in gaseous or aerosol form (e.g. radioactive dust dispersed by an explosion). In most cases of radioactive dust, the particles are intercepted in the nasal cavity and in the upper respiratory passages, where they are carried by movement of the ciliated epithelium and may enter the digestive system by swallowing. Substances which have penetrated deeply into the lungs may be phagocytosed and carried into the pulmonary lymphatic system. A very important factor is the solubility of these substances; in most cases insoluble particles are easily removed by the ciliated epithelium, provided of course that they are not deposited directly in the lungs, where they then become a source of continuing irradiation. Soluble radioactive substances pass into the blood and thence are deposited in the various parts of the body according to their nature.
Upon inhalation of radioactive substances, forced coughing and blowing of the nose should be induced immediately. Much radioactive material is deposited at the external nares and the nasopharynx. Some of this is removed by blowing the nose; nasal irrigations may be helpful in removing some of the deposited radioactive particles. If time permits, it is recommended that the surface of the nose and surrounding parts of the face be wiped with a filter paper, which should be retained for subsequent assay.

Samples of urine, etc., are to be collected later in the manner described in Chapter II.

(vi) Decontamination of the digestive tract

If a radioactive isotope has been accidentally ingested, the oral cavity must be immediately rinsed with water and vomiting induced either mechanically or by the administration of appropriate medications. The vomited material should be kept for examination and monitoring. Further action depends on the nature of the radioactive substance. If it is soluble, it is very important to render it insoluble, in order to decrease its absorption, e.g. by the administration of 10% MgSO₄. The solubility may be reduced by increasing the pH of the gastric juice through the use of MgO or Al(OH)₃. A non-specific adsorbent, such as ZrO₂, may also be used⁵. Insoluble radioactive isotopes are not readily absorbed in the digestive tract. A purgative or a laxative mineral water are then administered.

In some cases the method of isotopic dilution (e.g. for elimination of P³²) may be of particular value.

(vii) Action after incorporation of radioactive substances

In all cases of accident, the speed with which first aid is rendered is of decisive importance. It is vital to prevent the deposit of radioactive substances in the critical organs by rapid and properly directed measures of assistance.

In cases where radioactive substances have already been incorporated in the organism, it is even more necessary than in the case of first aid to take into account the nature of the radioisotope absorbed and to treat the patient accordingly.

In most cases it is necessary to transfer the patient to a clinic where expert treatment can be provided.

⁵ It has been found that high calcium intake reduced the absorption of Sr and Ra from the stomach. The calcium may be given in the form of calcium phosphate to form insoluble strontium orthophosphate. By prompt administration of zirconium citrate it may be possible to diminish the absorption of Sr⁹⁰ in the gut. A similar effect may be obtained by using ion exchanges, which fix radioactive isotopes in the digestive tract before their elimination.
The aim of internal decontamination is to accelerate the elimination of radioactive material at the stage of acute or chronic poisoning, as the case may be. It is to be remembered that the great majority of radioactive elements, when once absorbed, are eliminated only with difficulty. It is, for example, practically impossible to remove radium from the body once several weeks have elapsed since its ingestion. All attempts to bring about a speedier elimination of an absorbed radioisotope may be regarded as based on the following principles:

1. Taking advantage of the correspondence of the metabolism of the radioisotope with a related element in the patient (e.g. strontium and calcium);
2. Taking advantage of the discrimination made by the organism between a radioactive element and a chemically related but non-radioactive element; and
3. The utilization of complex-forming substances, such as EDTAA, BAL, zirconium citrate, or polyphosphates.

A certain measure of success in eliminating incorporated plutonium can be achieved by using the polyaminoacids, of which the most important is ethylene-diamine-tetra-acetic acid (EDTAA), which forms particularly stable chelates. Since EDTAA reacts very strongly with the calcium contained in the serum it is administered in the form of CaEDTAA in order to prevent hypocalcaemia. The CaEDTAA molecule is not metabolized and is rapidly eliminated in the urine, whereas the calcium is to a certain degree exchanged for other metallic cations. Persons who had suffered an accident involving plutonium were given not less than 2.5 g in 25 ml of physiological saline by infusion twice daily, the intravenous dose being administered over a period of five days with a rest interval of two days.

