Chapter 10 Environmental pollution

We have seen in Chapter 7 that natural radionuclides pervade our environment. This chapter deals with the artificial radionuclides that have been widely dispersed by events such as tests of nuclear weapons in the atmosphere and the Chernobyl accident and by the deliberate discharge of radioactive wastes from nuclear and other installations. Such radionuclides find their way from air and water onto the ground and into foodstuffs and so deliver radiation doses in various ways to human beings.

Pathways of human exposure to radiation from the release of radionuclides to the environment

Rain washing radioactive materials out of the air

External radiation direct from cloud

External dose direct from radioactive materials deposited on the ground

Internal dose from eating and drinking radioactive materials in food

Internal dose from water intake

Nuclear weapon tests

When nuclear weapons were tested above ground, they propelled a variety of radionuclides from hydrogen-3 (tritium) to plutonium-241 into the upper atmosphere. From there, the radionuclides transferred slowly to the lower atmosphere and then to the Earth's surface. Around 500 atmospheric explosions were conducted before the limited test ban treaty was enacted in 1963, with a few more until 1980. The concentrations of radionuclides in air, rain and human diet are now much lower than the peak values in the early 1960s.

Globally, the most important radionuclides from testing in terms of human exposure are now carbon-14, strontium-90 and caesium-137. Minute quantities of these are ingested with food and drink. Residual activity from radionuclides in the ground that emit gamma rays also causes a slight degree of human exposure. Internal and external irradiation contribute about equally to the global average effective dose of 0.005 mSv in a year. This compares with a peak of more than 0.1 mSv in 1963. Some groups of people who receive significantly higher doses from global fallout than average have been identified. For example, it was found in the 1960s that reindeer and caribou herders in northern Europe and Canada received significantly higher doses than other people, because they eat the meat of animals that eat lichen, which is a very efficient collector of airborne caesium-137. The global collective dose from weapon tests fallout is now about 30 000 man Sv annually, assuming a world population of 6 000 million.

Site, country (country that conducted tests, if different)	***Type(s) of weapons test***	***Highest individual dose to local people at time of tests (mSv)***	***Collective dose (man Sv)***
Nevada, USA	*Atmospheric and underground*	*60–90*	*470*
Bikini and Enewetak, Marshall Islands (USA)	*Atmospheric*	*1100–6000*	*160*
Semipalatinsk, Kazakhstan (USSR)	*Atmospheric and underground*	*2000–4000*	*4600–11 000*
Novaya Zemlya, Russian Federation (USSR)	*Atmospheric*	*low*	*low*
Maralinga and Emu, Australia (UK)	*Atmospheric*	*1*	*700*
Christmas Island, Australia (UK)	*Atmospheric*	*low*	*low*
Reganne, Algeria (France)	*Atmospheric*	*unknown*	*unknown*
Lop Nor, China	*Atmospheric*	*0.1*	*unknown*
Mururoa and Fangataufa, French Polynesia (France)	*Atmospheric and underground*	*1–5*	*70*

In addition to assessments over many years of the doses from widespread dispersion of radionuclides from atmospheric testing of nuclear weapons, studies have been carried out by the IAEA on the longer term local effects of weapons testing in the atmosphere and underground. The results of these studies are summarized in the table opposite, and estimates have been made of the maximum annual radiation doses that would occur if people lived on some of these sites now. For the uninhabited atolls of Mururoa and Fangataufa in the South Pacific, where most of the testing was underground, the dose would be no more than 0.25 mSv even if the atolls were inhabited. At Bikini Island, also in the Pacific, the potential doses could have been up to 15 mSv, but remedial measures are being applied to reduce that figure by about 90 per cent before the islanders return.

Remnants of nuclear testing at Semipalatinsk: A goose tower built to observe nuclear tests.

For Semipalatinsk in Kazakhstan, where about one hundred atmospheric tests were conducted, a preliminary assessment showed that the maximum annual dose could be as high as 140 mSv if people were to live in the most heavily contaminated areas. Nobody does so at present, but with the potential for such high doses there is a need either to clean up the contamination or to make sure people cannot spend significant amounts of time in the most contaminated areas. There is an international effort, involving several UN organizations, to improve conditions for people in the Semipalatinsk area. The radioactive contamination on the test site is only one of the problems, but it will need to be addressed.

