Briefing

April 2016

Chernobyl 30 years on

Environmental and health effects

SUMMARY

In the early hours of 26 April 1986, an accident at the Chernobyl nuclear power plant and the explosions it triggered caused a major release of nuclear radioactive material into the atmosphere. Radionuclides were scattered in the vicinity of the plant and over much of Europe.

The Chernobyl fallout had a major impact on both agricultural and natural ecosystems in Belarus, Russia and Ukraine, as well as in many other European countries. Radionuclides were taken up by plants and later by animals. In some areas, they were subsequently found in milk, meat, forest food products, freshwater fish and wood.

Environmental impacts vary according to location and ecosystem. Forests and fresh water bodies have been among the most affected ecosystems. The impacts on wildlife in the vicinity of the Chernobyl plant are disputed.

The impacts on human health have been extensively studied, although experts are not unanimous in their views. Official assessments by United Nations agencies have been challenged.

The major population groups exposed were clean-up workers, evacuees and residents of contaminated areas of Belarus, Russia and Ukraine. There has been no clear evidence of any measurable increase in radiation-induced adverse health effects in other European countries.

The immediate and short-term effects resulting from heavy fallout exposure include radiation sickness and cataracts. Late effects are thyroid cancer, especially in children and adolescents, and leukaemia among exposed workers. The accident has also had important psychosocial effects.

The town of Pripyat, in the Chernobyl exclusion zone.

In this briefing:

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The Chernobyl accident

In the early hours of 26 April 1986, an accident at the Chernobyl nuclear power plant in the Soviet Union (now Ukraine) resulted in explosions which completely destroyed reactor 4 of the plant and severely damaged much of the building. Some 116 000 people living within a radius of 30 km around the reactor (later known as the 'exclusion zone') were evacuated in the spring and summer of 1986. Another 220 000 people were relocated from other contaminated areas in subsequent years.[1]

Contamination pathways

Major **releases of nuclear radioactive material** (radioactive gases, condensed particles and nuclear fuel particles, collectively referred to as radionuclides) continued for 10 days after the accident. It is estimated that a total of 14 exabecquerel (EBq)[2] of radioactive substances were released. Table 1 provides an overview of the major radioactive substances released.

Table 1 – Selected radioactive substances released by the Chernobyl accident (EBq)

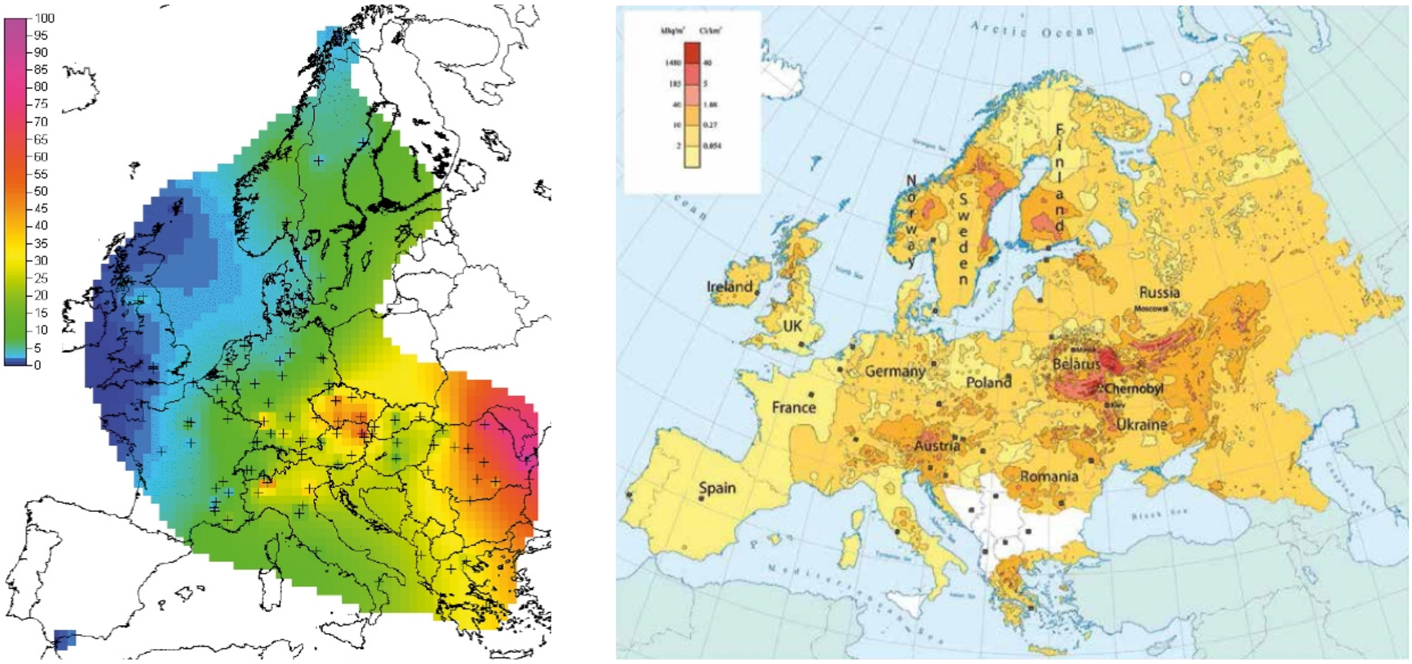
Radioactive substance	Half-life	EBq
iodine-131	8.04 days	1.8
caesium-137	30 years	0.085
caesium-134	2.06 years	0.047
strontium-90	29.12 years	0.01
plutonium-241	14.4 years	0.003

