

IRSN

INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety



Chernobyl 25 years on

In late April 1986,
a major nuclear accident
released a large quantity
of radioactive material
into the atmosphere...

Units

Becquerel

The becquerel (Bq) is the unit of measurement of radioactivity. It corresponds to one decay per second, for all types of radiation emitted (α , β , γ).

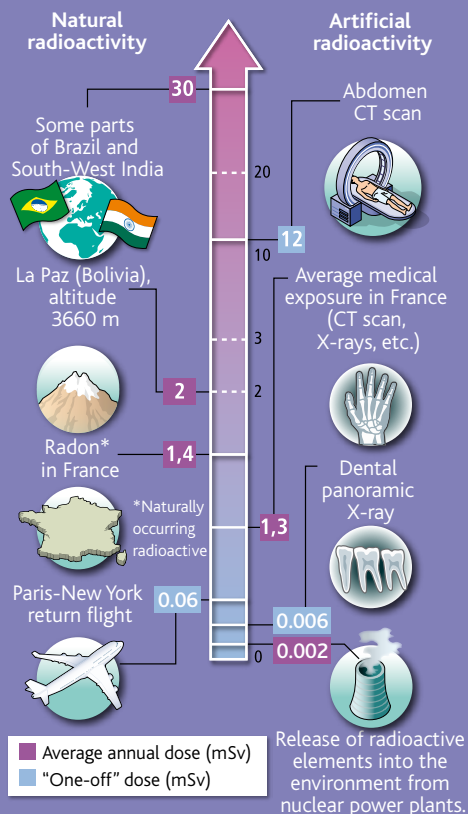
Gray

The gray (Gy) is the unit of absorbed dose. It corresponds to the quantity of energy (measured in Joules – J) transferred by ionising radiation to the mass through which it passes (expressed in kilograms – kg).
1 Gy = 1 J.kg⁻¹.

Sievert

The sievert (Sv) is the unit of equivalent dose received by a specific organ or tissue, and the unit of effective (whole body) dose. The equivalent dose is determined from the dose absorbed, taking into account differences in the ability of different kinds of radiation to damage organs or tissues. The effective dose is determined from the equivalent doses delivered to the various body organs or tissues, taking into account their relative sensitivity to the effects of ionising radiation. These sievert doses can be used to estimate the risk of stochastic effects (cancers or hereditary effects) which may affect the exposed organism.

Some sources of radiation exposure for humans



An introduction to the Chernobyl accident

What is radioactivity?	p. 2
1 ■ The accident	p. 4
2 ■ Radioactive releases	p. 7
3 ■ Spread of the radioactive plume over Europe	p. 8
4 ■ Radioactive deposits in Europe	p. 12
5 ■ Contamination of various environments and the food chain	p. 17
6 ■ Health impact in the most contaminated areas	p. 24
7 ■ Doses received in France and their associated risks	p. 31
8 ■ The site today	p. 35
9 ■ Lessons learned from Chernobyl	p. 38

What is radioactivity?

Radioactivity is a natural phenomenon which has existed ever since atoms were formed billions of years ago.

Chemical elements present in matter are made up of atoms with a nucleus of protons and neutrons, surrounded by a cloud of electrons. Atoms of the same element all have the same number of protons (e.g. uranium has 92) but different isotopes of the element can have different numbers of neutrons.

Most isotopes have a stable nucleus and stay the same indefinitely. Others have an unstable nucleus because they have too many or too few neutrons. They spontaneously decay into more stable atoms and, in the process, they release energy in the form of ionising radiation. This is the phenomenon known as radioactivity.

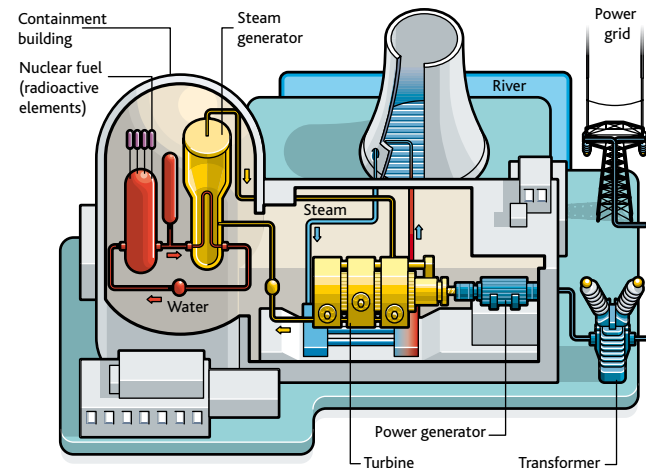
A source consisting of radioactive isotopes is characterised by its activity, expressed in becquerels (Bq): 1 Bq corresponds to one radioactive decay per second. The higher the activity of a source, the more radiation it emits. As the radioactive nuclei contained in a source decay, its activity decreases. The half-life is the time taken for a source's activity to decrease by half.

The radiation emitted by a radioactive source carries a great deal of energy that is gradually absorbed by the matter it passes through. The absorbed dose, expressed in grays (Gy), measures this transfer of energy.

When a person is exposed to radiation emitted by a radioactive source, the dose absorbed by the tissues through which the radiation passes can cause biological damage. The risk of harmful effects on health is evaluated on the basis of the effective dose (whole body) or the equivalent dose received by a specific organ or tissue, both expressed in sieverts (Sv), depending on the nature of the radiation and the sensitivity of the irradiated organs.

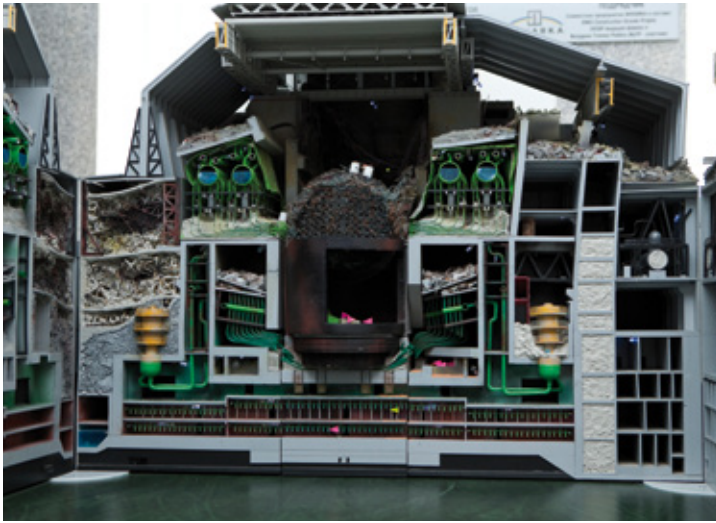
We are constantly exposed to natural sources of radioactivity, in our environment, in the air we breathe, in the food we eat and even inside our bodies.

We are also exposed to radiation from man-made sources (such as medical X-rays, fallout from atmospheric nuclear weapons tests, nuclear facilities, etc.). The average individual effective dose due to natural radioactivity in France is 2.4 millisieverts a year.



Operation of a power plant

Thermal, hydroelectric and nuclear power plants are all based on the same principle. A turbine drives a generator which produces electricity. In conventional thermal power plants, fossil fuels (coal, natural gas or oil) are used to produce the heat which turns water into steam to drive the turbine. In nuclear power plants, fossil fuels are replaced by nuclear fuel made up of fissile uranium or plutonium atoms. Fuel assemblies are placed in the nuclear reactor and produce heat by fission of the uranium and plutonium nuclei. They break up under the impact of neutrons and produce radioactive fission products that must be contained in the reactor, and neutrons which maintain the fission reaction.



