Working with Radiation

BNFL

British Nuclear Fuels Limited

Contents

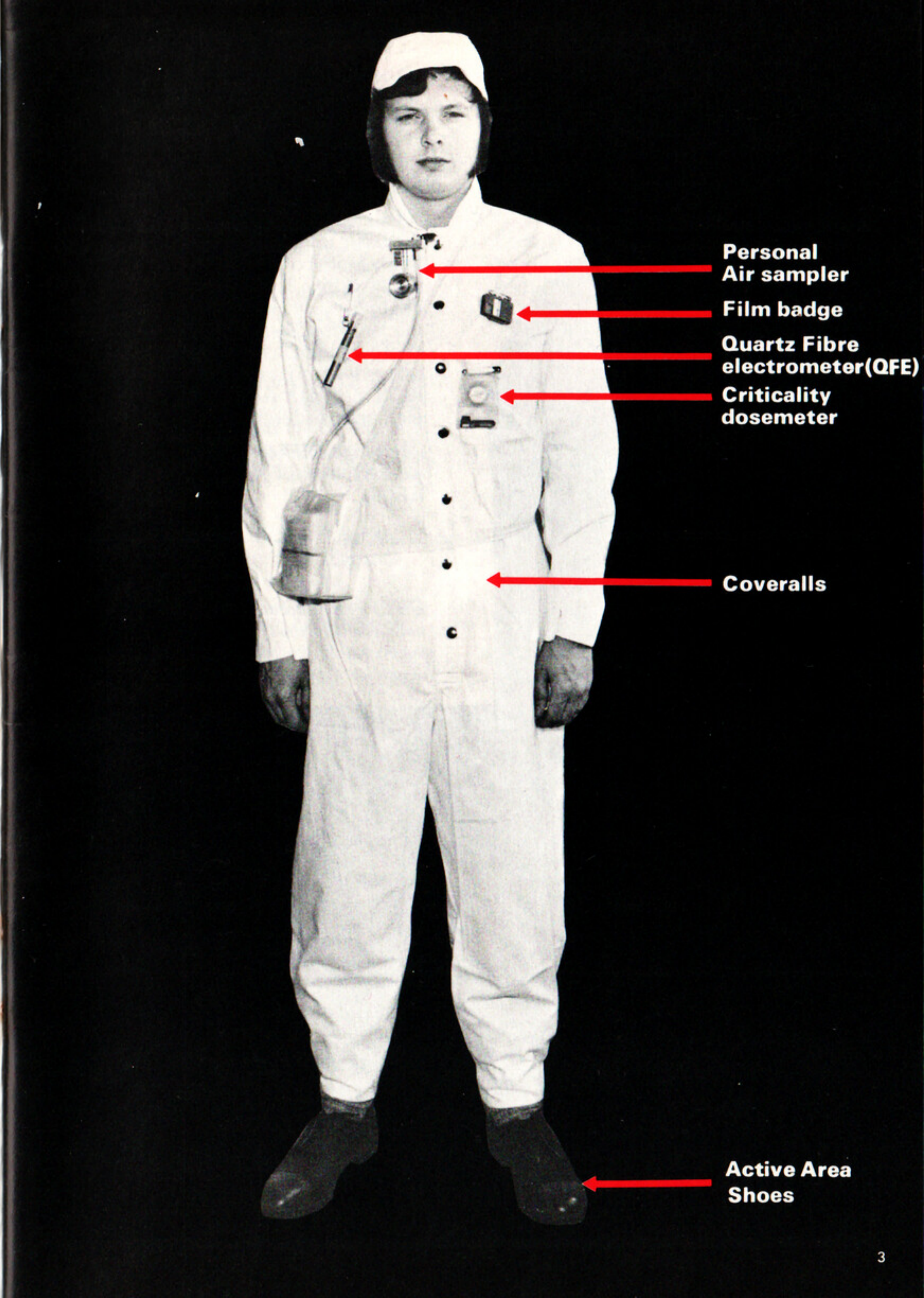
This booklet explains the nature of radioactive material and radiation, describes some of the benefits and risks arising from the use of sources of radiation and outlines the principal steps taken to protect radiation workers from these risks.

While written primarily for workers employed on BNFL's sites, the booklet also seeks to explain radiation in its wider context and does not confine itself to the nuclear industry alone.

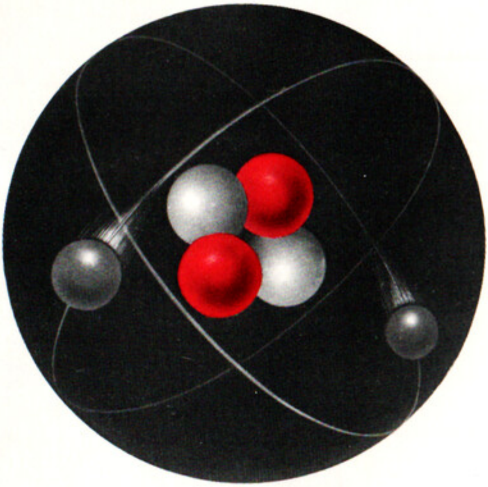
Sources of radiation are now widely used in medicine, research and industrial processes, as well as being found in nuclear energy. Many products and devices available to the public or used in general industry incorporate radioactive substances.

It is the responsibility of every person working in the nuclear industry to have an adequate knowledge of the hazards of radiation and of the precautions which must be taken to safeguard against them.

Protective clothing and other precautions, including appropriate personal dosemeters, may be specified for work in radioactive areas.



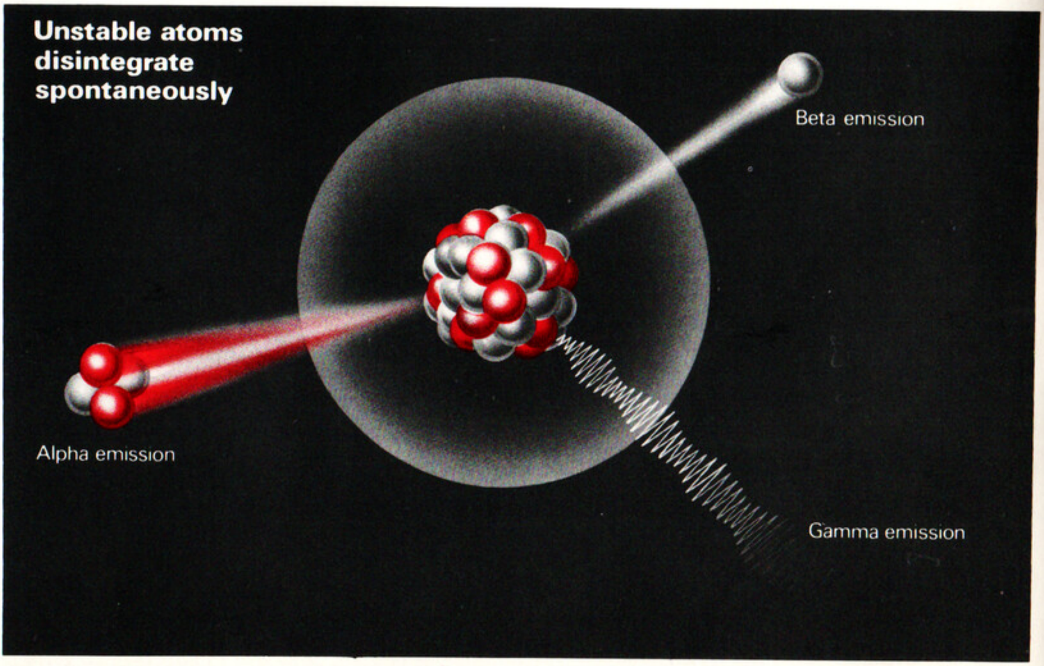
The nature of Radioactivity



All material is made up from elements and the basic unit of any element is the atom. Every atom consists of a nucleus around which orbit a number of negatively charged particles called electrons. The nucleus itself is made up of positively charged particles, called protons and others with no charge, called neutrons. All or most of the atoms of a particular element are identical in structure.