Because of their size, fuel particles and larger particles (containing mostly strontium and plutonium) were deposited less than 100 km away from the reactor. Most radioactive elements released had short half-lives and have thus long decayed away, while long-lived radionuclides were released in much smaller amounts. Table 1 shows selected radionuclides with high impacts on the environment and health.

However, the releases affected large areas of Europe to some degree. Over 200 000 km^2, of which 71% are in the three most affected countries (Belarus, Russia and Ukraine) were contaminated with caesium-137, which has a 30-year half-life. As shown in Figure 1, the deposition occurred in patches, as it was strongly influenced by rainfall.

Figure 1 – Distribution of iodine-131 and caesium-137 released after Chernobyl

Cumulative iodine-131 air concentration in May 1986 (Bq*d/m^3) Deposition of caesium-137 (kBq/m^2)

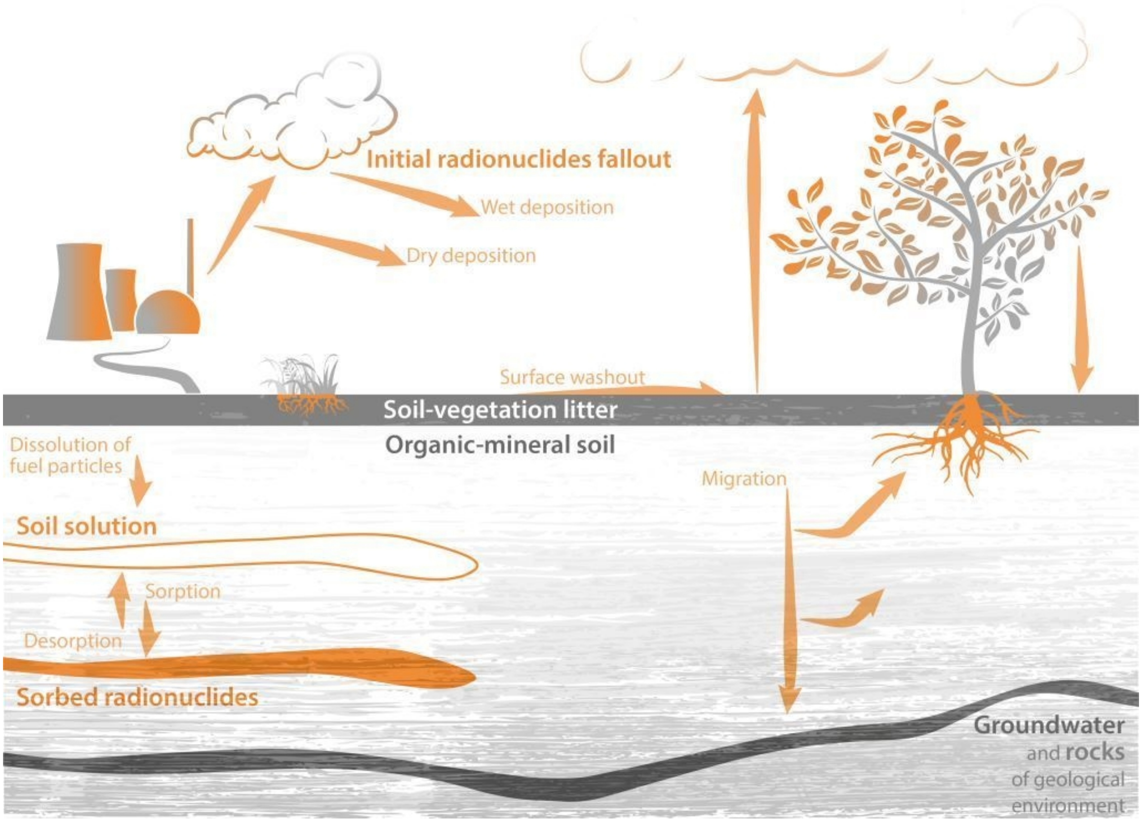


Data source: TORCH 2016, based on data from the European Commission Joint Research Centre; UNSCEAR, based on De Cort et al., 1998.

According to a 2005 report by the United Nations (UN) Chernobyl Forum, the Chernobyl fallout contaminated large areas of **terrestrial environment** with a 'major impact both on agricultural and natural ecosystems' in Belarus, Russia and Ukraine, as well as in many other European countries. Contamination occurred through 'dry' deposition (by atmospheric mixing and absorption) or 'wet' deposition (by precipitation) of radionuclides present in the air. In the longer term, the soil became the main reservoir of radionuclides, which moved down the soil layers at various speeds, depending on radionuclide and soil type.

Radionuclides may be absorbed by **vegetation**. In the days and weeks after the accident, plant contamination occurred through deposition, although in the longer term, uptake through roots became the main pathway. Absorption depends on the type of radionuclide (iodine, caesium or strontium, for instance, can readily transfer to vegetation, whereas other radionuclides may remain largely in the