PRACTICAL RADIATION TECHNICAL MANUAL

HEALTH EFFECTS AND MEDICAL SURVEILLANCE

IAEA
International Atomic Energy Agency

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INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

Occupational exposure to ionizing radiation can occur in a range of industries, such as mining and milling; medical institutions; educational and research establishments; and nuclear fuel facilities. Adequate radiation protection of workers is essential for the safe and acceptable use of radiation, radioactive materials and nuclear energy.

Guidance on meeting the requirements for occupational protection in accordance with the Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (IAEA Safety Series No. 115) is provided in three interrelated Safety Guides (IAEA Safety Standards Series No. RS-G-1.1, 1.2 and 1.3) covering the general aspects of occupational radiation protection as well as the assessment of occupational exposure. These Safety Guides are in turn supplemented by Safety Reports providing practical information and technical details for a wide range of purposes, from methods for assessing intakes of radionuclides to optimization of radiation protection in the control of occupational exposure.

Occupationally exposed workers need to have a basic awareness and understanding of the risks posed by exposure to radiation and the measures for managing these risks. To address this need, two series of publications, the Practical Radiation Safety Manuals (PRSMs) and the Practical Radiation Technical Manuals (PRTMs), were initiated in the 1990s. The PRSMs cover different fields of application and are aimed primarily at persons handling radiation sources on a daily basis. The PRTMs complement this series and describe a method or an issue related to different fields of application, primarily aiming at assisting persons who have a responsibility to provide the necessary education and training locally in the workplace.

The value of these two series of publications was confirmed by a group of experts, including representatives of the International Labour Organization, in 2000. The need for training the workers, to enable them to take part in decisions and their implementation in the workplace, was emphasized by the

International Conference on Occupational Radiation Protection held in Geneva, Switzerland, in 2002.

This Practical Radiation Technical Manual, which incorporates revisions drawn up in 2002, was originally developed following recommendations of advisory group meetings held in Vienna, Austria, in November 1992 and October 1995, as well as a consultants meeting held in Vienna, Austria, in December 1992 involving A. Bianco (Italy), U. Desai (India), K.P. Duncan (United Kingdom), J.R. Harrison (United Kingdom), N. Nadezhina (Russian Federation), J.-C. Nénot (France), L.B. Sztanyik (Hungary), P.J. Waight (Canada), R.Wood (United Kingdom), A. Barabanova (IAEA) and I. Turai (IAEA). Major contributions were made by J.R. Harrison and R. Wheelton, United Kingdom. R. Wheelton also contributed to the present revision.

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IAEA PRACTICAL RADIATION TECHNICAL MANUAL

HEALTH EFFECTS AND MEDICAL SURVEILLANCE

This Practical Radiation Technical Manual is one of a series which has been designed to provide guidance on radiological protection for employers, Radiation Protection Officers, managers and other technically competent persons who have a responsibility to ensure the safety of employees working with ionizing radiation. The Manual may be used with the appropriate IAEA Practical Radiation Safety Manuals to provide adequate training, instruction or information on health effects and medical surveillance for all employees engaged in work with ionizing radiation.

HEALTH EFFECTS AND MEDICAL SURVEILLANCE

Introduction

Sources of ionizing radiations have a large number of applications in the workplace. Usually, even where the work is performed safely, the employees involved inevitably receive small, regular exposures to radiation that are not harmful.

Some applications involve sources that could deliver more significant radiation doses, particularly when poor methods are practised or an accident occurs. The radiations cannot be seen, felt or sensed by the human body in any way and excessive exposures may cause detriment to the health of a worker in a way that is not immediately apparent. When the symptoms occur, weeks or possibly years later, an untrained worker or inexperienced medical staff probably cannot recognize the effects to be due to the radiation exposure.

This Manual explains how ionizing radiations can interact with and affect human tissues, the various factors that influence the outcome and the detrimental effects that may result. The medical surveillance that is appropriate for those working with radiation sources, depending on the degree of hazard of the work, is described.

The Manual will be of most benefit if it forms part of more comprehensive training or is supplemented by the advice of a medically qualified expert. Where medical surveillance is appropriate for radiation employees, the services of a qualified doctor, occupational physician or other trained medical staff will be required.

1. RADIATION ENERGY

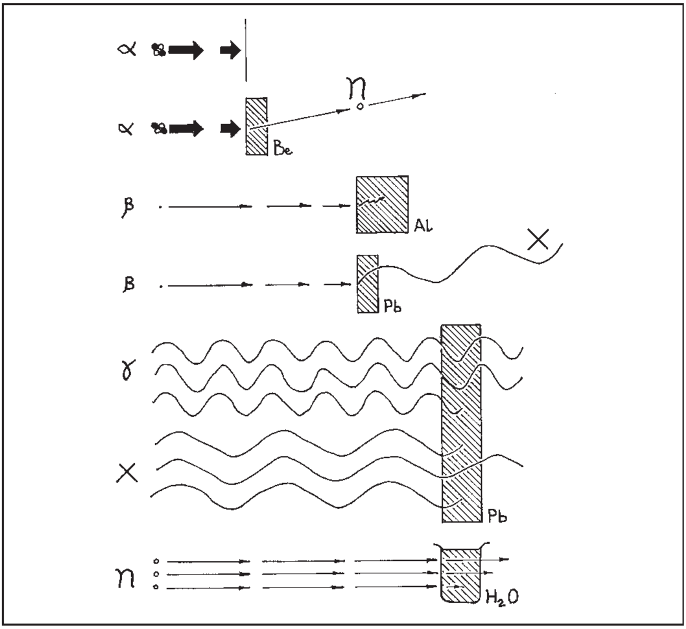
Radioactive materials emit energy in the form of *alpha* (α) particles, *beta* (β) particles and *gamma* (γ) rays. When these radiations interact with matter they can, in certain circumstances, give rise to the emission of *X rays* and *neutron* particles. Certain machines operated at high voltages can cause similar interactions between particles and matter to generate X rays and neutrons.

Gamma and X rays consist of physical entities called *photons* that behave like particles. However, large numbers of photons behave, as a whole, like radio or light waves. The shorter the wavelength of the gamma or X ray, the higher the energy of the individual photons. The very high energy of gamma rays and their ability to penetrate matter results from their much shorter wavelengths.

Beta particles are emitted by different radionuclides such as hydrogen-3 (^{3}H) and phosphorus-32 (^{32}P). The beta particles are emitted with a range of energies up to a maximum value which is a characteristic of each radionuclide. The maximum beta particle energy emitted by ^{3}H is almost one hundredth of that emitted by ^{32}P. The higher energy beta particles move faster and their range and penetrating properties are greater.

Alpha and neutron particles in general travel more slowly than beta particles, but they are heavier particles and consequently they usually have higher energies.

The energy of all these radiations is expressed using a unit called the electron-volt (eV). Typically, radiations have initial energies measured in thousands of electron-volts (kiloelectron-volt, keV) and millions of electron-volts (megaelectron-volt, MeV).



Penetrating properties of radiations.

Alpha particles (α) are unable to penetrate the dead skin layer (see Section 16). Low density materials (e.g., aluminium, Al) are good shields against beta (β) particles, and high density materials (e.g., lead) are used against photons (γ, X). Hydrogenous materials are effective against neutrons (n).

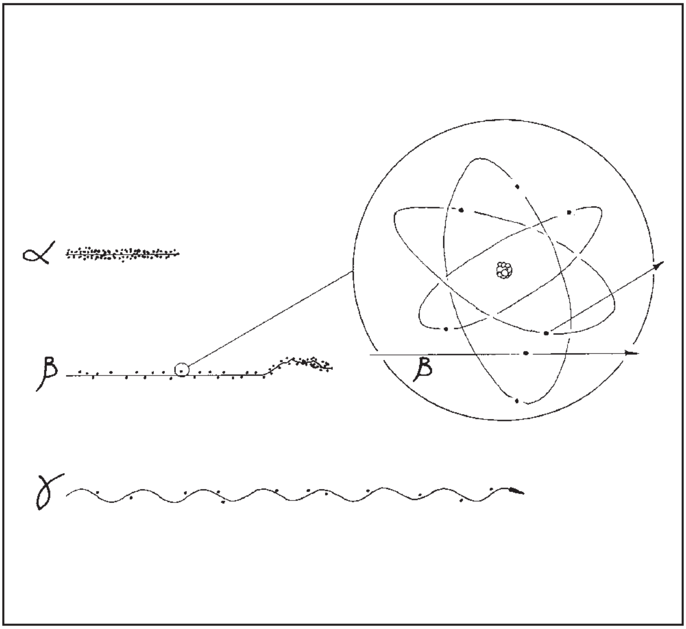
Interactions between radiations and beryllium (Be) may produce neutrons. Beta particles absorbed by high density materials, such as lead (Pb), may produce X rays.

2. RADIATION TRAVELLING THROUGH HUMAN TISSUE

As radiation travels through any medium, including human tissue, it collides and interacts with the component atoms and molecules. In a single interaction the radiation will generally lose only a small part of its energy to the atom or molecule. However, the atom or molecule will be altered and become an ion. The radiation leaves a trail of ionized atoms and molecules, which may then behave in a changed way. The density of ions in the trail is an indication of the amount of energy deposited per unit path length, the linear energy transfer (LET). Radiation may be described as high or low LET.

Alpha particles are high LET. After successive collisions, an alpha particle loses all of its energy and stops, having created a short, dense trail of ions. This occurs within a few centimetres in air or about 50 micron (millionths of a metre, μm) in human soft tissue. Depending upon their initial energy, beta particles can travel several metres in air and about a centimetre in tissue. Eventually, as the beta loses energy, it slows down and is absorbed by the medium. Gamma and X rays interact least as they travel through matter, losing part or all of their energy to an atom or molecule with which they interact. They have a range of many metres in air and many centimetres in tissue. When photons are attenuated, that is when they continue to travel with lower energy and diminish in number, they will eventually pass through a human body.

Neutrons interact with atoms and molecules in complex ways. Collisions between the neutron and the smallest atom, hydrogen, results in the greatest transfer of energy from the neutron to the absorbing medium. Neutrons have a range of many metres in air and many centimetres in tissue. When neutrons are moderated, that is slowed down, they will eventually be absorbed or pass through a human body.



Ionizing radiation tracks.

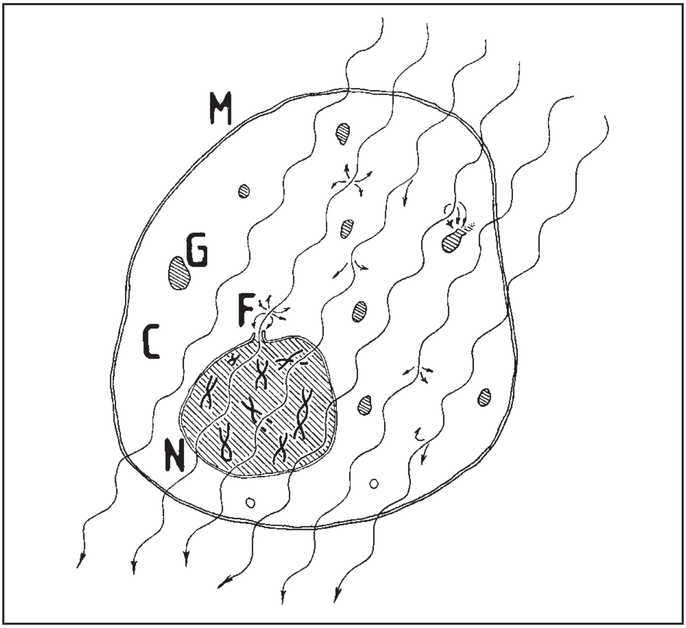
The radiation ionizes individual atoms and molecules, losing energy in the process.

Alpha particles (α) have a high LET producing a dense track of ions. Beta (β) particles and photons (γ) are low LET radiations. The beta track becomes more dense as the particle slows down.

