Radiation and health*

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Radiation has been a source of fascination and concern ever since Wilhelm Konrad Rontgen discovered X-rays on 8 November 1895. Over the years, health workers as well as the public have been concerned about medical uses of X-rays, the presence of radon in buildings, radioactive waste from nuclear power stations, fallout from nuclear test explosions, radioactive consumer products, microwave ovens, and many other sources of radiation. Most recently, the tragic accident at the Chernobyl nuclear power station in the USSR, and the subsequent contamination over most of Europe, has again wakened interest and concern and also reminded us about a number of misconceptions about radiation. This article describes the essentials about radiation (especially ionizing radiation) and its health effects.

Radiation is the straight-line transport of energy through space and, sometimes, through matter. The simplest physical analogy is energy transported by fast moving particles, although sometimes the propagation of waves may better describe the phenomenon.

IONIZING RADIATION

In the case of light the radiated energy can best be perceived as electromagnetic waves. In other cases, however, the energy may be described more conveniently as being transported by particles. In the latter instance, an irradiated body may be likened to a target being showered by fast, submicroscopic bullets.

An athlete running a 100-m race and a bullet leaving a rifle have about the same kinetic energy. However, their effect on a person whom they happen to hit is quite different! For the athlete, the energy is distributed over several kilograms, and the impact on colliding with another person will also be distributed over many kilograms, with little harmful effect. In contrast, the energy of the bullet is concentrated in a few grams which will strike a small area of the recipient’s body, where it will cause considerable harm and perhaps prove lethal for the body as a whole. So, on a smaller scale, will the energy of radiation particles. Their most important action is to rip electrons away from atoms and molecules, leaving them ionized. Radiation that has such an effect, either directly or through secondary particles, is therefore referred to as ionizing radiation. The most common ionizing radiations are X-rays and radiation from radioactive substances. Ultraviolet radiation is a borderline case, while visible light and electromagnetic radiation of longer wavelength (such as infrared radiation, microwaves, and radio waves) are non-ionizing (1, 2).

X-rays

X-rays consist of electromagnetic radiation of wavelength less than 0.1 μm. They are produced, inter alia, in X-ray tubes, devices in which electrons can be accelerated in a

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vacuum to high kinetic energies by an electric field. When the electrons hit the anode target of the tube they are suddenly stopped, and this results in the emission of an electromagnetic wave in the form of X-rays. The wave analogy, however, becomes less helpful at these short wavelengths, and it becomes increasingly helpful to view the radiation as a flux of energy quanta or photons. The photons from an X-ray tube take some or all of the energy of the bombarding electrons and therefore show a spectrum of energies.

In many national legislations, accelerating tubes with voltages less than 5 kV are exempted from rules and regulations, since the X-rays produced have so little penetrating power that they hardly escape through the walls of the tube. For diagnostic radiography of soft tissues, e.g., mammography, tube voltages of less than 50 kV are used. Also for dental radiography, the voltages are relatively low (50-70 kV). Most X-ray tubes for medical diagnostic radiology, however, operate at between 60 kV and 150 kV, usually above 100 kV, in order to avoid unnecessary absorption of low-energy photons.

For radiotherapy, tube voltages of up to 400 kV are used in conventional X-ray tubes, but higher photon energies (up to 50 MeV) are produced in high energy accelerators. Some radiation therapy, however, is carried out using “soft” X-rays; for example, for dermatological treatment the voltages used can be below 10 kV (3, 4).

**Gamma radiation**

There is no difference between gamma rays and X-rays, except in their mechanism of formation. High-energy photons emitted as the result of processes within the nucleus of atoms, however, are called gamma radiation rather than X-rays. They have unique photon energies that are characteristic of the radionuclide from which they are emitted.