For the elimination of incorporated radium, parathormone accompanied by a diet poor in calcium was used with some measure of success.

For the removal of strontium, the available chelates are not particularly helpful because the majority of them bind calcium more strongly than strontium-90.

* Various other procedures, such as blood substitution, interruption of innervation, ion exchange and artificial kidney, are at the experimental stage. It should be emphasized that all these therapeutic treatments are to be applied with caution after consultation with specialists, and should preferably be carried out in an institute specializing in and frequently dealing with the problems in question.
From the foregoing it will be clear that at the present time it is not possible to give a complete picture of the procedure to be adopted in cases of poisoning with radioactive substances. Much of the available information is based on experiments with laboratory animals and reliable data for human beings are at present lacking.

(viii) Treatment of contaminated persons simultaneously traumatized by other causes

In cases where contamination is accompanied by wounds or burns, the injury should be very carefully decontaminated before any kind of surgical intervention, e.g. before surgical or dermatological treatment of the wound, is undertaken. The basic principle must always be to remove the radioactive materials from the body as quickly as possible, and only then to proceed with normal treatment. A difficult situation may arise when, for example, poison has been ingested at the same time as radioactive substances. In such cases antidotes are to be used with care, in order to prevent a given poison antidote from accelerating absorption of the radioactive element from the gastro-intestinal tract.

(e) Diagnosis, prognosis and treatment of radiation sickness

I. Acute radiation syndrome

The course of radiation sickness after whole-body irradiation is governed by the dose received and its distribution in time. Acute radiation sickness may be divided into the following categories, depending on the dose:

**Category 1** occurs after a dose of 100 to 200 r. It is accompanied by temporary changes in the blood picture (mild leukocytosis, accompanied later by leukopenia) and may be associated with temporary clinical symptoms (nausea or vomiting);

**Category 2** occurs after a dose of 200 to 300 r. It is accompanied by severer clinical symptoms and significant changes in the blood picture. Recovery usually occurs but delayed effects may appear;

**Category 3** occurs after a dose of 300 to 500 r, which is approximately LD 50* for man. Clinical symptoms are severe and are accompanied by haematological changes. Proper treatment may be of decisive importance;

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* 50% lethal dose, i.e. a dose which is fatal in 50% of the cases.
Category 4 occurs after a dose exceeding 500 r. The course of the sickness is serious and the outcome usually fatal. Following a dose of 300–500 r the following clinical picture may ensue:

(a) Nausea and vomiting;
(b) Susceptibility to infection (2nd–3rd week);
(c) Somnolence, fatigue, lack of ability to concentrate, etc.;
(d) Rapid decrease in the sperm count;
(e) Ulceration of the mouth, severe halitosis, rhagades;
(f) Weight loss as from second week;
(g) Significant drop of the lymphocyte count during the first 24–48 hours;
(h) After initial rise during first day, a rapid drop of granulocyte count;
(i) Reduction of blood platelets, beginning during the first or second day. Haemoconcentration during the first three days;
(j) Erythema may appear, but is a confusing sign unless the energy distribution of the irradiation is well known;
(k) Epilation (2nd–3rd week);
(l) Haemorrhage (4th or 5th week) associated with the disappearance of platelets;
(m) Except where patient is successfully treated, death between 7th and 40th day, depending on the dose.

With the gastro-intestinal type of radiation sickness, which occurs after doses of 1,000 to 3,000 r, death ensues within three to six days, accompanied by such characteristic symptoms as haemorrhage from the intestinal tract and massive damage and dehydration of the organism.

With the central nervous type of radiation sickness, after doses of many thousand r, death may occur after a few hours, and is characterized by neuromuscular symptoms.

The clinical course of acute radiation sickness with intermediate doses may be divided into four stages:

(1) Early symptoms;
(2) Latent period (no clinical symptoms);
(3) Period during which the main symptoms appear;
(4) Convalescent period.

