Chernobyl

25 years later

STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

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Preface

On April 26, 1986, reactor number 4 in Chernobyl exploded. It is regarded as the worst accident in the history of the peaceful use of nuclear energy. Today, 25 years later, the causes as well as the consequences have been studied thoroughly and many lessons have been learned from the results.

The main causes were:

- the unsafe and unstable RBMK reactor design.
  In addition to electricity production, the RBMK reactors used in Chernobyl were also designed for the production of plutonium for military purposes. Consequently, the accident cannot be dissociated from the politico-military context in the former Soviet Union;
- the lack of theoretical training and knowledge of the operators.
  During the cold war, safety was clearly not a priority and there was a critical lack of a safety culture;
- the atmosphere of complete confidentiality in the former Soviet Union.
  In the context of that time, operators were not supposed to think critically or take initiatives in the event of officially unthinkable emergency situations.

This brochure describes the main technical elements and human errors that caused the accident. It also describes the repercussions for the population and the environment, as well as the institutional consequences. However, the text does not examine the underlying political and military aspects.

Locally, the accident has caused great human sorrow. This is by definition difficult to quantify. However, the number of casualties that can be directly attributed to the accident is known, namely 49. In 2006, the number of additional deaths due to cancer was estimated at 4 000, a very uncertain figure though. Nevertheless, reducing human sorrow to a number of deaths is much too restrictive. In the former Soviet Union, the social consequences are difficult to determine objectively because of the considerable conflict between economic and political interests, the much better medical follow-up after the accident in comparison with before, the uncontrolled evacuation of hundreds of thousands of people, etc. This text gives a description, as objective as possible, of the consequences of the accident for employees, emergency services and the local population.

Chernobyl is located in Ukraine, over 2 000 km eastwards on the same latitude as Brussels, near the place where current Belarus, Russia and Ukraine meet. A couple of days after the accident, the radioactive cloud reached Belgium via Eastern, Northern and Southern Europe. SCK•CEN as well as other institutions followed the evolution of the radioactivity increase in Belgium very accurately. This never resulted in alarming doses, and today, the residual radioactivity is negligible. One of the chapters of this brochure will deal with the consequences of the accident for health and for the food chain in Belgium.

The main international consequence of this accident was undoubtedly the impact on public opinion. The population was rightly concerned about the consequences of the accident; it was, amongst other things, the atmosphere of secrecy, created by the Soviet authorities for instance, which contributed to this feeling. We have all drawn our own individual conclusions. Institutional decisions have caused, amongst other things, the reorganisation of actions in emergency situations and the foundation of the Federal Agency of Nuclear Control (FANC). The accident's impact on the emergency planning organisation is explained in the text.

As a federal research centre, SCK•CEN has the statutory assignment to "give priority to research related to safety, radioactive waste management, protection of man and environment, management of fissile and other strategic materials and social implications as part of the pursuit of sustainable development" and "to develop, gather and spread the necessary knowledge through education and communication".

In 2010, the Belgian government provided funds for the development of a new type of nuclear reactor for research, named MYRRHA. It will be used for, amongst other purposes, the study of material within the framework of fourth generation nuclear reactor development, as well as for the production of radioisotopes for medical and industrial applications.

In co-operation with national and international partners, SCK•CEN conducts or has conducted much research related to the accident or its consequences:

- radio ecological research on the behaviour of radionuclides in the most contaminated area close to the site of the Chernobyl accident;
- research on the influence of weather patterns on the spread of radionuclides;
- software development for the safety analysis of nuclear reactors in accident situations;
- assistance with the development of adapted decontamination and decommissioning techniques for RBMK reactors in the former Eastern bloc.

You can consult the complete summary of this research, conducted by SCK•CEN, on our website (http://www.sckcen.be).

The mission of SCK•CEN emphasizes quite clearly its role in disseminating its knowledge. The purpose of this text is to provide scientific facts concerning the accident and its consequences to the media, the political authorities and to all those who are interested, and to give them sources of more detailed information. When editing this brochure, SCK•CEN stressed its pursuit of scientific openness, independence and integrity as stated by its ethics charter.

Prof. Frank Deconinck
Chairman of the Board of Directors

1

The accident

Description of the accident

On Friday April 25, 1986, reactor number 4 at the Chernobyl nuclear power plant (see figure 1) was scheduled to be shut down for maintenance. It had been decided to take this opportunity to carry out a test. In order to keep some important components working, a continuous supply of electricity is needed in a nuclear power plant. In the event of an emergency, back-up diesel generators are available but they need a few seconds to start up. After shutting down the reactor, the steam turbine keeps on spinning because of its large mass and speed. This energy can be used to generate electricity in the short period between shutting down the reactor and starting up the emergency diesel generators. This system did not work well in the Chernobyl power plant. A new system had been installed and needed to be tested. In order to be able to carry out the test, a number of safety systems were taken out of service. The test was considered to be a routine job that required no special safety measures.

› *Fig. 1 – The Chernobyl site with four reactors. The accident occurred in unit number 4.*

On April 25, 1986, at one o'clock in the morning, the operators began reducing the power output of the reactor. At two o'clock in the afternoon the reactor was still providing half of its maximum power output; it was ready for the test. At that moment the company that distributed electricity asked for electricity production not to be stopped because of a too high consumption demand on the electricity grid. At eleven o'clock in the evening, after nine hours of waiting, the operators received permission to stop the electricity production, and the tests could be carried out. Due to a mistake in the setting of a regulation system, the power output decreased too much. At that moment the reactor should have been shut down without carrying out the tests. However, the operators wanted to perform the test programme and tried to raise the power output again. This could only be achieved by pulling many more control rods out of the reactor core than permitted.

On April 26 at 1:22 a.m., the operators began carrying out the test programme while the reactor was running under unacceptable conditions. The automatic protection device that shuts down the reactor when the steam flow to the turbine is shut off, was disconnected. This was not foreseen in the test programme but it gave the operators the opportunity to repeat the test in case the test failed.
At 1:23:04 a.m., the steam turbine was shut down. The cooling pumps of the reactor began to halt. The operators, however, saw that the power output of the reactor was increasing!
At 1:23:40 a.m., they pressed the button that stops the reactor manually by dropping the control rods. A few seconds later, shocks were felt in the control room. Some control rods had not fallen entirely into the core. Witnesses outside the power plant heard two explosions that followed each other closely. Pieces of burning material flew into the air and the turbine building caught fire.

› *Fig. 2 – The destroyed reactor.*

Causes of the accident

The accident was caused by a number of human mistakes, combined with the unsafe reactor design. The control rods were pulled up much higher than permitted by the procedures of the power plant. A second, very serious, human mistake was shutting down the automatic protection device just before the test. This was a violation of the instructions for performing the test. There are two reasons why the operators acted in such way. Firstly, the test had to be postponed because they were asked to keep the reactor working longer. Due to this delay, it was already Friday night and the operators wanted to perform the test quickly before the weekend. Secondly, the responsibility of the test was left to the operators without the presence of supervisory staff. The operators improvised a few interventions that would apparently facilitate the test, but they acted without thinking about the possible consequences.

A second cause of the accident was the reactor design. The RBMK reactor type differs fundamentally from the reactors that are used in the Western world. In Russian the acronym RBMK stands for "Reaktor Bolshoy Mosjtsjnosty Kanalny", which means "High Power Channel-type Reactor". The problem with the reactor types such as the ones used in Chernobyl is that they behave unstably under certain circumstances.

An increase of the power output, due to a failure for instance, raises the temperature of the cooling water. In order to be safe, the reactor has to react to this by decreasing the power production, due to physical effects, without intervention of regulation systems.
In some circumstances, RBMK reactors react oppositely. An increase of the power output causes a rise in temperature, resulting in a further increase of the power output. This causes the temperature to rise further, which raises the power output again. If this nuclear chain reaction is not interrupted soon enough, an explosion is inevitable. This explosion is comparable to, for instance, an explosion of a steam installation by overheating. By violating the procedures, the operators brought the reactor into a dangerous condition.

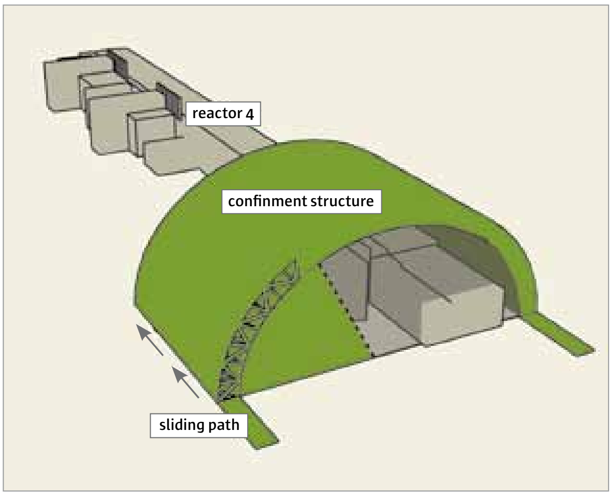
Further development of the accident

After the explosions one of the operators went to look at the reactor that was completely destroyed (see figure 2). The reactor cover, a heavy concrete cover, had been lifted from the reactor and lay crookedly. The reactor core, composed of graphite blocks in which the nuclear fuel elements are located, was on fire. The operator in question suffered a fatal radiation dose.

RBMK power plants are not equipped with a containment building that is completely isolated from the environment. Because of this, the radioactivity could spread much more easily into the environment.