There were four reactors on the Chernobyl power plant. On 26th April 1986, reactor no. 4 exploded. The 2000 tonne reactor vessel head destroyed the roof (reconstructed) and ended up on its end (model of destroyed reactor 4).

□ The Chernobyl power plant

On 26th April 1986 at 01:24, reactor 4 at the Chernobyl power plant, which had been in service since 1983, exploded in an accident during a technical test.

It was a RBMK type reactor, a Soviet model designed in the 1960s. The reactor core was made up of a huge block of graphite containing vertical channels in which

pressure tubes were placed, each of which contained several nuclear fuel assemblies. The graphite functioned as a moderator – neutrons had to be slowed down to maintain the chain reaction. Cooling was provided by boiling water flowing through the pressure tubes in contact with the fuel.

□ Combined causes of the accident

The initial design of the RBMK reactors had some significant weaknesses from a safety standpoint. In particular, they were highly unstable at certain power ranges, the emergency shutdown system had too long a response time and there was no containment around the reactor. In addition, the lack of sufficient prepa-

ration for the conditions required for the planned test, and the lack of time to complete it, meant that operators did not follow all the operating rules. They also violated them by suppressing some important safety systems.

□ Spiral to disaster

In the morning of 25th April, operators began the power reduction procedure.

Between 13:00 and 23:00, the reactor was held at half-power, contrary to the initial test schedule, at the request of the electric power distribution centre.

At about 23:00, power reduction was resumed. However, the reactor state was now inappropriate for the test to be performed. The core was very difficult to control with the systems available. The reactor should have been stabilised at this stage. However, operators were in a hurry to catch up the delay in the schedule, and decided to perform the test regardless.

On 26th April at 01:23:04, the test was launched, and the turbine steam supply valves were closed. The temperature rose in the core, causing reactivity to increase.

The reactor started to go critical and out of control. At this point, the operators realised the seriousness of the situation.

At 01:23:40, the chief operator ordered an emergency shutdown. All control rods began to enter the core, but did not have time to stop a runaway chain reaction.

At 01:23:44, power peaked, exceeding the reactor's nominal power by a factor of more than 100.

2 Radioactive releases

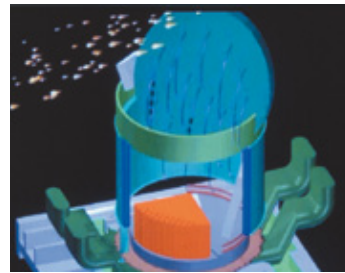
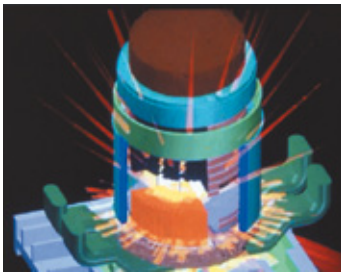
□ An explosion followed by a fire

The high pressures reached in the pressure tubes caused them to rupture. An explosion lifted the upper reactor cover, weighing about 2000 tonnes, off the reactor.

The top of the reactor core was exposed to the open air. The graphite ignited, and a number of fires broke out in the facility. It

took fire-fighters three hours to extinguish the fires. The graphite fire reignited. It was not fully extinguished until 9 May.

Between 27th April and 10th May, 5000 tonnes of material (sand, boron, clay, lead, etc.) were poured onto the reactor by helicopter to cover it.

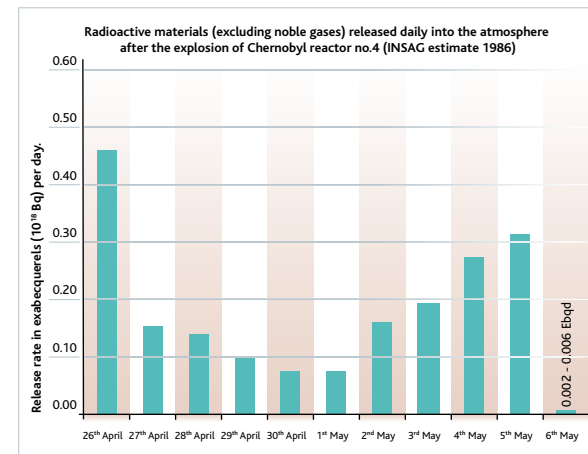


The fuel rods in the core broke up. The overheated uranium oxide pellets exploded.

Most of the radioactive material released was discharged at the time of the reactor's explosion.

The energy of the explosion propelled radioactive materials contained in the nuclear reactor core into the atmosphere, to altitudes of over 1200 metres. These materials continued to be released until 5th May as a result of the fire that followed the accident and then the residual heat released by the remains of the core destroyed by the accident.

All together, nearly 12 billion-billion becquerels were ejected into the environment in 10 days, that is 30,000 times the radioactive emissions released into the atmosphere by all the nuclear facilities operating in the world at that time in one year. The vast majority (84% of the total activity released) of the radioactive elements had a half-life of less than one month.



Spread of the radioactive plume over Europe

Nuclear fuel debris and pieces of the reactor were thrown into the environment around the power plant. Radioactive dust, fine particles (aerosols) and gases rose to high altitudes and formed a plume which was carried over great distances in air masses by changing winds.

Between 26th April and mid-May 1986, the radioactive plume scattered radioactive elements such as iodine-131, caesium-134 and caesium-137 over most of the countries in Europe.

As time passed, this dispersion resulted in the dilution of the radioactive elements in the air. Some of the aerosols were deposited along the way, gradually depleting the radioactive cloud. Finally, the radioactive elements

with a very short half-life (a few hours) disappeared quickly as a result of radioactive decay in the plume. This meant that the concentration of radioactive elements in the air, which was over 10 million becquerels per cubic metre (Bq/m³) in the vicinity of the damaged reactor on 26th April, decreased as it travelled and was no more a few tens of becquerels per cubic metre over France on 1st May.

□ Plume paths

Initially, the wind carried the radioactive material released on 26th April in a north-westerly direction. The plume passed over the Baltic countries and then Scandinavia on 28th April, and was then blown eastwards and then south, carrying the contaminants towards central Europe and the Balkans.

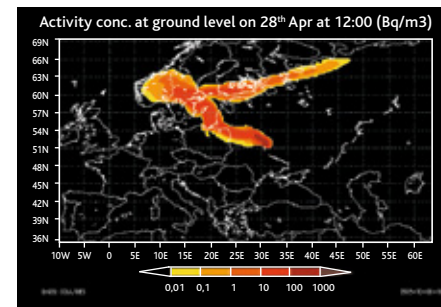
The plume of material released on 27th April travelled towards western Europe - Germany,

France and Northern Italy - which it reached between 30th April and 5th May, before being picked up by a south wind which took it to the British Isles, avoiding Spain and Portugal. Emissions from the power plant from 28th April were carried east and south, towards Russia, the Caucasus, the eastern Mediterranean and central Europe.

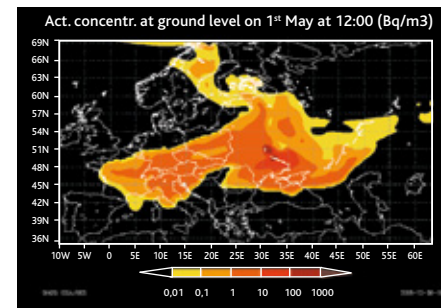
Over time, the radioactive materials released at different

times and the various plumes mixed to form a mass of contaminated air which covered most of Europe in decreasing concentrations. These radioactive elements then contin-

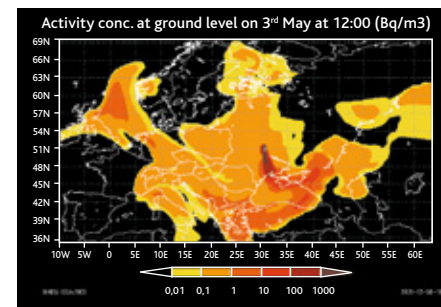
ued to be dispersed across the whole of the northern hemisphere and were detected in North America and Japan, in extremely low concentrations.