soil), as well as on the soil characteristics (such as soil type or presence of microorganisms). Because caesium-137 and strontium-90 share many physicochemical properties with potassium and calcium, respectively, both radionuclides are easily taken up by plants and animals. The transfer of radionuclides to vegetation also depends on the ecosystem type: it is generally much higher in semi-natural ecosystems (such as forests or extensive agriculture) than in intensively managed agricultural ecosystems.[3]

Figure 2 – Main terrestrial environmental pathways of radionuclides



Data source: adapted from UN Chernobyl Forum, 2005.

Radionuclides may subsequently be transferred to humans via various **products**. In the first two months after the accident, the **milk** of cows, goats and sheep grazing outside, both in the former Soviet Union and in other European countries, may have been contaminated with iodine-131 deposited on plants, although concentrations declined rapidly due to iodine's short half-life. Later on, caesium-137 became the main radionuclide contaminating milk and **meat**, although its levels decreased sharply in the first four to six years after the accident. Radionuclide transfer to **crops** depends mainly on the soil type, with higher uptakes of caesium-137 in peaty soils. As they grow in (semi-)natural ecosystems, **forest food products** (for instance mushrooms or berries) have been particularly contaminated: the highest levels of caesium contamination have been observed in mushrooms (as a result of their great capacity to accumulate nutrients); this contamination has also been passed on to game animals such as deer.[4] As a result of bioaccumulation, radionuclide concentrations in **freshwater fish** have been above safe consumption levels, both in the most affected region and in parts of western Europe. **Wood** and derived products may have been contaminated as well. The use of wood for fuel generates ashes with caesium concentrations 50 to 100 times higher than the original firewood, which means that the storage and disposal of the ash may cause exposure.

