1981
The Effects and Control of Radiation

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Summary:

British government pamphlet intended to calm public fears about radiation and the nuclear energy industry. Describes sources of radiation in the United Kingdom and biological effects of exposure, arguing that health risks are minor and the industry is safe.

Original Language:

English

Contents:

Original Scan

The effects and control of radiation

Front cover: Cosmic rays – radiations continually bombarding the earth from outer space – produce ionisation tracks as they pass through matter

Introduction

Energy is essential for survival. All methods of producing energy, however, can cause some damage to the environment and to health. The burning of fossil fuels, such as coal, results in the production of ash which contains a variety of toxic substances, and in the release to the atmosphere of gases and solid particles, which can be harmful to health and to the environment. The burning of uranium in nuclear power stations is associated with the emission of radiation and the production of radioactive materials, which can also cause harm.

In each case the harm has to be weighed against the benefits that arise from the availability of the energy source. In the case of nuclear power the principal benefit is the large potential contribution to the world's energy resources, releasing fossil fuels for other essential purposes such as transport, industrial process heat and raw material for chemicals and fertilisers. Furthermore the total impact on the health of workers and the public is no greater and probably less than that of fossil fuels.

There is nothing unique about the materials released in the burning of fossil fuels; they are released from many industrial processes and the majority are also present in the natural environment. In the same way there is nothing unique about the radiation associated with the nuclear industry. Man has evolved in a naturally radioactive environment, subject to radiation from outer space, from the earth, from substances within the body and even from burning wood and cultivating the ground. Since the beginning of this century, man has added to this natural background through medical and industrial uses of radiation, mainly in the form of X-rays, through the testing of nuclear weapons, and through the increase in air travel, the intensity of cosmic rays being greater at altitude.

In fact, natural background radiation is responsible for about three-quarters of the total with the great majority of the balance resulting from medical X-rays. Other sources of 'man-made' radiation account for less than two per cent of the total.

Extensive studies have been carried out on animal and human populations exposed to radiation. As a result more is known about its hazards than about those from almost any other physical or chemical agent. This understanding, and the strict application of internationally agreed protection measures, has ensured that radiation from the nuclear industry has little impact on the environment, and on the health of its workers and the general public. As more reliance is placed on nuclear power in an era of rapidly diminishing fossil fuel reserves, it is important that this record is maintained.

This booklet describes the effects of ionising radiation on people and the measures that are taken to ensure the safe operation of the nuclear industry.

Ionising radiation

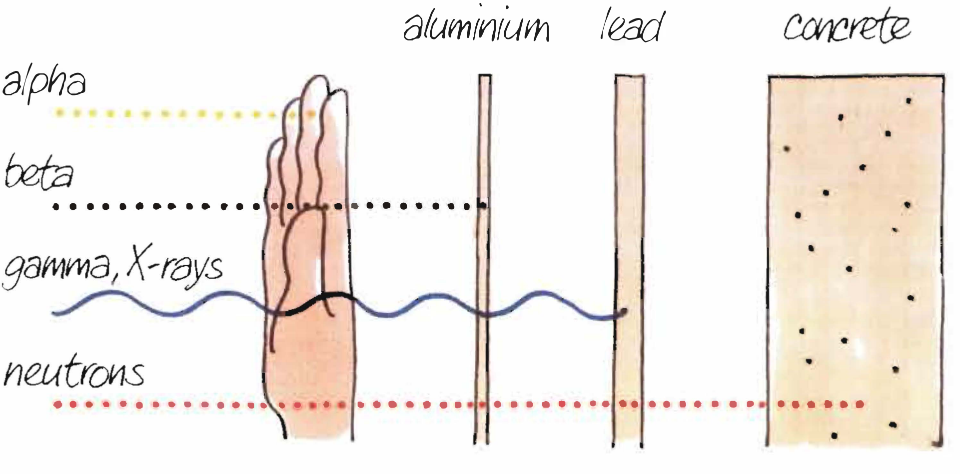
The term 'radiation' now embraces electromagnetic waves, such as light, radio waves and X-rays, and the particles emitted by radioactive materials as they disintegrate or decay to reach a non-radioactive state. The particles and the more energetic electromagnetic waves produce electrically charged particles called 'ions' in the materials they strike. This ionisation frequently results in chemical changes which, in living tissue, can lead to injury in the organism. The non-ionising radiations, such as those produced by ultra-violet lamps, lasers and radio transmitters are only hazardous in special circumstances. Only the ionising radiations are considered here.

These consist of:

Alpha particles *(the nuclei of atoms of the element helium)*
These are easily stopped and do not penetrate the skin. Radioactive materials that emit alpha particles can only be hazardous if swallowed or breathed into the body, or if they enter the body through a wound.

Beta particles *(electrons)*
These have greater penetrating powers than alpha particles but are stopped by relatively thin layers of water, glass or metal. Beta

Types of radiation



emitters can also be hazardous if taken into the body.

Gamma radiation and X-rays *(electromagnetic radiations similar to light and radio waves)*
These can penetrate relatively great thicknesses of matter before they are absorbed but can be screened by sufficient thickness of lead and concrete.

Neutrons *(neutral particles present in all nuclei except hydrogen)*
These are also very penetrating but can be screened by thick layers of concrete or water.