Spread of caesium-137 released into the atmosphere by the Chernobyl accident: situation at 12:00 on 28th April 1986 (modelling: IRSN 2006).



Air contamination by caesium-137: situation at 12:00 on 1st May 1986 (modelling: IRSN 2006).



Air contamination by caesium-137: situation at 12:00 on 3rd May 1986 (modelling: IRSN 2006).

□ In France

In France, the concentration of radioactive elements in the air increased in the east of the country during 30th April 1986, peaking on 1 May.

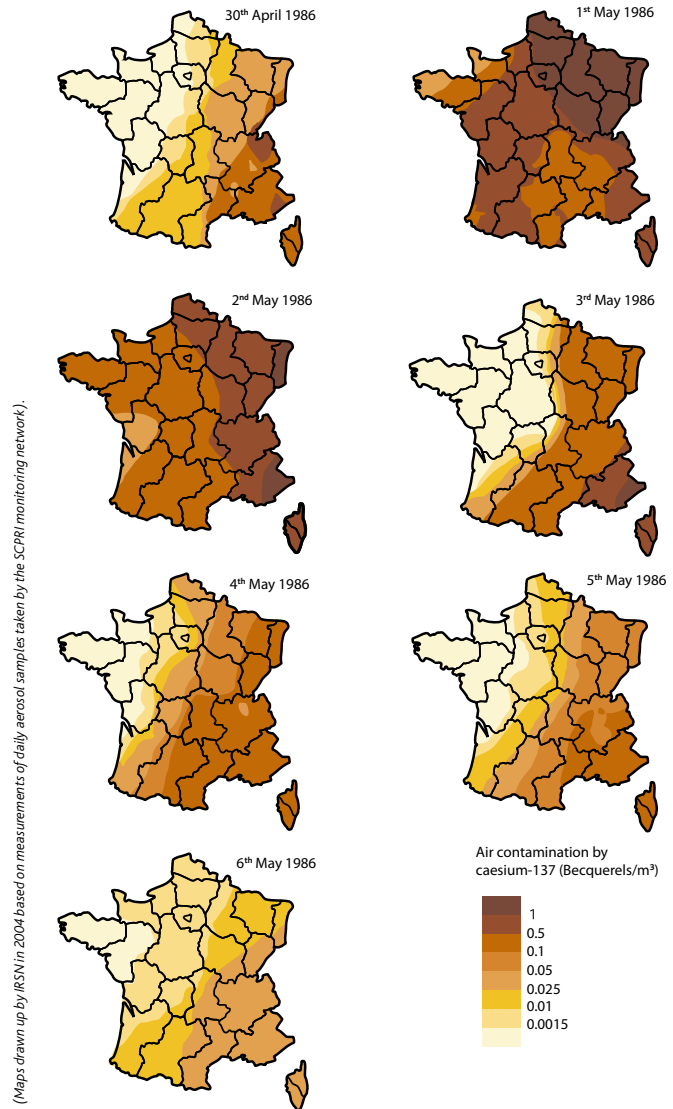
The main radioactive elements measured in the air in early May 1986 are given below, in decreasing order of concentration:

Radioactive elements

Radioactive elements	Half-life
■ Iodine-131	■ 8 days
■ Tellurium-132	■ 78 hours
■ Tellurium-129m	■ 33 days
■ Ruthenium-103	■ 39 days
■ Caesium-137	■ 30 years
■ Caesium-134	■ 2 years
■ Barium-140	■ 13 days

The air contamination lasted until 5th May, but continued to decrease. It remained highest in the east throughout this period.

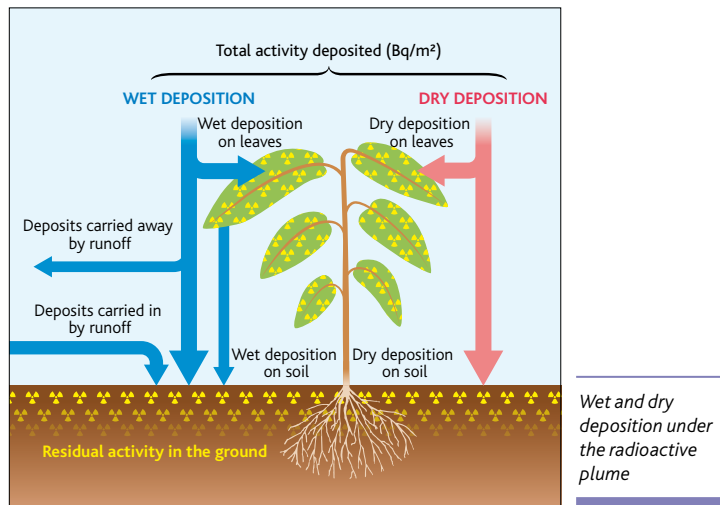
After 6th May, it decreased considerably as the plume headed back towards Eastern Europe.



Mean concentration of caesium-137 in the air over France between 30th April and 6th May 1986.

Radioactive deposits in Europe

The radioactive particles carried in the air masses fell to the ground as dry deposition when the particles were near the ground and as wet deposition with rain or snow.



These deposits covered plants, soil and surface water but also built-up areas and inhabited locations. When deposits were formed by rain, they were distributed across the surface or into the ground by runoff. The extent of deposits in Europe varied according to many different factors.

■ The biggest and heaviest particles, especially nuclear fuel debris, fell in the immediate vicinity of

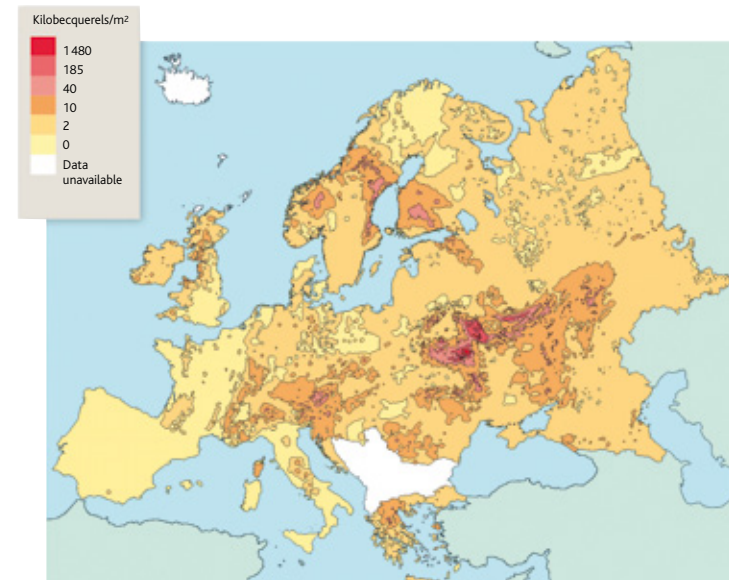
the power plant, forming very highly active deposits within the 30-kilometre exclusion zone around the power plant.

■ The severity of the concentration of radioactive elements in the air and the length of time the surrounding air was contaminated resulted in highly active deposits in the three most severely affected countries - Ukraine, Belarus and Russia. Deposits were much higher in

areas where it rained, and their activity was up to 10 times higher than dry deposits formed in the same places. Contamination "patches" thus formed depending on when and where it rained.