With doses of more than 100 r the early symptoms may include malaise, loss of appetite, nausea, dryness of the mouth, headaches and, occasionally, vomiting. Where vomiting persists, the prognosis
is very serious and may indicate a dose of more than 400 \text{r}^*$. Sometimes, with a very large dose, the shock pattern may be observed to be accompanied by a decrease in blood pressure, periods of loss of consciousness and disturbance of the heart rhythm. Immediately after irradiation, leukocytosis may be observed accompanied by rapid drop of the lymphocyte and eosinophil counts.

There then follows a latent period when the patient feels relatively well, a circumstance perhaps related to a reduction of the initial irritation of the nervous system. At the same time, however, the blood picture must be further traced, since the lymphocyte count in particular drops in relation to the radiation dose. In the majority of persons receiving a dose greater than 100 \text{r} a general drop of the white blood components ensues. There is an accompanying drop in the count of thrombocytes, of reticulocytes and, occasionally, of erythrocytes. A marked reduction of the blood platelet count may occur; this may be sufficient to aggravate haemorrhage. A lower rate of blood formation, or its complete suspension, may be observed in the bone marrow.

The third period begins with moderate fever. Inflammatory processes appear in the oral cavity, and there is gastro-intestinal lesion accompanied by haemorrhage; loss of hair suddenly occurs. The fever during this period is caused by the fact that the organism, as a result of pancytopenia, has lost its powers of defence and is attacked by infections which may lead to a general sepsis resulting from penetration of intestinal bacteria into the blood stream. The fluid and electrolytic balance of the body is seriously disturbed at this time.

Recent laboratory tests have revealed an increased sedimentation of erythrocytes, changes in the plasma protein spectrum, a drop in the cholesterol level, nitrogen loss, increased elimination of uric acid, urinary syndrome (albuminuria, haematuria, cylindruria), increased elimination of normal aminoacids, the appearance of abnormal aminoacids (e.g. beta-amino-isobutyric acid) and other symptoms. The activity of the sexual glands is impaired, a drop in the sperm count occurs, the kidney function is seriously affected and death ensues as the result either of haemorrhage with severe anaemia and perforation or occlusion of the intestinal tract or of infection and sepsis occasioned by failure of the kidneys or circulatory system.

\* However, one must consider the possibility of the vomiting being of psychogenic origin, resulting from the shock received when the patient realizes that he has been exposed to a radiation dose above the permissible level.
Some patients may die of pneumonia or bronchopneumonia. With those who survive this stage there is always danger of a breakdown of the blood-forming or immunological system, with the result that the required treatment period is usually long.

Patients who have received a smaller dose may convalesce and recover completely. The pathological symptoms gradually disappear, and the organism returns to normal, with a very late lymphocyte recovery. Frequently a reticulocyte crisis is observed. In the blood picture and the bone marrow, however, morphological changes persist for a long time, possibly even for years, during which time the patient may complain of weakness and fatigue.

Persons who have survived radiation sickness are in later years still exposed to the danger of leukaemia, a shortened expectation of life, aplastic anaemia, etc. It is observed that in all these phases the individual symptoms may vary, with regard to both their frequency and their intensity. Particularly with radiation doses of the order of LD 50 the range of variation is especially wide.

In order to arrive at a correct diagnosis, a good knowledge of the history of the case is essential, i.e. of all factors which will facilitate a retrospective determination of the radiation dose received; in addition, radiological assay of the blood, stools and urine, in cases where radiation sickness from internal irradiation has occurred, and examination of the haematopoietic system are required. The following haematological indices are of value in determining the extent of injury:

1. If the lymphocyte count remains steady 24 hours after irradiation, the dose has probably not exceeded 25 r;
2. Temporary lymphopenia with insignificant clinical symptoms usually indicates a dose of less than 100 r;
3. A 10—20% drop of the lymphocyte count in relation to the initial values, possibly persisting for several days, may indicate a dose of more than 100 r;
4. Long-persisting agranulocytosis is a serious symptom. If the reticulocyte, granulocyte, thrombocyte and lymphocyte counts are slow in rising, the case is very serious.