An atom of helium has two protons and two neutrons in its nucleus, around which orbit two electrons

Unstable atoms disintegrate spontaneously with the emission of an alpha or a beta particle. In this process there is often excess energy which is given off as gamma radiation.



The atoms of many of the elements are stable because they have a correct balance of protons and neutrons in the nucleus. Where, however, there is an imbalance of protons and neutrons, the atoms are unstable and may change spontaneously into atoms of other elements. When this happens energy is emitted in the form of radiation.

The radiations emitted by unstable atoms fall into five main categories which are described in Appendix I. These are alpha, beta, gamma, X-ray and neutron emissions. These radiations unlike light and heat, which are also forms of radiation, cannot be detected by the body's senses but can be detected by photographic film or electronically as with a geiger counter.

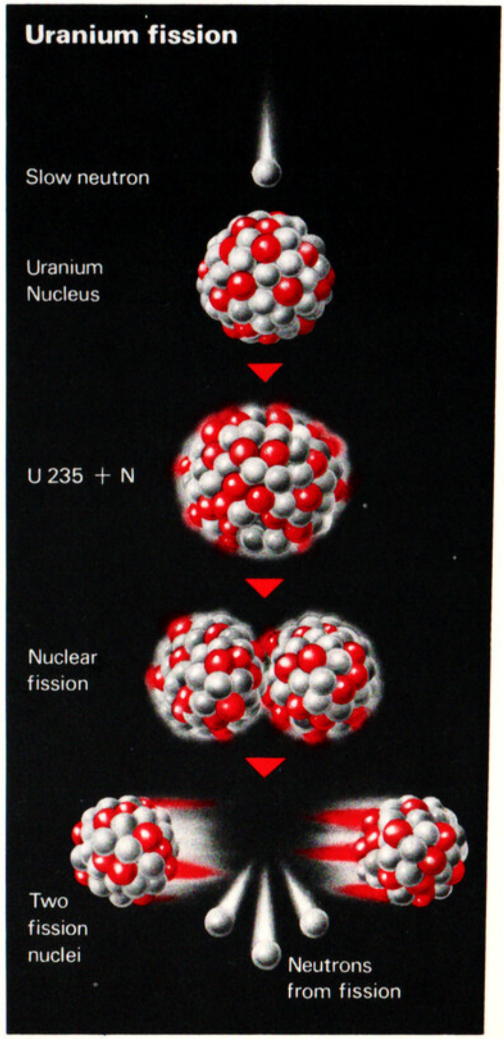
A special and important case of nuclear change is nuclear fission. The atoms of the heavy elements uranium and plutonium can in certain circumstances change by breaking in two or fissioning.

Portable beta/gamma monitor in use.

The result is the production from each atom of two lighter atoms described as fission products, together with the emission of radiation and the release of energy. This is the source of the energy released in nuclear weapons and nuclear power reactors.

Some of the more important radioactive isotopes, with their relevant properties, are listed in Appendix II

The fission process in a uranium nucleus.

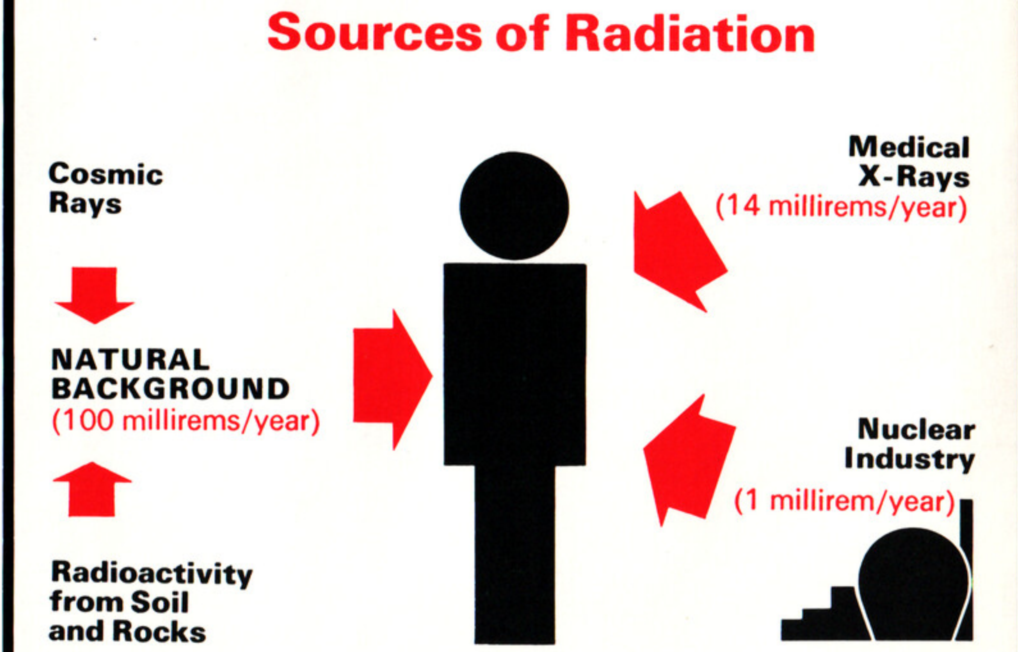


Natural and man-made Radiation

Natural Sources of Ionising Radiation

Naturally occurring radioactive substances are distributed over the whole of the earth, in rock, soil, water, plants and animals, including our own bodies. Cosmic rays from outer space bombard the earth incessantly. This cosmic radiation is largely absorbed by the atmosphere but some penetrates to ground level where it contributes to the natural background of radiation.

The exposure of persons to radiation is expressed in units called rems, or millirems (1/1000 of 1 rem). The annual radiation dose to persons from all natural sources (*ie*, cosmic, earth and within the body) is typically 100 millirems. In some areas the natural background dose may be up to four times higher than this typical value. It has not been possible to establish any link between the intensity of natural background radiation and the incidence of disease or premature death.

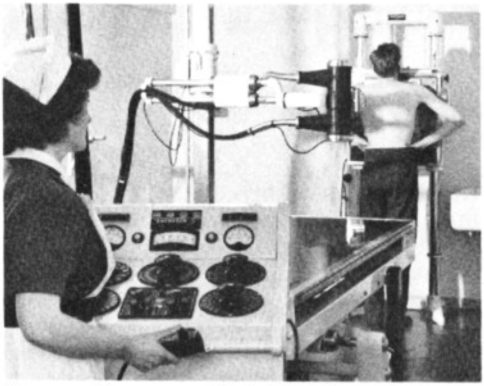


The radiation dose received by the body in a year, averaged over the whole population, is about 115 millirems.

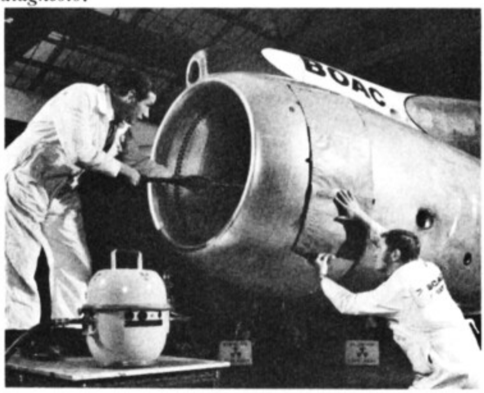
Man-made Sources of Radiation

The major sources of exposure from man-made radiation are the X-ray machines used in medical diagnosis. These contribute a dose to the general population of this country of about one-seventh of the dose from natural background radiation.