**NUCLEAR RADIATION AND RADIOACTIVITY**

The nuclei of some atoms are unstable and disintegrate spontaneously, emitting energy that is carried by nuclear particles and/or by gamma radiation photons. The phenomenon of radioactive decay with emission of radiation is called *radioactivity*. The word should not be used as a synonym for radioactive substance: it is not “radioactivity” but radioactive substances that are released from, for example, nuclear power stations.

Another concept is the activity of a radioactive substance. This is the number of radioactive disintegrations per unit time. The unit of activity is therefore “1/second” but it has been given the special name becquerel (Bq). The number of becquerels therefore indicates “how much” there is of a radioactive substance in terms of its activity rather than its mass.

Each atom of a given radionuclide has the same probability of undergoing radioactive decay per unit time. For a given period of time, therefore, some atoms decay while others remain unchanged. In particular, after a period of time that is called the radioactive half-life, only half of the atoms originally present remain intact. After a second half-life period the number of atoms remaining is further halved, i.e., a quarter of the original number then remain, and so on. The half-life is characteristic of each radionuclide.

When a radioactive atom disintegrates the particulate energy emitted is usually in the form of alpha or beta radiation. Alpha particles consist of helium nuclei, and, because they are relatively heavy, can only be emitted by atoms of high mass number, such as radium, uranium, or plutonium. Beta rays consist of the much lighter electrons. Alpha particles have short ranges, a few centimetres in air and less than 0.1 mm in soft tissues.
Alpha radiation is therefore of no biological concern if it originates from sources outside the body. However, if alpha-emitting radionuclides are taken into the body, for example by inhalation, the alpha particles can cause cellular damage. In contrast, beta particles, being much lighter, are more penetrating, and in air have ranges of several metres, while in soft tissue their range is from a tenth of a millimetre to several millimetres. Sources of beta particles outside the body are likely to affect mainly the skin and eyes; however, sources within the body will affect cells in or near the tissue or organ where they are retained.

Gamma radiation is highly penetrating but is not emitted by all radioactive substances. It is this type of radiation that is mainly responsible for exposure of internal organs and tissues when the radiating substances are outside the body. For sources within the body, however, a substantial part of the energy carried by gamma radiation escapes without causing any harm.

RADIOACTIVE SUBSTANCES

Radioactivity is not a rare phenomenon. Almost any material around us as well as our own body contains naturally-occurring radionuclides. Some of these, for example uranium-238 (with a half-life of $4.5 \times 10^8$ years), thorium-232 (half-life $14 \times 10^9$ years), uranium-235 ($0.7 \times 10^9$ years), and potassium-40 ($1.3 \times 10^9$ years) have not totally decayed away since the creation of the earth. They are present in rocks and soil and, therefore, also in most building materials.

Radium-226, which is a late daughter-product in the radioactive decay series that begins with uranium-238, is present in most foodstuffs as is also potassium-40, which is not easily separable from stable potassium. Radon-222, which is the immediate gaseous daughter-product of radium, occurs in ground water and in air, into which it emanates from the decay of radium in soil. Radon in indoor air may also be produced by the decay of radium in building materials but mainly originates from the ground. The concentration of radon in indoor air is usually 5–25 Bq/m³, but values of more than 10,000 Bq/m³ have been detected. When radon-rich air is inhaled, short-lived radon daughter-products are also taken in. These remain in the lungs long enough to decay there, thus mainly exposing cells in the basal layer of the tracheobronchial epithelium.

In addition, some radioactive substances, for example carbon-14, are continuously produced by interactions between cosmic rays and nuclei in the atmosphere. The human body normally contains about 10,000 Bq of natural radionuclides. This activity is dominated by potassium-40 (4000 Bq) and carbon-14 (3500 Bq), while the amount of radium-226 is only about 1 Bq. In addition to the naturally-occurring radionuclides, since the mid-1950s radioactive fallout from nuclear test explosions has contaminated the environment and our bodies. The most important nuclides from this source are the long-lived carbon-14 (half-life 5700 years), strontium-90 (29 years), and caesium-137 (30 years), while immediately after atmospheric nuclear tests the short-lived zirconium-95 (64 days), ruthenium-106 (1 year), iodine-131 (about 8 days), barium-140 (13 days), and cerium-144 (285 days) are also present significantly (3, 4).

