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Chernobyl: Assessment of Radiological and Health Impact
2002 Update of *Chernobyl: Ten Years On*

Chapter VI
Agricultural and environmental impacts

Conclusions

(Conclusions will open in a pop-up window)

Agricultural impact

All soil used anywhere in the world for agriculture contains radionuclides to a greater or lesser extent. Typical soils (IA89a) contain approximately 300 kBq/m^3 of 40K to a depth of 20 cm. This radionuclide and others are then taken up by crops and transferred to food, leading to a concentration in food and feed of between 50 and 150 Bq/kg. The ingestion of radionuclides in food is one of the pathways leading to internal retention and contributes to human exposure from natural and man-made sources. Excessive contamination of agricultural land, such as may occur in a severe accident, can lead to unacceptable levels of radionuclides in food.

The radionuclide contaminants of most significance in agriculture are those which are relatively highly taken up by crops, have high rates of transfer to animal products such as milk and meat, and have relatively long radiological half-lives. However, the ecological pathways leading to crop contamination and the radioecological behaviour of the radionuclides are complex and are affected not only by the physical and chemical properties of the radionuclides but also by factors which include soil type, cropping system (including tillage), climate, season and, where relevant, biological half-life within animals. The major radionuclides of concern in agriculture following a large reactor accident are ^{131}I, ^{137}Cs, ^{134}Cs and ^{90}Sr (IA89a). Direct deposition on plants is the major source of contamination of agricultural produce in temperate regions.

While the caesium isotopes and ^{90}Sr are relatively immobile in soil, uptake of roots is of less importance compared with plant deposition. However, soil type (particularly with regard to clay mineral composition and organic matter content), tillage practice and climate all affect propensity to move to groundwater. The same factors affect availability to plants insofar as they control concentrations in soil solution. In addition, because caesium and strontium are taken up by plants by the same mechanism as potassium and calcium respectively, the extent of their uptake depends on the availability of these elements. Thus, high levels of potassium fertilisation can reduce caesium uptake and liming can reduce strontium uptake.

Within the former Soviet Union

The releases during the Chernobyl accident contaminated about 125 000 km^2 of land in Belarus, Ukraine and Russia with radiocaesium levels greater than 37 kBq/m^2, and about 30 000 km^2 with radiostrontium greater than 10 kBq/m^2. About 52 000 km^2 of this total were in agricultural use; the remainder was forest, water bodies and urban centres (Ri95). While the migration downwards of caesium in the soil is generally slow (Bo93), especially in forests and peaty soil, it is extremely variable depending on many factors such as the soil type, pH, rainfall and agricultural tilling. The radionuclides are generally confined to particles with a matrix of uranium dioxide, graphite, iron-ceramic alloys, silicate-rare earth, and silicate combinations of these materials. The movement of these radionuclides in the soil not only depends on the soil characteristics but also on the chemical breakdown of these complexes by oxidation to release more mobile forms. The bulk of the fission products is distributed between organomineral and mineral parts of the soil largely in humic complexes. The 30-km exclusion zone has improved significantly partly due to natural processes and partly due to decontamination measures introduced.

There were also large variations in the deposition levels. During 1991 the ^{137}Cs activity concentrations in the 0-5 cm soil layer ranged from 25 to 1 000 kBq/m^3 and were higher in natural than ploughed pastures. For all soils, between 60 and 95% of all ^{137}Cs was found to be strongly bound to soil components (Sa94). Ordinary ploughing disperses the radionuclides more evenly through the soil profile, reducing the activity concentration in the 0-5 cm layer and crop root uptake. However, it does spread the contamination throughout the soil, and the removal and disposal of the uppermost topsoil may well be a viable decontamination strategy.

The problem in the early phase of an accident is that the countermeasures designed to avoid human exposure are of a restrictive nature and often have to be imposed immediately, even before the levels of contamination are actually measured and known. These measures include the cessation of field work, of the consumption of fresh vegetables, of the pasturing of animals and poultry, and also the introduction of uncontaminated forage. Unfortunately, these measures were not introduced immediately and enhanced the doses to humans in Ukraine (Pr95).