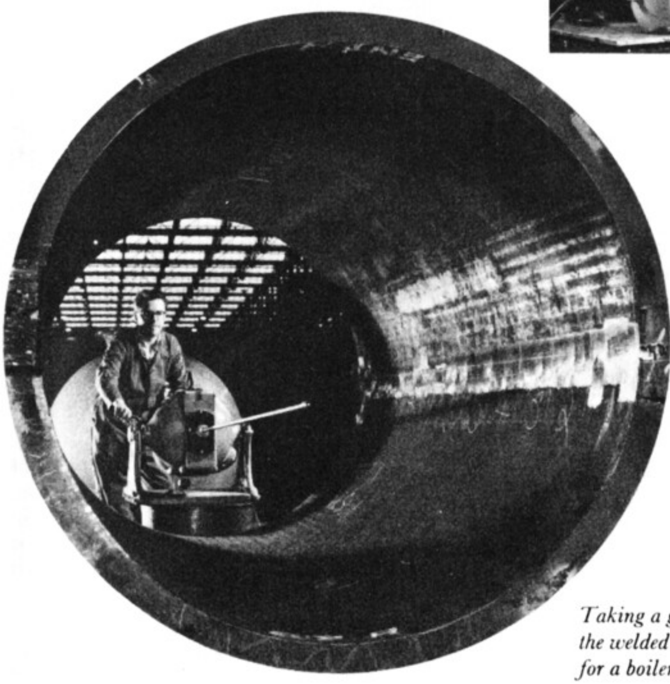
Other common man-made sources of radiation are the radioactive isotopes used widely for industrial, medical and research purposes. The nuclear generation of electricity is another man-made source of radiation. The contribution to the dose of the general population of this country from all these sources, including the nuclear power industry, is estimated to be only about one-hundredth of the dose from natural background radiation.



X-ray machines are used in hospitals for medical diagnosis.



Preparing to radiograph an aeroplane engine intake. The radioactive source is iridium 192 in a depleted uranium container.



Taking a gamma-ray photograph of the welded seam in a 3" thick steel belt for a boiler drum.

Biological effects of radiation

Radiation can destroy, damage or disturb the function of living cells in body tissue. The effect depends on the type of radiation, its intensity, the period of exposure and the extent to which the body is irradiated. Radiation exposure is categorised as acute (brief and intense) or chronic (continuous or occurring over a period).

The biological effects of radiation exposure are either somatic or genetic.

Somatic Effects

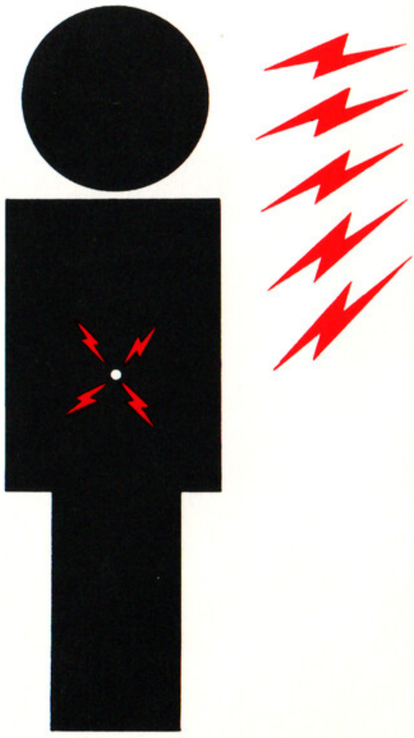
Radiation effects are called somatic if they occur within the exposed individual causing biological changes in his body. Very large radiation doses of hundreds of rems, received over a short period of time and involving a large fraction of the body, will result in obvious injury, or even death if the dose is sufficiently high. Delayed effects may occur in the survivors of these very large doses.

Occupational exposure involves much smaller doses incurred continuously or intermittently over a long period.

Knowledge of the effects of radiation has led to the establishment of maximum permissible levels of radiation exposure to provide for safe working conditions.

Genetic Effects

Genetic changes occur in both male and female reproductive cells and arise from a variety of internal and external factors. About 6% of all live born infants show some evidence of genetic change.
It has been shown that naturally occurring, background radiation accounts for a very small fraction of genetic change. The exposure of populations to radiation resulting from the development of nuclear power is very low as compared with natural background radiation. Its effects can therefore only be described as infinitesimally small, with the overall incidence of genetic change not measureably affected. Nevertheless it remains important to continue to monitor and control the exposure of populations during the continuing and future development of the nuclear power industry.



Radiation may come from sources external to the body or internally, through the intake of radioactive substances.

Control and assessment of Radiation exposure

As a result of the knowledge of the effects of radiation and radioactive materials on the body it is necessary to set standards of protection to safeguard people, such as those engaged in the nuclear industry and radiographers, who are required to work with materials or machines which emit radiation.

These standards are set by the International Commission on Radiological Protection (ICRP) a body established in 1928 which collects and assesses evidence on the effects of radiation. The recommendations of the ICRP are accepted throughout the world as the basis for establishing standards of radiological protection. In the United Kingdom the recommendations are considered by the Medical Research Council and the National Radiological Protection Board and are used as a basis for codes of practice and legislation concerned with radiological protection.

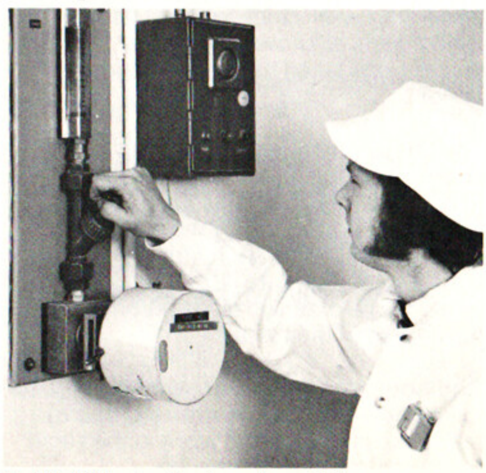
The Health and Safety Department of each BNFL establishment is responsible for advising management on the application of ICRP recommendations and statutory regulations. Health and Safety Departments monitor the environment within and in the vicinity of each establishment and monitor the personal exposure of radiation workers.

The maximum permissible levels of radiation exposure of the body and of various parts of the body, are given in Appendix IV. The figures quoted are maximum permissible levels and any unnecessary exposure must be avoided. The source of radiation is usually external to the body but exposure resulting from any intake of radioactive material into the body must also be assessed and taken into account.

Intake of radioactive material into the body may occur whenever there is significant contamination of the environment (*ie*, whenever there is radioactive material on surface or dispersed into the air).

Many locations are continuously monitored for radiation and airborne radioactivity.

Installed gamma monitor and alarm.



Installed plutonium-in-air monitor and alarm.

The ICRP and in turn the Medical Research Council, have made recommendations as to the maximum permissible concentrations (MPC) of the radioactive materials (radionuclides) in the air we breathe and the water we drink, based on the biological effects of the radionuclides concerned. BNFL has adopted these recommendations which have also been incorporated into the conditions of each of the Nuclear Site Licences issued under the Nuclear Installations Act. A selection of the MPCs for some radionuclides of interest are given in Appendix V.