Directly after the accident, two actions needed to be taken immediately. Of course, the fires had to be extinguished, but it was crucial to make sure that the nuclear chain re-

› *Fig. 3 – First sarcophagus.*



› *Fig. 4 – Project for a new sarcophagus.*

action was stopped. The only possible way to do this was by dropping a substance that, like control rods, absorbs neutrons. This was achieved by helicopters flying over the destroyed reactor. Moreover, the population should have been informed immediately, which did not happen until much later.

At a later stage, the radioactivity that was still present in the core had to be prevented from spreading further in the environment. For this purpose the so-called "sarcophagus" (see figure 3) was built. This is a complete concrete covering placed around the reactor building. Concrete was also poured under the building in order to prevent radioactivity from penetrating the groundwater. Cracks appeared in the first sarcophagus and it has also become unstable. The building of a new sarcophagus was started in September 2010. This new sarcophagus will be constructed near the reactor and will be placed over the existing one using a rail system (see figure 4). In this way, it will become possible to dismantle the reactor and the old sarcophagus.

Today, all reactors in Chernobyl have been stopped definitively. A notable fact is that a few years after the accident there was an outbreak of fire in one of the other reactors of the power plant, but not in the nuclear part. In the former Soviet Union there are still a few operational reactors of this type. However, a number of adaptations that enable safer working have been made.

Comparison with Belgian nuclear reactors (pressurized water reactor type)

The Belgian nuclear reactors are totally different from the reactors that were used in Chernobyl. Instability, causing the power output to rise more and more, is not possible in pressurized water reactors such as in Doel or Tihange. Thanks to the special construction of these reactors, a rise in the temperature of the cooling water will always cause a decrease in power output, which stabilizes the working of the reactor. Furthermore, in the Belgian nuclear reactors, several barriers have been put in place in order to avoid uncontrolled discharge of radioactive materials: the reactor vessel, the main safety equipment and the steam generator are located in a building with a double steel and concrete wall. This containment building can resist internal pressure and external forces, such as the impact of a plane crash.

The efficiency of such a containment building was demonstrated in 1979 in the United States. On March 28, several things went wrong in the power plant on Three Mile Island in Harrisburg, where they also used a pressurized water reactor. Due to a lack of cooling water, a few nuclear fuel elements melted. Although the reactor itself suffered severe consequences from the accident, the amount of radioactivity that escaped into the environment was limited thanks to the design of the reactor building.

Concerning the management of the reactor we can state that an experiment like the one conducted in Chernobyl would not be carried out in such a way in Belgium. Such tests require the prior approval of the supervisory authorities, sometimes even the attendance of an inspector. In addition, such tests would never be left to the operators alone and special supervision would be provided.

2

Consequences of the accident for employees, emergency services and the local population

Summary of the exposure

The Chernobyl accident affected several population groups: the on-site reactor staff, the fire brigade and other emergency services, the clean-up workers who carried out the subsequent containment of the accident's consequences, and the local population in the contaminated zones.

A short summary of the radiation doses to which these population groups were exposed is given below. For comparison: the average annual exposure in Belgium, chiefly due to natural radioactivity and medical applications, amounts to 4.6 mSv (millisievert); in 1986, the annual limit for professionally exposed employees was 50 mSv; in 2001, this figure was reduced to 20 mSv. We will use this last figure as a reference in this exposure summary and call it the "employee's limit". For gamma radiation this also equals 20 milligray (mGy). The figures mentioned below mostly come from the UNSCEAR reports of 2000 and 2008. (UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation).

Which units?

Becquerel (symbol Bq) is the unit used to measure radioactivity. Some elements can change into other elements by spontaneous disintegration of the atomic nucleus, releasing alpha, beta or gamma radiation. This physical phenomenon is called radioactivity. 1 Bq means 1 disintegration per second.

Gray (symbol Gy) is the unit of absorbed dose. This is the quantity of radiation energy that is deposited on a certain material. 1 gray equals an energy deposition of 1 joule per kilogramme. The gray is the appropriate unit for very high radiation doses that can cause short-term effects (acute radiation syndrome).

Sievert (symbol Sv) is the unit that represents the long-term health effects of ionizing radiation on man (cancer and physical defects). The millisievert (symbol mSv), one thousandth of a sievert, is used more often.

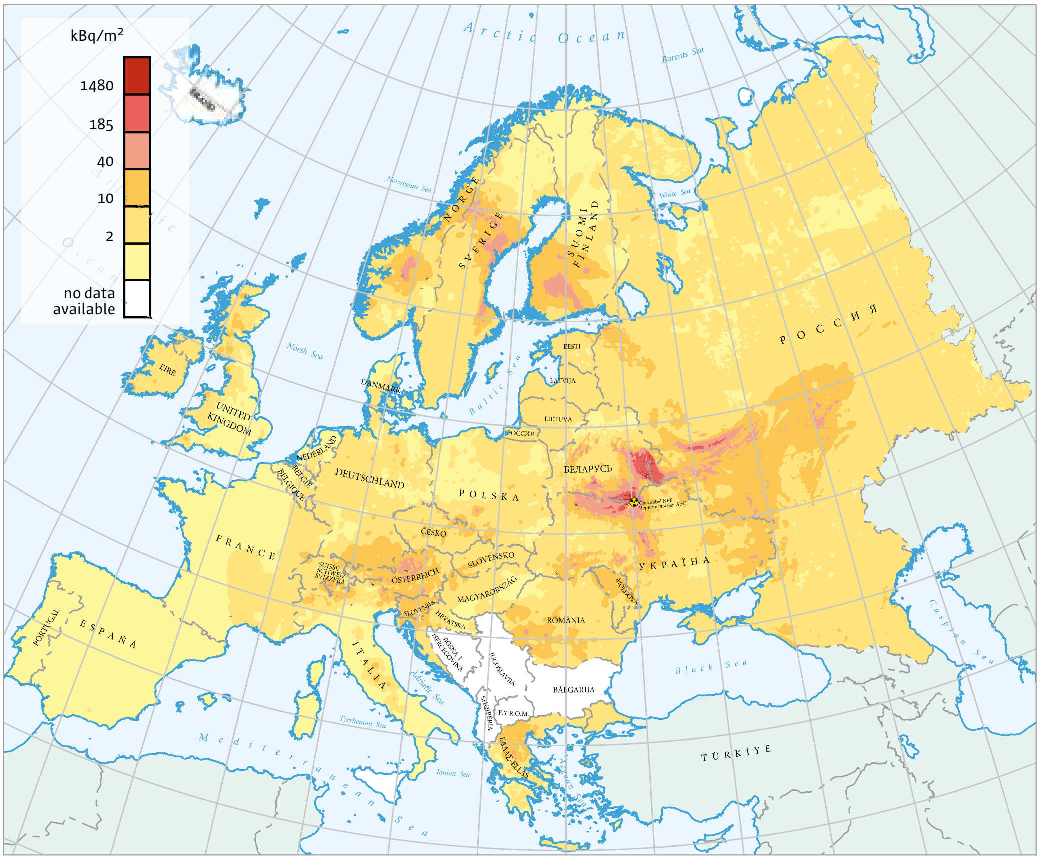
Discharge of radioactive materials from the reactor

During the 10 days after the accident, gases and a portion of the other radioactive materials (radionuclides) in the reactor core were spread into the air. It has been estimated that half of all the iodine activity (1 760 10^{15} Bq) present in the core before the accident was released into the air. The current estimate of the iodine discharge is five times higher than that assumed during the initial period (1988). The current estimate of the radioactive caesium discharge is 30% (85 10^{15} Bq), which corresponds rather well to earlier estimations.

Contamination of the environment around Chernobyl

Due to the accident, large areas in Ukraine, the Republic of Belarus and the Russian Federation suffered radioactive contamination. Over the long term, it is the radioactive caesium contamination in particular which should be taken into account. The weather conditions during the accident resulted in a very irregular distribution of the contamination.

In total, an area of about 150 000 km^2, this is 5 times the area of Belgium, in the three republics was seriously contaminated with radioactive caesium (more than 37 kBq/m^2



› *Fig. 5 – The caesium-137 soil contamination in Europe on May 10, 1986. This contamination is due to the Chernobyl accident as well as to earlier atmospheric nuclear weapons testing.*

or more than 10 times the contamination in Belgium). The degree of contamination due to caesium-137, expressed in kBq/m², is shown on the map of Europe in figure 5.

Exposure of employees and emergency services

About 600 members of the reactor staff and emergency services were present that night and during the hours that followed the accident. The reactor staff wore dosimeters of which the measuring range was limited to roughly 0.02 Gy (gray). Due to the high radiation fields in the surroundings of the reactor, the absorbed doses were greater than this measuring range, so the dosimeters could not be used for the estimation of the radiation exposure. The firemen did not wear dosimeters. The exposure of all these people was determined by means of biological dosimetry, which is reasonably accurate when it comes to high doses.

237 of the people mentioned above showed symptoms of radiation syndrome. Later on, 134 of them were diagnosed as suffering from acute radiation syndrome. 41 people were exposed to an external physical dose of less than 100 times the annual employee's limit (2.1 Gy), 50 people to a dose of between 100 and 200 times the limit (2.2 and 4.1 Gy), 22 to a dose between 200 and 300 times (4.2 and 6.4 Gy) and 21 to a dose between 300 and 800 times the annual employee's limit (6.5 and 16 Gy).