The major injection of radioactive substances into the atmosphere by nuclear test explosions occurred in 1961 and 1962. Contamination with carbon-14, strontium-90, and caesium-137 from this time is still measurable in the environment. Since carbon-14 emits beta radiation of low energy, it causes only a very low radiation dose to any one individual. However, in addition it has a long half-life and is globally dispersed so that it produces a substantial collective dose. Strontium-90 follows the same metabolic path as calcium and, when ingested, is deposited mainly in the skeleton. Caesium-137 mimics potassium and is mainly found in muscle tissue.
The radioactive fallout produced by nuclear test explosions largely consists of fission products, i.e., they are the fragments of the split uranium or plutonium nuclei. The same fission products are formed in controlled reactions in nuclear power reactors. In this case, however, only insignificant amounts, mainly radioactive noble gases, are released into the environment during normal operations.

More concern has been expressed about the problems involved in the management of spent reactor fuel and radioactive waste, because of the presence of the radionuclides strontium-90 and caesium-137 (both of which have half-lives of about 30 years) and, also, alpha-emitting transuranic substances, such as isotopes of plutonium, neptunium, americium, and curium, which are formed in the reactor by nuclear interactions with uranium.

The enormous activity in the reactor core is a matter of great concern in the case of a major accident. However, only a few radionuclides in the reactor have the potential to cause large doses of radiation in the environment. They are those which fulfil most of the following conditions:

— they are present in large activities in the core;
— they are volatile enough to permit escape of a large fraction from the reactor after an accident;
— they have long enough half-lives to persist for a significant time outside the reactor;
— they are readily transported through food-chains or otherwise irradiate humans;
— they are effectively retained in the human body if inhaled or ingested; and
— they emit enough radiation to cause significant radiation doses.

All of these conditions are satisfied by iodine-131, caesium-134, and caesium-137. Near the reactor, however, in the case of a major accident inhalation of other isotopes of iodine and those of ruthenium may also cause high radiation doses, and various gamma-emitting short-lived radionuclides may cause dangerous radiation exposures from deposition on the ground.

From the health point of view, iodine-131 (half-life about 8 days) is dominant in the first few weeks after a reactor accident. For example, if radioactive iodine falls on land where cows are grazing, contamination of milk will be the main problem. Short-lived radionuclides from a reactor accident may also fall as (invisible) dust on fresh vegetables.

When iodine-131 has decayed to insignificant levels, ground contamination with radioactive caesium is the main problem. Caesium-137 and caesium-134 (a nuclide with a half-life of about 2 years that is produced in reactors rather than in nuclear explosions) expose people both externally, with gamma radiation from the ground, and internally, after intake of radioactive caesium with contaminated food. Milk is the most critical foodstuff in this respect, but meat, freshwater fish, and cereals can also be significant sources. Other radioactive substances, such as strontium-90 and isotopes of plutonium and other transuranic elements, in spite of their high-energy radiation, are of less importance after a reactor accident than after a nuclear explosion, because the quantities released are relatively small.

Much of the radioactive caesium will fall directly on soil or be washed into the soil from grass or other vegetation by rain. Uptake by plants through their roots in subsequent years depends on the type of soil, but is usually much lower for caesium than strontium. The external gamma radiation from the ground, however, persists for many years (3–5).

**RADIATION DOSE**

The energy that ionizing radiation imparts to an irradiated body is eventually absorbed due to excitations and ionizations of its constituent atoms and molecules. The energy
absorbed per unit mass is called the absorbed dose. Absorbed doses of different types of radiation do not always have the same biological effect. For example, alpha radiation is assumed to be 20 times as biologically effective as gamma radiation. When this factor is taken into account, the resultant quantity is called the dose equivalent, and this is what is usually referred to as "dose" in radiation protection. The unit of dose is the sievert (Sv); previously the unit used was the rem and 1 Sv = 100 rem (6).