Furthermore, some initial extreme measures were introduced in the first few days of the accident when 15 000 cows were slaughtered in Ukraine irrespective of their level of contamination, when the introduction of clean fodder could have minimised the incorporation of radiocaesium. Other counter-measures, such as the use of potassium fertilisers, decreased the uptake of radiocaesium by a factor of 2 to 14, as well as increased crop yield.

In some podzolic soils, lime in combination with manure and mineral fertilisers can reduce the accumulation of radiocaesium in some cereals and legumes by a factor of thirty. In peaty soils, sand and clay application can reduce the transfer of radiocaesium to plants by fixing it more firmly in the soil. The radiocaesium content of cattle for human consumption can be minimised by a staged introduction of clean feed during about ten weeks prior to slaughter. A policy of allocating critical food production to the least contaminated areas may be an effective common sense measure.

In 1993, the concentration of ^{137}Cs in the meat of cows from the Kolkhoz in the Sarny region, where countermeasures could be implemented effectively, tended to be much lower than that in the meat from private farms in the Dubritsva region (Pr95). The meat of wild animals which could not be subjected to the same countermeasures had a generally high concentration of radio-caesium. Decontamination of animals by the use of Prussian Blue boli was found to be very effective where radiocaesium content of feed is high and where it may be difficult to introduce clean fodder (Al93). Depending on the local circumstances, many of the above mentioned agricultural countermeasures were introduced to reduce human exposure.

Since July 1986, the dose rate from external irradiation in some areas has decreased by a factor of forty, and in some places, it is less than 1% of its original value. Nevertheless, soil contamination with ^{137}Cs, ^{90}Sr and ^{239}Pu is still high and in Belarus, the most widely contaminated Republic, eight years after the accident 2 640 km^2 of agricultural land had been excluded from use (Be94). Within a 40-km radius of the power plant, 2 100 km^2 of land in the Poles'e state nature reserve have been excluded from use for an indefinite duration.

The uptake of plutonium from soil to plant parts lying above ground generally constitutes a small health hazard to the population from the ingestion of vegetables. It only becomes a problem in areas of high contamination where root vegetables are consumed, especially if they are not washed and peeled. The total content of the major radioactive contaminants in the 30-km zone has been estimated at 4.4 PBq for ^{137}Cs, 4 PBq for ^{90}Sr and 32 TBq for ^{239}Pu and ^{240}Pu.

However, it is not possible to predict the rate of reduction as this is dependent on so many variable factors, so that restrictions on the use of land are still necessary in the more contaminated regions in Belarus, Ukraine and Russia. In these areas, no lifting of restrictions is likely in the foreseeable future. It is not clear whether return to the 30 km exclusion zone will ever be possible, nor whether it would be feasible to utilise this land in other ways such as grazing for stud animals or hydroponic farming (Al93). It is however, to be recognised that a small number of generally elderly residents have returned to that area with the unofficial tolerance of the authorities.

Within Europe

In Europe, a similar variation in the downward migration of ^{137}Cs has been seen, from tightly bound for years in the near-surface layer in meadows (Bo93), to a relatively rapid downward migration in sandy or marshy areas (EC94). For example, Caslano (TI) experienced the greatest deposition in Switzerland and the soil there has fallen to 42% of the initial ^{137}Cs content in the six years after the accident, demonstrating the slow downward movement of caesium in soil (OF93). There, the ^{137}Cs from the accident has not penetrated to a depth of more than 10 cm, whereas the contribution from atmospheric nuclear weapon tests has reached 30 cm of depth.

In the United Kingdom, restrictions were placed on the movement and slaughter of 4.25 million sheep in areas in southwest Scotland, northeast England, north Wales and northern Ireland. This was due largely to root uptake of relatively mobile caesium from peaty soil, but the area affected and the number of sheep rejected are reducing, so that, by January 1994, some 438 000 sheep were still restricted. In northeast Scotland (Ma89), where lambs grazed on contaminated pasture, their activity decreased to about 13% of the initial values after 115 days; where animals consumed uncontaminated feed, it fell to about 3.5%. Restrictions on slaughter and distribution of sheep and reindeer, also, are still in force in some Nordic countries.