The average total physical dose from which victims die within a few weeks after the exposure is 5 Gy. In spite of medical care, 28 people died from radiation exposure within four months of the accident. Two people died as a result of accidents during the emergency interventions.

Exposure of clean-up staff

In total, 530 000 people were involved in the clean-up activities in Chernobyl and its surroundings. About half of them were soldiers. In 1986, a dose register was opened for these clean-up workers. Interpretation of the dose data is not easy; different kinds of dosimeters were used without mutually comparing them. A large number of measurements were close to the detection limits and sometimes the results were rounded off considerably. The average physical dose of the clean-up workers for the years 1986-2005 is estimated at about 117 mSv. This is equal to six times the employee's limit. In the following years, the dose decreased very quickly.

External exposure of the population around Chernobyl

Five million people lived in the seriously contaminated areas (more than 37 kBq radioactive caesium per m^2). The affected population was divided roughly equally between the three republics in question.

Within a few weeks, the governments of Ukraine and Belarus evacuated 115 000 people and 60 000 animals from the most contaminated areas. Extensive measuring campaigns and calculations were conducted in order to determine the external radiation dose of this population group. It is estimated that about 30% of these people were exposed to a dose lower than 10 mSv, 56% to a dose between 10 and 50 mSv, 10% to a dose between 50 and 100 mSv and only 4% to a dose higher than 100 mSv. After 1986, another 220 000 people were evacuated from even further afield.

A earlier warning and advice to stay inside would have limited the dose to the population.

Many people did not wish to leave certain areas that had not been evacuated and yet were very seriously contaminated with radioactive caesium (more than 550 kBq/m^2). In these areas, countermeasures succeeded in limiting the annual dose to 5 mSv, a quarter of the employee's limit. In 1986, 273 000 people lived in these areas; in 1995, emigration had caused this number to reduce to 150 000. There are still many people who live in these areas.

Internal exposure of the population around Chernobyl

During the accident, the population around Chernobyl inhaled radioactive iodine which was released due to the fire in the reactor. As a result of this internal exposure, thyroid cancer was found amongst children. The absorbed thyroid dose depends on age, place of residence, possible moment of evacuation and the consumption of contaminated food. This dose comprises about five per cent of the total physical dose. For those evacuated within 48 hours of the accident, the thyroid dose has been estimated at 0.07 Gy for adults. For infants, this estimate increases to a high dose of 2 Gy. For all evacuated people taken together, the average value is 0.47 Gy. As for the population groups that were not evacuated, thyroid doses of more than 1 Gy for the most exposed infants were found in each of the three republics.

During the first weeks after the accident, radioactive iodine contributed the most to internal exposure. Since 1987, however, the exposure in the contaminated areas has been attributable chiefly to radioactive caesium deposited on the soil. Not only is caesium responsible for the external exposure, it also enters the food chain. The sum of the internal and external caesium dose, suffered by the inhabitants in the contaminated areas during the first ten years after the accident, has been estimated on average as 10 mSv.

Health effects among reactor staff, emergency services and local population

We have to make a clear distinction between the short-term health effects that only occur after exposure to high radiation doses and the effects in the long term, like cancer for instance, which can also appear after exposure to lower doses.

Short-term effects: radiation syndrome

A number of employees at the nuclear power plant as well as some members of external emergency services absorbed such high doses due to a lack of supervision during the interventions that they had to be hospitalized with symptoms of radiation sickness. For 134 rescue workers (about half of all hospitalized patients) the diagnosis of radiation sickness, all to different degrees, was made. Among the neighbouring population there was no radiation syndrome observed.

Severity of the radiation syndrome	Number of patients treated* in Moscou	in Kiev	Number of deceases		Number of survivors
Minor (degree I)	23	18	0	(0%)	41
Moderate (degree II)	44	6	1	(2%)	49
Severe (degree III)	21	1	7	(32%)	15
Very severe (degree IV)	20	1	20	(95%)	1
Total	**108**	**26**	**28**		**106**

* Acute radiation syndrome has not been detected among another 103 patients who were hospitalized.

› *Medical follow-up during the first four months of the patients with radiation syndrome, attributable to the Chernobyl accident.*

The most frequent symptoms of radiation syndrome were related to bone marrow damage and injuries to the gastrointestinal tract. The 28 deceases were the result mostly of burns caused by irradiation of the skin and the mucous membrane of mouth and throat, together with radiation injuries to the lungs. The deceases during the first four months following the accident in 1986 were the consequence of radiation syndrome (see enclosed table). In the period 1987-2006, 19 people, who were originally hospitalized because of radiation syndrome, died. There were also 2 people who died during the emergency actions, which brings the total amount of direct casualties to 49 were all the above-mentioned casualties to be attributed to the accident.

Long-term effects

The studies

The year after the accident, the government of the former Soviet Union decided to also register continuously the long-term effects on people who had been most exposed to radiation, namely:

- people who participated in the clean-up activities;
- the people evacuated from the most contaminated areas;
- the people still residing in areas with relatively high contamination.

A follow-up also had to be organised for the offspring of the people in these three research groups (born after the accident in 1986).

After the collapse of the Soviet Union in 1991, the research projects continued in a decentralized way in the most affected states. At the national level, numerous registers were established for the analysis of blood diseases, thyroid cancers, cancers amongst children, hereditary defects, congenital malformations, and so on. Over the years, however, researchers in the individual states started applying their own methodologies more and more. As a consequence, merging of all the data is often hindered.

The results for cancer and physical defects

The only indisputably observed effect until now in the general population is a clear increase in thyroid cancer among young people in the most contaminated areas (Belarus, Ukraine and the adjacent areas of the Russian Federation). In figure 6 you can see the evolution of thyroid cancer incidence in Belarus after the accident (separately for girls and boys) for those who were children or adolescent at the moment of the accident. Only 4 years after the exposure to nuclear fission products, there was already a clear increase in this type of cancer. There was also a good geographical correlation between the occurrence of thyroid cancer and the degree of soil contamination. The risk of thyroid cancer is still increasing for those who were children or adolescent at the moment of the accident.

What can explain this clear increase in thyroid cancers among youngsters? Radioactive iodine isotopes constituted an important fraction of the released nuclear fission products. The thyroid gland concentrates these iodine isotopes, sometimes resulting in very high thyroid doses.

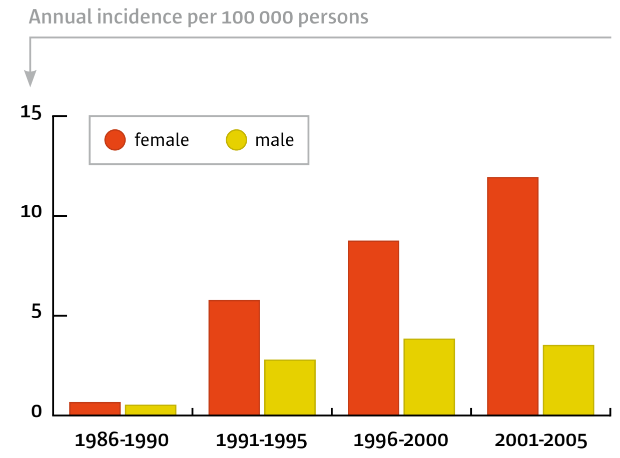


Fig. 6 – Thyroid cancer incidence among people in Belarus who were children or adolescents at the time of the Chernobyl accident (age under 18 years in 1986).

Moreover, in comparison with adults, young children are much more susceptible to thyroid cancer resulting from radiation. Age at the moment of the exposure plays a very important role among children: the largest thyroid cancer increase was found among children who were less than 4 years old at the moment of the accident (see figure 7a and 7b). Another reason for the increase is that for an equal absorption of radioactive iodine, the thyroid dose of children will be relatively higher, as the same amount of radioactive iodine is concentrated in a smaller organ. Furthermore, in some areas of the former Soviet Union there was already an iodine deficiency in the food before the accident, and this results in a bigger absorption capacity of the thyroid gland for iodine. The absorption of radioactive iodine occurred through inhalation, eating contaminated vegetables, but especially through the consumption of contaminated milk products (an important part of children's food).
The reason why the thyroid doses could increase that much in the most affected regions, is because no shelter measures were taken and because stable iodine was often distributed too late (or not at all) amongst the population. When taking up non-radioactive iodine at an early stage, the thyroid gland becomes quickly saturated and can no longer absorb radioactive iodine. In the most contaminated areas, more than 6 000 thyroid cancer cases were diagnosed in (ex) youngsters during the period 1991-2005. An important fraction of those thyroid cancers can be attributed to milk consumption. During a short period milk was contaminated with radioactive iodine (especially iodine-131).

It is clear that high doses of radioactive iodine can cause thyroid cancer. When receiving even much higher doses, however, these thyroid cancers (and even their metastases) can be cured again, since all cancer cells are killed because of the enormous local radiation doses. This treatment is very effective; experience has indicated that the chance of survival is very high with this therapy. This also explains why up to 2005 only 15 of the above-mentioned patients died. However, some caution is required here. On the one hand, the low mortality rate is not correlated with the misery experienced by the patient and the family due to the confrontation with cancer; on the other hand, the large dose of radioactive iodine used for the treatment can cause the development of other cancers in the long term.