The dose in different parts of an exposed body can vary. For example, ingested or inhaled iodine-131 mainly concentrates in the thyroid, while caesium-137 affects all tissues with about the same dose. In order to facilitate comparison of exposures, a quantity called the effective dose equivalent is used. This is defined as the uniform whole-body dose that is expected to cause the same risk of cancer and genetic damage as the actual, uneven dose distribution. For example, a thyroid dose of 1 Sv corresponds to an effective dose of 0.03 Sv, i.e., a uniform whole-body dose of 0.03 Sv is believed to have the same probability of causing harm as a dose of 1 Sv in the thyroid alone. When doses are specified, it is therefore important to know whether the local organ dose or the effective dose is meant.

Sometimes it is also of interest to know the "amount of radiation" at a point in space. For X-rays and gamma radiation this is often determined by measuring the ionization that the radiation causes in air. This is called the exposure and the old unit, still in use, is the roentgen (R). An exposure of 1 R results in a dose of a little less than 1 rem, i.e., about 0.01 Sv. The exposure rate due to gamma radiation from sources on the ground is usually expressed in microroentgens per hour (μR/h). If the exposure rate is constant over the year, an outdoor rate of 1 μR/h may be expected to cause an annual dose of about 0.03 mSv, taking into consideration that some time is spent indoors, where building structures shield against external radiation, and that also the body itself to some extent shields inner organs and tissues. Naturally occurring radionuclides in soil usually cause an outdoor exposure rate of about 10 μR/h. This is therefore equivalent to an annual dose of about 0.3 mSv.

**Radiation background**

We are all exposed to radiation, which has been a component of the environment since the earth was created. Cosmic radiation comes from the sun as well as from outer space. In addition, we are exposed to gamma radiation from the ground and from building materials, and to alpha and beta radiation from the naturally occurring radionuclides in our body tissues. The annual dose from external radiation differs from place to place, depending on local geology and types of building material, and differences may be as large as 1 mSv or more per annum. Typical annual effective doses from these natural sources are shown in Table 1.

<table>
<thead>
<tr>
<th>Source</th>
<th>Annual effective dose equivalent [mSv]</th>
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<tbody>
<tr>
<td>Cosmic rays</td>
<td>0.3</td>
</tr>
<tr>
<td>External gamma radiation from the ground and from building materials</td>
<td>0.30–0.6</td>
</tr>
<tr>
<td>Internal exposure, mainly from potassium-40</td>
<td>0.2</td>
</tr>
<tr>
<td>Total whole-body exposure</td>
<td>about 1</td>
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*See reference (3).*
In addition, radon daughter-products in the lungs typically contribute an effective dose of another 1 mSv per year, giving a total annual effective dose equivalent of about 2 mSv. However, in some cases this source may give an effective dose of several hundred mSv per annum and call for remedial action. If irradiation from radon in housing is also taken into consideration, there is a very large variation in the natural background dose, although the radon daughter-products only affect the lungs. Furthermore, we are exposed to various artificial sources of radiation, principally X-ray equipment for medical diagnosis and treatment. For example, diagnostic X-ray examinations in industrialized countries result in an average annual effective dose of 0.1–1 mSv (individual examinations are typically 0.05–10 mSv). In developing countries, where the examination frequency is lower, average annual doses are lower, even though individual doses may be higher because use of older equipment is more widespread (3, 4).