■ In mountainous areas, where it rains more, the activity of deposits was greater. In forest areas, the leaves on trees captured the radioactive dust in the air more readily, which increased the ac-

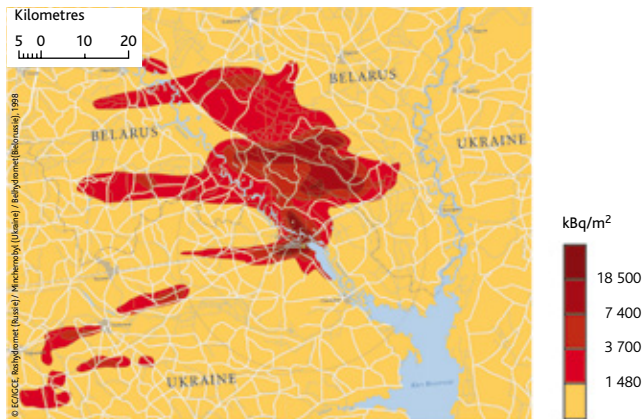
tivity of the radioactive deposits compared with those in open fields. This led to highly non-uniform radioactive deposits, with the greatest amounts being distributed around the Chernobyl site and in the countries neighbouring the power plant. Caesium-137 is a good indicator for measuring the distribution of deposits on a European scale.



Map of caesium-137 deposits over Europe immediately after the Chernobyl accident (source: European Atlas EC/IGCE 1998 and IRSN). No data is available for the Balkans.

□ **Contaminated areas in former Soviet Union countries**

In Russia, Belarus and Ukraine, vast areas were unevenly contaminated with radioactive deposits that reached several hundreds of thousands and sometimes exceeded a million becquerels per square metre. In the area around the power plant, varying deposits of strontium-90, plutonium, etc., were formed along the paths of the radioactive plumes.



Caesium-137 deposits in 1986 around the Chernobyl power plant.

□ **Central and Western Europe**

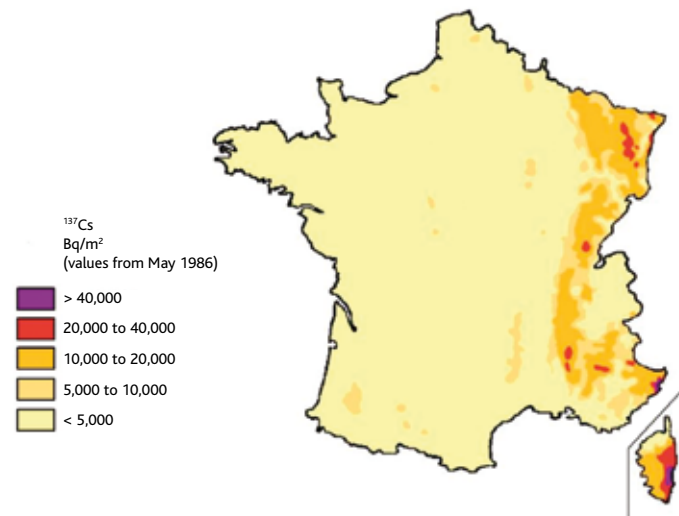
Outside the former Soviet Union, the Czech Republic and Poland, in Austria and northern Greece, as well as over smaller areas in the UK, Switzerland, Bavaria and Italy (Italian Lakes and the Dolomites). Outside the former Soviet Union, deposits exceeding 40,000 becquerels per square metre occurred in Scandinavia (southern Finland, central and eastern Sweden, central Norway), in central Europe - especially in southern Romania, on the border between

□ **France**

Due to the depletion of the radioactive plume and the short amount of time that the air over France was contaminated (about a week), deposits generally had low levels of activity, which tended to be greater in the east than in the west of the country.

Consequently, dry deposits of caesium-137 were estimated at around 1000 becquerels per square metre in the east and approximately 100 becquerels per

square metre in the more westerly départements of France. However, heavy localised rainfall, especially between 2nd and 4th May, resulted in greater wet deposition to the east of an imaginary line drawn between the Moselle river and Corsica. Some areas received deposits with activities exceeding 10,000 becquerels per square metre and even, locally, 20,000 becquerels per square metre. Départements in the North-East of France, the Franche-Comté region,



Reconstitution of caesium-137 fallout in May 1986 over France by modelling based on the amount of rainfall in early May 1986 (IRSN 2005).

Contamination of various environments and the food chain

the Southern Alps and Corsica were the worst affected.

On a very local scale, severe downpours led to even heavier deposits over areas of a few square kilometres.

In mountainous regions, the concentration of deposits due to melting snow, water dripping from trees and surface water runoff into basins at the base of the slopes, resulted in high-activity patches over very small surface areas (several becquerels per kilogramme of soil over a few square feet).

At a local level, widely varying deposits were found within the same department, with readings varying by a factor of 10 to 15. This made precise mapping impractical. Qualitatively, iodine-131 deposits in the same way as caesium-137, with an initial activity approximately 10 times higher. However, its short half-life (eight days) means that, unlike caesium, it quickly disappears from soil (80 days after the accident, iodine-131 activity had reduced by a factor of 1000, while that of caesium-137 was practically unchanged).



Soil sample used to measure deposits.

Radioactive fallout from the atmosphere was distributed over various environmental contexts.



This contamination extended to related production, such as dairy produce and meat.

Contamination reached a peak immediately after the deposits occurred and decreased considerably in the following weeks due to the continuing growth of plants and the disappearance of short-half-life radioactive elements (iodine-131). It was 100 times lower after three months.

Plants were directly contaminated by leaf-capture of radioactive products suspended in the air (aerosols). This phenomenon, which happens much more in dry deposition than in wet deposition, led to contamination of agricultural and natural food products. The time of year at which the accident occurred meant that grass and leafy vegetables, especially lettuces, spinach and leeks, were the plants most affected in May 1986. Livestock which grazed on the contaminated fields were also affected.

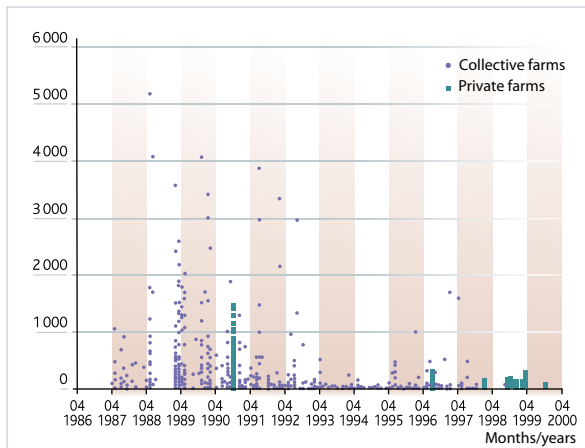
The soil retained part of the radioactive elements deposited and a persistent inventory was formed in the case of those with a long half-life and a tendency to become fixed in soil components (e.g. clays), such as caesium-137. From 1987, the transfer of radioactive elements via roots, while much less efficient than direct capture by leaves, contributed to maintaining chronic contamination of plants and the rest of the food chain in the most severely affected areas.

Contaminated areas in Russia, Belarus and Ukraine

□ Agricultural produce

In the severely affected areas of Russia, Belarus and Ukraine, high levels of contamination were detected in agricultural products both in 1986 and in the years that followed. After 1986, for most soils, the contamination was largely fixed in the upper 10 to 20 centimetres. Overall, the contamination of agricultural products decreased as the years passed, to differing extents

depending on the initial characteristics of the deposits, soil types and agricultural practices. Until the beginning of the 1990s, it was not unusual to find high concentrations of caesium-137. This was noted mainly in the Gomel region of Belarus, where contamination levels reached several thousand becquerels per litre for cow's milk, 1000 to 5000 becquerels per kilogramme of



Caesium-137 activity (in becquerel/litre) measured from 1987 in cow's milk collected from farms in contaminated areas. Contamination was extremely variable depending on the severity of the fallout and on rehabilitation measures on agricultural land..