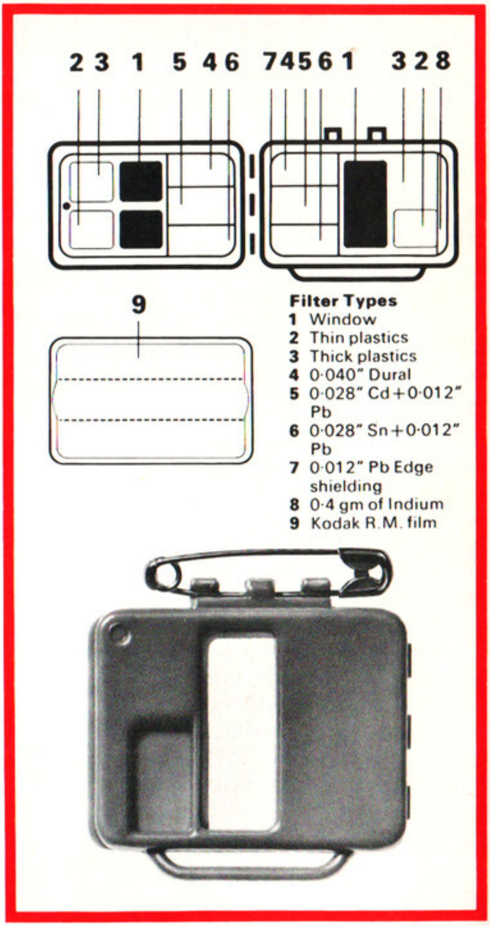
There are also control levels on the amount of radioactive material occurring as contamination on surfaces These are derived working limits, based on the ICRP recommendations for the control of radiation exposure and are included in the conditions of the Nuclear Site Licences. The control levels are summarised in Appendix VI.

Assessment of Radiation Exposure Arising from Sources of Radiation External to the Body

Measurement of radiation exposure is a most important feature of radiation protection work since without it there is no means of knowing whether the precautions taken have been adequate or not.

The primary means of measuring "whole body" radiation exposure is the routine film badge. This contains a photographic film which is affected by radiation in the same way in which such film is affected by light. Film badges are issued to all people who may be exposed to radiation during the course of their work.

Additional specialised dosemeters (*eg*, for the measurement of neutron exposure) may also be issued and worn in the same way as the normal film badge.



Routine Film Badge.

Assessments obtained from radiation films and specialised dosemeters are recorded in personal radiation dose records. Running totals are kept to ensure that the permissible levels are not exceeded. If it is found that any person has received radiation exposure above the permissible level the situation is investigated and recommendations are made in order to prevent a recurrence.

A disadvantage of the film badge is that the dose received cannot be read off directly, since the film requires to be developed and assessed. A dosemeter in common use which does provide this

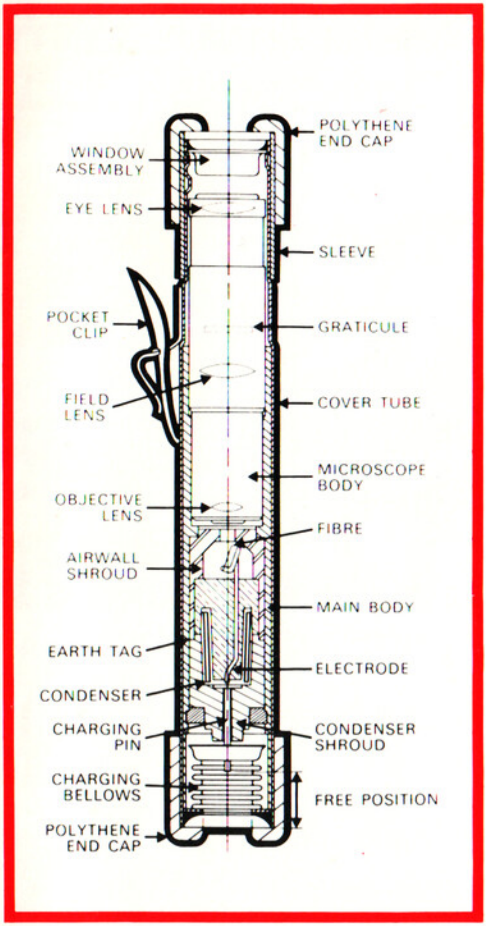
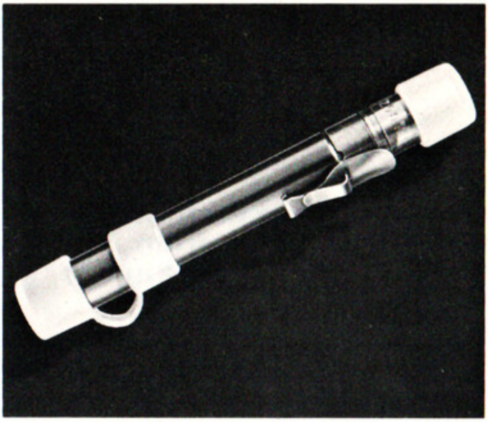
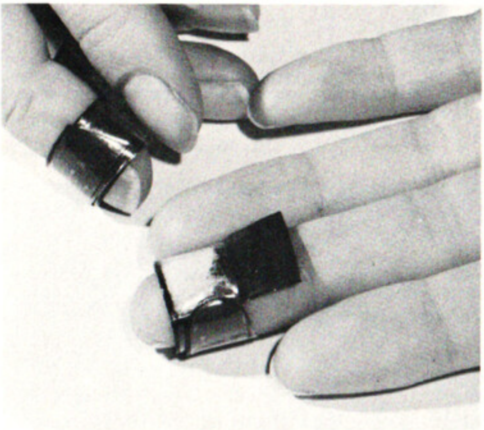


Diagram :- Quartz Fibre Pocket Electrometer.



The Quartz Fibre Pocket Electrometer.



Finger tip thermo-luminescent dosemeter.

facility is the quartz fibre electrometer (QFE) This is a simple instrument, the size and shape of a fountain pen, which measures the radiation exposure and indicates this immediately on a scale. It is useful for work in areas where radiation levels are above normal to control to a specified dose limit. Because the QFE does not provide a permanent record of the dose received the film badge must also be worn.

Thermo-luminescent dosemeters are also widely used. In this case the dose cannot be read-off directly at the time of the exposure but can be readily determined using special equipment.

Other specialised types of personal dosemeter are sometimes used. These may give audible warning at either a predetermined dose or at certain dose-rate levels. They have useful applications in abnormal or variable radiation fields.

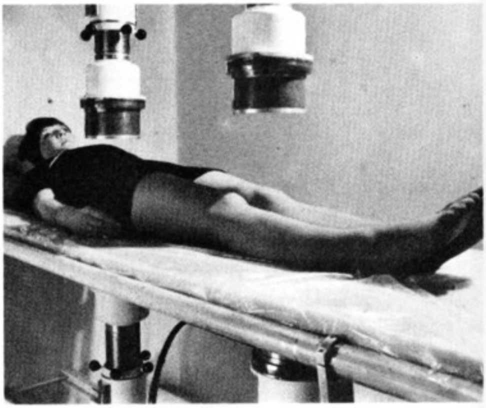
Assessment of Radiation Exposure arising from Radioactive Material inside the Body

Knowledge of the type, quantity, location, and time of residence of radioactive material within the body is required in order to assess this form of radiation exposure.

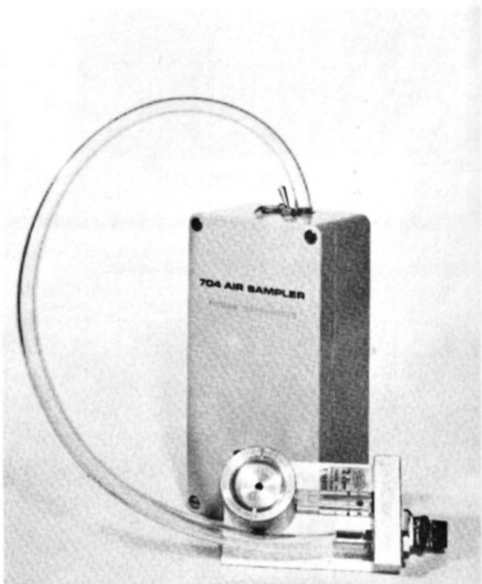
The analysis of urine samples and sometimes faecal samples provides a useful source of information, especially in the case of an intake of alpha emitters such as plutonium.