Until now, it has been difficult to prove an increase in other cancer types (including leukaemia). Some studies point to an eventual increase in the incidence of leukaemia (and also cataract or clouding of the eye lens) in some of the most exposed clean up workers who were called into action during the years 1986-1987. Even today, many scientists query these findings because of methodological deficiencies. The number of tumours or anomalies diagnosed amongst the liquidators, who had a more accurate follow-up, has been compared to the less well documented national figures. Any increase in various tumours or anomalies mentioned in these studies could therefore be, entirely or partly, the result of the so-called "screening effect". Nevertheless, one has to guard against falsely cataloguing the onset of a real

Fig. 7a

Yearly incidence of thyroid cancer per million women

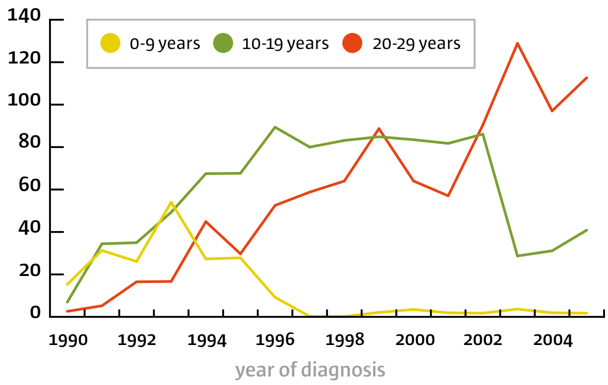


Fig. 7b

Yearly incidence of thyroid cancer per million man

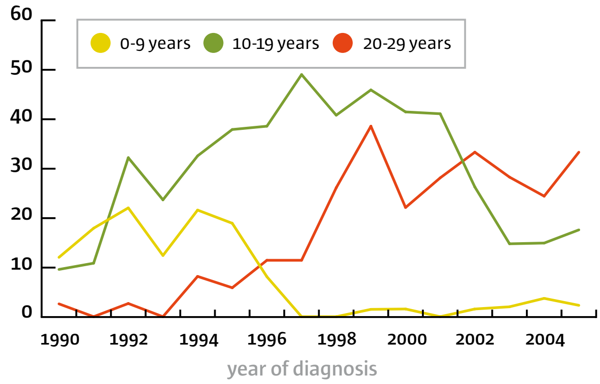


Fig. 7 – Thyroid cancer incidence for different age groups (age at diagnosis) of the Belarusian female and male population.

increase as a possible screening effect. For instance, some scientists suggested this hypothesis when the onset of an increase in thyroid cancer amongst youngsters in the most contaminated areas of the former Soviet Union was published in 1990. The results of the on-going follow-up clearly indicated that this hypothesis was erroneous.

Taking into account the radiation doses incurred by the 600 000 most exposed people (this means the clean up workers for the period 1986-1987, the evacuated population and the inhabitants from the most contaminated regions), model based estimates were made in 2006 of the additional expected cancer deaths. According to these estimates the total increase in cancer deaths (all cancer types) would be 4 000 for the most exposed.

Likewise, an increase of approximately 7 500 cases of thyroid cancer would be expected in the population (1.1 million inhabitants) of the most contaminated regions of Belarus, The Russian Federation and Ukraine.

However, these projections are only based on calculations. Indeed, until now it has been difficult to detect an increase of cancer types other than thyroid cancer. This is because radiation induced cancer cases and cancer deaths cannot be distinguished from the normal local cancer incidence/ cancer mortality. In Belarus the normal probability of developing cancer or of dying from cancer before the age of 75 is ± 22% and ± 15%, respectively. However, UNSCEAR does not advocate these model based extrapolations because of the huge uncertainties.

The increase in thyroid cancer is so striking because on the one hand this type of cancer occurs rarely in youngsters, and on the other hand because the average thyroid dose in this age category was quite high.

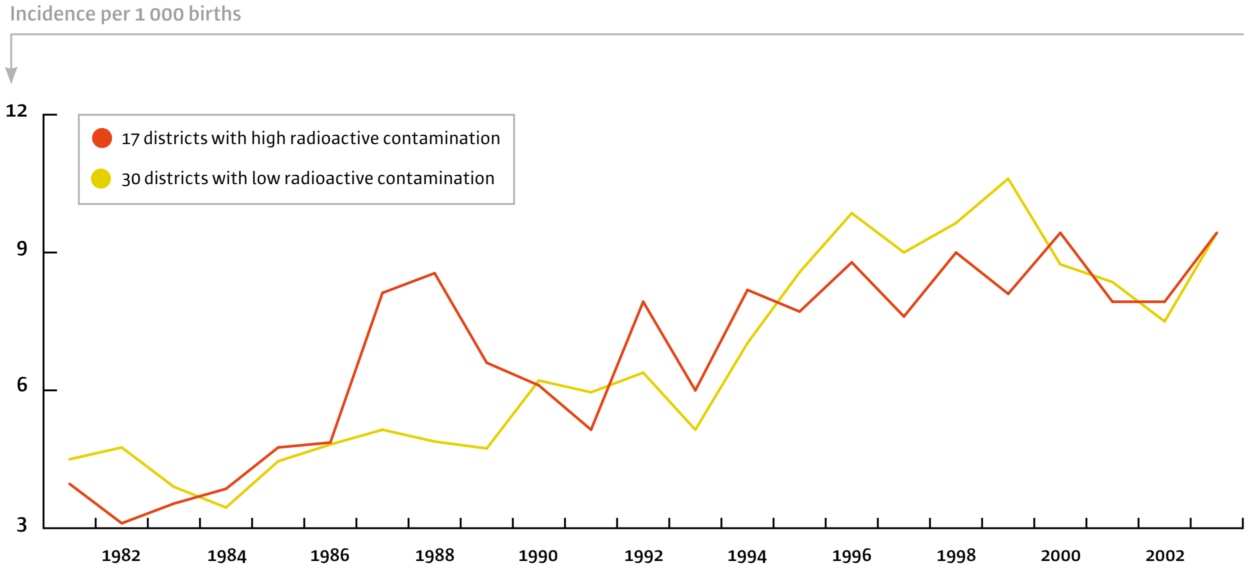
Nevertheless, there is little doubt that there is a lot more additional health damage due to the bad economic situation in which the affected regions ended up after the collapse of the former Soviet Union. The obvious worsening of the health care and the living conditions even result in a decrease of the average life expectancy. Attribute all of this to the Chernobyl accident would vitiate the truth (see further on).

According to UNSCEAR, no distinct increase in congenital malformations could be demonstrated, despite sensation-seeking coverage in the media. It is obvious that such malformations occurred. It remains to be seen, however, whether the increase is statistically significant compared to the normally expected number and whether the rise in these disorders can be attributed to the increased radiation exposure. This last additional condition is very important.

Just by using more accurate and specific detection techniques, or systematically referring cases to the better treatment centres, one can easily be confronted locally with pseudo-increases of all kinds of malformations.

According to UNSCEAR, most studies concerning the effects after radiation exposure as a result of Chernobyl do not indicate an unambiguous increase in the occurrence of Down's syndrome, miscarriages, perinatal mortality (death immediately or shortly after birth) or genetic effects. This applies to Belarus, Ukraine, as well as to most contaminated European regions.

It should be mentioned that some authors recently reported an increase in a number of some specific congenital malformations. One of those studies (which admittedly started late) demonstrated such an increase in the most contaminated regions of a certain province in Ukraine for the period 2000-2006, compared with both the less contaminated region of this province (Rivne), for the same period, and the European average. Although no data is available about this, the author of the abovementioned study suggested that the findings could be explained by the ingestion of contaminated food. On the other hand, he emphasized that other established causal factors could also be involved (e.g. indirect exposure of the embryo to alcohol or folic acid deficiency during pregnancy).



› *Fig. 8 – Evolution of the number of congenital anomalies in some districts of Belarus with high or low contamination level.*

Another study focused on Belarus and was based on data collected by The National Institute for Hereditary and Inborn Diseases. The evolution of the incidence of congenital malformations in 17 of the most contaminated districts (soil contamination by Cs-137 ≥ 555 kBq/m^2) was compared with the incidence in 30 much less contaminated districts (soil contamination by Cs-137 < 37 kBq/m^2). The results of both types of district are presented in figure 8.

In the period 1987-1989 there was a distinct increase in the number of congenital malformations in the most contaminated districts. After 1989 the statistically significant difference disappeared, although a slightly increasing trend remained discernable in both groups.

The increase in the incidence of congenital malformations during the period 1987-1989 was not observed in an earlier study, performed by the same authors, at the level of larger geographical areas ("oblasts"). According to the authors, the different findings were due to the fact that the results of the more recently studied 17 most contaminated smaller districts (soil contamination by Cs-137 ≥ 555 kBq/m^2) had been diluted by the results for the districts of the same oblasts with a lower level of contamination. Moreover, in the Minsk oblast (that was used as a control in the first study), there were areas which appeared to be more contaminated (≥ 185 kBq/m^2) than previously estimated.

Psychosocial effects

One can certainly not underestimate the psychological impact of this accident on the members of the emergency services and on the population. Some even state this might be the most important long-term effect.

Among the intervention teams that were immediately and directly involved, post traumatic stress symptoms, such as serious nightmares and obsessively reliving the traumatizing event, have been documented.

It is almost impossible to ignore the psychological consequences of the fact that families suddenly had to leave goods and chattels behind and that they were taken to settlements in totally unknown regions. The combination of broken social contacts and the important economic and political changes just prior to the collapse of the former Soviet Union can only have reinforced the feelings of doubt, helplessness, isolation and abandonment.