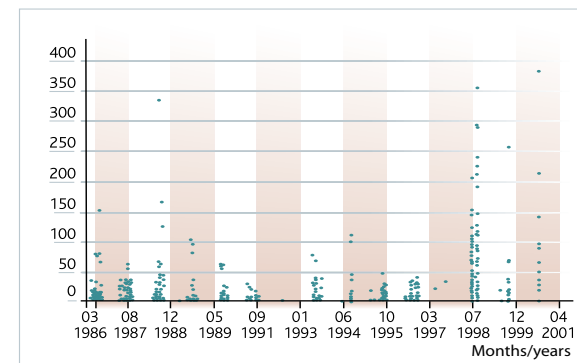
beef and 1000 to 2500 becquerels per kilogramme in cabbages. In the same period, most of the cereals and potatoes produced had an activity of less than 100 becquerels per kilogramme. However, activity levels remained high in some areas, with several thousand becquerels per kilogramme in natural grasses and some fodder. After a sharp

reduction up until the beginning of the 1990s, contamination levels in agricultural produce have continued to reduce more gradually (3% to 7% per annum) and is now largely due to caesium-137. It is more significant in animal products (meat, milk), especially from extensive farming, than in vegetable products.

□ Forests

Leaves on trees are especially prone to capturing ambient aerosols. When these leaves fall, they contaminate forest litter and soil,

which thus constitutes a persistent inventory of radioactive substances, that are recycled by the trees and plants of the undergrowth, especially new growth.



Caesium-137 concentration measured in mushrooms gathered between 1986 and 2000 in contaminated areas of Russia, Belarus and Ukraine.

Twenty-five years after the accident, the caesium-137 contamination persisting in plant litter and forest soil has essentially only reduced due to radioactive decay (i.e. to 56% of the activity initially deposited) and, via the roots, still contaminates wood and leaves, as well as mushrooms, berries and game. So, unlike for agricultural produce whose contamination has generally sharply decreased with pass-

River water

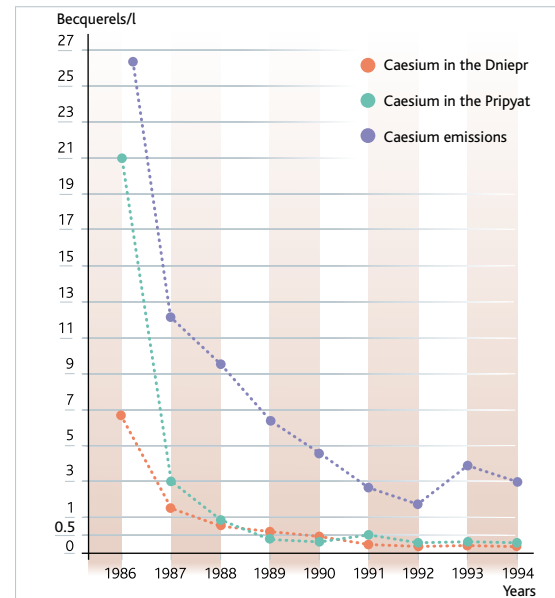
An impact on surface water was mainly found in the first few weeks following the accident in areas near the damaged power

ing time, very high caesium-137 activity is still found in natural products gathered in forests in the most contaminated regions. Levels as high as several tens of thousands of becquerels per kilogramme may be found in mushrooms, game and wild berries.

plant, where it was directly contaminated by radioactive fallout. After this, water contamination levels decreased rapidly, due to



Cargo port on the Pripjat (tributary of the Dniepr) and abandoned contaminated boats.



Graph showing changes in caesium levels (1986 to 1994) in the Pripjat and the Dniepr.

the disappearance of short-lived radio-isotopes and the absorption of radioactive substances by sediments. Thus, the Pripjat and the Dniepr which supply the main towns in Ukraine with drinking water were contaminated to such an extent that preventive actions had to be taken during the first few months: dykes were built, towns were supplied with water from uncontaminated areas and water use was restricted. In 1986 and the years that followed, rainwater runoff,

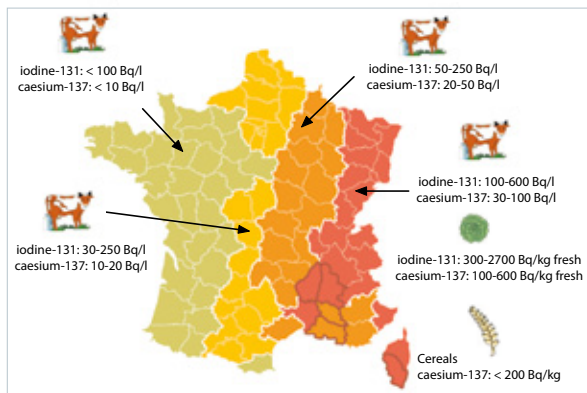
melting snow and flood water promoted the leaching of some surface-soil deposits into water courses. Caesium-137 and strontium-90 are the main radioactive elements that have been found in the long term in the Pripjat, near Chernobyl, in low concentrations (of the order of 0.1 Bq/l dissolved in the water). Groundwater was not affected, other than in the immediate proximity of the site due to infiltration into the soil where contaminated debris had been hastily buried.

In France

In France, the highest levels of contamination in agricultural and natural products were found in eastern regions.

The maximum levels measured in cow's milk and lettuces were found during the first half of May 1986. In areas in the east of the country, which had received particularly substantial wet deposition, the reduced efficiency of leaf-capture of radioactive fallout due to heavy rainfall resulted in contamination of these products that was only two or three times higher than that measured in areas of the same regions less severely affected by

this type of deposit. In the weeks following the initial deposition of radioactive substances, the concentrations of iodine-131 and caesium-137 in vegetables and dairy produce decreased very rapidly due to plant growth and radioactive decay of iodine-131. Some products are extremely sensitive to the effects of radioactive fallout. In particular, this is the case for goat's and sheep's milk as, in the Mediterranean area, these animals feed on plants with low water content scattered over large areas. Immediately after deposition, the contamination in this milk



Ranges of caesium-137 and iodine-131 contamination values: measured in the first half of May 1986.

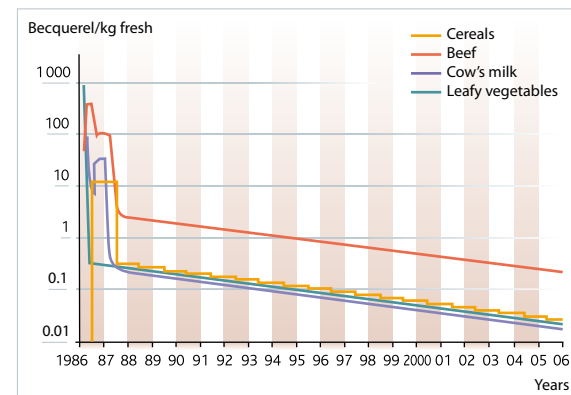
reached as high as 10,000 becquerels per litre for iodine-131 and 500 becquerels per litre for caesium-137.

From 1987, contamination of farm produce was due to the roots of plants absorbing caesium-137 and caesium-134 present in soil.