Another valuable source of information is the "whole body monitor". This is a very sensitive device for the measurement of very low levels of radiation emitted by very small quantities of radioactive material deposited in the body.

Exposure arising from contamination of the skin is very rarely of any significance because such contamination is very readily detected by the routine personal monitoring checks. In most cases such contamination is readily removed by washing before leaving the place of work.



The whole body monitor is used for measuring the radioactive content of the body.



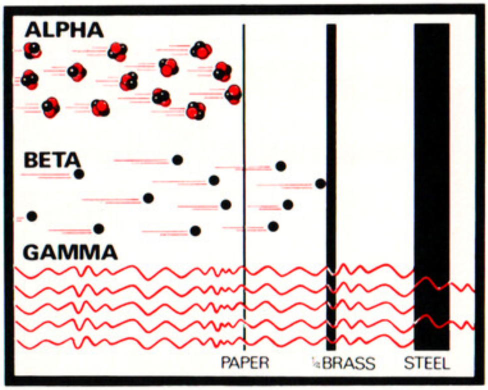
Personal air samplers are sometimes used to give an indication of possible exposure to airborne radioactive particles.

Precautions when working with Radioactivity

Protection from any work hazard, whether of a radiological or conventional industrial nature, can be achieved by:

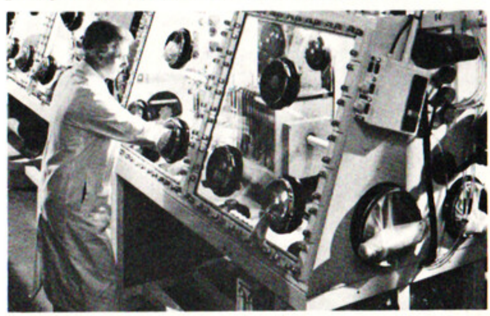
- I Removing the hazard, or
- ii Shielding or containing the hazard, or
- iii Protecting the individual worker, and
- iv Warning the worker.

In the majority of instances in BNFL establishments it may not be possible to remove the radiological hazard completely as the materials being used are radioactive. The second form of protection is, however, in considerable use, since all BNFL plants are designed to reduce the potential hazard to its lowest practicable level by the provision of plant safeguards which include containment and radiation shielding where necessary. There are nevertheless occasions when it is necessary to circumvent some of the built-in safety features of a plant. This may apply for example in maintenance and repair work when it may be necessary to remove shielding or break the containment. Such work is always carried out under controlled conditions and special precautions such as the wearing of protective clothing or restriction of working time may be specified.

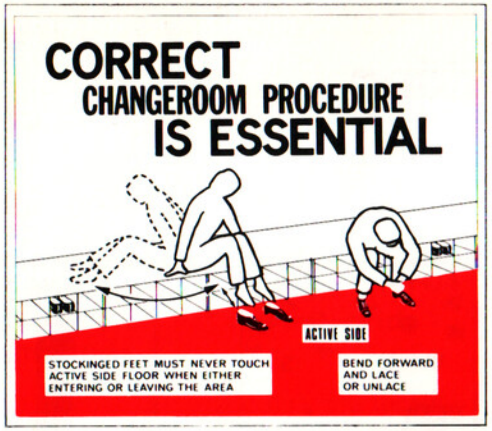


The diagram shows the relative penetrating power of alpha, beta and gamma radiations.

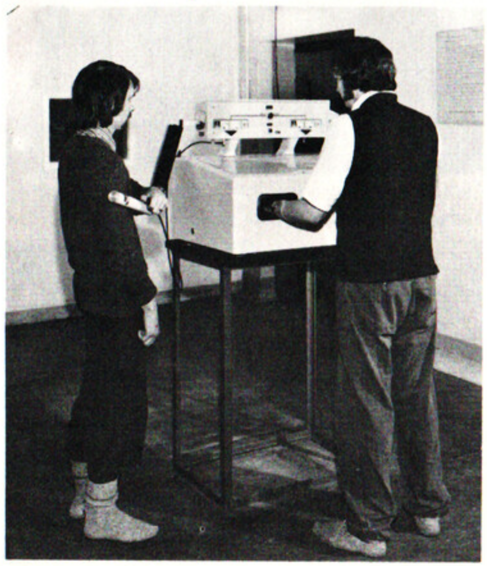
Here, a mobile lead wall is used for handling a source giving rise to high level beta gamma radiation.



Where high levels of airborne contamination would otherwise arise, operations are carried out in specially designed glove boxes.



Always wear dress appropriate to the working area and observe correct barrier procedures.



Personnel working in active areas of buildings monitor their hands, clothing and shoes before leaving.

Golden Rules for Radiation Workers

The following precautions should always be observed when working in a radiation or active area :

1 **Always wear your film badge in radiation areas. Wear it correctly and report promptly any loss or damage.**

2 **Wear the dress appropriate to your area of work and observe the correct barrier procedure; such drills have been introduced for your protection; their effectiveness is dependent on how well you carry them out.**

3 **Where hand and/or clothing monitors are provided, always wash and monitor your hands before leaving a changeroom and, if your hands are contaminated, check your clothing with the clothing monitors provided.**

4 **Always comply with notices and instructions concerning safety. If in doubt, ask your supervisor for advice.**

5 **Never handle radioactive materials with bare hands. This may produce contamination of the skin or radiation of the hands.**

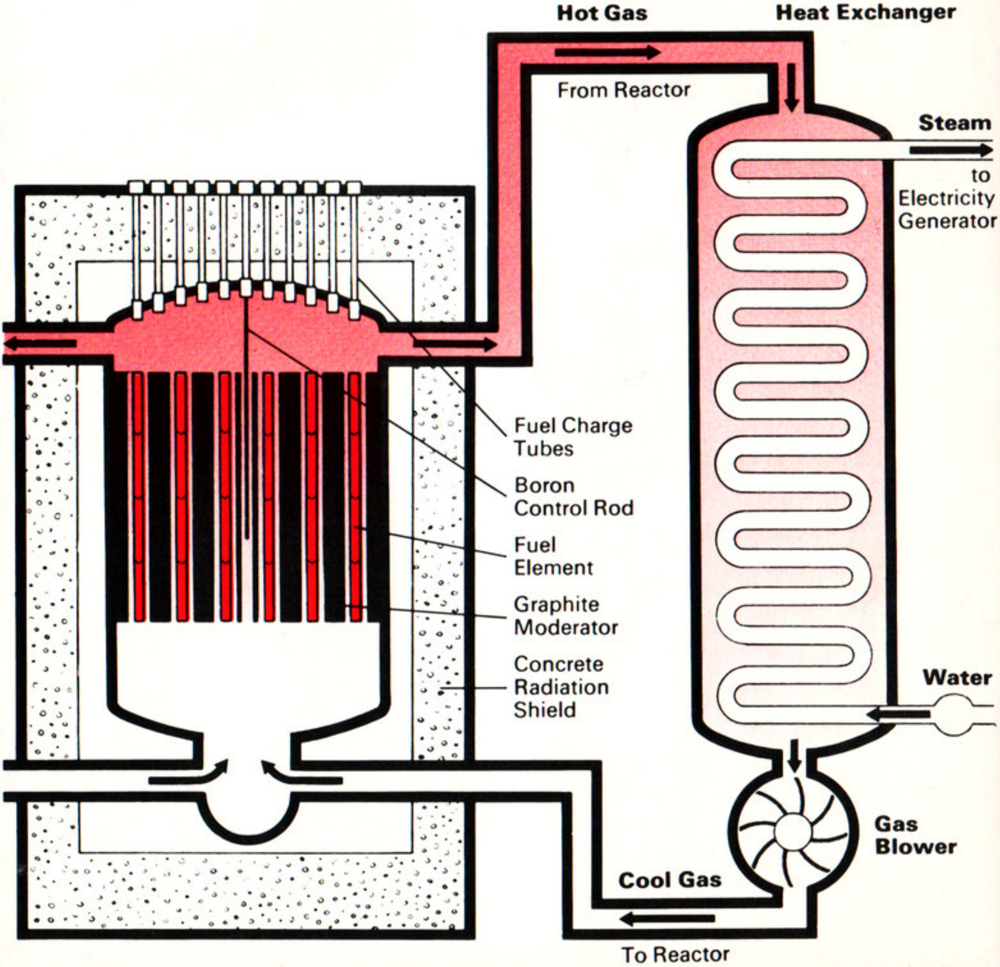
6 **Always follow the protective measures specified on Clearance Certificates and Access Certificates and carry out only the particular work stated, in the locations specified on such certificates.**