3. BIOLOGICAL BASIS FOR RADIATION EFFECTS

Human tissues are formed from cells that are grouped into organs and systems of the body to perform the many specialized functions, for example skin cells and blood cells. While the cells of different organs differ in size, shape and detailed structure, some features are common. Each cell is defined by a membrane (M) enclosing a gel-like cytoplasm (C) containing up to 85% water, chemicals and structures such as a nucleus (N) and organelles (G). Each organelle has a specific task to perform, for example, the lysosomes are tiny sacs filled with enzymes to enable the cell to use the nutrients with which it is supplied. The nucleus contains coded information in the form of DNA (deoxyribonucleic acid) organized into groups called genes which are arranged on thread-like chromosomes. Every chromosome contains thousands of genes which are responsible for determining every physical human characteristic. Many cells contain a system of channels (the endoplasmic reticulum) along which tiny spherical structures (ribosomes) are located. The proteins they contain are required for structural repairs and, in the form of enzymes, for cell chemistry and the manufacture of hormones which regulate bodily functions.

Ionizing radiation has a direct action on the complex vital molecules (for example the DNA) within the cell by breaking the bonds between the atoms. Ionization in non-vital molecules (for example, water molecules) produces very active chemicals (free radicals) which attack vital molecular systems. The damage may change the coded information in the cell nucleus, disrupt the cell's chemistry and function or physically rupture membranes some of which contain the digestive enzymes. Natural mechanisms are capable of identifying and repairing limited damage to improve the cell's chance of survival. However, incorrect or incomplete repairs are also a possibility: these may affect the cell's longer term viability or performance.



Photons interacting with a biological cell.

Direct action by the ionizing radiation causes damage to chromosomes in the nucleus (N).

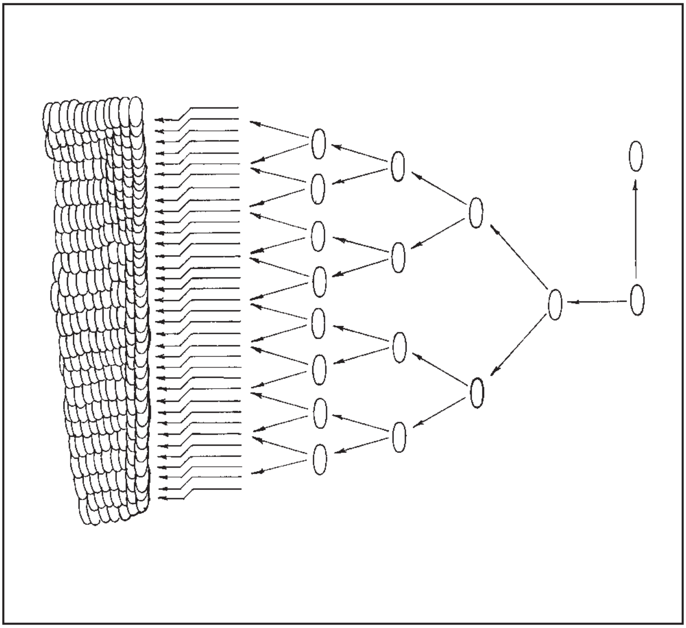
Free radicals (F), formed by interactions with non-vital molecules in the cytoplasm (C), may damage vital molecules, e.g., the membranes (M) and organelles (G).

4. CELL SENSITIVITY

The DNA of the chromosomes has the ability to reproduce itself to enable the cells to duplicate themselves. This process, called mitosis, involves the normal number of 46 chromosomes, each becoming shorter and thicker before splitting along their length. The double chromosomes then move to opposite ends of the cell and finally the cytoplasm is halved and new membranes form around the two new cells. The process is repeated to populate the specialized organs and systems of the body.

In an organ, the stem cells initiate the generation of new cells which, after further mitoses, will develop and differentiate (mature) to become the functional cells. The genes in cells can then switch off (or on as required) if the surrounding medium supplies a needed molecule or if the genetic code is redundant with the cell's functions. With much of their genes switched off to enable them to concentrate on the specialized duties of the particular organ, the functional cells are less radiosensitive than the mitotic cells. When an organ is irradiated, the greater damage to the mitotic cells may cause them to fail to reproduce and reduction in their number usually takes time to progress through the cell renewal system. A characteristic latent period occurs until the normal loss of functional cells results in observable effects on the function of the organ.

The radiosensitivity may be increased or decreased by factors which influence the cell's environment such as diet (possibly introducing radical scavengers into the cell), oxygen tension (concentration) and temperature.



Cell renewal cycle.

Stem cells undergo mitosis to form cells which further reproduce, differentiate and mature to form functional cells. Cells in the intermediate phases are usually most sensitive to radiation damage.

In spermatogenesis (see Section 17) the maturing spermatogonia are about 70 times more sensitive to radiation damage than the stem cell spermatogonia. The functional spermatozoa have only about 1/5 the sensitivity of stem cell spermatogonia.

5. RADIATION DOSE CONCEPTS

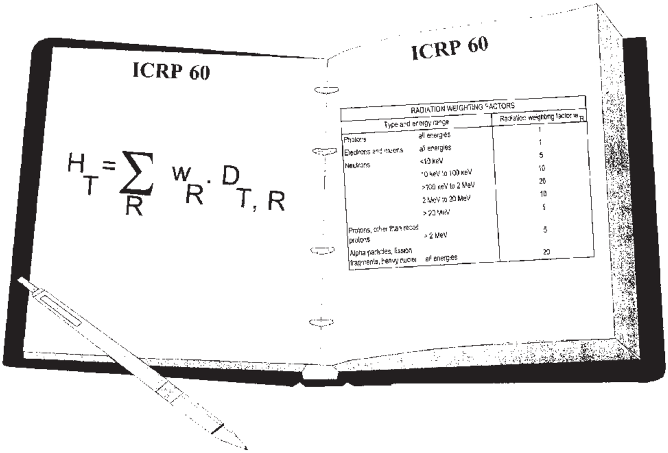
The harm or potential harm resulting from exposure to ionizing radiation is expressed as the equivalent dose (H). The term takes into account:

(a) the total energy absorbed per unit mass of a tissue or organ, the absorbed dose (D); and
(b) the type and energy of the radiation causing the dose, which influences how the energy is distributed in the tissue, represented by a radiation weighting factor (w_R). The table shows values of w_R, which have no units, for different radiation qualities.

The absorbed dose is the measured number of joules per kilogram ($J \cdot kg^{-1}$) expressed as a unit called the gray (Gy). 1 $J \cdot kg^{-1}$ of absorbed dose averaged over a tissue or organ T (rather than at a point) and weighted (multiplied by the appropriate w_R) for the radiation quality of interest, expresses the equivalent dose (H) as a unit called the sievert (Sv). The unit of equivalent dose is the joule per kilogram with the name sievert (Sv).

When a tissue or organ is exposed to several different types of radiation, the potential harm to it is the sum of the equivalent doses for each radiation quality as indicated by the formula. H_T is the sum of the individual equivalent doses and $D_{T,R}$ is the absorbed dose due to radiation R. For example, if an organ receives 1 Gy of gamma radiation (w_R of 1 for photons), its equivalent dose is 1 Sv. A further absorbed dose of 1 Gy due to 4 MeV neutrons (w_R of 10) would add 10 Sv. The organ has received 11 Sv equivalent dose (harm).

Absorbed dose was formerly expressed in a unit called the rad (equal to 0.01 Gy) and equivalent dose was formerly called dose equivalent and expressed in a unit called the rem (equal to 0.01 Sv).



Equivalent dose.

The equivalent dose to a tissue or organ exposed to several different types of radiation, H_T, is obtained by summing the absorbed dose for each radiation, $D_{T,R}$, multiplied by the appropriate w_R, for all radiations.

The radiation weighting factor (w_R) assigned to each radiation of specified radiation energy expresses the relative potential harm caused by an absorbed dose from that radiation.

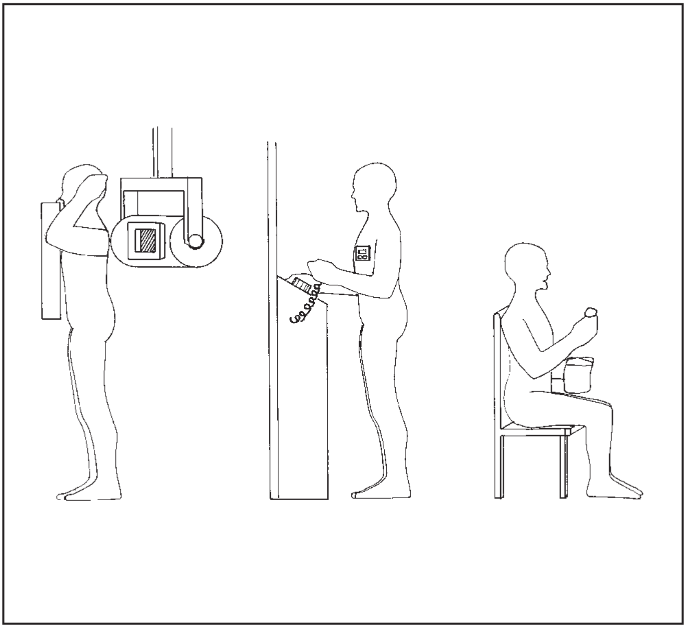
6. RADIATION DOSE IN PERSPECTIVE

1 Sv is a very large equivalent dose.

Naturally occurring radioactive materials in the environment and food, in addition to cosmic radiation, typically provide a background dose of a few millisieverts (thousandths of a sievert, mSv) per year to members of the public.

The medical use of X rays may deliver tens or hundreds of microsieverts (millionths of a sievert, μSv) per investigation to a patient.

Occupational exposed workers are commonly exposed to dose rates of tens of microsieverts per hour ($\mu Sv \cdot h^{-1}$) up to several millisieverts per hour ($\mu Sv \cdot h^{-1}$) for brief periods and accumulate a dose equivalent of millisieverts per year as a consequence.



Radiation exposures.

Occupationally exposed workers also receive doses even while off-duty from sources such as cosmic radiation, radioactive materials in environment and any medical diagnostic X-radiography examinations they may need.

Good radiation protection programmes (see Section 9) keep all medical and occupational doses as low as reasonably achievable (ALARA).

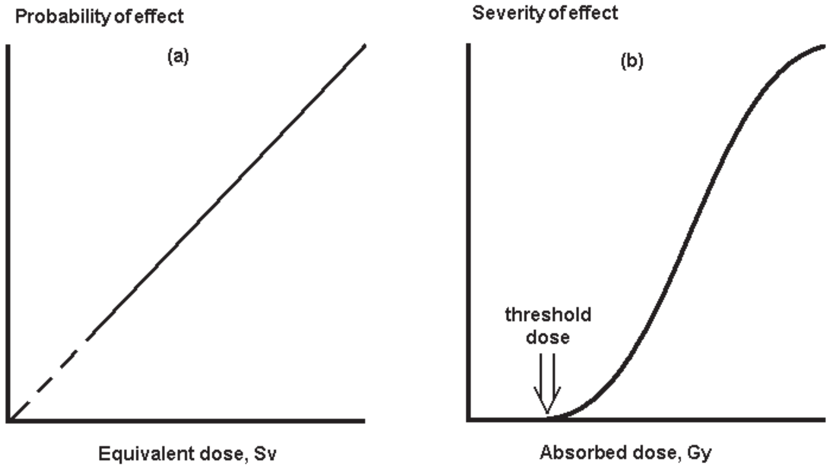
7. EVIDENCE FOR HEALTH EFFECTS

Radiation induced damage to cells can produce two types of biological effect in humans.

Stochastic effects occur at all dose levels as a result of damage to the DNA. A modified cell that is still able to perform mitosis can give rise to a clone of cells that may eventually result in a cancer in the exposed person. Such effects develop in the long term, often decades after the exposure. A modified stem cell in the reproductive organs (gonads) that transmits genetic code to the descendants of the irradiated person may provide incorrect hereditary information and cause severe harm to some of those descendants. The probability that effects will occur either in the exposed person (somatic effects) or in descendants (hereditary effects) increases in proportion to the equivalent dose.