Haemorrhagic symptoms must be differentiated from other haemorrhagic conditions. In the gastro-intestinal form, consideration must be given to the possibility of acute infectious diseases or poisoning from some source. In addition, "acute abdomen" must be excluded from the diagnosis.
Treatment of acute radiation syndrome:

The most striking features of radiation syndrome are haematopoietic and gastro-intestinal troubles, and infections. It must be remembered that we do not yet possess specific remedies for the treatment of radiation syndrome and therefore all treatment is symptomatic. All treatment should be applied judiciously, care being taken not to overload the system with drugs, etc.

When a diagnosis of acute radiation sickness has been made, it is important to isolate patients in accordance with their degree of injury. This process of classification is done on the basis of data regarding the magnitude of the dose to which the patient is exposed. Where uncertainty as to the physical or theoretical determination of the absorbed dose exists, the clinical symptoms after the first few hours may be taken as a rough guide approximately indicating the range of the absorbed dose.

There seems to be no need to hospitalize patients who have received less than 200 r. The most important range is that between 200 and 1,000 r, where medical treatment may be of real help. Especially after a dose of 500 r the development of acute radiation syndrome is very rapid and a radical therapy of all occurring symptoms is indicated.

The first important action in either case should be the introduction of a correctly ordered medical regimen and a rationally based diet. It is then necessary to prevent the spread of infection, and take all possible steps to restore the blood-forming functions and acid-base balance and prevent haemorrhage.

(i) Medical regimen

Patients, particularly those who are aware that they are suffering from radiation sickness, may undergo a stage of psychogenic shock during the first few hours after irradiation. Mild sedatives may be of help. Otherwise, shock should be treated in the same way as when occasioned by other agents (i.e. by keeping the patient warm, in good hygienic condition, and mentally and physically calm). Vomiting and diarrhoea may be countered by antispasmodics (atropine).

Patients should be given appropriate encouragement to prevent them from sinking into despondency.

As a rule, with intermediate radiation doses, the first few days of initial malaise are followed by the complete disappearance of all symptoms, with the result that the patient has a tendency to leave his bed. However, he must be persuaded to remain there in complete calm throughout the entire latent period, until the actual radiation
sickness declares itself. It is of particular importance to guard against infection and to attend to the hygiene of the mouth, where haemorrhage occurs during the sickness proper.

Particular attention must be given to the patient's diet. This should be rich in calories, and provide a high intake of protein. It may be advisable to reduce fat intake. Alcohol is to be avoided. The diet should contain a minimum of superfluous items, so as to spare the gastro-intestinal tract as far as possible. If nourishment cannot be taken per os, it is recommended that infusions of plasma or glucose be given. In all cases the diet must cover the basic requirements of the organism.

(ii) Combating infection

Infection is most likely during the second week after irradiation. Antibiotics with low antimitotic action can be given, particularly in delayed-action form, for as long as the granulocyte count fails to rise. It is not advisable to administer penicillin in combination with amidopyrine, as this might have a deleterious effect on the white blood picture. Similarly, sulphonamides damage the bone marrow and are therefore not recommended. There are varying views on the administration of antibiotics for prophylactic purposes; their premature use may give rise to the development of resistant strains. After high radiation doses, the administration of antibiotics may be an added burden to the organism, and should be resorted to only after careful consideration in each case.

(iii) Maintenance of acid-base balance

Glucose, fructose, physiological solution or Ringer's solution are of assistance in maintaining the acid-base balance. A mixture of 50% plasma and 50% salt solution has also been shown to be of value. For nitrogen loss resulting from increased protein breakdown and absence of normal absorption due to damage to the intestinal wall, there are as yet no suitable remedies. In serious cases it is only possible to effect compensation by plasma.