At this point, contamination was much lower and decreased steadily as the years passed. This decrease is explained by radioactive decay, especially that of caesium-134 with a half-life of 2.1 years, and the reduced availability of caesium for plants.

In 2010, contamination in farm produce was between 10 and 30 times lower than in 1987 and between 1000 and 10,000 times lower than immediately after deposition in May 1986. It continues to decrease slowly over time.

Some forest soils in the east of France still contain nearly 55% of the caesium-137 initially deposited. This radioactive element can still be measured in concentrations in the region of 100 becquerels per kilogramme in some species of mushrooms harvested from these soils.



Changes in caesium-137 contamination in various foodstuffs in France since 1986. From the mid-1990s, caesium-134 was no longer detectable.

Health impact in the most contaminated areas

In the days following the accident, the population of most of Europe was exposed to varying degrees of fallout from the Chernobyl accident.



Two elderly people living in the exclusion zone.

From 26th April 1986 onwards, people present on the site or in its immediate vicinity were severely exposed to radiation emitted by the reactor, to radioactive elements released into the external environment and to deposits that formed on the ground. These were mainly workers on the site and their families who lived in the nearby town of Pripjat.

First of all, these people were exposed to the plume that was highly charged with fine radioactive dust. The severity of this ex-

posure decreased with distance from the power plant. They were then exposed to radiation emitted by the radioactive deposits on the ground. Finally, they were exposed through food contamination due to deposition onto leaves (an important factor in the months after the accident) or to transfer via roots of residual contamination in the soil. Although these last two sources of exposure have considerably decreased over the years, they still persist in the most contaminated areas of Russia, Belarus

and Ukraine owing to the long half-life of caesium-137 (30 years).

The doses received by the people subjected to these various types of exposure depended on their relative intensity and each individual's way of life. Their intensity determined the risk of the occurrence of diseases

such as cancers in the exposed populations. In situations involving very severe exposure, as suffered by on-site personnel and the first emergency workers, the absorbed doses were so high that some people's exposure exceeded the thresholds at which acute radiation symptoms and radiation burns appear.

□ Fire-fighters and power plant personnel

Among the 600 emergency workers involved on the first day and who received the highest doses, two died immediately of burns and 28 others died in the four months following the accident as a result of their exposure to radiation.

Between 1987 and 2006, 19 more died from various causes, most of which were unrelated to expo-

sure to ionising radiation (cardiac arrest, pulmonary tuberculosis, cirrhosis of the liver, trauma, and cancer).

Among the survivors of the 134 who presented with acute radiation syndrome immediately after the accident, skin lesions secondary to the radiation burns and cataracts are the main effects seen today.



Monument in honour of the fire-fighters.

□ **Liquidators**

The “liquidators”, approximately 600,000 civilian and military personnel, worked on the site in the first few years after the accident to carry out various tasks: work on the reactor, site decontamination, construction of the sarcophagus, and burial of radioactive waste in the exclusion area.

Some of the personnel involved in the first few weeks received high effective doses (in some cases exceeding 1000 mSv).

However, for most liquidators the effective doses received were much lower (on average 120 mSv, with 85% of effective doses recorded being between 20 and 500 mSv), as they carried out tasks for limited periods and, in some cases, several years after the accident. The doses received by the liquidators were generally estimated with a great deal of uncertainty, except for those who were carrying a dosimeter during their work.

The rate of thyroid cancer seems to be higher among liquidators than among the general population, but this does not establish a clear cause-and-effect link to radiation exposure. There does not seem to be an overall excess of other types of solid cancer, despite the apparently contradictory results of two Russian studies that highlighted an increase in solid cancer mortality in proportion to dose received.

Although they are not definitive, recent reports suggest an excess in cases of leukaemia among liquidators in Belarus, Ukraine and Russia and the Baltic states. Additional studies are needed, in particular due to the numerous uncertainties surrounding the “reconstruction” of dose received.

Many studies also report on diseases other than cancer; for example, there is an excess of cataracts among liquidators who received doses over 0.7 Gray. Furthermore, a Russian study demonstrated a link between the doses received by the liquidators and an increase in cardiovascular disease mortality and the incidence of cerebrovascular disease. However, these latest results require confirmation because the study does not take into account other risk factors, such as obesity or alcohol and tobacco consumption.

Currently, it is not yet possible to reach a conclusion on the existence of a cause-and-effect link between radiation exposure due to the Chernobyl accident and the increases in cardiovascular and cerebrovascular mortality.



A funeral monument in honour of Chernobyl liquidators in Slavutyich, 38 km from the Chernobyl reactor.

□ **Inhabitants of the three republics**

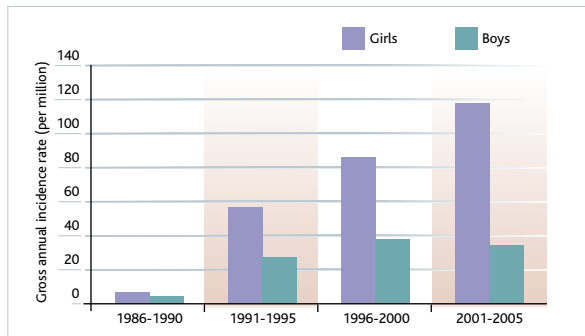
The areas of Belarus, Ukraine and Russia that received depositions of caesium-137 exceeding 37,000 becquerels per square metre after the accident cover a surface area of approximately 150,000 square kilometres with more than 5 million inhabitants.

The most severely affected were children and adolescents exposed at the time of the disaster.

Their thyroid glands, in particular, were irradiated by the radioactive iodine that they breathed in and ingested in milk. In Belarus, where the first cases of

cancer were detected, the number of cases of thyroid cancer in children aged under 15 years was very low before the accident. After a latency period of five years, this number rapidly increased at the beginning of the 1990s, especially among children who were under 10 at the time of the accident.

From 1991 to 2005, 6,848 thyroid cancers were observed in children who were under 18 in 1986, of which the majority (5,127 cases) were under 14 in 1986. Almost all of these cancers were treatable (there were only 15 deaths recorded up to 2005).



Rate of thyroid cancers among people exposed in Belarus during childhood and adolescence (under 18 in 1986).



A young girl undergoes a medical test to find traces of caesium-137 at school in Novozybkov.

For children born after 1986, no increase in thyroid cancers has been observed, the rate found among under 10s being 2 to 4 cases per million per year, which is similar to what was found before the Chernobyl accident.

The risk of thyroid cancer in people affected during their childhood or adolescence still exists 25 years after the Chernobyl accident. Monitoring of these cancers must therefore be continued. Similar results were observed in adolescents and young adults in Ukraine and some highly contaminated areas of Russia.

□ Psychological consequences

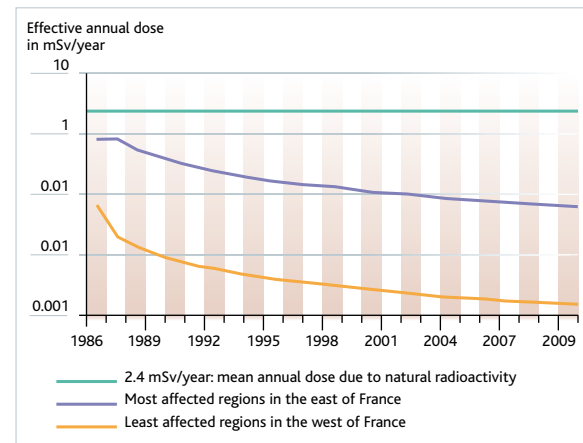
People were affected by the shock of the accident and of living in contaminated areas. Psychological problems (stress, depression, anxiety and physical symptoms that could not be explained medically) were found among people living in the contaminated areas.