Deterministic effects occur at high doses when enough cells in an organ or tissue are killed or prevented from reproducing and functioning normally and there is a loss of organ function. A threshold dose exists above which the effects on an organ or biological system are clinically observable. The onset of the symptoms usually shortens (from weeks to hours) and their severity increases with increasing equivalent dose.

The three principal sources of information on stochastic effects are epidemiological studies, involving statistical analyses, on the survivors of nuclear weapons attacks on Hiroshima and Nagasaki in Japan, on patients exposed to radiation for medical treatment or diagnosis, and on some groups of occupationally exposed employees. Some of these studies are ongoing. Data on the deterministic effects come from studies of the side effects of radiotherapy, from effects on the early radiologists, from the Japanese survivors, and from the consequences of severe accidents that have occurred from industrial radiation sources. Studies are published in IAEA, UNSCEAR, BEIR documents and scientific journals (see Section 30).



Dose-health effect relationships.

Studies provide evidence of health effects at high doses and dose rates. It is assumed that the risk of inducing stochastic effects (a) increases linearly as the dose is increased. There is a low risk associated with any low dose.

Deterministic effects (b) are only likely to occur when the threshold dose for each effect is exceeded. The severity of the effect increases at higher doses.

8. NON-UNIFORM EXPOSURES TO RADIATION

Most applications of radiation sources potentially give rise to external exposure. Radiation from a source outside the human body, excluding alpha particles and very low energy beta particles, will deliver a dose to one or more types of tissue. High output sources of penetrating radiations (e.g. photons and neutrons) may deliver a whole body dose. However, sources often emit less penetrating radiations, narrow (collimated) radiation beams, or are close to the body in a manner that will deliver non-uniform equivalent doses to different parts of the body.

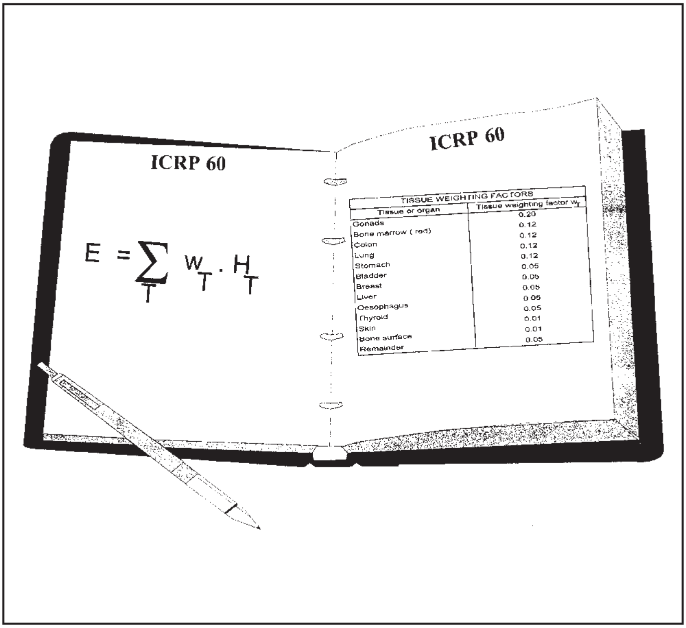
Radioactive materials will give rise to internal exposure when inhaled, ingested or taken into the body through the skin. Tissues in contact with the internal contamination may receive a dose that is significantly different from that received by the surrounding organs and tissues. A localized dose is likely if the radioactive material is metabolized by the body and moved into a specific organ or tissue.

Where the same equivalent dose is not delivered to different tissues, the effective dose (E) is calculated using the tissue weighting factors, w_T, shown in the table. The effective dose expresses the detriment to the whole body due to the risk of a fatal malignancy or serious hereditary damage. The effective dose is the sum of the weighted equivalent doses in all the irradiated tissues and organs of the body. H_T represents the equivalent dose in tissue or organ T. For example, if the stomach and liver receive equivalent doses of 100 and 300 mSv then the effective dose is ((100 × 0.12) + (300 × 0.05)), 27 mSv.

The sum of all values of w_T is numerically one and a uniform equivalent dose over the whole body and the effective dose are therefore equal.

Internal contamination may continue to irradiate tissue for some time after the intake. The committed effective dose (E) is calculated for up to 50 years from the intake for adults and to age 70 years for children.

Where the body is exposed to both internal and external doses, the measurement of effective dose allows the full detriment accumulated to be determined and taken into account.



Effective dose.

The effective dose (E) to the whole body is calculated when different organs receive non-uniform equivalent doses.

The effective dose (E) is the sum of weighted equivalent doses in all the irradiated tissues and organs. The equivalent dose to each irradiated tissue or organ is multiplied by the appropriate tissue weighting factor (w_T).

9. RISK ESTIMATES AND DOSE LIMITS

Quantitative estimates of the detriment (risk factors) obtained from the studies referred to in Section 7 may be overestimates. These groups received acute exposures (high doses received in short exposure times) and chronic exposures (prolonged exposure to moderately high doses) to high LET radiations such as alpha particles. It may be that the body's natural mechanisms efficiently repair radiation damage at the low dose levels normally encountered during occupational exposures. To allow for this possibility a dose and dose rate effectiveness factor (DDREF) of 2 is used, in accordance with the recommendation of the ICRP.

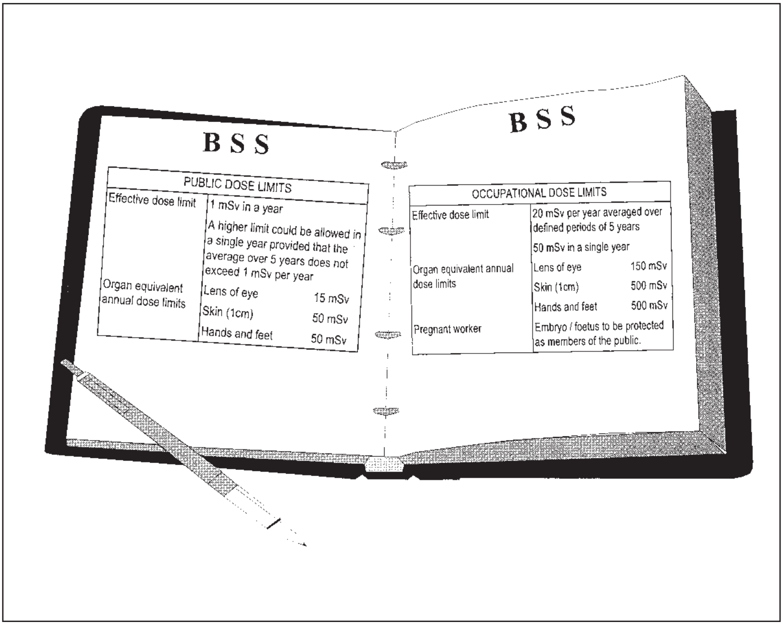
High doses and dose rates of low LET radiation produce a lifetime fatality probability coefficient (risk factor) for a reference population of both sexes and of working age (18–64 years) of about 8×10^{-2} Sv^{-1} for the sum of all malignancies. Applying a DDREF of 2, the nominal probability coefficient for employees is 4×10^{-2} Sv^{-1}. The probability coefficient for non-fatal cancers in the same reference population is 0.8×10^{-2} Sv^{-1} and for hereditary effects 0.8×10^{-2} Sv^{-1}. The aggregate detriment for employees is therefore is 5.6×10^{-2} Sv^{-1} (namely $4+0.8+0.8 \times 10^{-2}$ Sv^{-1}). In the whole population, including children, the aggregated detriment is 7.3×10^{-2} Sv^{-1}.

The indications that there is risk of stochastic effects from any dose requires a system of protection to ensure that:

(a) any practice and its protective system should do more good than harm, expressed as a net benefit to exposed individuals or to society (justification of a practice);
(b) the combined doses of all relevant practices to any individual should be subject to dose limits, or to some control of risk in the case of potential exposures (individual dose or risk limits); and
(c) for any source, doses to be received or the likelihood of being exposed should be kept as low as reasonably achievable (ALARA) and

constrained by limiting doses to individuals and by limiting risks to individuals from potential exposures (optimization of protection).

The individual dose limits for employees, shown in the table, are set below the threshold doses at which deterministic effects are known to occur.



Dose limits.

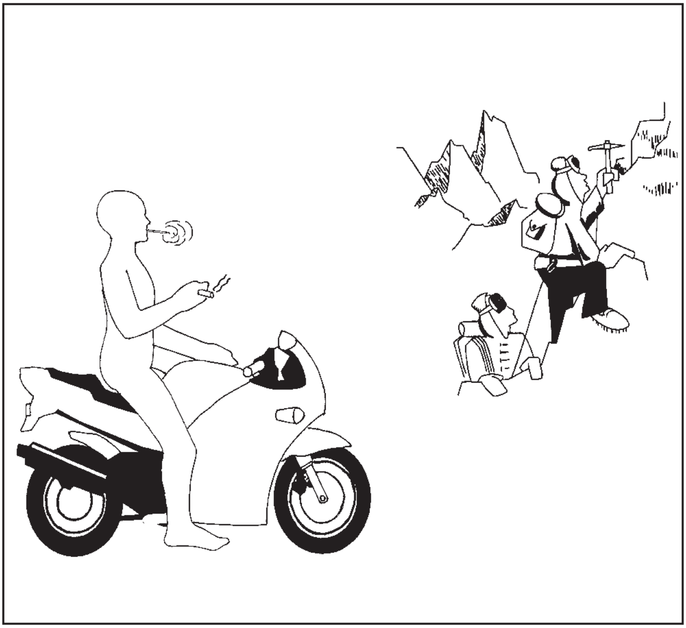
The combined doses of all relevant practices to a member of the public or an occupationally exposed worker should be subject to dose limits or to some control of risk in the case of potential exposures.

10. RADIATION RISKS IN PERSPECTIVE

Cancers account for typically 1 in 4 (25% or 25×10^{-2}) of all deaths in the developed countries. Many factors may cause or combine to cause cancer. Some causes occur naturally, for example solar ultra-violet radiation, and others may be related to occupation and lifestyle, such as tobacco smoking and sexual behaviour. Radiation is one of many environmental agents shown to be carcinogenic. The fatality probability coefficient of 4×10^{-2} Sv^{-1} for occupationally exposed employees indicates that a dose of 20 mSv (dose limit for workers; dose averaged over five years) will result in an increased risk of developing a fatal cancer of less than one-tenth of one per cent (0.08×10^{-2} or 800×10^{-6}). Radiation in the environment and at work is therefore neither a major cause of cancer nor a high ranking public health hazard.

Both employees and the public will accept a wide range of individual risk under different circumstances. Fatal accident risks at work depend on the type of work performed. Shop and office employees tolerate a risk of a few in a million per year (2×10^{-6}) but in coal mines the risk of a fatal accident is over 100 per million per year (100×10^{-6}). Someone of normal life expectancy is likely to reject as totally unacceptable a risk of 1 in 100 per year ($10\,000 \times 10^{-6}$). However, a risk of 1 in 1000 per year (1000×10^{-6}) may not be unacceptable if the individual was aware of the risk, enjoyed some commensurate benefit and everything reasonably practicable had been done to reduce the risk. It is in this context that the risk of receiving a dose of 50 mSv (2000×10^{-6}) in a year might be judged. Risk management, including what dose limit is acceptable, must take into account many factors including social considerations and personal judgements.

There are risks associated with recreational sports and pleasures such as mountain climbing and cigarette smoking that exceed those associated with occupational exposure. Common forms of transport such as motor cycles and cars also have high fatality risk factors.



Risks in perspective.