A lake produced by a nuclear explosion during an excavation experiment V. Mouchkin/IAEA

Chernobyl accident

An explosion in a nuclear reactor at the Chernobyl nuclear power plant on 26 April 1986 caused the release of substantial quantities of radionuclides during a period of ten days. Airborne material was dispersed throughout Europe from the site in Ukraine. As the contaminated air spread throughout Europe and beyond, local weather conditions largely determined where the radionuclides were to fall. Rainfall caused more radionuclides to be deposited in some areas rather than others.

High volume air sampler

The accident had a catastrophic effect locally. Furthermore, altogether 134 emergency workers were confirmed as suffering from acute radiation syndrome having received doses of external radiation to the whole body in the range of 0.8 and 16 Gy. Of these, 28 died in 1986, their doses of external radiation to the whole body being between 2.2 and 16 Gy. In addition to these doses to the whole body, contamination on the skin caused severe erythema, mostly by beta emitters. In some cases, the subsequent skin injury contributed to the deaths of the 28.

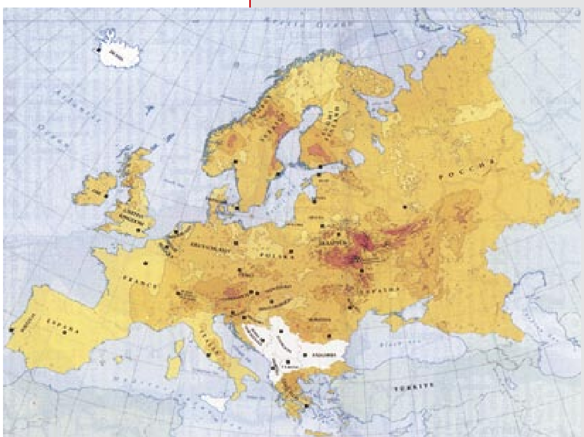
In terms of doses to people in the vicinity and beyond, the most significant radionuclides were iodine-131, caesium-134 and caesium-137. Almost all the dose was caused by external irradiation from radionuclides on the ground, by inhalation of iodine-131 giving rise to thyroid doses, and by internal irradiation from radionuclides in foodstuffs.

Nuclear power plant at Chernobyl V. Mouchkin /IAEA

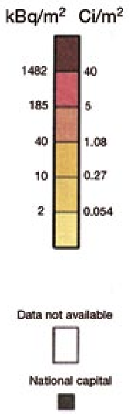
Following the accident, over 100 000 people were moved from their homes in what are now Belarus, Ukraine and the Russian Federation, and various areas became "restricted" because of the levels of fallout on the ground. A vast clean-up operation was mounted at the Chernobyl reactor site itself involving over 750 000 people. The people doing the decontamination work became known as "liquidators", and some of them received doses above the ICRP dose limit of 50 mSv. Such exposures may be justified in accident situations and ICRP recommends that exposures should not exceed 500 mSv in such circumstances. This ensures that workers could not experience any deterministic effects of radiation exposure, and published data from monitoring teams show that the average doses were kept below 165 mSv in the first year after the accident. In subsequent years, they were gradually reduced to below 50 mSv.

2000 UNSCEAR Report to UN Assembly

There have been exhaustive studies of populations in the vicinity of Chernobyl and elsewhere, looking for possible health effects from the accident. The only significant effect that has so far been shown to be caused by radiation is in children in regions of Belarus and Ukraine, who have an increased incidence of thyroid cancer due to intakes of iodine-131, particularly through drinking milk contaminated with iodine. Iodine-131 is a short lived radionuclide (8 days half life) known to concentrate in the thyroid, and using monitoring and other data it has been possible to estimate risk factors for this health effect in children. In 2000, UNSCEAR published a review of the effects of the Chernobyl accident. Their scientific assessments indicated that there had been about 1800 cases of thyroid cancer in children who were exposed at the time of the accident. Fortunately, in the great majority of cases, it is not a fatal condition, although it is a serious illness.



Distribution of ^{137}Cs following Chernobyl accident



UNSCEAR found no scientific evidence of increases to date in the incidence of any other health effects that could be related to radiation exposure. This does not mean that there will not be any other effects — the most highly exposed individuals have an increased risk of suffering radiation-associated effects in the future — but UNSCEAR concluded that the great majority of the population are not likely to experience serious health consequences attributable to radiation from the accident.