Environmental impacts

The UN Chernobyl Forum describes the **effects** of the accident **on plants and animals**. In the exclusion zone, it noted increased mortality of coniferous plants, soil invertebrates and mammals, as well as reproductive dysfunction in plants and animals. It points out that both in and outside the exclusion zone, genetic anomalies in plants and animals attributable to radiation have been reported, in particular in the years after the accident.

On **specific environments**, it notes in particular:

- **Forests** (in the Soviet Union, but also in northern Europe and Austria) were among the major semi-natural ecosystems to be contaminated. Compared to other ecosystems, natural decontamination of forests is proceeding 'extremely slowly', at less than 1% per year. Other research conducted recently suggests that radioactive contamination has reduced the speed of biomass decomposition, thereby increasing the accumulation of dead wood and affecting plant growth. In contaminated areas, this increases the likelihood of forest fires releasing radionuclides contained in trees.
- **Freshwater ecosystems** have been affected by radioactivity fallout in many parts of Europe. Because some radionuclides are transferred from contaminated catchment soils to water bodies, contamination levels have remained relatively high for years. Activity concentrations in some lakes in western Europe were similar to those in some lakes in the more highly contaminated areas in Ukraine and Belarus.
- **Marine ecosystems** were far less affected, although earlier work by the International Atomic Energy Agency (IAEA) concluded that the Chernobyl accident had a 'measurable impact' on the marine environment, with radionuclide levels two to three times higher than pre-Chernobyl levels.
- **Urban areas** contaminated with radionuclides have experienced a very significant decline in contamination levels, especially on roads, roofs and (to a lesser extent) walls. Radionuclides have migrated down into the soil.

The UN Chernobyl Forum indicates that after the environmental stress caused by irradiation, **ecosystems close to Chernobyl** have recovered and are now 'flourishing'. It concludes that the exclusion zone has become a 'wildlife sanctuary' as a result of the large availability of food and the absence of human activity. It highlights an increase in wild animal populations (for instance wild boar, deer, elk, wolf, bear and beaver) and the successful reintroduction of endangered Przewalski wild horses to the area. However, this assessment has been disputed by scientists who stress that the ecological effects of radiation on animals remain an unresolved question. They note, on the basis of field trips to forest sites around Chernobyl, that 'species richness, abundance and population density of breeding birds decreased with increasing levels of radiation.'

Effects on human health

The health impacts of the Chernobyl accident have been extensively studied, but experts are not unanimous in gauging their extent and ramifications. Official assessments of health effects were provided by UN agencies, notably by: (1) the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), in its reports from 2000 and 2008; and by (2) the World Health Organization (WHO), in a 2006 report published under the auspices of the Chernobyl Forum. A working group of the International Agency for Research on Cancer (IARC), a branch of the WHO, analysed the cancer burden from Chernobyl in Europe in a 2006 report.

Alternative analyses, such as the Greenpeace report from 2006 and TORCH ('The Other Report on Chernobyl'),[5] with its editions from 2006 and 2016, challenge official figures and conclusions.

Major population groups exposed and levels of exposure

Individuals were mainly exposed to three radionuclides after the fallout: iodine-131, caesium-134 and caesium-137 (see also Table 1). Iodine-131, which can be transferred to humans from the air and by consumption of contaminated milk and leafy vegetables, becomes localised in the thyroid gland. Caesium-134 and 137 cause longer-term exposure through ingestion and through external exposure from their deposition on the ground.

The average effective doses[6] of the population groups most exposed to radiation were assessed as follows (these doses are additional to those from natural background radiation):

- about 120 mSv among 240 000 clean-up workers ('liquidators') involved in the recovery operation (in the first two years after the accident, 1986-1987));
- about 30 mSv among 116 000 residents evacuated from the highly contaminated zones (accumulated over 20 years, 1986-2005); and
- about 9 mSv among residents of areas of Belarus, Russia and Ukraine with low levels of contamination (accumulated over 20 years, 1986-2005).