The risk of stochastic effects at doses below the occupational dose limits compares with other fatality risks from hazards at work and activities such as mountain climbing (600×10^{-6} rising to 6000×10^{-6} per year for dedicated climbers), riding a motor cycle (2000×10^{-6} per year, and 6000×10^{-6} per year for riders who do not wear a helmet) and cigarette smoking (5000×10^{-6} per year at 10 cigarettes per day).

11. RADIATION PROTECTION PROGRAMMES

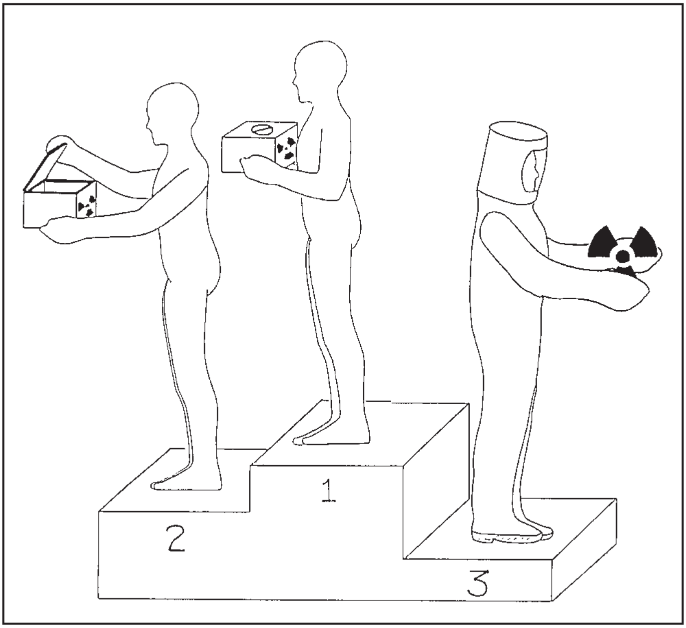
Radiation protection involves the use of appropriate means to restrict exposure or potential exposure. Appropriate means may involve:

(a) engineering controls such as the effective application of distance and shielding to restrict external exposure and suitable containment to prevent the spread of unsealed radioactive materials;
(b) administrative methods such as documented procedures, good working practices, adequate supervision and restricted exposure times; and
(c) using personal protective equipment including suitable clothing such as lead aprons for work with low energy X rays, laboratory wear and industrial suits to protect against body contamination and devices such as respiratory protective equipment, where appropriate.

Good radiation protection programmes contribute significantly to limiting routine exposures and the risks of stochastic effects occurring, and to preventing accidents that may cause acute exposures which can result in deterministic effects.

An important feature of all radiation protection programmes is workplace monitoring for radiation and contamination. Radiation energy is detectable using a wide range of instruments and devices. The correct choice of instrument with appropriate calibration will allow meaningful measurements to be made of actual and potential equivalent doses, dose rates and radioactive contamination in the workplace. Further details are provided in the Practical Radiation Technical Manual on Workplace Monitoring for Radiation and Contamination (IAEA-PRTM-1).

The actual or potential doses received owing to external exposure are normally measured using personal dosimeters worn by individual employees. Personal exposure to hazards that might contribute an internal dose can be monitored using devices such as personal air samplers (PAS). Techniques which involve organ and body monitoring for internal exposue and biological assessments of intakes of radioactivity are used to determine internal doses. Further details are provided in the Practical Radiation Technical Manual on Individual Monitoring (IAEA-PRTM-2).



Restriction of radiation exposures.

Radiation exposures are most effectively restricted by engineering controls.

Administrative controls and, where appropriate, personal protective equipment are used, particularly when engineering controls are not reasonably practicable.

12. DETERMINISTIC EFFECTS ON THE BLOOD SYSTEM

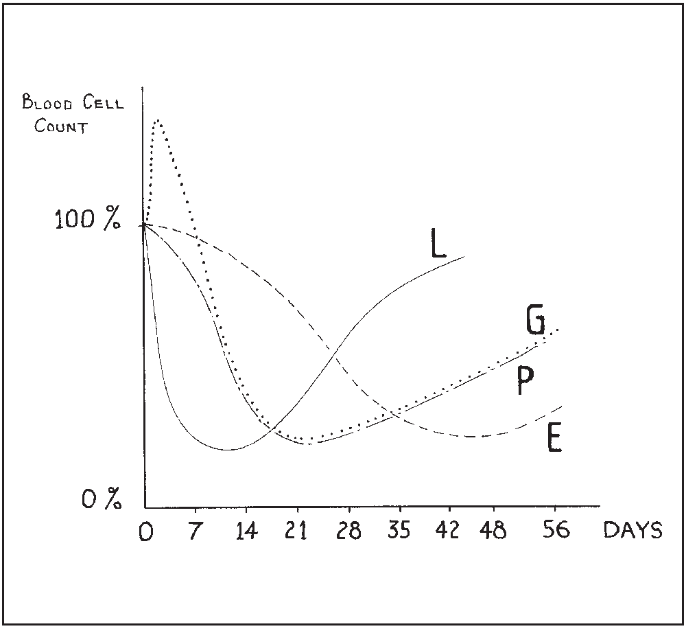
Blood contains different types of cells. The stem cells that form new blood cells occur mainly in the red bone marrow and in lymph tissues.

Red blood cells (erythrocytes) transport oxygen and carbon dioxide throughout the body. Their cell renewal system (see Section 4) has a turnover rate of 13–18 weeks resulting in a long latent period between irradiation and the maximum effect. The number of functioning cells (red blood count) may be only slightly reduced if the number of viable stem cells recovers after irradiation.

White blood cells (leucocytes) perform immunological duties and provide a defence against infections and foreign matter. There are different types of leucocytes with turnover rates of a few hours to many years. Granulocytes have a turnover rate of a few days, are full of lysosomes and digest general infections in the blood. Lymphocytes represent the specific immune response system. Their renewal system is not fully understood and, although it is a functional cell, the lymphocyte is one of the most radiosensitive cells. Damaged chromosomes (aberrations) in lymphocytes provide a sensitive indicator of accidental exposures to doses greater than about 0.1 Gy (see Section 19, IAEA-PRTM-2).

Platelets perform the blood clotting duties to prevent excessive blood loss and have a turnover rate of 5–10 days.

An acute whole body dose in excess of about 0.5 Gy to the bone marrow causes a sudden and dose-dependent clinically significant depression of the blood forming process which causes the numbers of lymphocytes, granulocytes, platelets and erythrocytes to reduce over the next 2–3 weeks. A dose of a few grays may depress blood cell numbers to the extent that septicaemia (blood poisoning) or haemorrhage (bleeding), due to bone marrow failure, may cause death unless the symptoms are treated. The dose rate threshold for protracted exposure over many years is more than 0.4 $Gy \cdot a^{-1}$.



Response of functional blood cells to radiation.

The number of granulocytes (G) may briefly increase (up to 30% at 2 Gy) following whole body exposure. Their number and that of the lymphocytes (L) and other blood cells then decreases until the stem cells recover.

A measurable reduction in the number of erythrocytes (E) may be due to internal bleeding that cannot be stopped because of the reduced number of platelets (P).

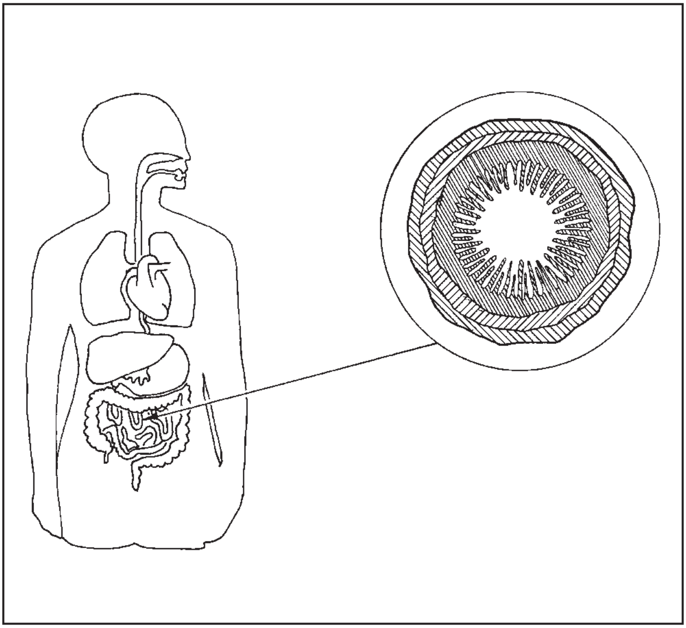
13. DETERMINISTIC EFFECTS ON THE INTESTINES AND LUNG

Acute whole body doses in excess of about 1 Gy generally cause ‘radiation sickness’. The first symptoms, called the prodromal phase, may appear within a few hours and cause feelings of being unwell, nausea and, possibly, vomiting. After about a day the exposed person may feel better as the body copes with what is possibly a release of toxins and histamine-like substances occurring either at or shortly after the exposure. The symptoms that follow are dose-dependent.

The most radiosensitive section of the gut, the small intestine, is lined by a single layer of epithelial cells with numerous villi to increase the absorption of nutrients. Cells are continually worn off the ends of the villi by the passage of food and are replaced by stem cells (crypt cells) at the base of the villi. The epithelial cells take 3–5 days from formation to migrate to the tip of the villus.

An acute dose of about 5 Gy to the gut causes an immediate reduction in the crypt cells which results in ulceration and, at higher doses, denuding of the gut surface 5–10 days later. Blood from the damaged blood vessels as well as body fluids are lost into the gut. If the bone marrow has also been irradiated, the depressed platelet count at these doses leaves the body unable to stem the bleeding. Normally harmless bacteria from the gut contents may pass through the damaged blood vessels into the bloodstream, where they become pathogenic. A depressed leucocyte count leaves the body defenceless against the bacteria. Loss of appetite, fever, haemorrhage, diarrhoea, weight loss, etc., may lead to death 10–20 days after exposure.

Damage to the cells lining the air sacs may result in acute inflammation of the lungs (pneumonitis) at doses in the range of 5–15 Gy. This may also occur after inhalation of high specific activity radioactive particles containing radionuclides with a short half-life. At a later stage, lung fibrosis occurs, which may be life-threatening.



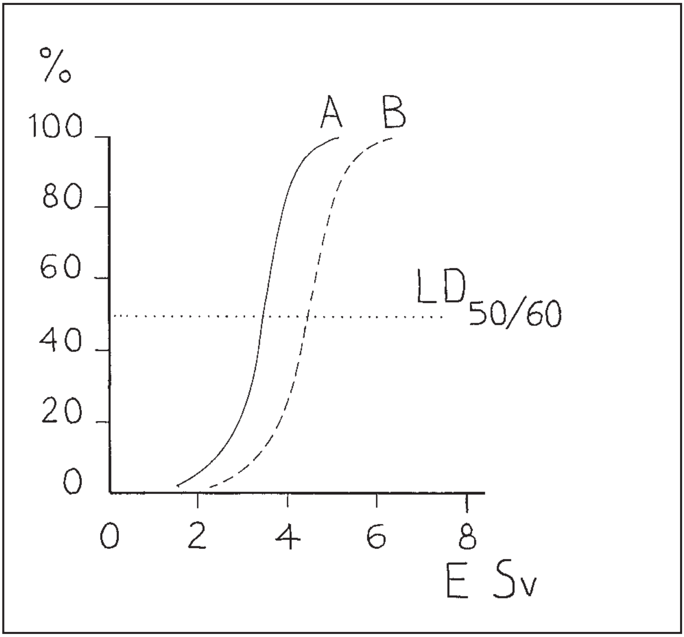
The gastrointestinal tract and other internal organs.

The detail shows a cross-section through the small intestine. The thin hair-like projections into the intestine, called villi, may be damaged by an acute radiation dose.

14. DETERMINISTIC EFFECTS ON THE CENTRAL NERVOUS SYSTEM AND LETHAL DOSES

At very high whole body doses in excess of 15 Gy, swelling (oedema) of the brain and generalized shock affecting the cardiovascular system leads to coma and death.