7 **Before starting a job think first of the potential hazards involved. Pre-planning can save a lot of trouble. Ensure that you have the proper tools for the job and the right protective equipment.**

Criticality, or Nuclear Safety

The diagram illustrates the working of a Calder Hall Reactor.

For the nuclear chain reaction to continue at a steady rate the number of neutrons which will carry on the reaction are controlled by absorbing excess neutrons in boron control rods. By surrounding the uranium fuel with a moderator the escaping neutrons are slowed down so that they can more easily split the uranium nuclei. This type of reactor uses graphite as the moderator.
Heat is removed from the reactor by circulating carbon dioxide gas and steam is produced to drive electricity generators.



Nuclear power reactors are carefully designed to provide for the assembly of nuclear fuel in an arrangement suitable for the achievement of a sustained nuclear chain reaction. Under controlled reactor operating conditions this results in a steady production of power arising from the heat generated in the fuel as a result of the energy released in the fission process.

In plant where nuclear fuel or fissile (fissionable) material is manufactured, reprocessed or stored, it is important to avoid the unwanted accumulation of fissile material in circumstances where an uncontrolled chain reaction—or state of criticality—could inadvertently occur.

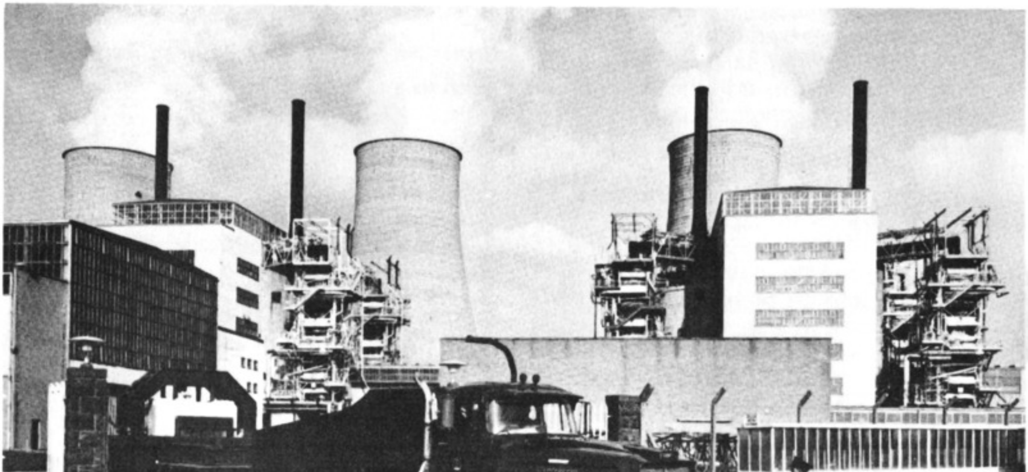
A criticality incident is unlikely to result in a significant release of energy but the gamma and neutron radiation emitted can result in serious radiation exposure of any plant personnel in the immediate vicinity. Plant must therefore be designed and operated with adequate safeguards to avoid the accumulation of fissile material under conditions which could lead to criticality.

At each of BNFL's major establishments there is a nuclear safety section for the assessment of plant design and operation. Safe operating conditions are established and enforced, and the plant is subject to periodic inspection to ensure that these conditions are being observed.

Sensitive criticality detection and alarm instrumentation is installed to provide a strident and unmistakable warning of the occurrence of a criticality incident. Immediate evacuation of the building on hearing the alarm reduces exposure to the radiation which continues to be emitted after the initial intense emission.

Criticality Warning Notice.

Calder Hall, the world's first nuclear power station to produce electricity on a full commercial scale, was opened by H M The Queen in October 1956.



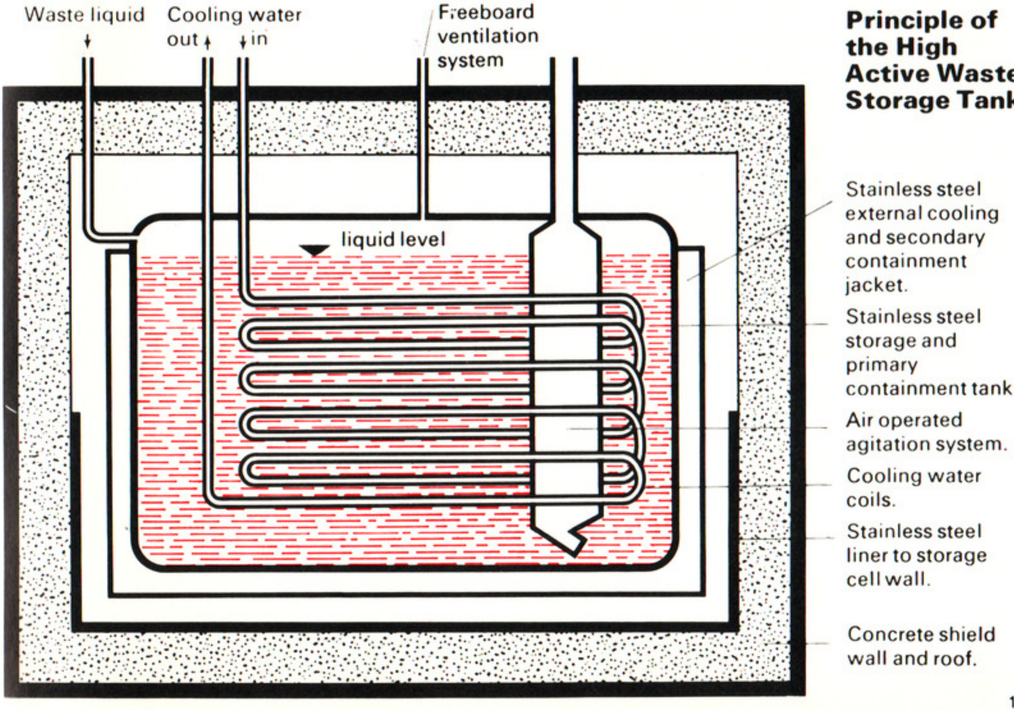
Spent fuel leaving BNFL's Chapelcross nuclear power station en route for reprocessing at the Company's Windscale Works.

The Growth of Nuclear Power

Over the past 20 years nuclear power has been increasingly exploited throughout the world. Already in the United Kingdom about one-tenth of all electricity is generated in nuclear power stations and there are more under construction. The removal, treatment and storage of fission product waste from spent nuclear fuel and other radioactive waste from research and development and allied nuclear energy activities, are important aspects of the work and responsibility of the nuclear industry.