The regional average levels of ^{137}Cs in the diet of European Union citizens, which was the main source of exposure after the early phase of the accident, have been falling so that, by the end of 1990, they were approaching pre-accident levels (EC94). In Belgium, the average body burden of ^{137}Cs measured in adult males increased after May 1986 and reached a peak in late 1987, more than a year after the accident. This reflected the ingestion of contaminated food. The measured ecological half-life was about 13 months. A similar trend was reported in Austria (Ha91).

In short, there is a continuous, if slow, reduction in the level of mainly ^{137}Cs activity in agricultural soil.

Environmental impact

Forests

Forests are highly diverse ecosystems whose flora and fauna depend on a complex relationship with each other as well as with climate, soil characteristics and topography. They may be not only a site of recreational activity, but also a place of work and a source of food. Wild game, berries and mushrooms are a supplementary source of food for many inhabitants of the contaminated regions. Timber and timber products are a viable economic resource.

Because of the high filtering characteristics of trees, deposition was often higher in forests than in agricultural areas. When contaminated, the specific ecological pathways in forests often result in enhanced retention of contaminating radionuclides. The high organic content and stability of the forest floor soil increases the soil-to-plant transfer of radionuclides with the result that lichens, mosses and mushrooms often exhibit high concentrations of radio-nuclides. The transfer of radionuclides to wild game in this environment could pose an unacceptable exposure for some individuals heavily dependent on game as a food source. This became evident in Scandinavia where reindeer meat had to be controlled. In other areas, mushrooms became severely contaminated with radiocaesium.

In 1990, forest workers in Russia were estimated to have received a dose up to three times higher than others living in the same area (IA94). In addition, some forest-based industries, such as pulp production which often recycle chemicals, have been shown to be a potential radiation protection problem due to enhancement of radionuclides in liquors, sludges and ashes. However, harvesting trees for pulp production may be a viable strategy for decontaminating forests (Ho95).

Different strategies have been developed for combating forest contamination. Some of the more effective include restriction of access and the prevention of forest fires.

One particularly affected site, known as the "Red Forest" (Dz95), lies to the South and West close to the site. This was a pine forest in which the trees received doses up to 100 Gy, killing them all. An area of about 375 ha was severely contaminated and in 1987 remedial measures were undertaken to reduce the land contamination and prevent the dispersion of radionuclides through forest fires. The top 10-15 cm of soil were removed and dead trees were cut down. This waste was placed in trenches and covered with a layer of sand. A total volume of about 100 000 m^3 was buried, reducing the soil contamination by at least a factor of ten.

These measures, combined with other fire prevention strategies, have significantly reduced the probability of dispersion of radionuclides by forest fires (Ko90). The chemical treatment of soil to minimise radionuclide uptake in plants may be a viable option and, as has been seen, the processing of contaminated timber into less contaminated products can be effective, provided that measures are taken to monitor the by-products.

Changes in forest management and use can also be effective in reducing dose. Prohibition or restriction of food collection and control of hunting can protect those who habitually consume large quantities. Dust suppression measures, such as re-forestation and the sowing of grasses, have also been undertaken on a wide scale to prevent the spread of existing soil contamination.

Water bodies

In an accident, radionuclides contaminate bodies of water not only directly from deposition from the air and discharge as effluent, but also indirectly by washout from the catchment basin. Radionuclides contaminating large bodies of water are quickly redistributed and tend to accumulate in bottom sediments, benthos, aquatic plants and fish. The main pathways of potential human exposure may be directly through contamination of drinking-water, or indirectly from the use of water for irrigation and the consumption of contaminated fish. As contaminating radionuclides tend to disappear from water quickly, it is only in the initial fallout phase and in the very late phase, when the contamination washed out from the catchment area reaches drinking-water supplies, that human exposure is likely. In the early phase of the Chernobyl accident, the aquaeous component of the individual and collective doses from water bodies was estimated not to exceed 1-2% of the total exposure (Li89). The Chernobyl Cooling Pond was the most heavily contaminated water body in the exclusion zone.