The range of doses associated with death from acute exposure of the blood system, the gastrointestinal tract and the central nervous system is based upon sparse human data, supplemented by knowledge of the dose-response relationship derived from animal experiments. No individual would be expected to die after receiving an acute whole body dose at or below 1 Gy unless the person was seriously ill before irradiation. In an exposed population of 100 people, about 5 individuals would probably die after receiving about 2 Gy and about 50 would die within 60 days of receiving a homogeneous whole body dose of 3.5 Gy. This is called the Lethal Dose, $LD_{50/60}$. When the correct treatment is provided by a specialized hospital, the survival rate improves and the $LD_{50/60}$ increases to between 4 and 5 Gy. Most individuals would be expected to die after receiving an acute exposure to a whole body dose of between 6 and 10 Gy unless they receive treatment to prevent infection and bleeding. Above about 10 Gy death is most likely, even after attempts to stimulate the bone marrow or administration of a bone marrow transfusion from a compatible donor.



Percentage of mortality following whole body exposure.

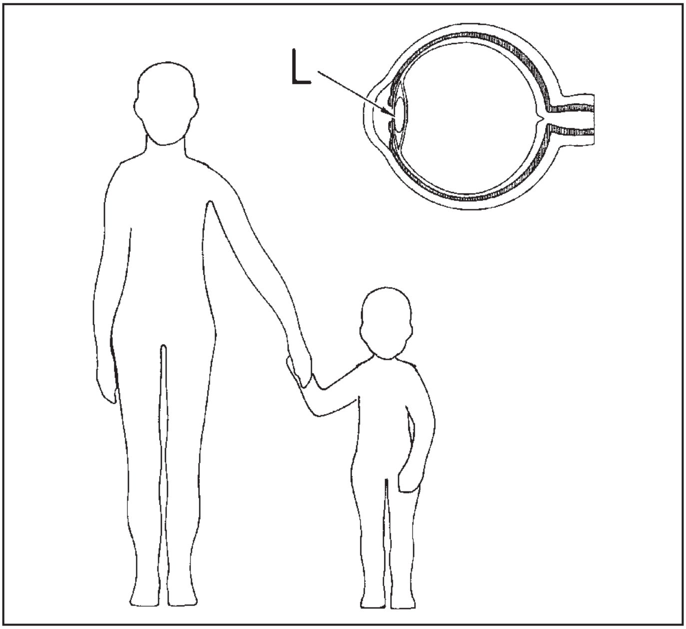
Curve A indicates the likelihood of death when no treatment is provided. With specialized medical support provided, and the possible rescue of bone marrow, the survival rate is likely to improve (curve B).

15. DETERMINISTIC EFFECTS OF PARTIAL BODY EXPOSURE, INCLUDING THE EYE

Relatively few radiation sources are capable of irradiating the whole body to deliver doses above the thresholds for deterministic effects to occur. However, accidents or misuse of radiation sources that are common to normal practices can deliver significant doses to localized parts of the body, termed acute and chronic partial body doses.

Acute partial body doses are used for radiotherapy. These will usually be 'fractionated doses' of perhaps 1 MeV gamma radiation delivered in 2–3 Gy increments over several weeks, resulting in 20 to 70 Gy to parts of the body receiving treatment. Occupational exposures are unlike medical exposures in that acute doses are more likely to be from mixed radiations; and chronic occupational exposure is likely to be intermittent, non-uniform and spread over many years. Protracted doses are less damaging than acute or fractionated exposure.

The threshold dose for a cataract (opacity or cloudiness) on the lens of the eye, sufficient to impair vision, is 5 Gy for an acute exposure to low LET radiation and 2–3 times less for high LET radiation. The action level of dose of 2 Gy is recommended for an acute exposure received in less than 2 days. The latent period is between 6 months and 35 years (average 3 years), because cells on the surface of the lens divide infrequently and grow slowly. The dose rate threshold is less certain for chronic exposure, but for exposure over many years it is above 0.15 $Gy \cdot a^{-1}$.



Partial body doses.

Adults have a much higher tolerance to radiation than children. This is also reflected in the different risk factors calculated for workers and the whole population (see the second paragraph of Section 9).

The detail is a section through the eye, indicating the position of the lens (L).

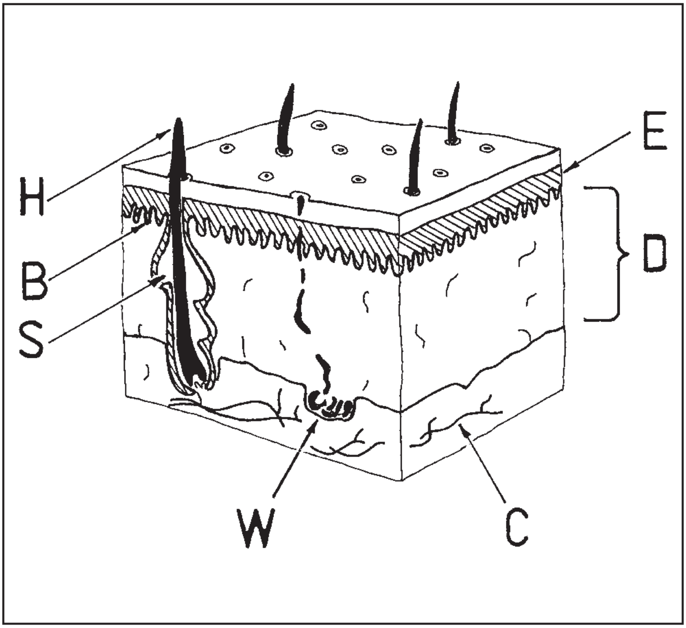
16. DETERMINISTIC EFFECTS ON THE SKIN

The surface skin cells are dead and are continually replaced by the action of stem cells below. Just below the surface there are small blood vessels (capillaries). Quantifying threshold doses is complicated by the difficulty of defining a single depth at which to specify the dose to the skin.

An acute photon dose of about 2 Gy to more than about 10 cm^2 of skin will cause a transient reddening (erythema caused by dilated capillaries) within a few hours. A few weeks later erythema will recur owing to the loss of basal cells from the epidermis (outer layer of skin). This damage might last several weeks. Slight blistering is usually followed by a brown pigmentation which can last a considerable time.

Desquamation (death of the entire skin thickness) over a large area of skin is fatal. An acute photon dose of about 3–8 Gy, or 20 Gy for fractionated doses, causes erythema followed by hair loss (depilation) and peeling dry skin (dry desquamation) after 3–6 weeks. Depilation is temporary in the lower range. At 12–20 Gy, blisters (moist desquamation) occur after 4–6 weeks owing to loss of basal cells in the epidermis; ulceration caused by infection of the dermis (inner layer of skin) follows moist desquamation after about 6 weeks; and doses greater than 20 Gy damage blood vessels, causing necrosis (death) of the dermis after about 10 weeks. Months to years later, changes in pigmentation; atrophy of the epidermis, sweat glands and sebaceous glands and hair follicles; and fibrosis of the dermis may occur. The threshold for damage to large areas is about 20 Gy. Protracted irradiation decreases the effect and at 0.4 $Gy{\cdot}h^{-1}$ no acute tissue breakdown may occur at total doses as high as 100 Gy.

Contamination can deliver highly localized doses but the threshold doses are higher for smaller areas of skin. Moist desquamation occurs at about 70 mSv from a 5 mm diameter, 2.27 MeV beta source, but after a dose of 27 Gy for sources of 23–40 mm in diameter. The ulcers resulting from highly localized doses are usually transient, lasting less than a week unless the total dose exceeds 250 Gy.



A section of skin.

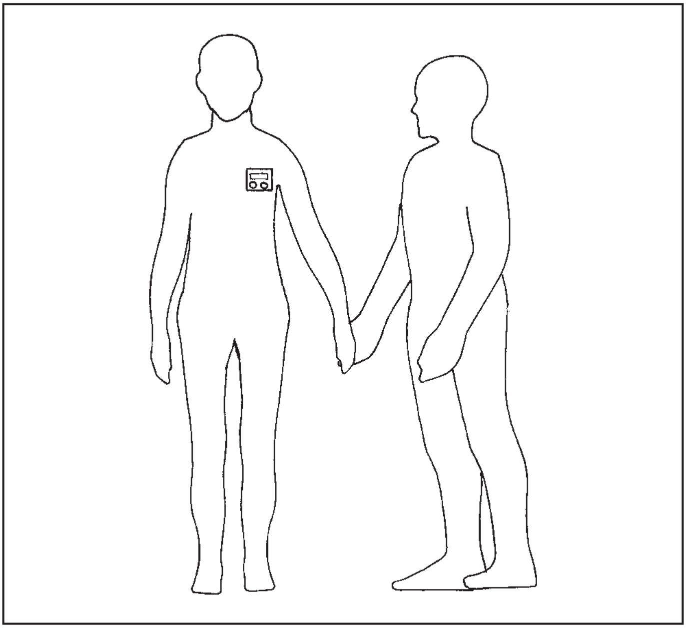
Acute exposures of the skin to radiation may damage the epidermis (E), the basal cells (B), the dermis (D), sweat glands (W), the sebaceous glands (S) and capillaries (C). Damage to hair follicles (minute pits in which hair grows) may result in the loss of hair (H).

17. IRRADIATION OF THE MALE REPRODUCTIVE ORGANS (GONADS)

The reproductive cells of the testes originate from germinal cells in the foetus that proliferate into spermatogonia. When the male reaches sexual maturity, the spermatogonia begin to proliferate rapidly, generating some cells that retain the capacity to continue dividing (stem cell spermatogonia) while other cells (maturing spermatogonia) proceed to differentiate into spermatocytes, spermatids and then spermatozoa (also called sperm, sperm cell and zoosperm) containing half the number of chromosomes present in the original stem cell. There is a supply of sperm from stem cell spermatogonia from the time of puberty and for many years thereafter. An average ejaculation in a young adult contains about 500 million sperms. A single sperm is capable of fusing with an unfertilized egg, combining to form a cell with the normal number of 46 chromosomes.

Irradiation of the male reproductive organs may interfere with spermatogenesis (the generation of spermatozoa), resulting in a significant but reversible depression of the sperm count after a brief exposure to about 0.1 Gy. The threshold dose for temporary sterility lasting several weeks is about 0.15 Gy; the spermatogenesis restarts if a sufficient number of stem cells spermatogonia remain viable. Under conditions of prolonged exposure the dose rate threshold is about 0.4 $Gy{\cdot}a^{-1}$. The corresponding values for permanent sterility are about 3.5–6 Gy and 2 $Gy{\cdot}a^{-1}$.

The risk of damage to genes and chromosomes of spermatozoa exists at any dose or dose rate and increases with increasing dose, potentially causing developmental defects in children (see Sections 8 and 9).



Response of the male gonads to radiation.

Acute doses to male workers may cause somatic effects such as sterility in the worker.

Such matters are of concern to the worker and are also likely to generate anxieties for the worker's partner and family.

18. IRRADIATION OF THE FEMALE REPRODUCTIVE ORGANS (GONADS) AND EMBRYO

Gonads

The reproductive cells of the ovary develop from germinal cells into primary oocytes. They remain primary oocytes until the female becomes sexually mature, when some develop further under the influence of hormones to become secondary oocytes and eventually mature egg cells (ova), which contain half the number of chromosomes present in the original stem cell. One egg cell is released from an ovary each month for potential fertilization. An ovum fertilized by a single sperm will have 46 chromosomes.