Low activity liquid and gaseous wastes may be discharged routinely from nuclear power stations and from nuclear research and development establishments and factories. These discharges are subject to control under authorisations granted under the Radioactive Substances Act by the Department of the Environment and the Ministry of Agriculture, Fisheries and Food. Disposal of low active solid waste by burial in the ground under controlled conditions is also subject to authorisation by the same two Government Departments. The controls in the authorisations ensure that there will be no significant exposure of members of the general public as a result of the controlled discharges.

Highly active waste is stored in liquid form in stainless steel tanks inside stainless steel lined concrete enclosures. Storage of waste in this form is safe for many decades but development of a process to convert the waste to solid form for long-term storage is in progress.



Principle of the High Active Waste Storage Tank

Conclusion

"Working with Radiation" has attempted to outline something of the nature of radioactivity, the significance of radiation and contamination and the safe guide limits which BNFL applies. It also indicates how in the UK the exposure to radiation of both the general public and in particular BNFL's own workers is very carefully controlled.

Man-made sources of radiation are almost certainly more effectively monitored than any other potentially harmful feature of the environment. Radiation safety is nevertheless not a simple matter. It requires highly specialised instruments to make the necessary measurements and, in many cases, these must be interpreted before they become meaningful and can be related to control levels.

It has been demonstrated over many years of operation that highly radioactive materials can be handled and processed with a high standard of safety. This has been achieved by careful design of plants and choice of operating methods; and by personnel following the instructions issued for their safety.

Appendices

Properties of Radiations

Radiation and Symbol		Mass (atomic mass units)	Electrical Charge	Range in air	Range in body tissue
Alpha	α	4	+ 2 units	Up to 5 or 6 centimetres	Fraction of 1 millimetre
Beta	β	0·00055	− 1 unit	Up to 4 or 5 metres	Up to 2 centimetres
Gamma	γ	0	0	Up to several hundred metres	Very penetrating
X-ray	X	0	0	Usually less than gamma	Usually less than gamma
Neutron	n	1	0	Up to several hundred metres	Very penetrating

Some Important Radioactive Isotopes

Radioisotope and symbol	Radiations emitted	Principal energies of radiations MeV	Specific activity Ci/g	Half-life
Tritium, H^3	β	0·018	$9{\cdot}8 \times 10^3$	12·3 years
Carbon, C^{14}	β	0·16	4·6	5600 years
Krypton, Kr^{85}	β γ	0·69 0·54	$4{\cdot}0 \times 10^2$	10·6 years
Strontium, Sr^{90}	β	0·54	$1{\cdot}4 \times 10^2$	28 years
Zirconium, Zr^{95}	β γ	0·40 0·72	$2{\cdot}1 \times 10^4$	65 days
Niobium, Nb^{95}	β γ	0·16 0·77	$4{\cdot}0 \times 10^4$	35 days
Ruthenium, Ru^{106} with Rhodium, Rh^{106}	β γ	3·53 0·51	$3{\cdot}4 \times 10^3$	1·0 years
Iodine, I^{129}	β γ	0·15 0·04	$1{\cdot}8 \times 10^4$	$1{\cdot}7 \times 10^7$ years
Iodine, I^{131}	β γ	0·6 0·36	$1{\cdot}2 \times 10^5$	8 days
Caesium, Cs^{137}	β γ	0·51 0·66	$1{\cdot}0 \times 10^2$	30 years
Uranium, U^{235}	α γ	4·2 to 4·6 0·19	$2{\cdot}1 \times 10^{-6}$	$7{\cdot}1 \times 10^8$ years
Uranium, U^{238}	α γ	4·19 0·05	$3{\cdot}3 \times 10^{-7}$	$4{\cdot}5 \times 10^9$ years
Plutonium, Pu^{239}	α γ	5·15 0·01 to 0·04	$6{\cdot}10^{-2}$	$2{\cdot}4 \times 10^4$ years
Americium, Am^{241}	α γ	5·48 0·04 to 0·4	3·3	460 years

Notes:

MeV is a unit of energy

Ci/g means curies per gram

Radiation Units

Since neither radiations nor their effects on the body can be sensed naturally in any way, it is necessary to detect these radiations by means of instruments and, where possible, the reading recorded on the instrument should be a measure of the exposure or dose received. This raises the concepts of dose and dose-rate.

The exposure of living tissue to ionising radiations is characterised by the transfer of energy from the radiation to molecules of the cells, with possible adverse effects on their normal functions.

The energy of radiation is measured in terms of electron volts (eV), KeV (1000 eV), or MeV (1,000,000 eV).

The traditional unit of exposure dose is the *Roentgen* which is strictly a unit of dose of X and gamma rays but not other radiations. The absorbed dose equivalent to 1 roentgen is 84 ergs per gram of air (the "erg" being a unit of energy). This energy transfer to air produces a known amount of ionisation and since instruments used to measure radiation detect the ionisation current so produced, they can be calibrated using roentgen units. However, it will be appreciated that living tissue has different properties from air and indeed different organs in the body will have dirrerent properties also, so that the roentgen, a measure of the ability of radiation to produce ionisation in air, is not an adequate measure of energy absorbed in the body. A unit, the Rad, is therefore used to describe the absorbed dose arising from any form of radiation. It is defined as an energy transfer of 100 ergs/gram in the material of interest. When used to imply a quantity of radiation it is therefore necessary to specify the absorbing medium, *eg*, one rad in tissue, or one rad in bone.

For an exposure of 1 roentgen the absorbed dose in *tissue* is 95 ergs/gram, or very nearly 1 rad, so that for protection purposes the roentgen and the rad may be regarded as numerically equal.

It has also been found that for a given absorbed dose the magnitude of some biological effects differs depending upon the type of radiation used, that is biological damage is not solely dependent upon absorbed dose, and some factor must be introduced to take this into account. This factor is the Quality Factor (QF)—a measure of the biological effect of radiation relative to X-rays. Some typical values of QF for different radiations are as follows:

X-ray, gamma and beta radiation	1
Neutrons	10
Alpha particles	20

This leads to another unit, the Rem, which is the unit of biological effectiveness of absorbed dose called the "dose equivalent" (DE). A dose in rem is equal to the dose in rad multiplied by the appropriate quality factor (note that for most X-ray, gamma and beta radiations 1 rem = 1 rad). Other modifying factors may apply in some cases.

The effects of radiation exposure are therefore related to the so-called "rem dose" or "dose equivalent", which depends on the total energy transfer to tissue taking into account the quality of the incident radiation.

Irradiation of body tissue may arise due to *external* radiation, where the radiation impinges on the body from outside, or *internal* radiation, when radioactive material has been taken into the body and irradiates the tissue from sources within the body. The latter form of exposure can result from inhalation or ingestion, absorption of radioactive material through the skin, or entry to the body via a cut or wound. The control limits applied to such cases are particularly strict since, until radioactive material is eliminated from the body by excretion or radioactive decay, the exposure will continue.

Radiation Control—Radiation Dose Limits

Category of person	Dose-equivalent limit (whole body)
Radiation Worker	5 rems/year
Member of the public	0·5 rems/year

Notes:

1 Radiation workers are designated as "classified persons" and are subject to medical supervision.

2 Special restrictions apply to pregnant women and young persons aged 16 to 18.

Radiation workers are employees who have reached the age of 18 years and have been declared medically acceptable for work involving exposure to ionising radiations and for whom appropriate medical supervision is provided. They are designated as "classified persons". Their exposure to radiation is monitored and records are kept of the results.

Controls are applied as necessary to keep radiation exposure below the radiation dose limits.