Half-life

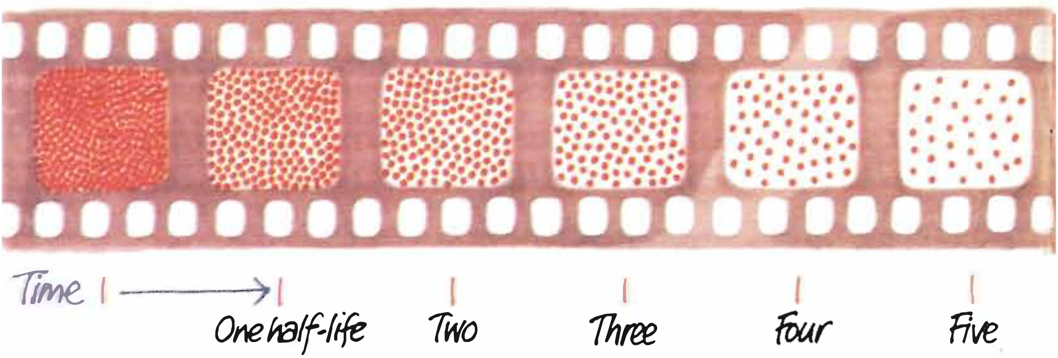
An important feature of all radioactive materials is that their activity decays with time. Each material is characterised by a 'half-life', the time taken for half the radioactivity to decay. In two half-lives this is reduced to a quarter of its original level, and in ten half-lives to about one thousandth.

Half-lives vary from fractions of a second to millions of years. In general the most radioactive materials, emitting intense penetrating radiation and requiring heavy shielding, decay to negligible levels relatively rapidly. Long-lived radioactive materials emit very little radiation, generally with low penetrating power; such materials are only hazardous if taken into the body.

Sources of radiation

The units used to measure doses of radiation to individuals are the

Half-life



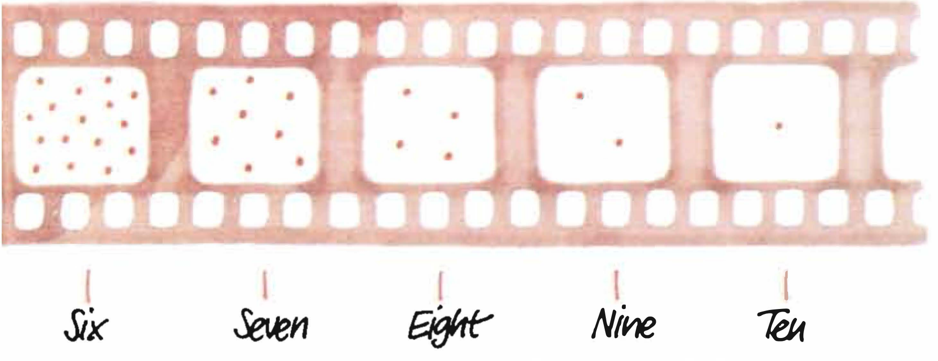
After one half-life only
half the radioactivity remains

rem* and the millirem (mrem) which is one-thousandth of a rem. Doses of thousands of rem to small regions of the body are used in radiotherapy to destroy cancerous growths. A single dose of about 1,000 rem to the whole body, however, is generally fatal.

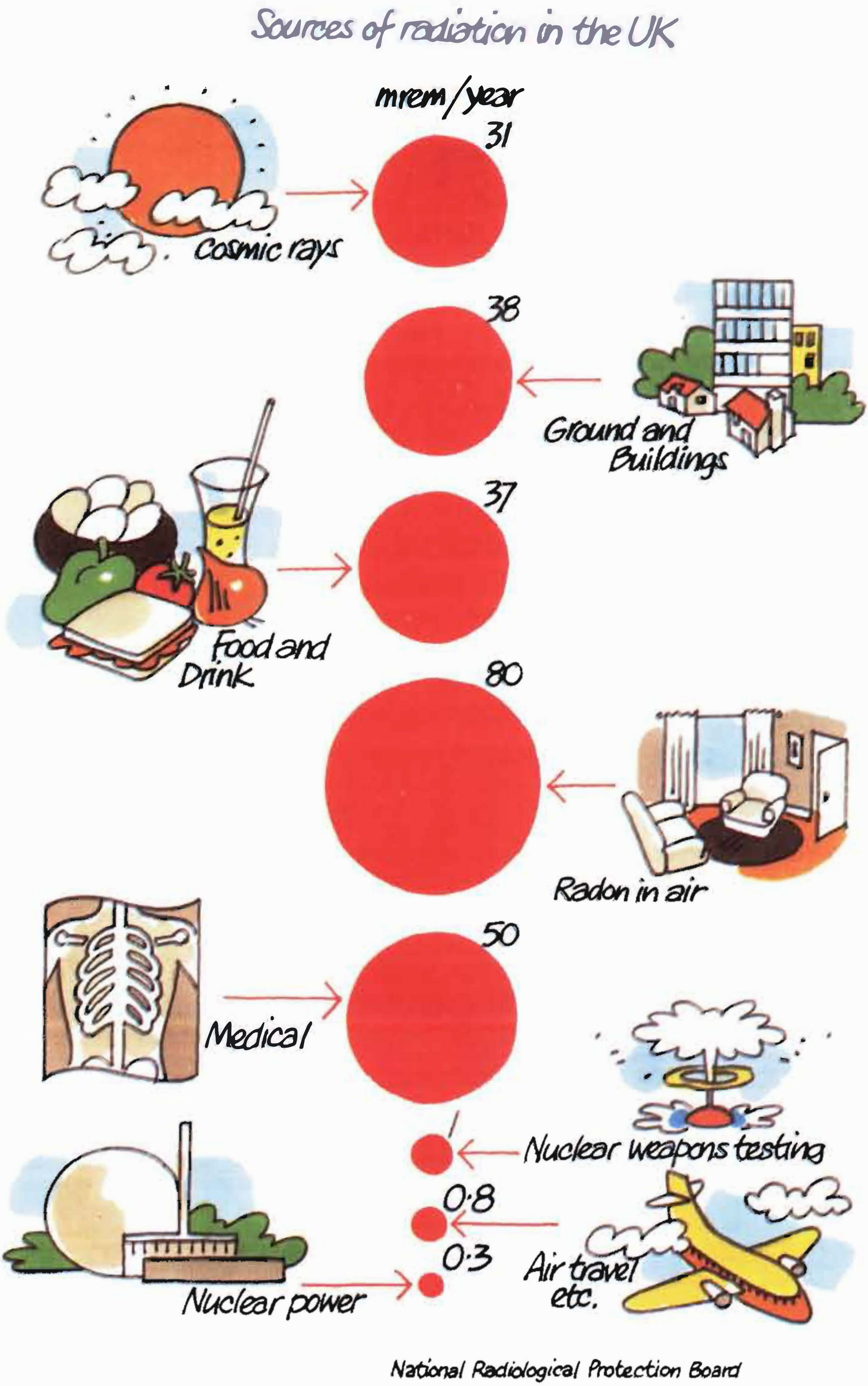
To put this into perspective, the average dose from the natural background in the UK, including the radiation from naturally occurring radioactive materials swallowed or breathed into the body, is about one fifth of a rem per year (200 mrem). In some areas of the UK, where the rocks and soil contain higher than average concentrations of radioactive minerals, background levels are up to double the average value. Doses also depend on the types of building material and on ventilation rates and average time spent indoors.