Radioactive contamination of the river ecosystems (see Chapter 2) was noted soon after the accident when the total activity of water during April and early May 1986 was 10 kBq/L in the river Pripyat, 5 kBq/L in the Uzh river and 4 kBq/L in the Dniepr. At this time, shortlived radionuclides such as ^{131}I were the main contributors. As the river ecosystem drained into the Kiev, then the Kanev and Kremenchug reservoirs, the contamination of water,sediments, algae, molluscs and fish fell significantly.

In 1989, the content of ^{137}Cs in the water of the Kiev reservoir was estimated to be 0.4 Bq/L, in the Kanev reservoir 0.2 Bq/L, and in the Kremenchug reservoir 0.05 Bq/L. Similarly, the ^{137}Cs content of Bream fish fell by a factor of 10 between the Kiev and Kanev reservoirs, and by a factor of two between the Kanev and Kremenchug reservoirs to reach about 10 Bq/kg (Kr95). In the last decade, contamination of the water system has not posed a public health problem. However, monitoring will need to be continued to ensure that washout from the catchment area which contains a large quantity of stored radioactive waste will not contaminate drinking-water.

A hydrogeological study of groundwater contamination in the 30-km exclusion zone (Vo95) has estimated that ^{90}Sr is the most critical radionuclide, which could contaminate drinking-water above acceptable limits in 10 to 100 years from now.

Outside the former Soviet Union, direct and indirect contamination of lakes has caused and is still causing many problems, because the fish in the lakes are contaminated above the levels accepted for sale in the open market. In Sweden, for instance, about 14 000 lakes (i.e., about 15% of the Swedish total) had fish with radiocaesium concentrations above 1 500

Bq/kg (the Swedish guideline for selling lake fish) during 1987. The ecological half-life, which depends on the kind of fish and types of lakes, ranges from a few years up to some tens of years (Ha91).

In the countries of the European Union, the content of ^{137}Cs in drinking-water has been regularly sampled and reveals levels at, or below, 0.1 Bq/L from 1987 to 1990 (EC94), which are of no health concern. The activity concentration in the water decreased substantially in the years following the accident due largely to the fixation of radiocaesium in the sediments.

Sixteen years later

Over sixteen years after the accident, exposures of populations are mainly due to the consumption of agricultural food contaminated with ^{137}Cs. Production is today based on the following criteria:

- The contamination of foodstuffs should be at a level not leading to an average individual doses higher than 1 mSv per year.
- Production of these foodstuffs should not be more expensive in either economical or social terms.
- Some large population groups may receive low doses from these contaminated foodstuffs, but collective dose and excess risk should be evaluated.

In the Ukraine, agriculture in most contaminated territories produces foodstuffs respecting the limits fixed the 25 June 1997: 100 Bq/l for milk products; 200 Bq/kg for meat; 20 Bq/kg for potatoes and bread. Currently, milk contamination levels are about 50 Bq/l.

However, there are large disparities in production in Ukraine, and some private farms continue to produce milk more contaminated than the level fixed by the new limits. This is due to animal grazing in contaminated meadows, and to the large differences of transfer coefficients for caesium (1 to 20) depending on the chemical composition of soils. Some experts predict that the fixation of caesium in soils will be enough in the next 4 to 8 years to prevent more contamination of foodstuffs, but some predictions seem more pessimistic. (Sm00).

In Ukraine, 8,4 million hectares of agricultural soil are contaminated with ^{137}Cs, and are subject to countermeasures, mostly the use of fertilisers:

- The 54 900 hectares in the exclusion zone and the 35 600 ha contaminated with more than 555 kBq/m^2 are exclude from agricultural farming.
- 130 800 ha are contaminated between 185 and 555 kBq/m^2, including 15 000 ha of peat bog where the transfer of caesium to plants is the highest.

- 1.1 million ha contaminated between 37 and 185 kBq/m^2, including 99 500 ha of peat bog.
- 7 238 millions ha contaminated between 3.7 and 37 kBq/m^2.

An exclusion zone of about 4 000 km^2 has been defined, including a circular area with a radius of 30 km around the reactor. The areas affected are 2 100 km^2 in Belarus, 2 040 km^2 in Ukraine and 170 km^2 in the Russian Federation. All agricultural activities are forbidden, as is transfer of products. However, studies are underway as to how the less contaminated portions of this excluded land can be used.