(iv) Prevention of haemorrhage

There is likewise no specific treatment for the increased tendency to haemorrhage. The use of blood platelets in suspension, where the platelet level has dropped below 25% of normal, and likewise of fresh blood or plasma has been shown to be of value. Standard preparations show a certain effectiveness against increased permeability of the capillaries.
(v) Restoration of haematopoiesis

During the course of radiation sickness proper, blood transfusions are important, and also the administration of erythrocytes and plasma or plasma substitutes. The action taken depends on the requirements of each individual case. Of value also are liver preparations, raw liver and dried stomach preparations. Good results have been obtained with transfusion of leukocytes in cases of leukopenia. In large centres, transplantation of bone marrow may be attempted, but as a result of immunological complications a complete regeneration can only be obtained with genetically specific bone marrow or at least with phenotypically related donors.

(vi) Treatment of the skin

Hygiene of the skin is important. After large radiation doses, erythema may become exudative and is then difficult to treat. Infected skin can be suitably treated by delayed-action penicillin.

(vii) Informing the patient

Every patient should in due course be informed of the dose he has received and of the probable course of the radiation sickness.

II. Chronic radiation injury

Chronic radiation injury occurs as a delayed effect of a single irradiation by a large dose of ionizing radiations or after persistent irradiation with small doses. However, with the exception of haematological changes, the results of examination are usually normal. The clinical history of the case is important.

(i) Haematological changes

An estimate of haematological changes and of general trends therein must be based on a comparison with normal values, i.e. usually with those which are applicable to the geographical region in question.

Deviations from normal are, as will be understood, of a varying character, and writers differ as to which factors are of most importance. It is essential to make a statistical comparison of observed changes with the condition of populations living in similar circumstances but not having been exposed to radiation effects.

Persistent leukopenia (under 3,500 cells per cu mm), persistent neutropenia (under 2,400 cells per cu mm), or persistent leukocytosis (above 15,000 cells per cu mm) are among the haematological signs of chronic radiation injury.
(ii) Chronic skin changes
In cases of chronic skin injury after local irradiation, pigmentation, dryness and telangiectasis are manifested. Fissures are formed in the skin, which heal with difficulty. In most serious cases the skin is atrophied, and becomes hard and warty. These warts may change into squamous cell epithelioma which resists treatment and forms metastases comparatively easily.

(iii) Cataract formation
Workers who have been exposed to fast neutrons or high-energy particles may develop cataracts.

(iv) Induction of tumorous diseases
One effect of chronic radiation injury is the induction of tumours in the blood-forming organs (e.g. leukaemia), in the skeleton, after incorporation of radium or other bone-seeking radioelements, and in the lungs after prolonged exposure to radioactive aerosols and radon. These events all occur after a long latent period, which may last for several decades. (Only in the case of leukaemia resulting from whole-body high acute external irradiation does the maximum incidence of the disease become manifest within 5 to 10 years.)

(v) Treatment of chronic radiation injury
The first requirement is leave from employment, a suitable light diet and abstinence from alcohol and tobacco, combined with fresh air and exercise. Chronic changes in the organs and bones (radionecroses) require special methods of treatment, although in the case of the latter a conservative approach is rather to be recommended.

In the case of persons who have been exposed to large radiation doses, it is advisable to take precautionary measures against delayed effects such as disturbances of the haematopoietic system and the possible occurrence of radiation-induced tumours. For this reason such persons should be placed under medical supervision.
4. MEDICAL FACILITIES AND EQUIPMENT

The provision of medical facilities should be governed by the needs of the installation. Large atomic establishments have their own complete medical and health protection facilities at the site, while the situation may be different in smaller laboratories, where only relatively simple facilities are available, or none at all.

The extent of the medical facilities required depends not only on the size of the installation, but also on the nature and scope of the radiation work carried out. Small establishments may enter into an association with one another or co-operate with the local health authorities and available consultants for the purposes of organizing a health and safety programme and facilities. Certain basic facilities must, however, always be immediately available to deal with some of the health hazards associated with work with radiation. In planning a medical unit for a small user of ionizing radiation, arrangements should be made to utilize the services of locally available medical staff, and attention must be paid to ease of access to the unit, to the availability of additional outside help and medical facilities, to safety considerations in the event of an accident, and to the specific conditions of exposure to radiation and radioactive contamination that may be encountered. In addition, emphasis should be placed on such features as simplicity of construction and ease of modification, convenience of physical layout, free movement of traffic (patients and medical personnel), cleanliness, light and ventilation, freedom from excessive noise and vibration, ease of decontamination and availability of essential services such as electricity, water, heat and sanitation.