Medical practices, mostly diagnostic X-rays, contribute a dose of about 50 mrem per year to the average UK citizen. A typical chest X-ray gives about 20 mrem. Medical radiation is unique in the sense that it is used with the express purpose of benefiting the individual receiving the dose. However, the risk of hereditary disease in future generations must also be considered. Only some of the radiation received in a typical medical investigation reaches the

*The rem is a measure of the biological effectiveness of radiation. For X-rays and gamma rays 1 rem corresponds to the deposition of 0.01 joule of energy per kilogram of material. For simplicity, this unit is used throughout although, strictly speaking, it should only be used when discussing delayed effects: the appropriate unit for early effects is the rad. A new unit, the sievert (Sv) is now being introduced. 1 Sv = 100 rem.



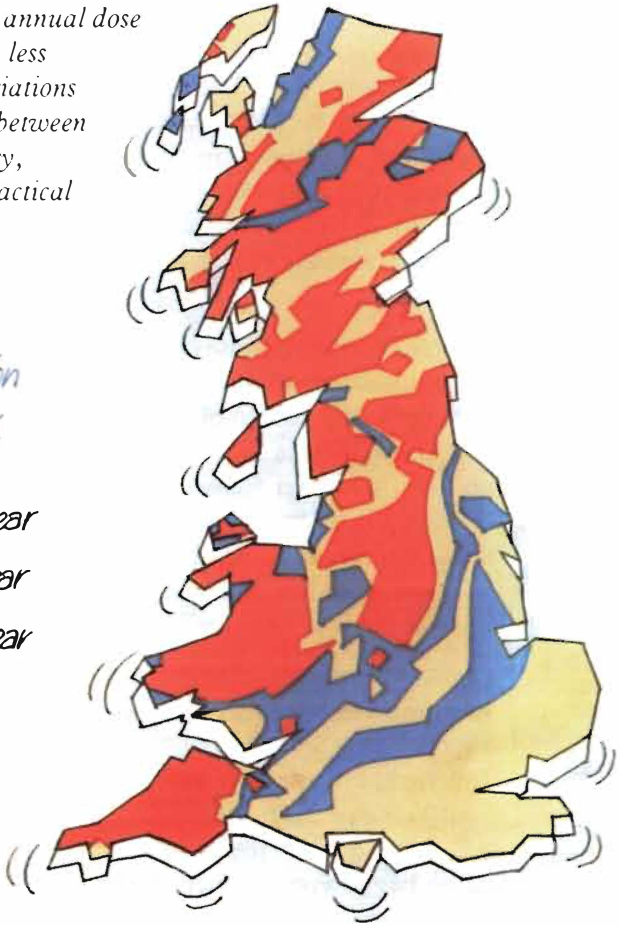
After ten half-lives only one thousandth of the radioactivity remains


Sources of radiation in the UK
mrem/year
31
Cosmic rays
38
Ground and Buildings
37
Food and Drink
80
Radon in air
50
Medical
1
Nuclear weapons testing
0·8
Air travel etc.
0·3
Nuclear power
National Radiological Protection Board

reproductive cells and many investigations are carried out on patients beyond child-bearing age. The average genetically significant dose per person in the UK from medical practice is about 10 mrem.

Debris from atmospheric testing of nuclear weapons during the 1950s and 1960s currently contributes an average of about one mrem per year and a similar dose results from air travel and miscellaneous sources of radiation such as luminous watches and TV sets.

The activities of the nuclear power industry in the UK result in an average dose to members of the public of 0.3 mrem per year, less than one-fifth of one per cent of the average dose from the natural background. *The average annual dose from the nuclear industry is less than one per cent of the variations in the natural background between different parts of the country, variations that are of no practical significance to health.*