Even now, the people who were not evacuated live with the residual contamination as an invisible threat that cannot be located or quantified, unless one possesses measuring equipment.

Without its own measurement equipment, the population is dependent on experts who are – together with the physicians and politicians – still not completely trusted. Many see the measuring teams and researchers come and go. Eventually, people feel as if they are only being used as guinea pigs. The inhabitants often think that the experts deny or minimize the risks when trying to explain those risks, and in particular that they try to bring them into perspective by comparing them to the current risks in society. Thus, the disbelief further intensifies the anxiety. Furthermore, a clear association between this anxiety amongst the parents and stress amongst their children has been demonstrated.

In the above-mentioned population there were more symptoms of headache, sleep problems, concentration disorders, emotional instability and depressions. Many have linked the poorer general health directly to the accident, rather than to the bad economic situation. This tendency to attribute all problems to the nuclear disaster regularly leads to avoiding everyday realities, excessive dependence, unwillingness to cooperate and the conviction that the social security system and the government must solve all the problems. More than once, low self-appreciation has also lead to alcohol and drug abuse, traffic accidents and suicides. So, it is clear that, even now, Chernobyl – in combination with the above-mentioned political changes – still has a very considerable effect on the well-being of the people in the most contaminated regions.

Contamination of the food chain

In the first days after the Chernobyl accident, contamination of the food chain was mainly due to atmospheric deposition of radioactivity on leafy vegetables and in particular on grass, which permitted the transfer of radioactivity to the milk.

Several radioactive elements were released into the biosphere during the accident. During the first weeks it was mainly iodine, a radioactive element with a short half-life, which was responsible for the absorbed radiological doses in the population. Especially children, who are big milk consumers, were exposed to a considerable extent. Then long-lived isotopes like caesium and, to a lesser extent, strontium contributed to the residual contamination of the food chain.

The radionuclides deposited on the soil as a result of the accident are absorbed through the roots, along with the nutrients necessary for the plant growth. The availability of radioactive elements to plants depends mainly on the type of soil and on the solubility of the deposited radionuclides. Caesium, for instance, will remain very available in organic soils (peat, woodland soils and natural grasslands), whilst in mineral soils it is much more immobilized by clay particles. This explains the fact that in the surroundings of Chernobyl, which is dominated by sandy and organic soils, part of the agricultural produce still shows concentrations above the permitted levels.

Several countermeasures have been taken in order to reduce the contamination of the agricultural produce. The main ones are:

- ploughing the soil to a sufficient depth in order to dilute the radioactivity that was originally concentrated in the root zone;
- liming acid soils to reduce the solubility of caesium and to limit the absorption of strontium through the input of calcium;
- applying mineral fertilizers (mainly potassium), given that the input of potassium makes the plants absorb less caesium;
- selecting certain varieties of agricultural crops that absorb fewer radioactive elements;
- rationalizing the feed regime for cattle by feeding with clean fodder before slaughter;
- administering animals certain supplements (e.g. Prussian blue, clay minerals) that reduce the absorption of radionuclides (mainly caesium) through the digestive tract;
- processing agricultural produce (mainly milk) to less contaminated derivatives such as butter and cheese;
- banning agricultural production in the most contaminated regions.

Fig. 9a

% of the yearly production above reference values (Belarus)

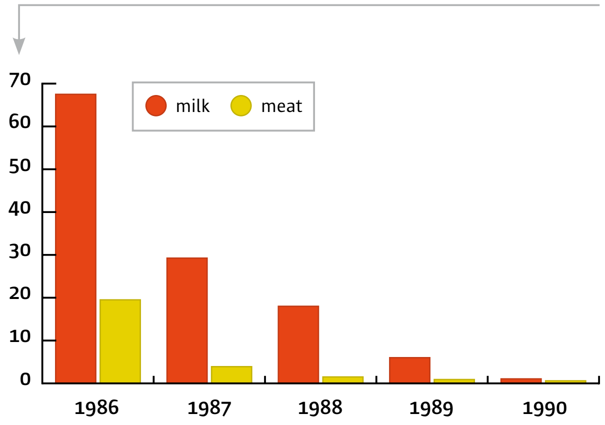


Fig. 9b

% of the yearly production above reference values (Russia)

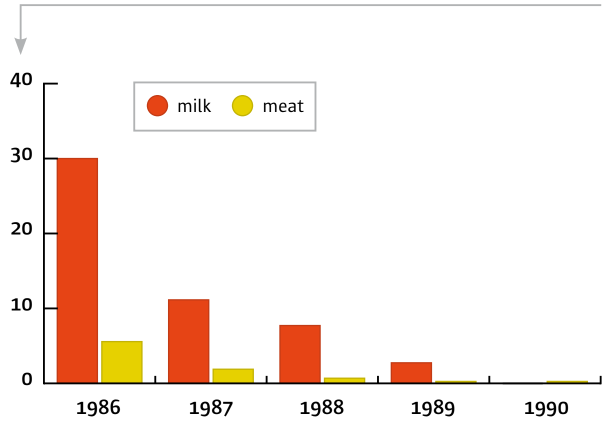
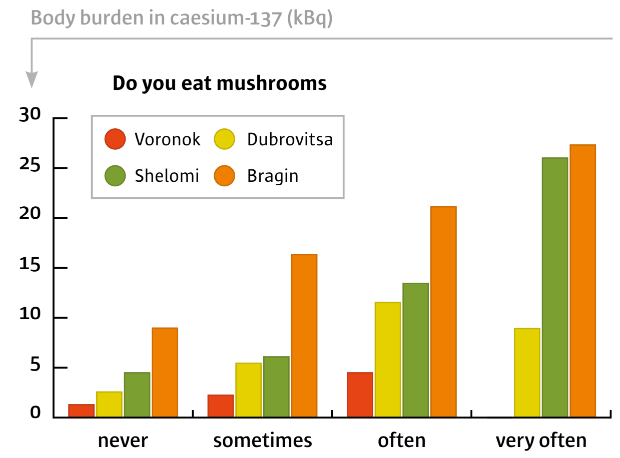


Fig. 9 – Time evolution of the milk and meat production fraction in Belarus (Gomel region) and Russia that exceeds the reference values. The observed reduction results from both the implementation of agricultural countermeasures and the natural processes that reduce the availability of caesium-137.

Between 1986 and 1990, these countermeasures, combined with the natural processes that immobilize caesium in soil, have lead to a consistent decrease in the amount of agricultural produce exhibiting caesium concentrations above the permitted values (see figure 9).

Later on, the economic downturn in the republics of the former Soviet Union led to these countermeasures being applied less stringently. As a consequence, an increase in the concentration of radionuclides in agricultural crops was observed in several regions. An example can be found in the District of Novozybkov (region around Briansk), where the decrease in the budget for countermeasures led to a 10 fold increase in the contamination level in hay, root crops and potatoes between 1991 and 2003.

Traditionally, the consumption of mushrooms and other wild products represents a considerable part of the population's diet in the woody regions around Chernobyl. Due to the typical characteristics of woodland soils (rich in organic matter and poor in nutrients like potassium), the amount of caesium available for plant uptake decreases very slowly. As a result, the caesium levels in forest food products (such as mushrooms, berries and other forest fruits, but also wild boars) remain fairly high. A clear relation was found between the physical caesium contamination of the rural population and its consumption of mushrooms (see figure 10).



› *Fig. 10 – Relation between the mushroom consumption and the caesium-137 contamination for the inhabitants of four villages [from Strand et al., 1996, EUR 16539 EN].*

Consumption of mushrooms by game during autumn has been shown to have a direct influence on their caesium contamination level. Nevertheless, individual contamination levels are very variable, depending on the region in which the animals live and on their seasonal dietary pattern.

Locally, the contamination level of fish in lakes can reach some tens of kBq/kg. Predatory fish, such as river perch and pike, clearly show a higher contamination level than herbivorous fish, such as roach and carp. In some regions, restrictions regarding the hunting of game, fishing and consumption of natural products are still applicable.

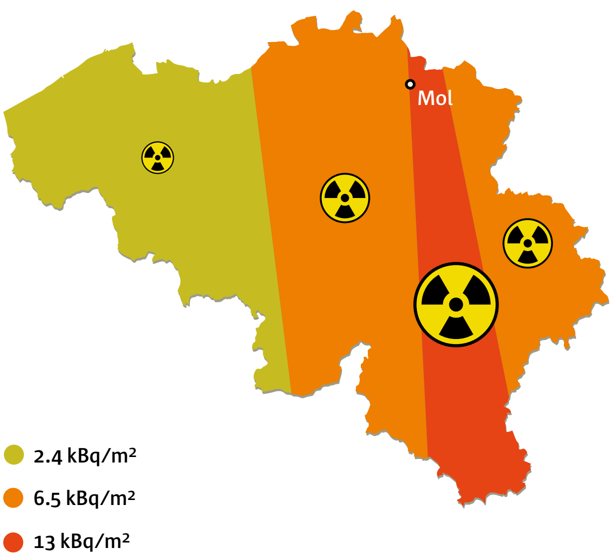
3

Consequences of the accident in Belgium

Summary of the exposure

In the period after the accident in Chernobyl, the Belgian population was exposed to radioactive contamination in different ways. The main exposure was caused by the external radiation of the radioactive materials that were deposited on the ground, by inhalation of contaminated dust and by eating contaminated food.