Radiation emitted by various consumer products, such as watch dials, with radioactive luminescent paint, smoke detectors, and X-ray-emitting TV sets, is usually well controlled today and contributes only insignificant doses. Environmental exposure of the public to releases of radioactive substances from nuclear power stations is restricted by internationally recommended dose limits. The limit recommended for the total dose from all radiation sources, with the exception of natural sources and medical exposures of patients, is 1 mSv per year (7, 8). For individual installations, such as nuclear power plants, the operational limit usually corresponds to a fraction of this dose. Members of the public are therefore exposed normally to doses of 1–3 mSv per year, i.e., to a life-time dose of the order of 100 mSv.

The dose limit recommended by the International Commission on Radiological Protection (ICRP) for workers is 50 mSv in a year, but additional requirements usually result in much lower annual doses; typical values are 1–2 mSv per year (8, 9).

RADIATION EFFECTS

Non-stochastic effects

The energy transferred by ionizing radiation to body tissues does not affect all molecules. Although many ionizations may be caused in cells by absorbed ionizing radiation, the vast majority are unimportant. Most of the molecules involved are water, but larger molecules may also be affected. The most important of these is DNA, which carries the cell's genetic code, and if one of these molecules is damaged, the cell may fail to reproduce. The number of cells killed in this way increases with the dose until the irradiated tissue is damaged to such an extent that its correct function is impaired; as a result, erythema, skin blisters, or a dangerous reduction in the number of blood cells, for example, occur. Such effects are an inevitable consequence of exposure to high doses but do not occur with doses that are below the threshold value needed to destroy a sufficient number of cells. Because these effects do not occur randomly they are called non-stochastic: if the dose is high enough they will always occur.

For whole-body exposure, the acute radiation sickness resulting from doses of a few Sv is characterized by depression in the number of peripheral blood cells that reaches a minimum 3–6 weeks after the exposure. During this period the risk of death is at its highest because of reduced resistance to infections. Acute skin doses exceeding 3 Sv may cause temporary loss of hair, while doses exceeding 6–8 Sv produce reactions such as erythema, ulceration, and necrosis. After an initial erythema during the first week, the main reaction occurs about 2 weeks after the exposure and, if the dose was high, may be followed by several “waves” of severe reaction (3).
Since quite high doses are needed to cause non-stochastic effects, and the limits enforced for the use of radiation sources are designed to prevent this, early harmful effects can only arise from accidental exposures.

After a severe reactor accident, radioactive contamination of the air and the ground, under the worst conditions, might cause such effects up to distances of 40–80 km from the plant, unless some remedial action (such as sheltering or evacuation) is taken.

The reactor accidents at Windscale, England, in 1957, and at Three Mile Island, USA, in 1979, did not cause any non-stochastic harm. However, for the Chernobyl accident, 203 cases of acute radiation sickness among power plant workers and firemen have been reported, and 31 persons died within 4 months of exposure. Those who died had received absorbed doses corresponding to 4–16 Sv, but had also suffered severe and, in some cases, lethal skin burns from both heat and beta radiation. Outside the power plant, radiation doses received by the public before evacuation of the most affected area were not high enough to cause acute radiation sickness (14).

**Stochastic effects**

An individual who has received a high accidental whole-body dose of radiation but has survived for 2 months is likely to have overcome all non-stochastic damage. However, although the damage due to cell killing will have been repaired, some cells may have survived with impaired DNA that will be reproduced by cell division, leading to new generations of cells that are no longer able to fulfill their normal role. Some of these changes may initiate cancer, seemingly at random, which is therefore called a stochastic effect of radiation. The probability of such an effect increases with the radiation dose, but there is no evidence of a threshold dose below which the probability is zero. In contrast to non-stochastic effects, the severity of a stochastic effect does not depend on the dose. If changes to DNA are induced in germ cells, they may be carried over to the offspring of the exposed individual and cause hereditary harm.

No direct information is available on the probability of cancer arising from exposure to effective doses of below 0.1 Sv, i.e., for the region of annual doses permitted by the occupational dose limits. This is not an unfortunate lack of information, because it means that the risk is so small that it has not been possible to prove and quantify convincingly any increased cancer frequency in human populations exposed to low doses of radiation. It has therefore been assumed that there is the same risk per Sv at low doses as at the high doses for which an increased incidence of cancer has been observed.