Variations in radiation from rocks in the UK

60-130 mrem per year

50-60 mrem per year

30-50 mrem per year

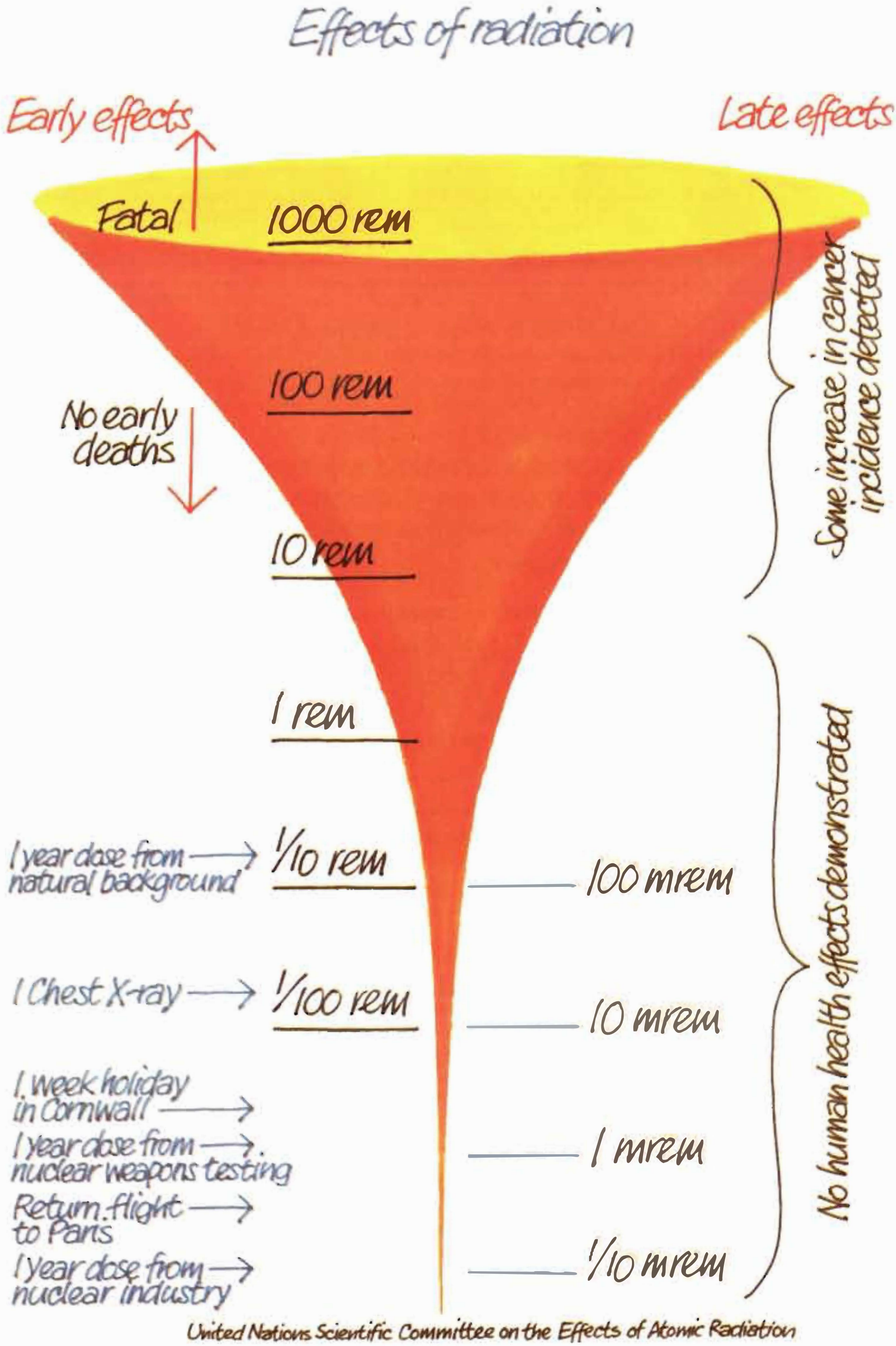
Biological effects

When ionisation occurs, the resulting chemical changes in living tissue can affect the behaviour of cells. The critical targets are the DNA molecules. These structures, present in every cell of the body, carry the information required for the development and division of cells and for the growth, proper function and reproduction of the organism. The damage to the DNA is often reparable but in some cases can result in cell death or transformation.

Dead cells are normally absorbed or rejected by the organism. However, if a sufficient number of cells are killed, the function of the organism will be affected and it may die. Cell transformations (or mutations) do not necessarily lead to any deleterious effects. Indeed many such cellular changes occur normally during the lifetime of any organism. Very rarely, they result in a cancer or, in the case of the reproductive cells, in hereditary damage in later generations. Thus radiation can affect both the individual receiving the dose (somatic effects) and subsequent generations (hereditary effects).

In man, very large doses of radiation delivered in a brief period – many hundreds of rem in a few minutes – result in widespread damage to the gut, to blood cells and to bone tissues. Doses like this generally lead to death within a few weeks. Such **early effects** and also skin burns, loss of hair and reduction in fertility have occurred as a result of the Hiroshima and Nagasaki bombs and a small number of accidents mostly in the early days of nuclear weapons research. Skin burns were also experienced in the early days of medical radiology.

Smaller or more localised doses, or doses spread out over a period of time do not produce these early effects. Indeed there is only a small chance (or risk) that any effects whatsoever will be observed. It is highly likely there will be no detectable damage to health or well-being in the future, either in the exposed individual or in his or her offspring. However, individuals who have received such doses have a very slightly enhanced risk of contracting cancer. Animal experiments have shown that there is also a small increase


Effects of radiation
Early effects
Late effects
Fatal
1000 rem
100 rem
No early deaths
10 rem
Some increase in cancer incidence detected
1 rem
1 year dose from natural background
1/10 rem
100 mrem
1 Chest X-ray
1/100 rem
10 mrem
1 week holiday in Cornwall
1 year dose from nuclear weapons testing
1 mrem
Return flight to Paris
1 year dose from nuclear industry
1/10 mrem
No human health effects demonstrated
United Nations Scientific Committee on the Effects of Atomic Radiation

in the chance of hereditary defects appearing in subsequent generations. Unlike the early effects, cancers and hereditary defects do not appear till a considerable time after the dose of radiation. They are therefore called **delayed effects.**

The evidence for a link between radiation exposure and human cancer comes from a number of particularly well documented groups of people: the Hiroshima and Nagasaki bomb survivors, patients who have received large doses of radiation for medical purposes and workers who, in the past, have been exposed to high levels of radiation such as radium watch-dial painters and tin, fluorspar, uranium and iron ore miners working in inadequately ventilated mines.

Hereditary defects related to radiation exposure have only been found in animal experiments. *Although similar effects may occur in man, no significant clinical defects have ever been detected, even following very high doses.*

No harmful effects that can unequivocally be ascribed to radiation have ever been found at the dose levels associated with the natural background or with the operations of the nuclear industry. This does not necessarily mean that such levels are absolutely harmless and the measures taken to protect people from radiation are based on the cautious assumption that any dose of radiation, however small, carries some risk of injury. Numerical estimates of the risks of radiation are given in the next section.