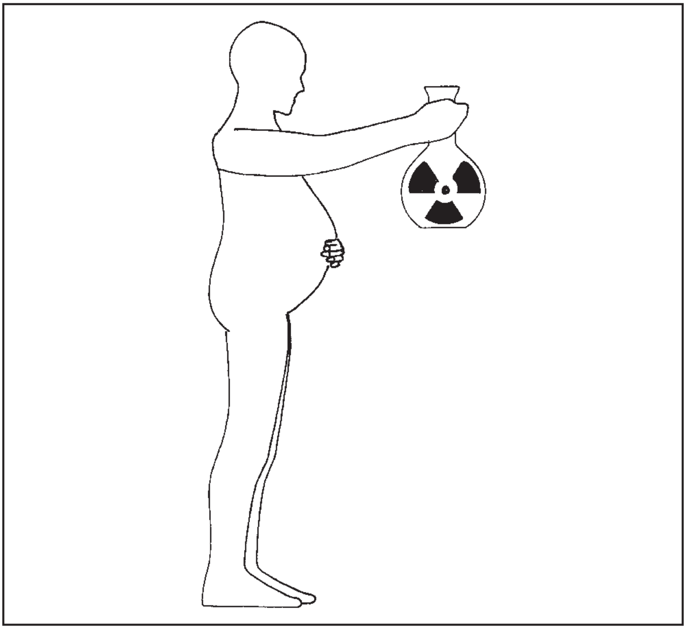
Irradiation of the female gonads may reduce fertility or induce sterility. If enough oocytes remain viable, then it is possible to restore fertility, but there is no possibility of deriving more oocytes. The threshold for permanent sterility in women is an acute absorbed dose in the range of 2.5–6 Gy, older women being more sensitive, or a protracted dose rate over many years of more than 0.2 $Gy{\cdot}a^{-1}$.

Embryo

Animal experiments indicate the possibility of deterministic effects on the embryo during the first two months of pregnancy and on the foetus after the second month of pregnancy. Effects on the embryo depend on the time of exposure relative to its development and include the possibility of the embryo failing to implant in the wall of the uterus, skeletal abnormalities, impaired fertility of a female, functional disorders of the central nervous system and growth retardation. Threshold doses are suggested to be in the range of 0.05–0.5 Gy. The exposure of a foetus may affect brain development, perhaps affecting the IQ or increasing the risk of learning disabilities. Doses below 0.1 Sv are unlikely to produce any discernible reduction in the general IQ level.

Late effects

The embryo and foetus are expected to be at risk of stochastic effects (see Sections 7 and 8). Risk factors are not established, but the greatest risk to the foetus from effects such as childhood leukaemia (a cancer involving uncontrolled proliferation of leucocytes) is associated with exposure during the first three months of pregnancy.



Response of the female gonads to radiation.

Acute doses to pregnant workers may cause somatic effects in the woman. The possibility also exists that radiation may cause teratogenic effects involving the improper development of the embryo or foetus. Females may decide to work through a pregnancy provided that the doses are strictly controlled and kept within the dose limit of the effective dose for members of the public (i.e. below 1 mSv during the whole pregnancy).

19. MEDICAL SURVEILLANCE

Employees should be medically examined prior to employment involving work with ionizing radiations, and thereafter their medical fitness should be reviewed at periodic intervals (usually annually). The primary purpose of this medical surveillance is to assess the initial and continuing fitness of workers for their intended tasks. It should however be rare for the radiation component of the working environment to significantly influence the decision about the fitness of a worker to undertake work with radiation, or to influence the general conditions of employment.

The three main objectives of the medical surveillance are:

(a) to assess the health of the workers,
(b) to determine the fitness of the worker for tasks expected to be undertaken, and
(c) to provide a baseline information useful in the case of accidental exposure.

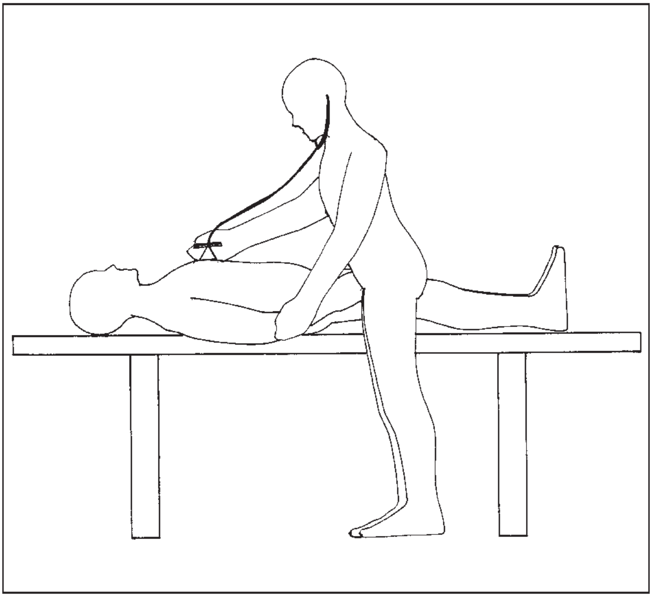
The nature of the periodic reviews will depend on the type of work that is undertaken and the state of health of the worker. The frequency of medical examinations should normally be comparable to that of any other occupational health surveillance programme.

As in other health surveillance programmes, depending on the type of work and the state of health of the worker, three situations may require special medical examination. These are:

(a) where the work involves potential exposure to airborne radioactive material and it is necessary to assess an individual's fitness to wear protective respiratory equipment in some areas, verification of lung function will be essential;

(b) where the work involves potential skin contamination and it is necessary to assess an individual's skin condition for disease or damage that could either be exacerbated by contamination, accelerate absorption or preclude the wearing of necessary personal protective clothing; and

(c) where the work is such that employees with psychological disorders may be a hazard to either themselves and/or their colleagues.



Routine medical surveillance.

The occupational physician carries out appropriate medical examinations to confirm a worker's fitness to work with ionizing radiations. Reviews of continuing fitness are carried out periodically and on finally ceasing work.

20. MEDICAL STAFF

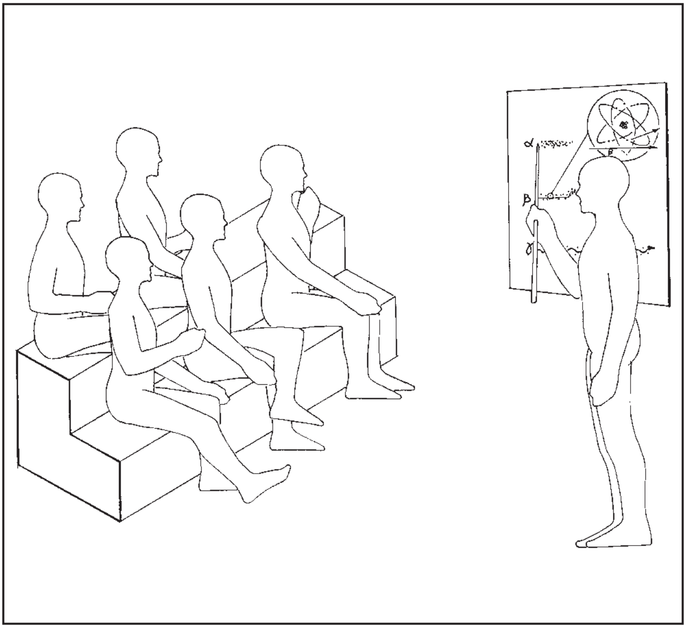
The decision on fitness for radiation work must be based on the professional judgement of a medical officer who is familiar with and understands the working conditions and the specific hazards associated with the anticipated tasks. The occupational physician should ensure that the medical staff are trained to deal with routine and emergency situations.

The medical staff:

(a) should be familiar with and understand the processes of the workplace;
(b) need to be trained to understand the radiation risks;
(c) must have sufficient knowledge of radiation protection programmes and monitoring;
(d) must be aware of the likely consequences of potential radiation incidents and accidents;
(e) must know the appropriate medical treatments to deal with potential occurrences;
(f) need to maintain a working relationship with the radiation protection officer to be able to obtain appropriate information if an incident or accident occurs.

The occupational physician should provide training for the medical staff to enable them to:

(a) administer conventional first aid;
(b) handle contaminated patients while minimizing the risks to themselves and containing the potential spread of contamination;
(c) decontaminate wounds;
(d) obtain early biological samples such as nose blows, oropharyngeal swabs, blood samples, etc.; and
(e) administer routine (appropriate) prophylactics such as stable iodate tablets in circumstances where it is necessary to saturate the thyroid to block an uptake of released radioiodine.



Medical staff.

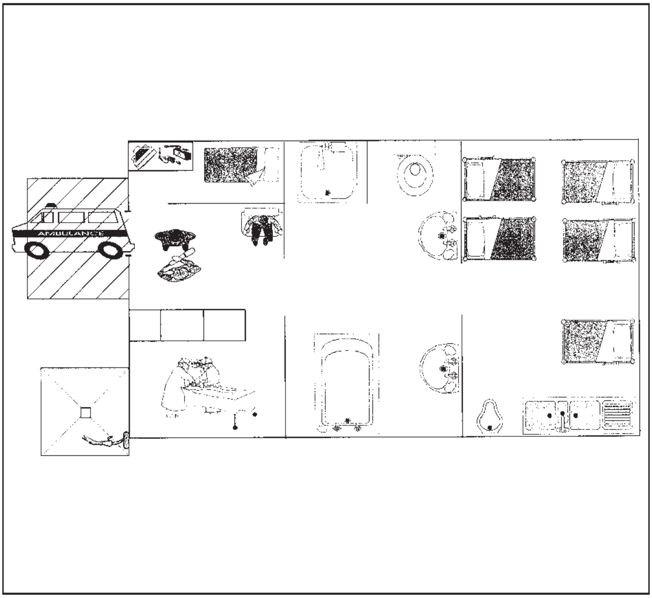
Suitable training is carried out by or under the direction of the occupational physician.

21. MEDICAL FACILITIES

The medical facilities required for the routine health surveillance of occupationally exposed employees are the same as for any other occupational medical practice. In addition to a reception and waiting area, at least one room is required where the worker and the occupational physician may consult in private. A treatment room with washing facilities and couch is needed where physical examinations may be carried out, samples and specimens can be taken and measurements can be made. Office accommodation is needed for support staff to work in and maintain and store appropriate records.

Where a hazard assessment shows a potential need to deal with casualties who may be contaminated by radioactive material, arrangements need to be in place to receive and manage the casualties so that the facilities and other persons do not become adversely affected. The contingency plans should include the following arrangements:

(a) A suitable, clearly defined entrance that allows a contaminated worker to be promptly received, contained and segregated from other patients.
(b) Suitable protective clothing for the receiving staff.
(c) Suitable radiation monitoring instruments, including wound monitoring equipment where appropriate, to determine the extent of radioactive contamination and minimize the transfer and spread of contamination to other surfaces.
(d) A prepared appropriate treatment area where the patient can be given priority examinations and treatment.
(e) Decontamination facilities such as showers.
(f) Staff co-ordination to be able to accommodate multiple casualties likely to result from reasonably foreseeable accidents.
(g) Capability to obtain and process appropriate biological samples.
(h) Containers for, and management of, contaminated clothing, equipment and other waste.



Reception centre for radiation casualties.

In an ideal reception centre a covered area is provided for ambulances and there are facilities for decontaminating vehicles. Initial triage is provided in the ambulance or on the stretcher.

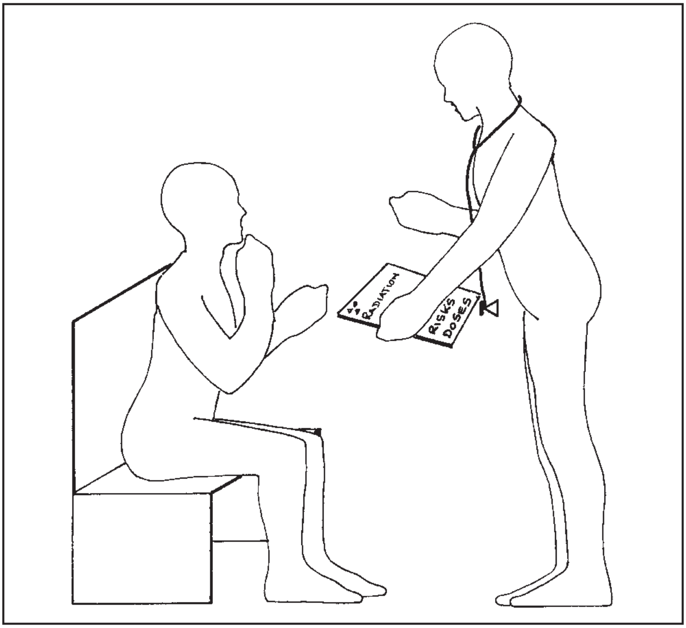
Casualties are monitored on entering the facility. Contaminated clothing is removed and bagged. A waiting area, and intensive care and surgery facilities are close to the entrance. Casualties progress into the second stage monitoring area, where there are decontamination facilities.