Table 2 – Comparison of radiation doses

Average natural background radiation	2.4 mSv/year (typical range 1 to 10 mSv)
Recommended dose limits in planned exposure situations	
Occupational	20 mSv/year (with no more than 50 mSv in any one year; additional restrictions apply to pregnant women)
Public	1 mSv/year (exceptionally, a higher value of effective dose could be allowed in a year provided that the average over 5 years does not exceed 1 mSv in a year)

Data source: Review of the 2007 Recommendations of the International Commission on Radiological Protection (ICPR), 2008.

The average national doses in other European countries affected were less than about 1 mSv in the first year after the accident. Doses progressively decreased in subsequent years.

It should be noted that estimates across the literature vary, both in terms of the number of people exposed and the level of exposure. Table 2 provides a comparison with natural background radiation and recommended limits for occupational and public exposures.

Immediate and short-term effects: radiation sickness and cataracts

In the immediate aftermath of the accident, reactor staff and emergency workers were heavily exposed to high-level radiation. Of the 600 workers present on the site, 134 suffered from radiation sickness. Of those, 28 died in the first three months. Another 19 died in the 1987-2004 period of various causes, not necessarily associated with radiation exposure. Among those who survived radiation sickness, many developed radiation-induced cataracts (clouding of the eye lens) in the first few years following the accident. According to WHO/IAEA/UNDP, most emergency workers and people living in contaminated areas received relatively low whole-body radiation doses, comparable to natural background radiation.

Late effects: thyroid cancer, leukaemia and possible non-malignant disorders

Thyroid cancer, in particular, has been the main direct consequence of the fallout. In the first few months after the accident, the radiation doses to the thyroid gland received were particularly high among children and adolescents[7] living in the most affected regions, and among those who consumed milk and dairy products with high levels of radioactive iodines. By 2005, there had been more than 6 000 cases of thyroid cancer reported among children and adolescents, and at least nine died.[8]

According to the WHO, there is some indication of an increased incidence of **leukaemia** (malignant blood cancer) among the workers, but no clearly demonstrated increase among children or adults living in the contaminated areas. Also, there is no clearly demonstrated increase in the number of non-thyroid **solid cancers** (cancers in 'solid' organs other than the thyroid) in the exposed population, nor is there convincing proof of increases in other, non-malignant, diseases related to the fallout. Yet, as suggested in 2015 by Prof. Elisabeth Cardis of the Centre for research in environmental epidemiology (CREAL), recent findings seem to indicate an increase in the incidence of pre-menopausal breast cancer in the most contaminated areas, and possible low-dose effects on the risk of cardiovascular disease.

Effects of radiation exposure

Ionising radiation can cause damage to the genetic material contained in the body cells. This damage may lead to cell death and early 'deterministic' effects (such as radiation sickness) or to changed genetic properties resulting in late-onset 'stochastic' effects (such as cancer or inherited diseases). Scientists are divided over the magnitude of the stochastic effects in relation to the absorbed dose, especially where low doses are concerned, as is the case of Chernobyl. The only certainty seems to be that some effects may appear with a delay ('latency period') of up to several decades (in some cases, more than 40 years) after the exposure.

Other investigated effects: potential birth defects and hereditary effects

According to UNSCEAR (2008), there has not been any evidence of increases in birth defects that can be attributed to Chernobyl radiation exposure. The 'modest, but steady increase' in reported birth defects in contaminated and uncontaminated areas of Belarus is attributed to better reporting, not radiation. As stated by UNSCEAR (2001), research into possible genetic effects associated with exposures in Belarus or Ukraine and in a number of other European countries has provided no unambiguous evidence for increased frequencies of Down syndrome, birth defects, miscarriages or perinatal mortality.