Risk estimates (somatic)

Early effects

A dose of 1,000 rem* or more delivered to the whole or a substantial part of the body within a few minutes is almost invariably fatal. A single dose of about 350 rem will result in a one in two chance of death in the absence of medical treatment. The same dose delivered gradually over a year, however, would probably be tolerated because of the action of the body's natural repair processes.

No early deaths have resulted from single doses of 100 rem or less and at these doses patients generally show good recovery from skin burns, loss of hair and radiation sickness. Thus the risk of early death from a single exposure to radiation of the whole body can be taken to rise from zero at 100 rem or below to 100 per cent at 1,000 rem and above.

Delayed effects

Cancer is the most important delayed somatic effect of radiation. Cataract of the eye can result from radiation exposure but only at

*See footnote on page 5.

Somatic effects in exposed individuals

		Annual risk of death
Disease	Heart disease	1 in 300
	Cancer	1 in 400
	Flu	1 in 4000
Accidents	All accidents	1 in 3000
	Road accidents	1 in 7000
	Electrocution	1 in 400,000
	Lightning	1 in 6 million
Radiation	Estimated effect of	
	- natural background	1 in 60,000
	- radiation from UK nuclear industry	1 in 30 million

doses of around one hundred rem. Even among the Hiroshima and Nagasaki bomb survivors there is no evidence of life shortening from any cause other than cancer.

Numerical estimates of the risk of radiation-induced cancer are based mainly on studies of the bomb survivors and of groups of patients given large doses of radiation for medical purposes, for example radiotherapy for diseases of the spine, uterus and breast. At Hiroshima and Nagasaki, 82,000 of the 285,000 bomb survivors have been studied extensively for more than 30 years. Some 4,000 have since died of cancer. The number of cancer deaths expected in a similar Japanese population of the same size is about 3,800, thus only about 200 of these cancer deaths can be ascribed to the radiation from the bombs.

From bomb survivor and other data, the major international groups working on the subject – the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) – and the American National Academy of Science's Commitee on the Biological Effects of Ionising Radiations (BEIR) have calculated the risk of a fatal cancer following a given dose of radiation.

Their findings are similar. ICRP concluded that the risk of a fatal cancer developing in a person who has been exposed to one additional rem above natural background during his or her lifetime is one in 8,000. Thus if a population of one million people were exposed to a dose of one rem each, the incidence of cancer deaths would increase from the 200,000 normally expected to 200,125. Such a small increase would not be detectable because of the normal variability in cancer frequency.

The doses at which enhanced cancer rates have been observed are hundreds of thousands of times greater than those received by typical members of the public as a result of the activities of the nuclear industry. The probability of radiation-induced cancers resulting from the normal operations of the nuclear industry is thus extremely low. According to the ICRP figure, a typical person, receiving 0.3 mrem per year from this source has a probability of about one in 30 million per year of developing a fatal cancer. An additional cancer death might be expected to occur just over once a year among the UK population of about 50 million.

Moreover there is a considerable body of scientific opinion that regards even these risk figures as overestimates, particularly for the types of radiation of most concern. The figures are based predominantly on observations of cancers following doses of the order of 100 rem, usually delivered over a short period of time. The true risk of radiation-induced cancers from doses of radiation below a few rem, particularly if the dose is spread over a long period, may be even lower because of the body's repair processes. Indeed a zero risk is not incompatible with the evidence.

The one fatal cancer per year predicted should be set against the current cancer death rate in the UK of approximately 140,000 per year. Many of these cancers are thought to be due to environmental agents, since known carcinogenic (cancer-producing) substances are produced in various industrial processes and some during the incomplete combustion of fossil fuels. On the basis of the ICRP figures, about 1,000 of these deaths per year might be ascribed to natural background radiation, although there is of course no evidence that such deaths occur. Calculated deaths from the medical uses of radiation would be about 300 on the same assumptions.

Workers in the nuclear industry in the UK, receiving an average of 0.5 rem per year for a 40-year period, increase their risk of dying of cancer from about 200 in 1,000 to about 202 in 1,000, an increase of one per cent. Other workers, such as coal miners, also carry additional risks of premature death from occupational exposures to harmful agents. However, the average risk of an eventual fatal cancer from occupational exposure to radiation in the nuclear industry (2 in 1,000) is below the average industrial risk of occupational death.

Probability of fatal accident at work during working lifetime

Textiles	1 in 1000
Chemicals	2 in 1000
All industries (average)	2.7 in 1000
Shipbuilding	4 in 1000
Coal mining	10 in 1000
Construction erectors	30 in 1000
Deep Sea fishing	100 in 1000

Probability of fatal cancer from radiation received during working lifetime

Radiation worker in nuclear industry (average)	2 in 1000

Some recent American studies have suggested that observations on some groups of workers exposed to low levels of radiation for long periods are consistent with substantially higher risks of cancer than given in the ICRP, UNSCEAR and BEIR reports. The statistical methods used and the conclusions of these studies have been severely criticised by many leading independent authorities on radiation and health effects. The most widely discussed of these studies is of the mortality of workers at the Hanford plant in Washington State. The data used have recently been reanalysed by independent expert groups using correct statistical techniques and no significant radiation effect was found.

Risk estimates (hereditary)

Hereditary effects of radiation – defects in the offspring of parents exposed to radiation doses, ranging from trivial to lethal – have been observed in studies of animal populations. No unequivocal evidence of similar effects in man has yet appeared at any dose level. Even in the Hiroshima and Nagasaki studies, no hereditary defects that can be ascribed to the radiation from the bombs have been observed in any of the children subsequently conceived by exposed parents. All estimates of possible hereditary effects in man, therefore, have to be based on extrapolation from results obtained with other species, notably mice. Such extrapolation involves considerable uncertainties.