The ICRP has assumed that the frequency of deaths from cancer in a population of normal age and sex distribution is about 1% per man Sv. The “man Sv” is the unit of collective dose, which is the product of the number of persons exposed to radiation and their average dose. The uncertainty in this estimate is considerable; however, it is unlikely that the actual figure is higher by more than a factor of five, and a value of 1–2% per Sv is usually thought to be the most likely frequency. This is then also the probability of death from cancer for an average member of the public. In each individual case, the probability may be different. Because of its long latent periods, the actual risk of cancer among older persons would be very much lower, while that among young persons would be somewhat higher (although it would be expressed first after perhaps 10–30 years).

The risk of hereditary damage to man caused by radiation has never been demonstrated, but there is no reason to believe that it differs from genetic risk estimates determined theoretically and from observations on animals. The prevailing view is that the frequency of hereditary harm is smaller than that of cancer.

The official report of the USSR to the International Atomic Energy Agency (IAEA) in August 1986 gave some estimates of doses received by the Soviet public from the radioactive contamination caused by the Chernobyl accident. Altogether, 135 000 persons were
moved from the area within a 30-km radius of the power station. It is estimated that the population received a collective dose of 16,000 man Sv. Radioactive contamination of the ground in the European part of the USSR is expected to cause a collective dose of about 300,000 man Sv from external gamma radiation over the next 50 years (14).

Further exposure will be caused by the use of contaminated food. The collective dose from this source over the next 70 years was estimated by the Soviet experts at 2 x 10^9 man Sv, although this may be too high. In addition, populations were exposed outside the USSR; these exposures have not yet been fully assessed but may add significantly to the numbers estimated for the USSR. With the expectation of a cancer death frequency of 1% per man Sv, this would mean tens of thousands of deaths from cancer because of the accident. However, these deaths will appear first after long latent periods (perhaps 10-30 years) and will be scattered over several decades.

**Developmental effects**

Fetal damage caused by exposure to radiation during pregnancy represents a borderline case between stochastic and non-stochastic effects. A loss of some of the hundred thousand billion cells in the adult body is understandably not necessarily serious, but for a growing embryo or a developing organ even the loss of a few cells may have serious consequences and result in developmental deficiencies. In this respect it has been suggested that the most frequent developmental harm to fetuses from irradiation is mental retardation caused by damage to the developing brain. The critical period of exposure is the 8th to 15th weeks of pregnancy, and the probability of damage is believed to be as high as 40% per Sv if the exposure falls within this period. There is no evidence of any threshold dose for this effect (10).

**PROTECTIVE MEASURES**

After the Chernobyl nuclear accident, governments and public health authorities in Europe advised the public on protective measures to reduce radiation exposures. In the most affected areas within the USSR, remedial actions were urgent, and large regions were evacuated.

In the aftermath of the accident, there has been considerable unnecessary, but understandable, fear of radiation and of contaminated food. Many have seen it as paradoxical that the public health authorities advised on a number of remedial actions while, at the same time, they were reassuring the public that any risk was negligible. However, even a very small individual risk to a large number of persons can be expected to cause some harm in the form of cancer and hereditary detriment. This may be too low to be measurable by health statistics, but if some of this harm can be avoided by reasonable means—why should this not be done?

What can be done to protect the public from the effects of radioactive contamination of the environment? After a reactor accident people are initially exposed to a radioactive cloud, but this exposure is likely to be of relatively short duration, corresponding to the time required for passage of the cloud. Inhaled radionuclides cause internal exposure of the lungs but also of some other organs, particularly the thyroid, which retains inhaled radioactive iodine. In addition, there is direct external exposure by gamma radiation from the cloud.