Members of the public. This group includes both adults and children and may in terms of numbers be the largest group of people concerned. The limits of permissible exposure are therefore more restrictive. In this context it is important to remember that everyone is subjected to natural radiation including cosmic radiation, terrestial radiation due to radium and thorium in the soil and the air, and radiation from radioactive potassium present in the body. These natural sources contribute an exposure of about 0·1 rem per year.

Persons in this category must be safeguarded against radiation arising due to operations with radioactive materials and any radiation exposure kept to less than 0·5 rem in a year.

Maximum Permissible Concentrations in Air for Radiation Workers —some examples

Radionuclide	**MPC$_a$ in *air* for radiation workers**		
	μCi/cm^3	**dpm/M^3**	
Tritium, H^3	5×10^{-6} =	10^7,	Beta
Strontium, Sr^{90}	10^{-9}	2×10^3,	Beta
Ruthenium, Ru^{106}	8×10^{-8}	2×10^5,	Beta
Iodine, I^{131}	9×10^{-9}	2×10^4,	Beta
Caesium, Cs^{137}	6×10^{-8}	10^5,	Beta
Uranium, natural	10^{-10}	200,	Alpha
U^{238}	10^{-10}	200,	Alpha
U^{235}	10^{-10}	200,	Alpha
Plutonium, Pu^{239}			
— soluble compounds	4×10^{-12}	9,	Alpha
— insoluble compounds	6×10^{-12}	13,	Alpha

Note: All values quoted are related to a 40 hour week, 50 weeks in a year, for a full working lifetime.

Notes:

1. μCi/cm^3 means microcuries per cubic centimetre.
   A microcurie is one millionth of a curie.
   A curie is a measure of radioactivity (see glossary).

2. dpm/M^3 means "disintegrations per minute per cubic metre".
   One curie is equivalent to approximately 2 million million disintegrations per minute.

Maximum Permissible Levels of Surface Contamination

Type of Surface	Maximum Permissible Level $\mu Ci/cm^2$			
	Class I Alpha Contaminants	Class II Alpha Contaminants	Beta Contaminants Class I	Class II
Interiors and contents of total enclosures, fume cupboards and other controlled areas	The minimum that is practicable			
Active Areas	10^{-4}	10^{-3}	10^{-3}	10^{-2}
Non-active Areas	10^{-5}	10^{-4}	10^{-4}	10^{-3}
Active Area clothing	10^{-4}	10^{-3}	10^{-3}	10^{-2}
Personal clothing	10^{-5}	10^{-4}	10^{-4}	10^{-3}
Skin	10^{-5}	10^{-5}	10^{-4}	10^{-3}

Note:

Class I alpha emitters include Plutonium.
Class II alpha emitters include natural, depleted and enriched Uranium.
Class I beta emitters are all those not in Class II.
Class II beta emitters are Tritium (H^3); Carbon (C^{14}); Sulphur (S^{35}).

$\mu Ci/cm^2$ means micro-curie per square centimetre.
One micro-curie is one millionth of a curie.

Technical Terms

Alpha A positively charged particle emitted in the radioactive decay of some heavy nuclei, for example uranium and radium; identical with the helium-4 nucleus.

Atoms The atom is the smallest amount of an element which has the chemical properties of that element. The atom consists of a comparatively massive central nucleus carrying a positive electric charge, around which electrons move in orbits at relatively great distances away. According to present theory the nucleus is made up of protons and neutrons. The number of protons present is the atomic number of the element and determines the charge on the nucleus—and hence its chemical properties. The sum of the number of protons and neutrons is called the mass number and determines the mass of the nucleus. The number of neutrons in an atom of a given element can vary, resulting in nuclei that have the same atomic number but different mass numbers; these variants are called isotopes of the element. The number of electrons in a neutral atom is equal to the number of protons in the nucleus and their charges balance the equal and opposite charge of the nucleus. All atoms of the same atomic number (*ie*, same number of protons) are atoms of the same element, irrespective of the number of neutrons present.

Beta An electron, positive or negative, emitted from the nucleus in certain types of radioactive disintegration.

Cosmic rays Very penetrating ionising radiation which reaches the earth mainly from unidentified sources in outer space and occasionally from the sun.

Criticality A state of affairs in which a sufficient quantity of fissile material is assembled in the right shape and concentration for a self-sustaining chain reaction to take place.

Curie The quantity of a radioisotope that decays at the rate of $3{\cdot}7 \times 10^{10}$ disintegrations/second; approximately equal to the activity of one gramme of radium (abbreviation Ci).

Disintegration Any process in which a nucleus sends out one or more particles (including photons) either spontaneously or on being hit.

Electron The negatively charged particle (mass $m = 9 \times 10^{-28}$ gram) which is a common constituent of all atoms. Its positively charged counterpart, of equal mass, is the positron.

Fission The splitting of a heavy nucleus into two (or very rarely more) approximately equal fragments—the fission products. Fission is accompanied by the emission of neutrons and the release of energy. It can be spontaneous, or it can be caused by the impact of a neutron, a fast charged particle or a proton.

Gamma Electromagnetic radiation emitted by the nuclei of radioactive substances during decay, similar in nature to X-rays.

Half life The time taken for the activity of a radioactive substance to decay to half its original value, that is for half the atoms present to disintegrate. Half-lives may vary from less than a millionth of a second to millions of years, according to the isotope and element concerned.

Ionising radiation Radiation which knocks electrons from atoms during its passage, thereby leaving ions in its path. Electrons and alpha particles are much more ionising than neutrons or gamma rays.

Isotopes Two atoms are said to be isotopes if they are of the same chemical element but have different masses. This means that isotopic nuclei contain the same number of protons but different numbers of neutrons.

Neutron A nuclear particle having no electric charge and the approximate mass of a hydrogen nucleus. It is found in the nuclei of atoms and plays a vital part in nuclear fission. Outside a nucleus a neutron is radioactive, decaying with a half-life of about 12 minutes to give a proton and an electron.

Nucleus The core of an atom, which may be said to comprise protons and neutrons. It is about 10^{-12}cm in diameter (a millionth of a millionth of a cm). The detailed structure of nuclei is not fully known.

Nuclide An atomic species of a single atomic number and a single mass number.

Proton The nucleus of the hydrogen atom. It carries unit positive charge and has unit mass.

Rad The unit of ionising Radiation Absorbed Dose. One rad is equal to an energy absorption of a hundred ergs per gram of tissue.

Radiation A term which embraces electromagnetic waves, in particular X-rays and gamma rays as well as streams of fast-moving charged particles (electrons, protons, mesons, etc.) and neutrons of all velocities, *ie*, all the ways in which energy is given off by an atom.

Radiation decay The property possessed by some atoms of disintegrating spontaneously with the emission of a charged particle and/or gamma radiation. The rate of radioactive decay is not affected by any normal change of temperature, electric or magnetic fields or chemistry.

Radioisotope An isotope which is radioactive. Most natural isotopes of mass below 208 are not radioactive.

Rem Unit of exposure which takes into account the biological effectiveness of the particular type of radiation. 1 rem = 1 rad × QF × N, where QF is the quality factor attributed to the radiation and N is the product of any other modifying factors which may apply.

Roentgen The unit of exposure to X-ray or gamma radiation, based upon the capacity of the radiation to produce ionization in air. For a wide range of radiation energies, one roentgen will result in an absorbed dose in soft tissue of approximately one rad.

Specific activity The radioactivity of unit mass of a radioactive substance, usually expressed in curies per gram, *ie,* a measure of the intensity of the source.

X-rays Penetrating radiations, being electromagnetic waves similar to light but of much shorter wavelength. Generally speaking they are emitted when high speed electrons suffer an abrupt loss of energy. Whilst invisible, they can be detected by photographic films, luminescent screens and instruments.

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