As with the somatic risk estimates, it is assumed that risks of low levels of radiation can be estimated from observations of the effects of high doses. This is probably a conservative assumption because, as with somatic effects, natural repair mechanisms may reduce the damage caused by radiation, especially if the dose is spread over a long time.

The ICRP, UNSCEAR and BEIR analyses indicate that the risk of hereditary damage in the descendants of a parent who had been exposed to one additional rem above natural background is about one in 12,500. The risk would be spread over all subsequent generations. The risk of the damage appearing in the first generation is between one-fifth and one-tenth of this – between one in 60,000 and one in 125,000.

It would follow that the radiation exposure of the population to one year's activities of the UK nuclear industry (0.3 mrem per person) might result in one case of hereditary disease at some time in the future. Many years of continuous exposure at this level would result in one such case per year. This should be set against the background of a one in 30 risk of a child being born with a hereditary or congenital handicap. There are about 20,000 such births per year in the UK. As with the naturally occurring cancers, some of these defects may be due to environmental agents, to natural background radiation and to medical uses of radiation.

Hereditary effects in future generations

No radiation induced hereditary damage has ever been detected in humans

Annual UK incidence of hereditary defects from all causes	– about 20,000
Estimated effects of 1 year's natural background radiation	– 500
Estimated effect of 1 year's radiation from UK nuclear industry	– 1

It is generally accepted that the hereditary risk associated with nuclear power is smaller than the somatic risk. The sixth Report of the Royal Commission on Environmental Pollution (the Flowers Report) concluded that 'at the levels of radiation likely to be permitted in relation to possible somatic effects, the hereditary effects should be of little concern'.

Control of radiation

The measures used to control radiation and minimise the risks are elaborate and extensive. Limits on radiation exposure are recommended by ICRP and form the basis for legislation and practice in most countries. In the UK, the ICRP recommendations have been endorsed by the National Radiological Protection Board.

ICRP recommends that those whose occupations expose them to radiation such as X-ray technicians and nuclear industry workers, should not receive a dose greater than 5 rem per year. For the public the individual dose should not exceed 0.5 rem per year. However, mere adherence to these limits is not considered adequate. Because of the possibility of harm resulting even from the very lowest doses of radiation, the ICRP has also made the following recommendations:

no practice shall be adopted unless its introduction produces a net positive benefit

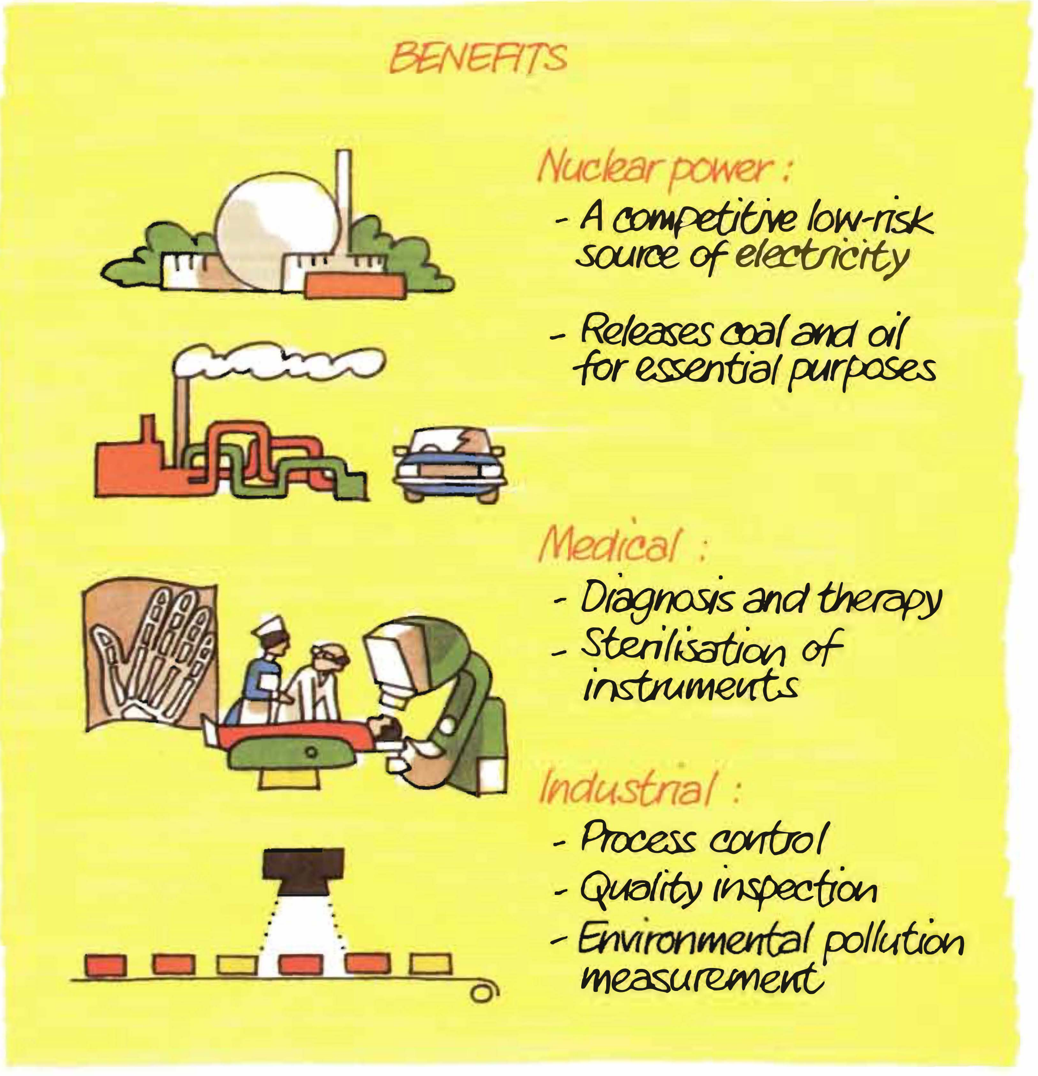
all exposures shall be kept as low as is reasonably achievable, economic and social factors being taken into account