Decontaminated patients enter the main hospital area, where there are arrangements for biological monitoring for internal doses.

22. ROUTINE MEDICAL COUNSELLING

All occupationally exposed employees should be given instruction and training appropriate to their work as well as information about the potential health effects associated with exposure to ionizing radiations. This will enable them to make informed judgements about the potential risks and will increase their understanding of the need to work in accordance with safety requirements. Some employees will not be comfortable with the concept of occupational exposure and may require reassurance on emotive issues such as the health effects of radiation. Although no evidence exists that irradiation of a father prior to conception affects the incidence of childhood disease in his offspring, media reports on this topic are not uncommon, prompting employees to seek advice on such issues.

Women of reproductive capacity who want to carry out work involving exposure to ionizing radiation may do so safely but must have the special risks explained to them. Female employees should be advised to inform the management or the occupational physician if pregnancy is suspected or confirmed, because the conceptus, the embryo and the foetus are most susceptible to ionizing radiations. Therefore, when a pregnancy is confirmed, doses should be strictly controlled throughout the remainder of the pregnancy. ICRP recommends that adequate protection is maintained by limiting the dose to the surface of the abdomen of a pregnant worker to 2 mSv following her declaration of pregnancy and by limiting the intake of radionuclides during the remainder of the pregnancy. According to the International Basic Safety Standards, the employer shall ensure that the embryo or foetus is afforded the same level of protection as required for members of the public. Pregnant women may choose to continue working. This special care should be extended to the post-natal period when women may be breastfeeding.



Routine medical counselling.

Occupationally exposed workers are encouraged to discuss their work and medical matters with their occupational health advisers.

Female workers who become pregnant should inform the occupational health physician to ensure that appropriate limitations can be applied.

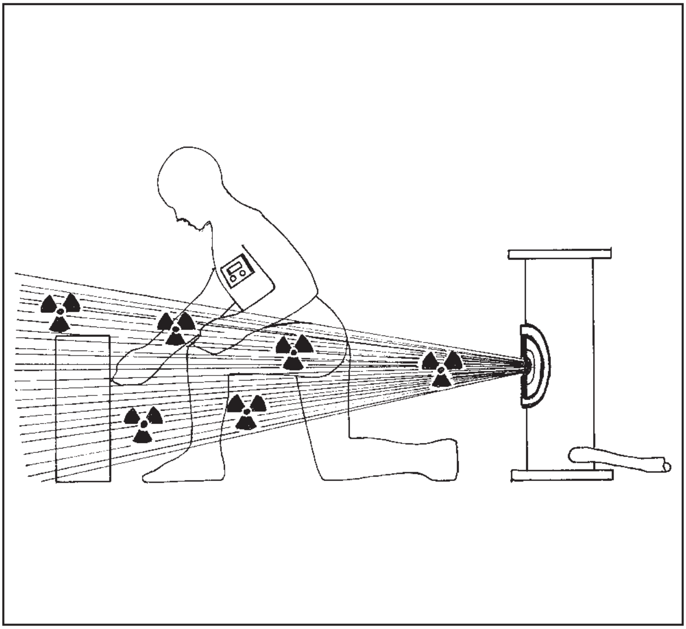
23. REPORTED EXPOSURES, INVESTIGATIONS AND ASSESSMENTS

Reports of excessive or unplanned exposure to external radiation and contamination can arise by various means.

Sometimes it is immediately apparent to a worker or the radiation protection officer (RPO) that an incident has occurred, for example when the worker has not carried out proper radiation monitoring and has moved close to the radiation source position before realizing that a shutter has failed to close, an exposure warning light is still illuminated, or a radiation source has not been retracted into its shielding. Contamination hazards may be immediately suspected when a major spill occurs or a special form source has been seriously damaged. Other incidents are discovered retrospectively, for example when the dose recorded by a dosimeter is much higher than normal or radioactive contamination is found unexpectedly.

Circumstances such as these must be investigated immediately by the RPO while the facts of the matter are still likely to be obtained. If an incident is immediately apparent, the dosimeters worn by those involved should be sent for emergency analysis. An investigation often needs to include a reconstruction of the accidental exposure conditions to directly measure the doses received by the worker or to make other measurements that will enable calculations to be made of potential doses. The doses recorded on a dosimeter must always be evaluated to ensure that the recorded dose is a true representation of the dose received by the worker. Non-uniform exposures can result in partial body doses that are either very much higher or lower than the dose recorded by the dosimeter.

As soon as an investigation indicates that a significant radiation dose is likely to have been received or a worker has been significantly contaminated, details must be given to the occupational health services and usually the competent authority must also be notified.



Investigations of accidents and incidents.

All reports of possible accidents and incidents must be fully investigated. The dose recorded by a dosimeter represents the whole body dose received, but an investigation may reveal higher partial body doses of significance.

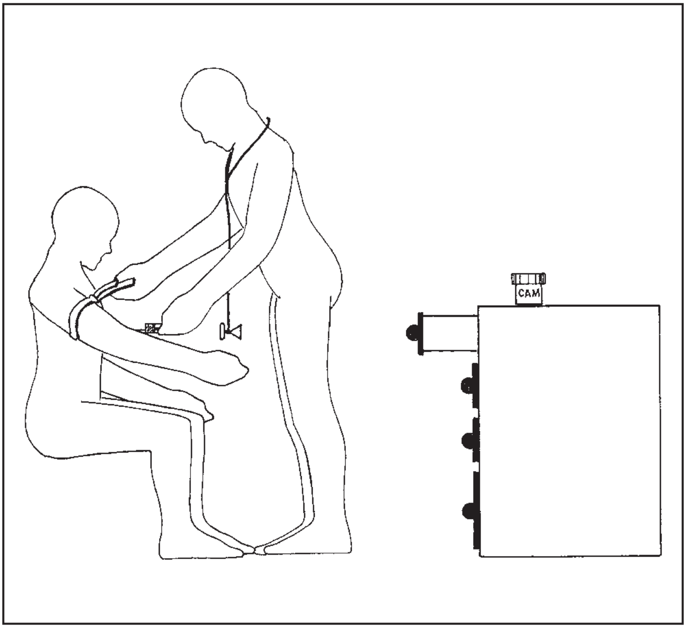
24. MANAGEMENT OF OVEREXPOSURE TO EXTERNAL IRRADIATIONS

When the occupational health services are informed of a potentially significant exposure to radiation, the occupational physician should ensure that adequate confirmatory investigations have been carried out. Overreaction to what becomes a false alarm can cause anxiety and unnecessary suffering to the employees involved. For example, reported dosimeter results have later been found to be due to an inadvertent exposure of the dosimeter while unattached to the worker or an error by the dosimetry service.

Various courses of action may be followed when an investigation confirms a positive result. The occupational health service may advise or arrange for further types of available dosimetry and tests as described in IAEA-PRTM-2. Other actions will depend on the level of the dose.

(a) At doses close to or just above the dose limits, no special clinical investigations or therapy will be needed. The occupational health personnel should counsel the worker that such an exposure is unlikely to produce adverse health effects, irrespective of whether or not the advice is solicited by the worker.
(b) At doses well above the dose limits but below the threshold for deterministic effects, the occupational physician must advise the worker and determine whether biological dose indicators, such as lymphocyte counts and chromosome aberration assays, are needed to confirm the dose estimates. Normally, no further action is required other than counselling.
(c) At doses at or above the threshold for deterministic effects, therapeutic action may need to be undertaken. Before making this decision, the clinician will clinically examine the worker and record any findings or symptoms. Blood samples will be obtained as soon as practicable, in order to plot the clinical developments. If the exposure is likely to lead to acute radiation syndrome (see Sections 11–15), early transfer to a

specialized treatment facility is essential. These facilities are normally at hospitals capable of dealing with haematological diseases (e.g., leukaemia), radiotherapy patients, major burns and radical surgery. The occupational physician should set in motion the initial investigations and treatment of the early symptoms.



Overexposure to external sources.

At doses reported to be well above the occupational dose limits, the occupational physician should take a specimen of blood for haematological chromosome aberration analysis or a blood cell count.

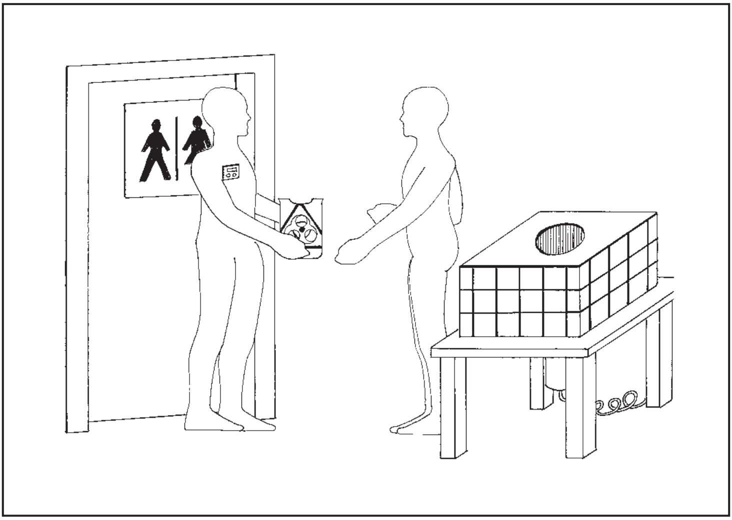
25. MANAGEMENT OF OVEREXPOSURE DUE TO INTAKES OF RADIONUCLIDES

When there are indications that a worker may have become internally contaminated, the worker should be removed temporarily from the workplace to prevent any further external exposure or intakes, even when the dose is expected to be below the dose limits. This action will allow more accurate dose estimates to be made. The occupational health service may advise or arrange for further types of available dosimetry and tests to assess the intake. Dose assessments may be carried out by various means including approximate, qualitative methods (for example nose blows) and more quantitative measurements by sequential counting using an organ or whole body monitor, or biological monitoring of body fluids (assessments of urine or faecal samples). These options are described in the Practical Radiation Technical Manual on Individual Monitoring (IAEA-PRTM-2). Other actions will depend on the level of the dose.

Significant intakes of radioactive material may warrant interventional therapy to accelerate excretion of the radionuclides. Such therapeutic measures may include the administration of chelating agents to enhance the excretion of transuranic radionuclides, dialysis to flush out tritiated water intakes and pulmonary lavage (injecting fluids into the lungs) to wash out some inhaled plutonium compounds.

Medical procedures are not without risk and should only be undertaken when the expected dose averted outweighs the risk of the intervention. Many of these therapeutic procedures would be undertaken only at a specialized treatment centre.

The occupational physician should be prepared to administer the first dose of chelating agents, stable iodide or iodate, or absorbents and adsorbents depending on the specific hazards of the workplace.



Overexposure due to intakes of radionuclides.

Biological samples are collected to estimate intakes of radioactivity (see Section 8). A proportion of an internal emitter is excreted. Urine and faeces are collected to measure the excreted radioactivity. Excretion rates are calculated to determine the total intake and the committed effective dose.