Outside this area, 1.4 million of people are living on 30 000 km^2 of land contaminated higher than 185 kBq/m^2, and 130 000 people are living in areas where the contamination is higher than 555 kBq/m^2. For the territories where the annual dose is lower than 1mSv, life is considered as normal. When the annual dose is higher than 1 mSv per year, people receive social compensations.

In Russia, some districts were declassified in January 1998, and this decision was accepted badly by the affected populations.

The amount of agriculture products exceeding trade limits fixed by Ukraine, Russia and Bielorussia are now very low, in spite of new restrictive limits given by Ukraine in 1997 (100 Bq/kg for milk, 200 Bq/kg for meat, 20 Bq/kg for bread and potatoes). Today, the combination of soil transfers, physical half-life of ^{137}Cs and efficacy of the countermeasures could lead to an agricultural production that is lower than the fixed limits within the next 4 to 8 years. This means that, 20 to 25 years after the accident, food production could be operated without any restriction.

In early 2001, 2 217 cities are still under radiological control in the Ukraine. In fact, only 1 316 need permanent controls, but the population of the 901 remaining cities refuse the declassification of their areas because this could be associated with the end of financial and social compensation.

In the exclusion zone, the impact on fauna and flora is characterised by the extremely heterogenous deposition of radioactive particles, which produces a wide range of doses to which the biota were subjected. In some cases, even in very small geographic areas, the impacts differed by an order of magnitude (IA01).

Somes consequences of the accident for the natural plant and animal populations are determined by secondary ecological factors resulting from changes in human activities. For example, the forbidding of hunting alters the types and numbers of birds. In general, animal numbers have greatly increased compared to adjacent inhabited areas. These favourable conditions for large numbers of commercially hunted mammal species will be preserved (IA01).

The transfer of radionuclides by water and wind, and by extreme seasonal weather conditions has not led to long term contamination beyond the exclusion zone. In the exclusion zone, the future radioactive contamination will be reduced slowly through radioactive decay.

The area in the exclusion zone covered by coniferous and deciduous forests will increase to 65-70% of the whole zone. The areas of meadowland and swap land will be correspondingly significantly reduced and gradually replaced by forests. These changes create a stable and fire-resistant vegetation layer. Associated with destruction of drainage systems, the level of groundwater will rise (IA01).

Since the accident, trade of wood is regulated. Depending upon its use, commercialisation levels range from 740 to 11 000 Bq of $^{137}Cs.kg^{-1}$. With this new regulation, 30% of pines trees in the excluding zone are not usable.

In summary

- Many countermeasures to control the contamination of agricultural products were applied with varying levels of efficiency. Never-theless, within the former Soviet Union large areas of agricultural land are still excluded from use, and are expected to continue to be so for a long time. In a much larger area, although agricultural and farm animal activities are carried out, the food produced is subject to strict controls and restrictions on distribution and use.
- Similar problems, although of a much lower severity, were experienced in some countries of Europe outside the former Soviet Union, where agricultural and farm animal production were subjected to controls and limitations for variable durations after the accident. Most of these restrictions were lifted several years ago. However, there are still some areas in Europe where restrictions on slaughter and distribution of animals are applied. This concerns, for example, several hundreds of thousands of sheep in the United Kingdom and large numbers of sheep and reindeer in some Nordic countries.
- Produce from forests, such as mushrooms, berries and game meat, may continue to be a radiological protection problem for a long time. The decrease of radioactivity will be now slow through radioactivity decay.
- At present drinking water is not a problem. Contamination of groundwater, especially with ^{90}Sr, could be a problem for the future in the catchment basins downstream of the Chernobyl area.

- Contaminated fish from lakes may be a long-term problem in some countries.
- However, the rehabilitation programmes must create conditions attractive enough for a younger workforce, especially engineers and qualified workers, to return. It is necessary and quite possible to create conditions where the environmental contamination will not result in the exclusion of important dietary components from consumption.

Next chapter: Potential residual risks

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