The requirement to demonstrate net positive benefit is satisfied for nuclear power generation by comparing the radiological consequences with the overall consequences of burning alternative fuels such as coal. Resource considerations and economic factors also need to be taken into account. The benefits resulting from

Principles of radiological protection

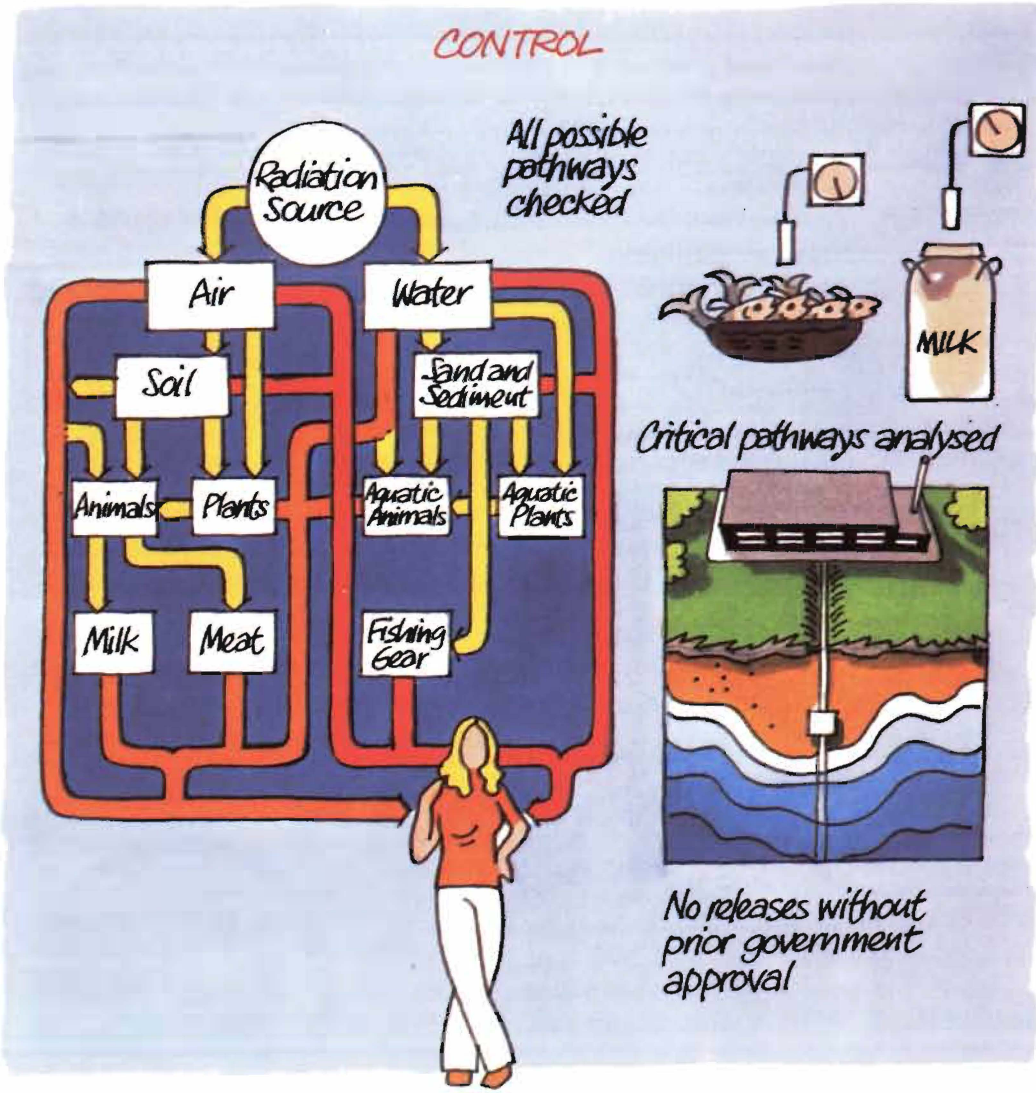
Practices involving radiation exposure	:	Benefits must be greater than harm
Radiation exposure levels	:	As low as reasonably achievable
Radiation doses	:	Not to exceed recommended dose limits

ICRP



medical uses of radiation are generally self-evident, but in some cases, such as X-ray examinations during pregnancy, the possibility of harm must be carefully taken into consideration. Industrial uses of radiation also need to be justified.

The requirement to keep exposure as low as reasonably achievable is implemented through legislation: no release of radioactive material is allowed without government permission. This is only

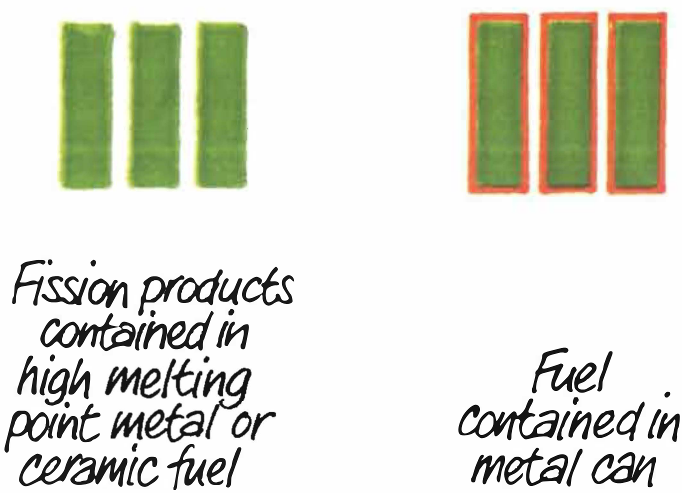


granted after detailed analyses of the possible pathways by which exposure of people might result. Generally it is found that one or two pathways will contribute most of the exposure and these are referred to as 'critical pathways'. The population affected may be a small group of people or even one person – the 'critical group'.