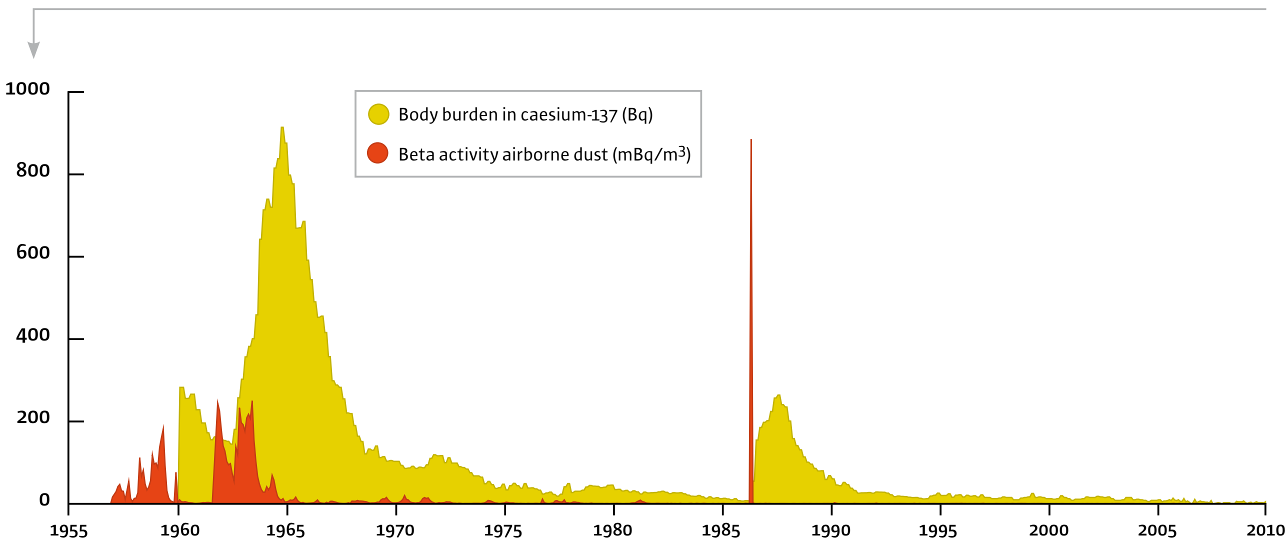
In Belgium, in 1986, the spread of the contamination was dependent on the weather conditions. In places where it rained, the air activity settled on the ground and the soil became more contaminated than in places where it did not rain. On figure 11, you can see the spread of the combined surface activity of iodine (I-131) and caesium (Cs-134 and Cs-137). In Mol, in the most contaminated part of the country, SCK•CEN carried out a large number of measurements, which became the reference values for Belgium.



› *Fig. 11 – The distribution of the surface contamination due to caesium-134 and caesium-137 and iodine-131 as measured in 1986.*

Next to environmental radiation, we mainly measured the iodine and caesium activity in airborne dust, grass, leaf vegetables, milk and meat. The additional resulting dose load in Belgium was very low. During the first year after the accident this exposure varied from 0.03 to 0.1 mSv for adults. Because of different eating habits and a greater susceptibility to radiation, the exposure for the most exposed young children could reach as much as 0.3 mSv. For the 30 year period after the accident, we estimate that an additional dose of 0.1 to 0.2 mSv can be expected across Belgian territory. The thyroid dose of a young child that has mainly drunk from the most contaminated milk would be 4 mSv for the first year after Chernobyl.

Figure 12 shows the development of the monthly measured average amount of caesium-137 in the body of people in Belgium (yellow graph). The large increase between 1962 and 1968 is due to aboveground nuclear bomb tests that were carried out mainly before 1963. From 1986 onwards, the increase is due to the Chernobyl accident. The amount of caesium absorbed by our body after the accident is about 4 times smaller than the amount absorbed due to the nuclear bomb tests in the sixties. Current measurement values are below the detection limit, which is about 25 Bq caesium-137.
The monthly average beta activity of airborne dust in Belgium (red graph) was 4 times higher after the accident than after the tests, but this increase lasted less than one month, so less caesium was available for absorption in the human body compared to the caesium available during the nuclear bomb testing.



› *Fig. 12 – Comparison between the evolution of the monthly measured average amount of caesium-137 in the body of people in Belgium and the monthly average beta activity of airborne dust in Belgium.*

Health effects amongst the Belgian population

Were there any effects observed?

As mentioned before, the additional radiation exposure in Belgium resulting from the accident was low in comparison with the average radiation exposure of our population (and even very low with regard to the geographical fluctuations in the natural radiation exposure). Even when using the most pessimistic risk figures concerning cancer induction and congenital or hereditary defects, it is not possible to show a potential increase. Other health effects (such as thyroid function problems, decreasing fertility, suppression of the bone marrow) could not be observed in our country because they only appear when a high threshold dose is exceeded.

Prevention of damage to health

The high thyroid doses and the occurrence of thyroid cancer amongst youngsters in the contaminated regions around Chernobyl were the result of insufficient protection of the thyroid gland shortly after the accident. Countermeasures, such as staying indoors and closing doors and windows during the passage of the radioactive cloud, not only protect against the radioactive iodine, but also against the other radioactive materials present in the cloud.

In the case of accidents with nuclear reactors, the thyroid gland can be saturated with “stable” iodine, from shortly before an imminent exposure until just after a real exposure to radioactive iodine. This will prevent radioactive iodine from concentrating in the thyroid gland. This reduces considerably the risk of thyroid cancer later on.

The Belgian authorities have already organised several information campaigns for physicians, pharmacists and people in charge of intervention services employed in the surroundings of the main nuclear installations. Subsequently, stable iodine was distributed preventively in the regions around nuclear sites. One only takes these tablets in the event of a nuclear accident and on the recommendation of the authorities.

Thyroid protection when travelling to the Chernobyl region

People regularly ask whether they still have to take iodine tablets preventively to protect the thyroid gland when travelling to the surroundings of Chernobyl. This is no longer necessary, because within a few months after nuclear accidents nearly all iodine isotopes have decayed completely. Some other fission products – against which the iodine tablets do not protect – can remain radioactive for a much longer period (e.g. caesium).

Contamination of the food chain in Belgium

In May 1986, numerous measurements on several foodstuffs indicated that, in general, their contamination levels remained far below the applicable standards. Certain vegetables, of which the leaves were directly exposed to at mospheric deposition, exhibited contamination levels for iodine-131 of up to 400 Bq/kg for corn salad, up to 300 Bq/kg for lettuce and between 100 and 200 Bq/kg for other crops (spinach, garden cress, endive, leek, celery). The contamination levels of caesium-137 in spinach decreased quickly from a maximum value of 200 Bq/kg immediately after deposition to 30 Bq/kg in the second half of May. As a result of the Chernobyl accident, legislation has been harmonized and new standards have been laid down for foodstuffs in case of a nuclear accident: in milk, the maximum permitted values are 1 000 Bq/l for caesium and 500 Bq/l for iodine; for other foodstuffs these figures are 1 250 Bq/kg for caesium and 2 000 Bq/kg for iodine.

The transfer of radioactive iodine and caesium from grass to cow's milk is very quick, making cow's milk a good bioindicator for the total radioactive deposition in a specific region. Moreover, because milk is an important food product, it can contribute greatly to the internal dose of the population. Therefore, milk from dairy farms and individual farms was monitored rigorously. A sampling campaign was set up over almost the entire territory. On May 5, 1986, the maximum iodine concentration measured in milk samples coming from dairy farms was found to be 225 Bq/l. The contamination in milk coming from individual farms has reached values between 100 and 660 Bq/l. On the other hand, the caesium concentrations in milk were limited to some tens of Bq/l.

Figure 13 represents the evolution of the caesium concentration in cow's milk in a farm in the Mol-Dessel region (province of Antwerp) since 1963. One can clearly see the effect of the Chernobyl accident in 1986. In the following months and years, the immobilization of caesium in the soil caused a rapid decrease in the contamination of the milk. Today, the accumulation of caesium in grass and feed is very limited, and the contamination in milk has reached very low values once again.