The other serious health effects seen in local populations appear to be the result of the stress and anxiety caused by the accident, including the fear of radiation itself. Although these effects are different in kind to the thyroid disorders mentioned above, they are no less real and occurred widely throughout Europe in regions affected by the fallout. For example in Scandinavia, doses of about 0.1 mSv were received on average during the first few weeks after the accident, and many people reported to their doctors feelings of nausea, headaches, diarrhoea and some skin rashes. Following a century of scientific study of the effects of radiation, it can be concluded that it is not possible that such low doses could lead directly to the effects reported. However, a potent fear of radiation is obviously real for some people, and this was one of the lessons of the Chernobyl accident.

Radioactive discharges

Radionuclides of artificial origin are discharged to the environment by the nuclear power industry, military establishments, research organizations, hospitals and general industry. Discharges of any significance should be subject to statutory control; they must be authorized and monitored. Owners or operators of the facilities from which radionuclides are discharged carry out monitoring programmes, as do some regulatory agencies.

The nuclear power industry discharges the most activity. At each stage of the *nuclear fuel cycle*, a variety of radionuclides are released in the form of liquids, gases, or solid particles. The nature of the effluent depends on the particular operation or process.

Each year, nuclear power reactors generate about 20 per cent of the world's electrical energy. During routine operation of nuclear installations, the releases of radionuclides are low and normally exposures have to be estimated with environmental transfer models. For all nuclear fuel cycle operations, including mining and milling, fuel fabrication, reactor operation and fuel reprocessing, the local and regional exposures are estimated by UNSCEAR to be about 0.9 man Sv per gigawatt-year (GW a). The present world nuclear energy generation is about 250 GW a annually, and so the total collective dose from a year's generation of nuclear energy is about 200 man Sv. Generally individual doses are low, being below 1 µSv in a year. However certain individuals might receive higher doses because of where they live and what they eat and these should be subject to dose constraints, the maximum value being 300 µSv in a year.

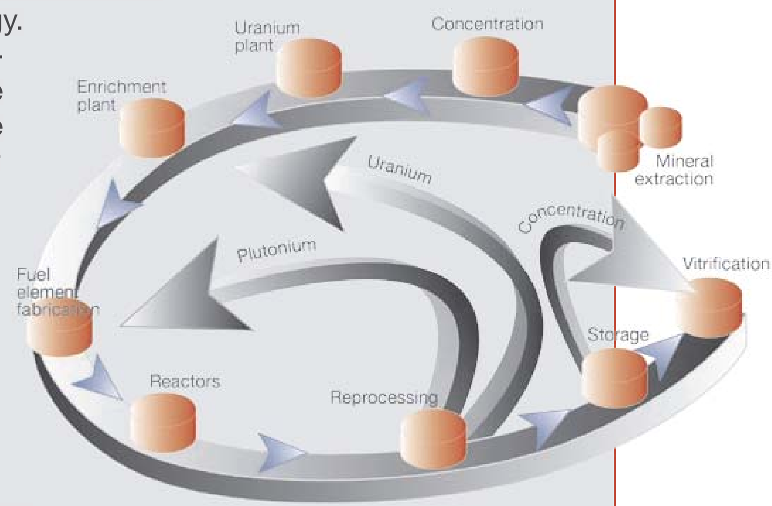


Diagram of nuclear fuel cycle showing fuel fabrication, reactor operation, fuel reprocessing, and waste management

In the case of accidents where there has been significant local contamination, the local doses can be significantly greater than the dose constraint. Where appropriate, measures are taken to minimize doses to people, such as the establishment of restricted areas in the vicinity of Chernobyl. Such measures can reduce both the individual and collective doses substantially.

Discharges from fuel reprocessing facilities give annual doses to the most exposed people — those who eat local seafood — up to 0.14 mSv mainly from *actinides*. Discharge to air of strontium-90 and other radionuclides leads to individual doses that are less than 0.05 mSv annually from the consumption of local milk and vegetables. The collective dose from airborne discharges, mainly due to carbon-14 in foodstuffs, is approximately 500 man Sv annually. From liquid discharges, it is about 4000 man Sv annually mainly due to caesium-137 in fish.