Decontamination facilities are essential where exposure to radioactive materials may occur and where the radioactive substances may become potential hazards as internal emitters. Any contamination of personnel liable to occur in a large installation could likewise occur in a small plant. Consequently, all establishments using radioactive materials should organize procedures and facilities to deal with an emergency. In the simplest cases, these would consist of the most suitable available premises equipped with:

1. Clean monitoring devices for determining the location and degree of skin contamination;
2. Scrub-up fixtures for the decontamination of persons who have assisted in the transport of non-ambulatory contaminated patients;
3. Sinks for the decontamination of parts of the body such as hands, face and hair; these can be ordinary sinks with shampoo attachment;
4. A shallow tub or a suitable table for decontamination of non-ambulatory patients;
5. Showers for general body decontamination of walking patients;
6. Medical equipment and supplies stored accessibly but in such a manner as to minimize the risk of contamination by radioactive material. The floors and walls should be of material that can be either easily decontaminated or readily exchanged.

A. Medical equipment

First-aid equipment

It has been pointed out on several occasions in this handbook that rapid first-aid measures, taken within the first half-hour, are of vital importance in cases of radioisotope accidents. Consequently, every radioisotope laboratory should have the basic equipment for rendering first aid. In larger institutes comprising a number of isotope laboratories, it is recommended that special premises should be set aside for this purpose.

General equipment

Filter paper, absorbent paper, towels, cloths, material for masking contaminated parts of the body (e.g. cellophane). Plastic sheets for the transport of contaminated persons, as well as the general medical equipment provided in factory medical units. The latter equipment, which is not here itemized, is stored separately from that used for first aid in radiocentamination cases. The range of general medical equipment will depend on the size of the installation.

Equipment for decontamination of the hands

Soap, lanolin, talc, a sufficient number of soft nail-brushes, detergent solutions. Paste composed of titanium dioxide and lanolin. Calcium ethylene-diamine-tetra-acetic acid. Potassium permanganate in a saturated solution, mixed with 0.2 N sulphuric acid. A 5% solution of sodium sulphite for removal of skin discoloration.

Equipment for decontamination of wounds

Equipment as for minor surgery, the individual instruments being as far as possible individually packed in transparent plastic envelopes to prevent unnecessary contamination. Sterile soap solution. Sterile physiological solution. Arterial tourniquet.
Equipment for decontamination of the eyes

Sterile boric acid, eye ointment, sterile glass rod in plastic packing, a large bulb syringe with nozzle for ocular irrigation.

Equipment for decontamination of the digestive and respiratory tract

Expectorants, emetics, diaphoretics, vasoconstrictive substances, purgatives, powdered barium sulphite, magnesium oxide, aluminium hydroxide, receptacles for stools, plastic bags.

B. Special decontamination premises

Large establishments usually possess their own decontamination premises, consisting, according to the size of the establishment, of several rooms, including a ward with beds, operating theatre, diet kitchen, linen-store, washrooms, etc. The exact disposition and description of these premises lie beyond the scope of this Addendum.

Scientific institutes comprising a number of radioisotope laboratories have their own medical unit, the equipment of which must be such as to permit the carrying out of effective decontamination work. This equipment should include a table provided with a warm water supply having a separate drain. This table may serve as an emergency operating table, but its principal use is for the rapid decontamination of the whole body by copious irrigation with warm water. Very small establishments, where there is, for example, only one radioisotope work place, should have one room available for any necessary decontamination operations. In an emergency, bathrooms may even be used for the purpose.

It must be emphasized that there must be in every establishment possessing even one radioisotope work place as complete a set as possible of decontamination equipment and a pre-determined place for the conduct of at least preliminary decontamination and first aid. It is definitely not recommended that patients should be transported in plastic sheets immediately following an accident to another, better-equipped point, since thereby valuable time is lost, which is of decisive importance for the success of subsequent decontamination.

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