Psychosocial effects

The accident has had important psychosocial effects on the communities affected. Symptoms of stress, depression and anxiety as well as multiple medically unexplained physical symptoms and subjective poor health have been reported. The origins of the effects are complex and are thought to be related to anxiety over the effects of radiation; extreme pessimism and fatalism; the sense of being a victim; and the distress associated with evacuation and resettlement.[9] The WHO (2006) assessed the mental health impact of Chernobyl as 'the largest public health problem caused by the accident to date', highlighting the central role of information and how it is communicated to the public in the aftermath of radiation incidents.

Estimated projections for other European countries

According to official estimates, a total of 4 000 eventual deaths from radiation-induced cancer and leukaemia can be expected among the higher-exposed populations, that is, the emergency workers from 1986-1987, evacuees and local residents of the most contaminated areas (this includes the workers who died of acute radiation syndrome and the children who died of thyroid cancer). According to the WHO (2011), there has been no clear evidence of any measurable increase in radiation-induced adverse health effects outside Belarus, Russia and Ukraine. The predictions of IARC (Cardis et al.) published in 2006 suggest that of all the cancer cases expected to occur in Europe between 1986 and 2065, around 0.01% may be related to radiation from the Chernobyl accident. The largest attributable fraction (about 1%) is predicted for thyroid cancer, with close to 70% of these attributable cases expected to occur in the most contaminated regions of Belarus, Russia and Ukraine. Overall, the estimated projection is of 25 000 potential excess cancers for Europe by 2065 that might be attributable to exposure to radiation from Chernobyl, of which 16 000 cases could be fatal.

Reviewing current knowledge and need for long-term research

The IARC project 'ARCH: Agenda for Research on Chernobyl Health' (2008-2010), which was co-financed by the EU under the Seventh Framework Programme for Research, focused on reviewing current knowledge about the health effects of the Chernobyl accident, identifying further research needs and creating a strategic research agenda. Building on this, CO-CHER (Cooperation on Chernobyl Health Research) aims to establish an international collaboration to facilitate long-term research on the health effects of the accident. The Chernobyl Research Programme is currently being finalised and will be presented during the Chernobyl symposium on 11 June 2016.

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UNSCEAR 2008 Report, Annex D: Health Effects Due to Radiation From the Chernobyl Accident (issued 2011).

UNSCEAR 2000 Report, Annex J: Exposures and effects of the Chernobyl accident.

Endnotes

1. For more details about the accident, the role of 'liquidators' who cleaned up the site and the socio-economic consequences of the accident today, read Chernobyl 30 years on: the EU's response, EPRS briefing, April 2016.
2. Becquerel is the unit of radioactivity equal to one nuclear decay per second. 1 EBq = 10^{18} or one billion billion Bq.
3. According to the 2005 report mentioned above, this difference is explained by a number of factors, including: physicochemical behaviour of radionuclides in soils; higher caesium uptake by plants in nutrient-poor ecosystems due to the absence of additional potassium from fertilisers; and specific foodchain pathways leading to highly contaminated produce from semi-natural ecosystems.
4. In its 2006 report on Chernobyl's legacy, the UN Chernobyl Forum noted that 'while the magnitude of human exposure through agricultural products has experienced a general decline, high levels of contamination of forest food products have continued and still exceed permissible levels in some countries.'
5. The 2006 report was commissioned by Rebecca Harms MEP (Greens/EFA, Germany). The 2016 update was commissioned by GLOBAL 2000 / Friends of the Earth Austria and financed by the Wiener Umweltanwaltschaft (Vienna Ombuds Office for Environmental Protection).
6. Effective dose is the weighted sum of equivalent doses to all relevant tissues and organs. The unit is the joule per kilogram ($J\ kg^{-1}$) and is called 'sievert' (Sv).
7. Radiation doses are usually higher in children. This is related to their intake of milk and dairy products, as well as the size of their thyroid glands and their metabolism.
8. According to WHO/IAEA/UNDP, the survival rate among the cancer victims, based on experience in Belarus, has been almost 99%.
9. One of the objectives of the joint IAEA, UNDP, Unicef and WHO project ICRIN (International Chernobyl Research and Information Network) was to address the stigma of psychological trauma in the affected communities in Belarus, Russia and Ukraine.

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