Annual doses due to discharges from the nuclear fuel cycle

Stage of cycle	*Type of effluent*	*Most exposed people (mSv)*	*Collective dose (man Sv)*
Fuel fabrication	*Airborne*	*0.01*	*350*
	Liquid	*0.01*	
Reactor operation	*Airborne*	*0.001*	*380*
	Liquid	*0.004*	
Fuel reprocessing	*Airborne*	*0.05*	*4500*
	Liquid	*0.14*	

Although radioactive discharges to the environment are now strictly controlled in most countries, in the past they have not always been managed as they should have been. In particular, some military facilities operating during the Cold War adopted waste management methods that would be unacceptable for a modern civilian facility. As a result of the operation of one such example, the Mayak facility near Chelyabinsk in the Russian Federation, areas around the plant and downstream on the Techa River have very high levels of contamination, and some local people may have received very high doses (up to 1 sievert or more) over their lifetimes.

Depleted uranium

Munitions using depleted uranium (DU) were used during the Gulf War in 1991 and in the conflicts during the 1990s surrounding the break-up of Yugoslavia. The risks of harm to military personnel on a battlefield should be put in context of the other self-evident risks, but the use of depleted uranium ordnance has raised concerns about subsequent health consequences, both to service personnel and to the public after the conflict.

As has already been discussed, uranium occurs naturally in the environment. It is widely dispersed in the Earth's crust, and in fresh water and sea water. As a result, we are all exposed to uranium isotopes and their decay products, and there are wide variations in doses received depending on local circumstances. DU is a by-product of the uranium fuel cycle where natural uranium is enriched to provide suitable fuel for nuclear power. It is called depleted because it has had some of its uranium-235 isotope removed. A large fraction of decay products of the uranium isotopes is removed during the fuel enrichment process.

Depleted uranium in munitions is in a concentrated metallic form, and there are understandable concerns about elevated levels in the environment due to spent munitions. There are also worries about people handling intact depleted uranium metal. Assessments of dose to military personnel who entered a tank shortly after it was hit by a DU weapon indicate possible doses of up to a few tens of mSv from inhalation of vapours and dust. In contrast, doses to people exposed some time afterwards to resuspended dust in the same local environment are likely to be a thousand times less, typically a few tens of µSv. Contact doses when handling bare DU metal are approximately 2.5 mSv/h, primarily from beta radiation, which is not penetrating and so affects only the skin. Even so, the collection of bare DU munitions needs to be discouraged and, if possible, avoided completely.

Doses from depleted uranium are, therefore, real and, in some circumstances, they could be appreciable for military personnel. Doses to people in the post-conflict phase are likely to be much lower and should be relatively easy to avoid.

Managing contaminated areas

As we have seen (and will see from other examples in later chapters), areas in various parts of the world have become contaminated with radionuclides as a result of various human activities. In cases where the level of contamination is high, measures might be needed to ensure that the area is safe for people to live or use for other purposes. For small areas, it might be possible to do this by removing contaminated soil and other materials, but for large areas the amount of material would be too large.

Pasture land nearby Semipalatinsk test site in Kazakhstan

Other ways of protecting people include restrictions on access to or use of areas, for example, preventing house building on areas affected by mining wastes that could produce high radon levels. Chemical treatments can also be used to reduce the amount of activity that gets from soil into food. Examples of this include giving 'Prussian blue' — a chemical that increases the rate at which caesium is excreted by the cow so that it does not get into milk and meat — to cows grazing on contaminated grass in the Chernobyl area and treating the soil on Bikini Island with potassium to stop the trees absorbing caesium.

Total doses

With the exception of some military facilities and those mentioned above, no other facilities that discharge artificial radionuclides to the environment cause doses much above 0.02 mSv in a year to the most exposed people; nor do they make a significant contribution to collective dose. On average, therefore, the maximum effective dose from the discharge of artificial radionuclides, other than some military facilities, is about 0.14 mSv in a year and the collective effective dose about 5000 man Sv in a year or 0.001 mSv when averaged throughout the entire global population.

Extracting oil from rapeseed provides new productive uses for land in Belarus contaminated by the Chernobyl accident
V. Mouchkin/IAEA