In 1986, certain wild mushroom species exhibited contamination levels for caesium above the reference values. In particular, mushrooms grown in the upper organic layer of forest soils, which was directly exposed to the radioactive deposition, contained high caesium levels. The contamination of these mushrooms reduced quickly because of the renewal of the litter and because of the downward migration of caesium in the soil profile. Other mushroom species

Caesium-137 concentration in cow's milk (Bq/l)

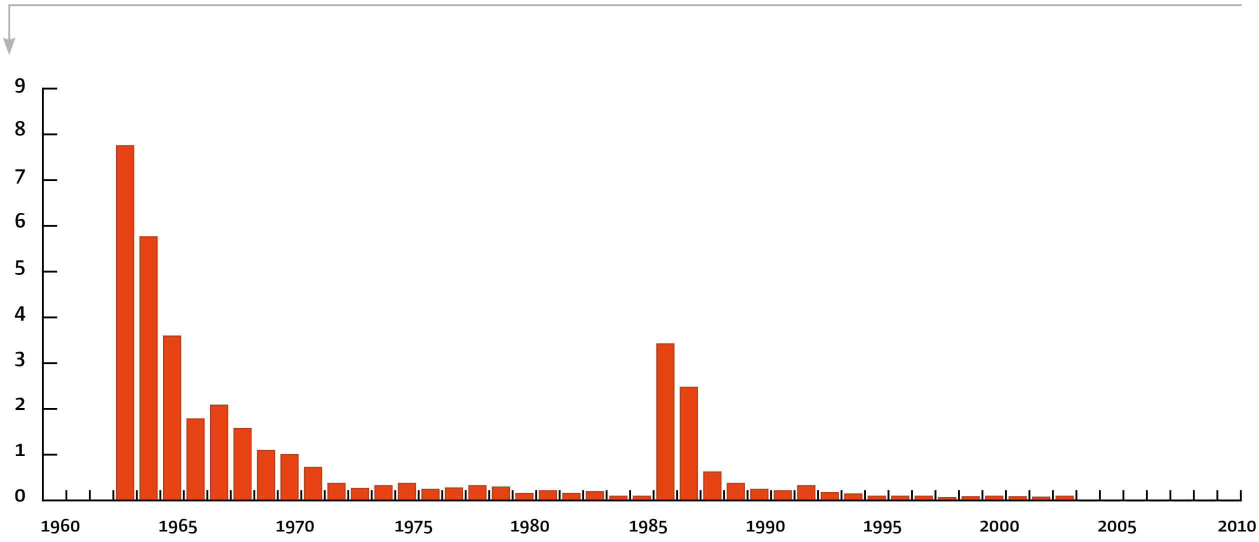


Fig. 13 – Caesium-137 contamination in cow's milk in a farm in the Mol-Dessel region (province of Antwerp). For comparison: the content of potassium-40, a natural radionuclide, is about 45 Bq/l in milk and its harmfulness is half of the harmfulness of caesium-137 (from 2004, the ceasium concentration is lower than measurable).

that obtain their nutrients from deeper humus layers in the woods, like the boletus, became contaminated much later, and their radio caesium levels have increased progressively. At present, certain mushroom species still show easily measurable caesium values, due to the long-lasting availability of caesium in the surface layers of forest soils.

Nowadays, very low contamination levels of caesium are found in almost all foodstuffs, comparable to the values before the Chernobyl accident. On the other hand, the contamination of soil in forests will decrease much more slowly during the coming decades. As a consequence, certain produce from semi-natural areas (mushrooms, berries and game) could very locally still show relatively high contamination levels.

4

Effect of Chernobyl on emergency planning in Belgium

After the Chernobyl accident, several measures were implemented to avoid certain problems in the event of future nuclear disasters. The lack of warning and notification by the Soviet Union showed the need for better communication, and the confusion concerning reference values for emergency measures led to European guidelines. We also discuss the organisation of the emergency response in Belgium.

Information flow and international assistance

The IAEA (International Atomic Energy Agency in Vienna) has established two conventions that are binding on all parties that have signed them: the “Convention on Early Notification of a Nuclear Accident” and the “Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency” – briefly referred to as the “Notification Convention” and the “Assistance Convention”. These conventions oblige all partners (including Belgium and its neighbouring countries) to notify the IAEA and to provide sufficient information in case of a nuclear accident with possible consequences for other countries. The IAEA then passes this information to the other partners. The Assistance Convention includes a number of agreements to officially request assistance from other countries, to simplify the formalities and to avoid administrative or legal problems as much as possible. At the European Union level there are also agreements to pass information to other member countries. At the moment, the aim is to harmonize the commitments towards Europe and the IAEA for the European member countries.

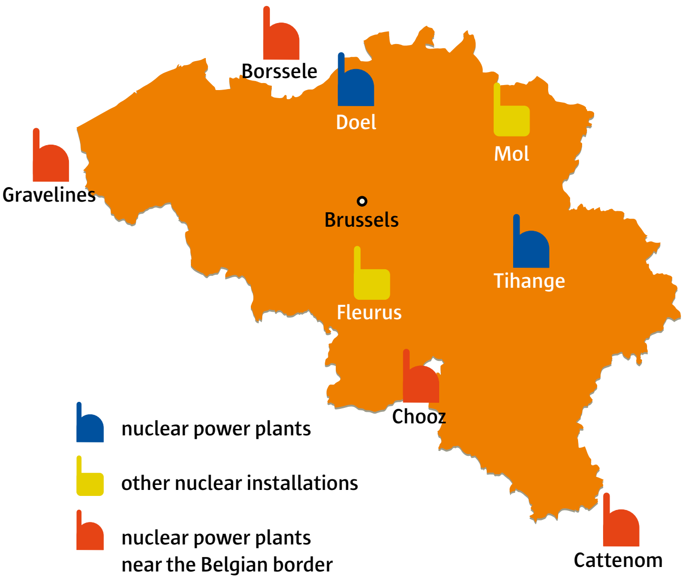
Reference values for contaminated agricultural products

At the moment of the Chernobyl disaster there were no unambiguous reference values for contamination levels below which agricultural produce could be sold and above which measures were necessary. This caused quite some confusion and led to different approaches being taken in several Western European countries as well as between the individual Belgian regions. In order to avoid similar problems in the future, the European Union issued regulations laying down the maximally permitted levels for trade in agricultural produce for human and animal consumption after a nuclear accident. The values depend on the nature of the products, their destination and the radioactive materials that cause the contamination. The European Commission decides on the implementation of these reference values in case of real need.

The Belgian organisation

After the nuclear disaster in Chernobyl, a senate committee investigated this crisis period. This led to detailed reports and recommendations. We describe below the main initiatives resulting from this investigation.

The Belgian emergency planning organisation
The responsibilities, organisational structure, intervention levels etc. concerning nuclear and radiological emergency planning were established by a Royal Decree in 1991. There was a review held in 2003 in order to include feedback from exercises and to address other important issues, such as radiological terrorism. The Royal Decree emphasizes the main Belgian sites and those in the vicinity of our borders (see figure 14).

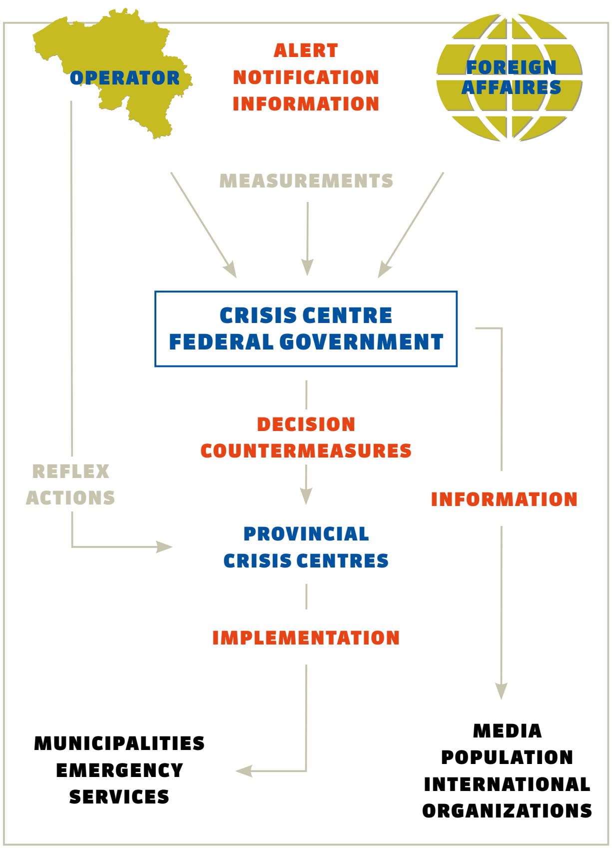


› *Fig. 14 – Key nuclear facilities in and around Belgium.*

The flow chart in figure 15 represents the structure of the organisation. If a nuclear disaster occurs in Belgium, the operator must inform (“notify”) the crisis centre of the government and pass on sufficient information so that the government can take a sound decision as to the necessary countermeasures for the population. If a serious accident occurs, a faster system called “alarm level reflex” would be initiated. In that case it is the governor’s responsibility to decide on a shelter measure in a pre-defined zone.

The operator is responsible for mitigating the consequences of the accident itself. If an accident occurs in another country, this is reported via the Ministry of Foreign Affairs, the European authorities or the IAEA. All data is passed to the government’s crisis centre in Brussels. This is where all information is collected and collated with available measurement data, weather forecasts and so on.

Radiological and technical experts analyse this data in the “evaluation cell”. This provides advice to the crisis committee, which consists of the main ministers under the leadership of the Minister of the Interior. In addition to the technical and radiological advice, a special advisory body provides socio-economic advice and operational and legal aspects are also taken into account. Taking all this advice into account, the crisis committee decides on which protection measures to take. The crisis committee in Brussels communicates its decisions to the provinces for further implementation. The provincial governors are responsible for the coordination of



› *Fig. 15 – Schematic representation of the organization of the Belgian nuclear emergency plan.*

measures affecting the population, in accordance with their own provincial nuclear emergency plans. The implementation occurs by activating several emergency services (fire brigades, police, medical services, civil protection) in co-operation with the municipalities. The flow of information to the population and the media occurs via the so-called “info cell”, which also operates from the government’s crisis centre. The most appropriate countermeasures that the government can take are: sheltering, evacuation, stable iodine administration (these iodine tablets are useful to protect the thyroid gland against radioactive iodine) and food chain restrictions (agriculture and drinking water), depending on the severity and the nature of the accident. The emergency preparedness is tested several times a year during nuclear emergency exercises.