If there is sufficient warning about an approaching radioactive cloud, the most effective precaution is to stay indoors and minimize any ventilation that brings in contaminated air (rooms should be aired when the cloud has passed). Staying indoors reduces both internal
and external exposure. Attempts to move away from the cloud are not advisable, since it may not be easy to predict its direction of drift. In any case, exposure from the cloud is unlikely to be the dominant exposure. If the authorities so advise, stable iodine in tablet form may be administered to the public. This is primarily recommendable for locations close to the reactor, where there should be an emergency plan that includes this action. It should be borne in mind, however, that stable iodine only prevents uptake of radioactive iodine by the thyroid and does not reduce or prevent any other exposure. Tablets should be taken before any radioactive iodine is inhaled, although some measure of protection may be achieved even if they are taken 4-5 hours after the exposure.

After the cloud has passed there may be continued exposure by gamma radiation from radionuclides deposited on the ground. It is likely that much of this is due to short-lived isotopes of iodine, and the wisest action is to remain indoors until competent authorities have assessed the exposure rate and the geographical distribution of the contamination. Only then can it be decided whether the area should be evacuated and, if so, to where. Like administration of stable iodine, evacuation is not foreseen except near a power station. After the Chernobyl accident, evacuation was not considered outside the Soviet Union.

Even if exposure from the ground does not justify evacuation, in the long term this source of radiation is likely to produce the major dose contribution. Prolonged exposure from the ground is not easy to avoid, and decontamination is difficult. The basic protection rules—increase the distance from the source, reduce the exposure time, and seek shelter behind absorbing walls—indicate the best course of action. Time spent indoors may therefore reduce the dose from contaminated ground. Compared to the dose caused by external exposure from the ground, additional doses of radiation from radionuclides taken into the body with contaminated water and food are usually low if the food originates from the same area.

The IAEA, ICRP, and WHO have produced guidelines on various remedial actions and action levels, i.e., the doses that are worth avoiding by taking remedial action (11-13). Such levels are not universal. Some actions are easy to take, e.g., washing fresh leaf vegetables before they are eaten, and are therefore recommended even though the dose avoided may be very small. Other actions, such as evacuation, which are more difficult, may themselves involve some risks and are therefore not recommended unless the dose reduction is substantial. Recommended action levels are often given as a range of doses: a value below which the action is not considered justified and a value above which the action is believed to be justified under any circumstances. For example, the ICRP recommends a dose of 50-500 mSv for evacuation (a level of 250 mSv was used for the evacuation of the area near the Chernobyl power plant). For sheltering and for administration of stable iodine tablets, action levels corresponding to an effective dose of 5-50 mSv are recommended. Because of the risk to the fetus, evacuation or sheltering are, in the first instance, considered for pregnant women. The action level for not accepting contaminated food on the market is given by ICRP in terms of a first year dose of 5-50 mSv. From this action level, derived action levels for the annual activity intakes of various radionuclides can be calculated. The corresponding activity concentration in foodstuffs, however, can only be calculated if assumptions are made about the quantities consumed.

Outside the USSR, external exposure to gamma radiation during 1986 is not likely to exceed 1 mSv, except in a few local areas where it rained during the early passage of the radioactive cloud. Exposure from contaminated food is expected to contribute even less than this, partly because of the actions taken to prevent sale of such food, but mostly because activity concentrations in basic foodstuffs were low. However, in some countries contamination of certain local foodstuffs with caesium has been considerable: for example, reindeer meat, goat and game meat, fresh-water fish, and wild berries, which had
activity concentrations substantially higher than the local action levels.

The action levels for caesium-137 in food were established to control the annual intake of this radionuclide and thus also the annual radiation dose. The activity concentrations in foodstuffs are only a means to control the intake and not of primary importance. It is important that derived action levels for concentration are not exceeded for staple foodstuffs but is of little significance if some items that are only consumed in small quantities exhibit high concentrations, since they will contribute very little to the total intake.

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