In most cases, the symptoms observed did not come from psychiatric problems as such. However, they probably played a part in changing the eating, smoking and drinking habits of the people affected.

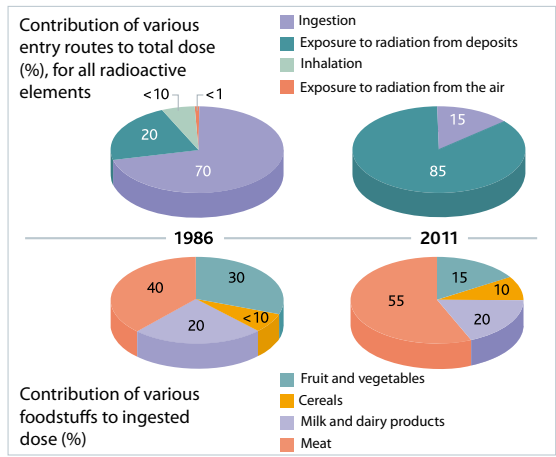
The effective (whole body) doses received by inhabitants of France were low. The highest levels were received in the east of France.

In 1986, the effective doses received by people living in the most affected areas in the east of the country were less than 1 mSv for the year. In subsequent

years, the doses received as a result of persistent radioactive elements in the environment were much lower and continuously decreased.



Changes in effective dose ranges received annually from 1986 to 2010 by inhabitants of France exposed to Chernobyl-accident fallout. The mean annual dose received due to natural sources of ionising radiation is also shown for comparison.



In 1986, doses received by locals were mainly linked to the ingestion of contaminated foodstuffs, especially milk and dairy products, leafy vegetables and beef. From 1987, the food chain was much less contaminated, so it was exposure to radiation emitted by remaining deposits that made the largest contribution to the annual dose.

Currently, the mean effective dose received by inhabitants of France due to residual contamination originating from the Chernobyl accident is less than 10 microsieverts per year.

However, some specific eating habits, such as consuming large quantities of forest mushrooms and game from the east of the country, can result in higher doses (of the order of tens of microsieverts per year).

In France, investigation of the risks associated with fallout from the Chernobyl accident has focused on thyroid cancers, due to the epidemic observed in the most contaminated regions of Belarus. On average, the highest equivalent doses in the thyroid gland were received by children living in the east of France in 1986. The doses

received by this organ were, in the great majority of cases, attributable to iodine-131 ingested by consuming fresh produce (milk, vegetables and meat) contaminated by this radioactive element. Given the short half-life of iodine-131 (eight days), the vast majority of thyroid-gland exposure occurred during the three months following the radioactive

deposition. In the table below, the equivalent doses at the thyroid are the mean values by age band. Thus, some children in the same age band may have received lower doses and others higher doses, which, depending on life-style, could be of the order of a hundred millisieverts in extreme cases.

Age of children

Dose received (half-life)

■ Infants	■ between 1.3 and 2.5 mSv
■ Children aged 1	■ between 6.6 and 13 mSv
■ Children aged 5	■ between 4 and 7.8 mSv
■ Children aged 10	■ between 2.1 and 3.9 mSv

Mean doses in the thyroid gland received by children living in the east of France in 1986. The range of estimated values for each age band corresponds to the variability of eating habits, a parameter that greatly influenced the dose.

In 2000, a study by IRSN and Institut National de Veille Sanitaire (InVS, the French national health monitoring institute) produced an estimate of the theoretical number of excess cases of thyroid cancer likely to occur between 1991 and 2015 among the 2.3 million children aged under 15 who were living in the east of France in 1986.

It is very difficult to assess any additional risk corresponding to fallout from the Chernobyl ac-

cident by means of an epidemiological study, as the estimated number of additional cases was less than or similar to the uncertainties in the predicted number of "spontaneous" thyroid cancers in this population (see table below). The existence of any additional risk is not certain for the doses received in France, as these were of the order of 100 times smaller than those received by Belarusian children among whom an epidemic of thyroid cancers was detected.

Forecast period

Forecast period	Number of spontaneous thyroid cancers	Number of additional cases theoretically attributable to the accident
1991-2015	889 (± 60)	7 to 55

Number of spontaneous thyroid cancers

Number of additional cases theoretically attributable to the accident

Between 1986 and 2000, all the reactors at the power station were shut down for decommissioning. Currently, there is intense activity on the site to construct a new containment building and to install a spent fuel storage facility.

□ The sarcophagus

The sarcophagus intended to contain the reactor's radioactive material, which was built under

particularly difficult conditions in the six months after the accident, rapidly deteriorated.



Chernobyl power plant. If the sarcophagus were to collapse, radioactive dust would be placed in suspension and could recontaminate the vicinity of the site.



Inside the sarcophagus. The corium will remain radioactive for thousands of years.

□ The new containment

A programme, jointly funded by Ukraine and an international fund administered by the European Bank for Reconstruction and Development, was launched in 1997 to reduce the risks posed by the sarcophagus.

In September 2007, a contract for the construction of a new containment building to enclose the old sarcophagus was signed with the Novarka (Vinci and Bouygues) consortium. This new arched structure will be very large: 250 m span, 150 m long and 105 m tall.

□ International cooperation

There is still a great deal of international activity in Ukraine. At present, it specifically concerns assessing the safety of the arch project and of the new facilities for storing spent fuel which are being constructed on the Chernobyl site.

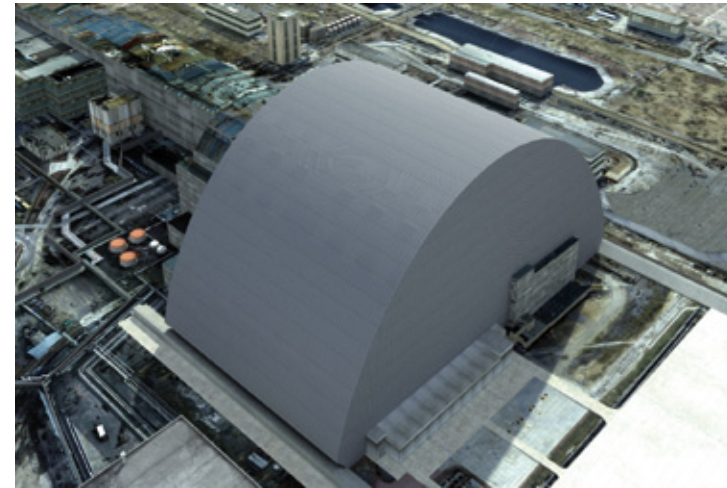
In addition, several specific safety projects, funded by the European Commission, are being pursued

The metal framework will weigh more than 18,000 tonnes. This structure should be completed in 2014.

This new arch has multiple purposes: to protect the sarcophagus from external hazards, to provide a perfect seal between the radioactive ruins of the destroyed reactor and the environment, and to eventually allow for the dismantling of the sarcophagus and the safe removal of the radioactive material.

on currently-operating nuclear power stations in Ukraine.

In the near future, safety assessments should also begin for the construction of two new reactors at the Khmelnytsky power station, the construction of a new research reactor and the construction of a nuclear fuel production plant.



Contractors for the sarcophagus arch project (EDF, Novarka: Vinci and Bouygues Travaux Publics).

Lessons learned from Chernobyl

This accident profoundly changed the perception of the consequences of a serious accident and how to manage them. It also highlighted the importance of information for that management.