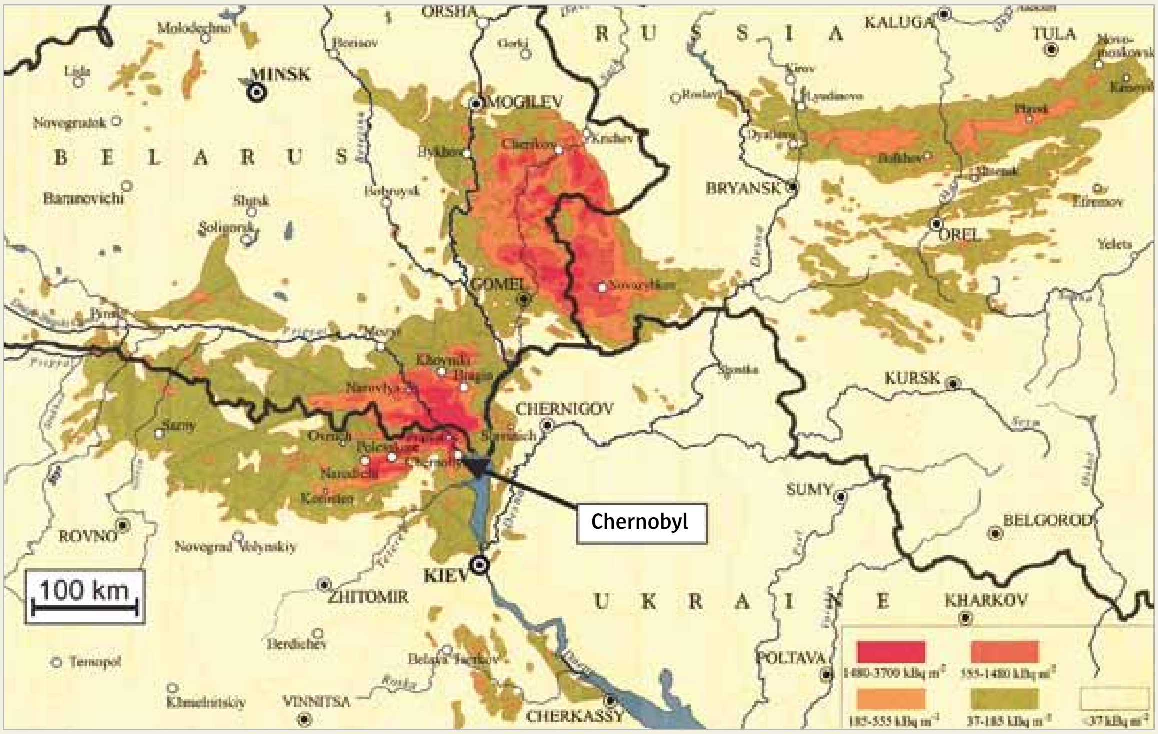
SCK•CEN is one of the main partners of the government for refining and maintaining the emergency organisation, including research and services in the field of atmospheric dispersion of radioactivity, development of measurement strategies and the preparation and integration of emergency procedures.

Federal Agency for Nuclear Control (FANC)

Another conclusion of the senate committee was that it would be better to entrust the control of the nuclear sector to a single government agency, the Federal Agency for Nuclear Control. This agency was founded officially by law in 1994, but it did not become operational until 2001 when the regulations concerning its financing were put into place. The members of the Scientific Board were appointed by a Ministerial Order only in 2003. At present, the Agency exercises control over the nuclear installations and supervises the safe use of ionizing radiation in Belgium (medical and industrial applications, energy production). It also plays an essential role in emergency planning.

TELERAD

Even before the Chernobyl accident, Belgium was already preparing an automatic measuring network for radioactivity, TELERAD. The accident led to a revision of the requirements of this network. The network consists of stations around the nuclear facilities as well as throughout the whole of Belgium. The network has been operational for many years. In case pre-defined radiation or activity levels are exceeded, an alarm is triggered automatically. The network is being modernised and adapted to further improve its sensitivity.



› *The radioactive contamination of the soil with caesium-137 up to some hundreds of kilometres from the reactor (situation on May 10, 1986). source: UNSCEAR 2000 Report, Annex J*

5

Summary

The accident in the nuclear power plant of Chernobyl was the worst accident ever in the history of the nuclear industry. During the execution of a test, the reactor was brought into an unstable and unverifiable condition, resulting in explosions and fires. Despite the valiant efforts of fire brigades and other emergency services, large quantities of radioactive materials were released during 10 days. In the absence of a reactor containment building, the entire inventory of noble gases and a large part of the volatile elements such as iodine and caesium spread into the atmosphere. Due to variable weather conditions (wind direction, precipitation...), the contamination pattern was very irregular and an area of about 150 000 km^2 in Belarus, Ukraine and Russia, i.e. 5 times the area of Belgium, became heavily contaminated by radioactivity.

The accident caused acute radiation syndrome amongst 134 rescue workers; 28 of whom died from this sickness in the first days and weeks after the accident. Later, 19 more people from this group died. Two people passed away due to accidents during the emergency actions, which brings the total of direct casualties to 49. The consequences for the local population were incalculable. Within a radius of 30 km round the power plant, everybody was evacuated. In 1986, 115 000 people were forced to leave their home; in the following years, another 220 000 people from more outlying regions were forced to do the same. Leaving goods and chattels behind was a very traumatic experience for many evacuated people. The accident also disrupted the life of the local population, resulting in various health complaints. The population had the feeling of being abandoned and of having to live as second-class citizens in an area contaminated by radioactivity.

During the past 25 years, the scientific community has examined the health effects of the radioactive contamination. Since 1990, a clear increase of thyroid cancer was found amongst people who as children were heavily exposed to radioactive iodine. The biggest increase is found amongst those who were younger than 4 years old at the time of the accident. Thus far, some 6 000 cases have been diagnosed and this higher risk is expected to remain for years. Only a few people in whom thyroid cancer was diagnosed have passed away. Experience has shown that people suffering from this type of cancer have a very high chance of survival.

It is difficult to prove scientifically other health effects. This does not mean that there are no additional cancers or hereditary defects, but that we are not able to distinguish them from the normal occurrence of these diseases. A limiting factor for epidemiological studies is the bad economic situation in which the affected regions found themselves after the collapse of the Soviet Union, with a worsening of the health care and a decrease in the average life expectancy. In these circumstances it is very difficult to draw scientifically significant conclusions about possible hereditary effects, congenital defects or cancers other than thyroid cancer.

The accident had no great impact in Belgium. In 1986, the dose due to Chernobyl was only a small fraction of the annual radiation exposure of the population and it has currently decreased to less than one ten thousandth of it.

The design of the Belgian nuclear power plants is completely different from the type in Chernobyl. Such an unstable operation causing the power output to increase quickly and automatically is not possible here. Our reactors are isolated from the environment by a containment building. A double structure of reinforced concrete and steel surrounds the Belgian power plants, in order to resist internal pressure and external forces, such as the impact of a plane crash. In addition to electricity production, the Chernobyl reactor was designed for the production of plutonium for military purposes. The nuclear fuel could be loaded and unloaded without shutting down the reactor.

Chernobyl had a great effect on the organisation of our nuclear emergency planning. The Soviet Union disguising the accident in the initial period, and the confusion afterwards as to which agricultural measures to take in the different countries of Western Europe, led to all kinds of measures:

- henceforth, national governments must immediately notify the IAEA (International Atomic Energy Agency in Vienna), the European Union and the affected neighbouring countries in case of a nuclear accident;
- the European Union established contamination levels for agricultural produce in case of future nuclear accidents;
- Belgium established a nuclear emergency plan, financed by a nuclear electricity production tax;
- Belgium established the automatic measuring network TELERAD for the permanent monitoring of radioactivity;
- Belgium founded the Federal Agency for Nuclear Control (FANC) in order to centralize the competences concerning radiation protection.

6 For more information

Relevant websites

www.sckcen.be
Contains all kinds of information, informative brochures and links to other sites concerning nuclear energy. The web versions of the Chernobyl brochure in English, Dutch and French are available at: http://www.sckcen.be/en/Science-Society/Documentation-Multimedia

www.iaea.org
Website from the International Atomic Energy Agency in Vienna. The Chernobyl Forum, a cooperative body between 8 institutions of the United Nations and the 3 affected republics, has made an estimation of the death toll among the most exposed population groups. The reports of the Chernobyl Forum are available via the IAEA website: http://www.iaea.org/NewsCenter/Focus/Chernobyl/

www.unscear.org
Website from the "United Nations Scientific Committee on the Effects of Atomic Radiation", an institution of the United Nations. The different UNSCEAR reports on the consequences of the Chernobyl accident are available on: http://www.unscear.org/unscear/en/chernobyl.html

www.nea.fr
Website of the "Nuclear Energy Agency". Here you can find a detailed report entitled "2002 update of Chernobyl: ten years on": http://www.nea.fr/html/rp/chernobyl/chernobyl.html

www.fanc.fgov.be
Website of the Belgian "Federal Agency for Nuclear Control" containing a link to the TELERAD website: http://telerad.fgov.be/

http://en.wikipedia.org/wiki/Chernobyl_disaster
Interesting site with a review of the Chernobyl accident

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SCK•CEN – Belgian Nuclear Research Centre
SCK•CEN is a foundation of public utility, with a legal status according to private law,
that operates under the tutorship of the Belgian Federal Minister of Energy.

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Publisher
Eric van Walle
Director-General

Design
meerwit.be

Picture cover
Evacuated town of Pripyat, abandoned shortly after the accident.
In the background the destroyed reactor complex (photo 2010).

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