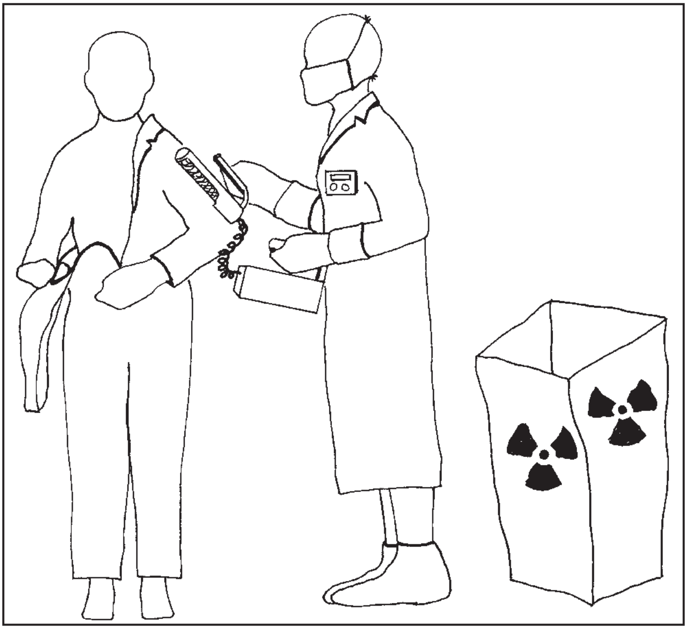
26. MANAGEMENT OF OVEREXPOSURE TO EXTERNAL CONTAMINATION

When there are indications that a worker may have become externally contaminated, decontamination should be undertaken as soon as possible. External contamination not only increases the risk of internal contamination but significant skin contamination with high energy beta emitting radionuclides can result in deterministic effects if the contaminant is not removed soon enough. Thermal burns and cuts or abrasions of the skin could complicate decontamination and need to be treated simultaneously. The only justification for delay would be the immediate treatment of life-threatening physical injuries.

In order to move a casualty for treatment, a clean blanket wrapped around the contaminated parts of the body will help to prevent contamination of the carers and ambulance. A contaminated casualty will not represent a hazard to the physician or attending staff wearing standard medical dress, such as a gown, gloves and a surgical face mask.

Treatment will generally involve the careful removal of contaminated clothing first and then attempts to remove contamination by gentle means that are not likely to damage the skin or push contamination towards the eyes, ears, mouth or nose. Mechanical means such as scrubbing are an extreme measure and generally should be considered only to decontaminate the palms of hands and the soles of feet. Bathing in lukewarm baths, with the use of acetic acid or ion exchangers if the surface contamination is thought to be soluble caesium, is another possibility. Later treatments might include the use of topical creams and medication.

Depending on their chemical form, some radionuclides may be absorbed through the skin and can lead to internal contamination. This is particularly true where skin contamination occurs with tritiated (^{3}H) water and some compounds of iodine and caesium.



Overexposure to external contamination.

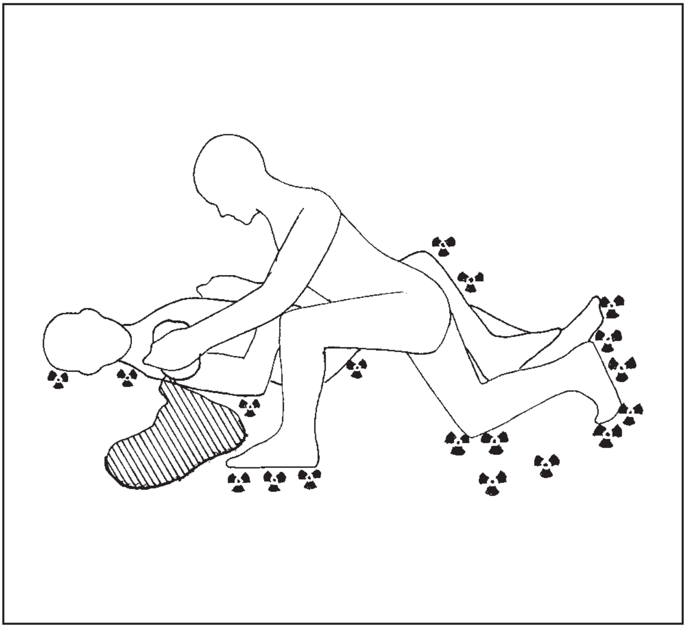
Monitoring instruments are used to detect the contamination on clothing and surfaces of the body. Contaminated clothing is removed and bagged. Skin is carefully decontaminated as soon as possible.

27. CONVENTIONAL HAZARDS, INJURIES, RESCUE CRITERIA AND COMBINATIONS

Where there are potentially life-threatening hazards such as a fire or a risk of explosion, combined with the risk of exposure to ionizing radiations, a sense of perspective of the relative risks must be maintained. Priority must be given to dealing with those conventional hazards that are normally the most immediate threat. Those seeking to provide emergency assistance in circumstances where a radiological hazard remains should, nevertheless, take whatever measures are reasonably practicable to reduce potential exposure, for example by making the radiation source safe or providing first aid at a safe location.

Immediate life-threatening injuries such as fractures and burns must be treated as a priority before transfer to a specialized centre.

The long term clinical management of highly exposed individuals would normally be beyond the competence of the occupational physician. Treatments would need to be undertaken by a specialist unit. Advice may be obtained from the IAEA and WHO on the location of appropriate medical centres and qualified medical advisers.



Conventional injuries.

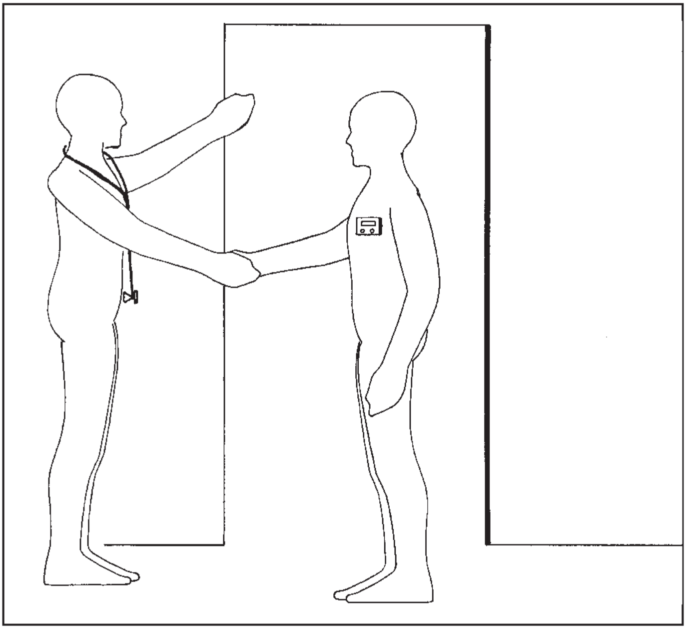
Conventional injuries that may be life-threatening must be given priority treatment.

28. RETURN TO RADIATION WORK

Exposures which do not approach threshold doses for deterministic effects need not affect a worker's fitness for further radiation work.

A worker should be advised by the physician on the level of the increased risk for stochastic effects. Where workers' own actions contributed to an exposure, consideration should be given by management to retraining or refresher training before authorizing a return to work. Return to work after internal contamination may be delayed until an adequate dose assessment has been made.

Where there is partial body overexposure which produces deterministic effects, for example in industrial radiography where the radiation source has been handled, the worker should be counselled on the future risks involved not only in radiation work but also in future manual work involving exposure to cold and other physical agents. The skin may continue to have heightened sensitivity to ambient conditions and physical agents.



Return to radiation work.

The occupational physician will advise when it is appropriate for a worker to resume work with ionizing radiations after an overexposure has occurred.

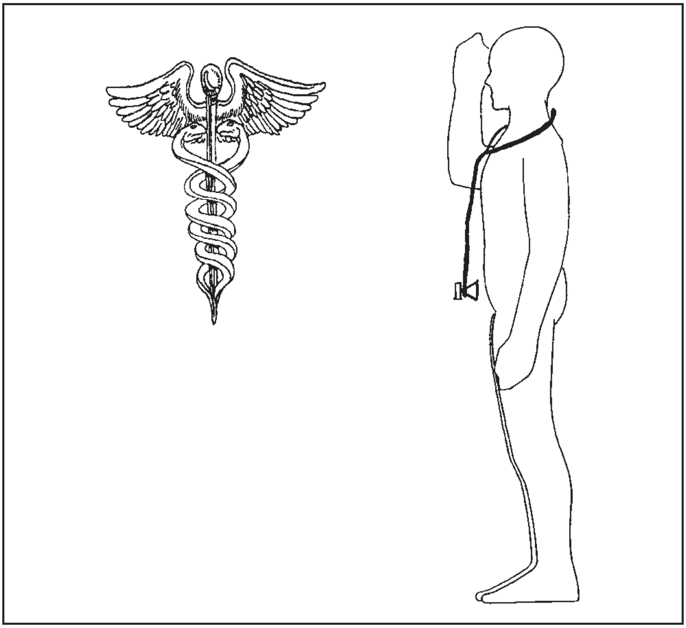
29. MEDICAL RECORDS AND CONFIDENTIALITY

A medical record should be kept by the occupational health service for each worker. The record should be as complete as possible and contain details of all examinations, treatment and advice. It may also contain appropriate summaries of any doses received (see Section 28, dose records, Practical Radiation Technical Manual on Individual Monitoring (IAEA-PRTM-2)) and should contain copies of any dose reconstruction or assessments carried out by the radiation protection officer.

Any overexposure resulting in a dose greater than a relevant dose limit should be recorded and flagged. The competent authority should be notified of precise details as soon as possible. Where an overexposure might have future detrimental effects, the worker's primary care physician should also be fully informed, with the worker's permission.

An investigation of the circumstances of any accident should be undertaken by the employer of the worker, with the participation of the competent authority and all those involved. The occupational health service should participate in such investigations and use the opportunity to review their arrangements and preparedness to respond efficiently to future calls. Where the law allows and the worker and employer agree in writing, consideration should be given to publishing information that might either prevent similar future exposures or provide medical insight into the treatment and care of accident victims.

Medical records should be retained for a sufficient period of time after the last entry. Bearing in mind the latency of stochastic effects, a period of 50 years would be appropriate. Such records must remain confidential and the content subject to normal medical ethics. The occupational physician is subject to professional standards and the Hippocratic oath. The doctor's primary duty is to the patient, while duties to the employer are restricted by medical confidentiality.



Medical records and confidentiality.

Occupational health physicians maintain strict codes of conduct in accordance with their Hippocratic oath as doctors. The physician is supported by medical staff who must operate in a professional manner and maintain confidential records.

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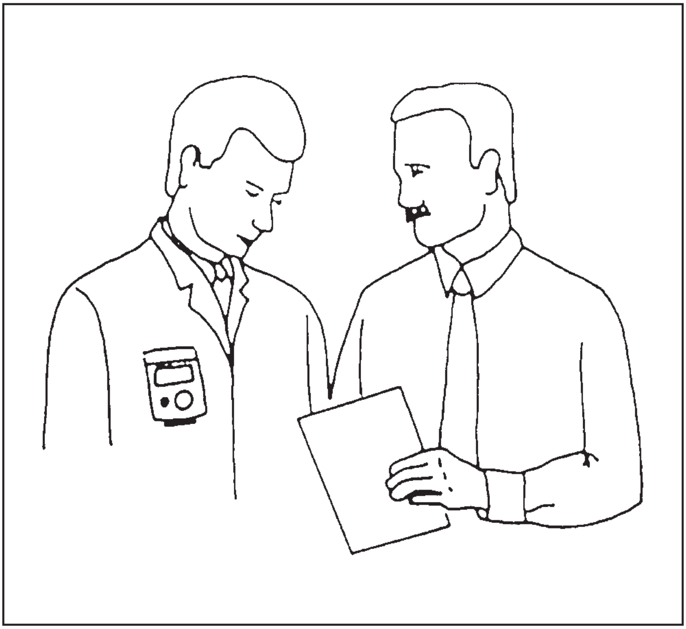

Further reading.

A qualified expert, a librarian or the IAEA can recommend further materials on health effects and medical surveillance in work with ionizing radiations.