□ Protecting people

In addition to the deaths and the immediate acute effects due to radiation that occurred shortly after the accident, studies conducted since 1986 clearly show an increase in the rate of occurrence of thyroid cancers, especially in children who inhaled or ingested radioactive iodine. Studies are being pursued to detect or assess other health consequences that could be connected with the accident. No definite conclusion has yet been reached. In any event, living conditions in the contaminated areas continue to pose problems. In particular, actions are being taken to reduce the doses that may result from the ingestion of contaminated produce.

Currently, crisis management policy is that, in the event of a reactor accident leading to radioactive releases and when ordered by the local authorities, stable iodine tablets should be taken to prevent doses being received in the thyroid gland by inhalation of radioactive iodine. Tablets were distributed on a preventive basis at the end of the 1990s around EDF power plants and this action is periodically repeated. Furthermore, orders prohibiting the consumption and sale of contaminated products would be issued with reference to the maximum permissible levels defined by European regulations.



A stabilised iodine tablet, an effective means of reducing dose at the thyroid in the event of exposure to radioactive iodine.

□ Transparency and information

An international convention was signed in 1986. It stated that immediate information should be given by the countries concerned in the event of an accident at one of their nuclear facilities.

Furthermore, an International Nuclear Event Scale (INES) was defined to ensure clear understanding of the relative severity of the various incidents and

accidents occurring at nuclear facilities.

Since 1981, local information commissions have been created for French nuclear facilities and, in particular, nuclear power plants.

IRSN provides assistance for these local information commissions either directly or through their national association, ANCCLI.

The role assigned to these organisations has been strengthened by the French Transparency and Nuclear Safety (TSN) Act of 2006.

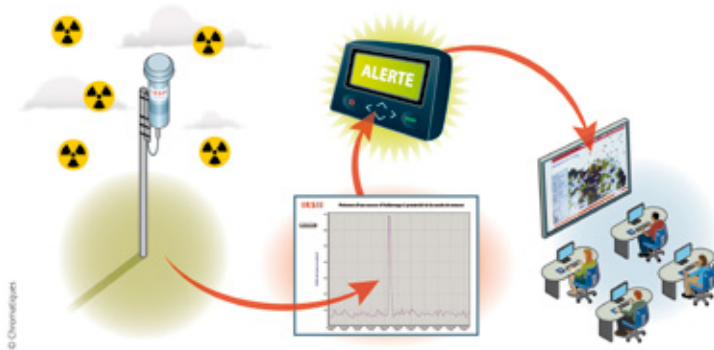
Other forms of dialogue are developing, such as multi-disci-

□ Crisis management

Since 1986, there have been important developments in the resources available in the event of a crisis. Operators, administrations and their technical agencies have all modernised their

plinary expert groups, in which technical topics can be discussed on the basis of operator documentation and IRSN surveys, with input from the various interested parties before decisions are made.

crisis centres, including with regard to communications. In this context, IRSN has gradually increased its technical capacities in the following areas:



TELERAY: a system for measuring ambient gamma radiation in real time and warning in the event of an increase in radioactivity.

- monitoring of radioactivity in the environment including, in particular, the setting up of the TELERAY network, which can detect any abnormal increase in ambient radiation in real time;
- methods and software for predicting the possible consequences of a crisis on the environment and people, to help decision-making for effective protective actions;
- field equipment that can be mobilised in emergencies to measure accidental contamination of the environment and people.

□ Power plant safety

Nuclear power plant safety has been considerably improved in Eastern European countries, with international and, especially, European help.

However, vigilance is required due to the original design of some facilities and the economic problems faced by many countries concerned.

About 15 crisis drills are conducted every year to train the various parties. Organisation for the emergency phase is now considered well tested, although care should be taken to maintain its effectiveness.

Studies are on-going to improve preparation for handling situations that may arise as a result of accidents: Chernobyl clearly demonstrated the problems involved in managing such situations, especially on a large scale.

In the West, the Chernobyl accident, coming on the back of the Three Mile Island accident (in Pennsylvania, USA), led to renewed analysis of serious accidents involving core meltdown with the aim of determining all possible means of reducing releases in such events, both for existing facilities and for any future facilities. These analyses have led

to significant improvements to nuclear facilities.

With regard to human intervention in the context of nuclear power plant safety, the Chernobyl accident led to thorough

re-examination of the concept of a safety culture and its implementation. This concerns not only operators but also managers and organisations.

□ Economic and social consequences

This disaster had major humanitarian, environmental and economic consequences in Ukraine, Russia and Belarus. Between them, these countries received 70% of the radioactive fallout. In addition to the 30-kilometre exclusion zone, which is located mainly in Ukraine, 23% of Belarusian land was con-

taminated by caesium-137. In this respect, Belarus is the most significantly affected country: with 1.6 million people living in the contaminated areas (15% of the population), the inhabitants of the worst-affected areas had to be permanently displaced; their original villages razed to the ground, and

homes and infrastructure rebuilt. In Belarus alone, nearly 235,000 people have had to be resettled.

Several million people benefit from health screening, including "liquidators" from the three countries concerned. New healthcare centres have been established and actions have been taken to protect children's health, thus building up health costs. People living in contaminated areas are exposed to specific difficulties, and their accompanying costs.

The three countries had to deal with significant agricultural and forestry losses. Some production was unfit for consumption and therefore banned while products

not banned were sometimes nevertheless rejected resulting in a double blow to affected areas. In areas contaminated but not evacuated, agriculture is still handicapped and radioactive waste management cannot be discontinued.

Work performed on the Chernobyl site itself has been very costly and this will continue even more so into the future. While Eastern Europe depended on nuclear power, many reactors had to be upgraded and the oldest ones shut down. Overall, despite large gifts from the international community, the three affected countries have been burdened with costs amounting to several hundred billion dollars.



Chernobyl Museum in Kiev (Ukraine): the names of villages razed in the exclusion zone.

COLOPHON APRIL 2011

Photographs by: **Sygma ■ Claude Cieutat ■ Campagne-Campagne ■ D.R.**
■ **IRSN/Hôpital Cochin/Seignette-Lafontan ■ Pascal Landmann**
■ **Noak/Le bar Floréal/IRSN ■ Jean Robert/IRSN ■ Novarka ■ Chernobyl museum/Brice Maire**
■ **Illustrations: P. 3 Stéphane Jungers. ■ P. 12 Laurent Stéfano - P. 40 Chromatiques Éditions**

IRSN

The French Institute for Radiological Protection and Nuclear Safety (IRSN) is responsible for the scientific assessment of nuclear and radiological risk.

It is an "EPIC" (a state-owned industrial and commercial enterprise) that carries out research and surveys for the French Government and the general public. It is a reference body both in France and internationally, with a workforce of over 1,700 people who cover a diverse range of disciplines ranging from life sciences to nuclear physics. It carries out research and surveys in its areas of expertise as follows:

- protection of people and the environment against the risks of ionising radiation,
- safety of facilities and transportation of radioactive material and its protection against malicious acts,
- monitoring of nuclear materials and products that may be used in the manufacture of weapons,
- crisis management.

It also contributes to providing the public with information.



Chernobyl

The accident that occurred in 1986 at the Chernobyl nuclear power plant in Ukraine had a profound impact on public opinion in Europe. Since then, IRSN has worked constantly to improve understanding of that catastrophe and its consequences on public health and the environment and to act to improve the safety of the sarcophagus built over the damaged reactor in 1986.

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Head office
31, avenue de la Division Leclerc
92260 Fontenay-aux-Roses
Registered at the Register of Commerce
of Nanterre under No. B 440 546 018

Telephone
+33 (0)1 58 35 88 88

Postal address
B.P. 17
92262 Fontenay-aux-Roses Cedex

Website
www.irsn.fr