Calculation of the likely environmental effect of a proposed release of radioactive material is based on these critical groups and pathways. Discharge limits ensure that any exposure of members of the critical group is well below the ICRP limit. Pathways are extensively monitored, by the nuclear industry, the Department of the Environment, the Ministry of Agriculture, Fisheries and Food and the Scottish Office.

The results of these monitoring procedures are regularly published and show that the average exposure of the public is less than one thousandth of the ICRP limit. A few people living or working near certain nuclear installations may receive higher doses. However, in over 25 years of nuclear electricity generation in the UK, no member of the public has received a dose higher than the ICRP limit from this source. The average exposure of workers in the nuclear industry in the UK is less than one tenth of the relevant ICRP limit.

Multiple containment

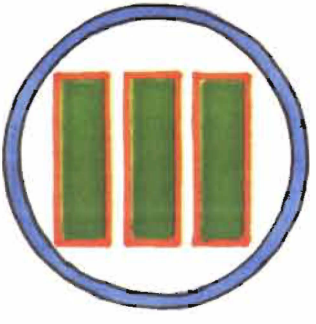


Risk estimates (accidents)

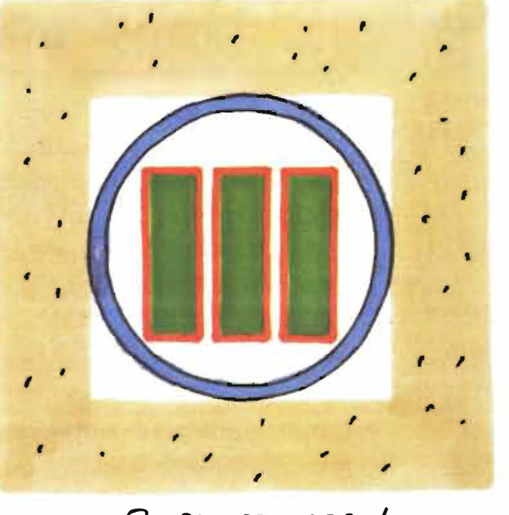
Despite tight control of routine emissions, there remains the possibility of a radiation release following an accident. Depending on quantities, wind, weather and population distribution, certain accidents could lead to radiation doses to some groups exceeding the ICRP limits.

The nuclear industry goes to unprecedented lengths to ensure that the probability of such accidents is reduced to acceptable levels. This is done by insistence on an extremely high standard of design, construction and operation of all nuclear installations. A 'multiple containment' approach means that a succession of barriers would have to be breached before a release of radioactivity to the environment would occur. Multiple independent safety systems ensure safe shut-down of plant in the event of failure.

In the worst accident in a commercial nuclear power station, at Three Mile Island in the United States, the built-in protective features ensured that only small doses of radiation were received and no one was killed or injured.



Reactor core contained in pressure vessel



Pressure vessel surrounded by reinforced concrete shield

The probability of an accident occurring can be estimated from data on component reliability and analysis of possible failure mechanisms and consequences. Such analyses are carried out by the Safety and Reliability Directorate of the UKAEA and by the nuclear construction industry. The Nuclear Installations Inspectorate, an independent Government organisation, will allow a nuclear installation to be built or operated only when it is fully satisfied that there is no appreciable danger to workers and the public. The design criteria that have been developed, combined with the relationship between radiation dose and cancer risk, indicate that if there were 100 reactors close to towns in the UK there might be an accident resulting in some tens of deaths once in 1,000 years. More serious accidents would be even less likely. Extensive studies in the USA and Germany have reached similar conclusions.

The same rigorous approach applies to the transportation of spent fuel. In Britain, 50-ton steel flasks are used. Tests include immersion in fire and water and a nine-metre drop onto an unyielding surface and a steel spike.

To put these risks into perspective it should be remembered that all industries involve some risks to workers and many present hazards to the general public. The average probability of a person dying as a result of an accident at work is about 3 in 1,000 over his entire career. While safety standards are continually being improved, about 50 coal miners in the UK still die each year as a result of immediately fatal pit accidents. In addition many more delayed deaths and incapacitating diseases arise from this occupation. The development of North Sea oil has claimed several hundred lives. Uranium mining is also a hazardous operation but vast amounts of electricity can be generated from small quantities of uranium, one ton being equivalent in a modern station to 25,000 tons of coal. The total hazard is therefore lower.

Large numbers of people can be affected by accidents involving toxic, flammable and explosive materials that are extensively used, stored and transported by a wide range of industries. Some of these materials can produce cancers and hereditary defects.

A very serious reactor accident, estimated to occur once in ten million reactor years, might cause 100 early deaths. In contrast there are 12 dams in California whose failure could cause between 10,000 and 250,000 deaths, where the failure probabilities are estimated at once in 100 to 1,000 years. In the UK the probability of a few people being killed as a result of an accident at a nuclear power station is less than the chance of the same number of people being killed by an aircraft crashing on them.

In a recent study the UK Health and Safety Executive concluded that, allowing for both routine and accidental risks across the whole of the fuel cycle from mining to waste disposal, nuclear systems involved "no more and probably less risk than oil or coal burning systems."

Summary

The effects of radiation have been extensively studied and are better understood than those of practically all other harmful agents

The nuclear industry is a very minor contributor to total radiation, most of which comes from the natural background and from medical uses

Nuclear power has an outstanding safety record and the industry is among the safest in the country

Nuclear electricity generation involves no more and probably less overall risk than coal or oil fired electricity generation

Radiation can be used beneficially in medicine and in manufacturing industry

P A H Saunders
Nuclear Environment Branch
Environmental and Medical Sciences Division
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