CHERNOBYL-RADIOLOGICAL AND HEALTH IMPACT

Introduction

Several years after the Three Mile Island accident, in the United States, the Chernobyl accident completely changed the public's perception of nuclear risk. While the first accident provided the impetus to develop new research programmes on nuclear safety, the second, with its human death toll and the dispersion of a large part of the reactor core into the environment, raised a large number of problems of "management" not only for the treatment of severely exposed persons, but also for the decisions that had to be taken affecting the population. Clearly, the national authorities were not ready to manage an accident whose consequences were not confined to their territory.

On 26 April, 1986, the Chernobyl nuclear power station, in Ukraine, suffered a major accident which was followed by a prolonged release to the atmosphere of large quantities of radioactive substances. The specific features of the release favoured a widespread distribution of radioactivity throughout the northern hemisphere, mainly across Europe. A contributing factor was the variation of meteorological conditions and wind regimes during the period of release. Activity transported by the multiple plumes from Chernobyl was measured not only in Northern and in Southern Europe, but also in Canada, Japan and the United States. Only the Southern hemisphere remained free of contamination.

This had serious radiological, health and socio-economic consequences for the populations of Belarus, Ukraine and Russia, and to some extent they are still suffering from these consequences. Although the radiological impact of the accident in other countries was generally very low, and even insignificant outside Europe, this event had, however, the effect of enhancing public apprehension all over the world on the risks associated with the use of nuclear energy.

This is one of the reasons explaining the renewed attention and effort devoted during the last decade to the reactor safety studies and to emergency preparedness by public authorities and the nuclear industry. This also underlies the continuing attention of the public opinion to the situation at Chernobyl. The forthcoming tenth anniversary of the accident appears, therefore, the right moment to review the status of our knowledge of the serious aspects of the accident impact, to take stock of the information accumulated and the scientific studies underway, as well as to assess the degree to which national authorities and experts have implemented the numerous lessons that the Chernobyl accident taught us.

The accident

The Unit 4 of the Chernobyl nuclear power plant was to be shut down for routine maintenance on 25 April 1986. On that occasion, it was decided to carry out a test of the capability of the plant equipment to provide enough electrical power to operate the reactor core cooling system and emergency equipment during the transition period between a loss of main station electrical power supply and the start-up of the emergency power supply provided by diesel engines.

Unfortunately, this test, which was considered essentially to concern the non-nuclear part of the power plant, was carried out without a proper exchange of information and co-ordination between the team in charge of the test and the personnel in charge of the operation and safety of the nuclear reactor. Therefore, inadequate safety precautions were included in the test programme and the operating personnel were not alerted to the nuclear safety implications and potential danger of the electrical test.

This lack of co-ordination and awareness, resulting from an insufficient level of "safety culture" within the plant staff, led the operators to take a number of actions which deviated from established safety procedures and led to a potentially dangerous situation. This course of actions was compounded by the existence of significant drawbacks in the reactor design which made the plant potentially unstable and easily susceptible to loss of control in case of operational errors.

The combination of these factors provoked a sudden and uncontrollable power surge which resulted in violent explosions and almost total destruction of the reactor. The consequences of this catastrophic event were further worsened by the graphite moderator and other material fires that broke out in the building and contributed to a widespread and prolonged release of radioactive materials to the environment.

Dispersion and deposition of radionuclides

The release of radioactive materials to the atmosphere consisted of gases, aerosols and finely fragmented nuclear fuel particles. This release was extremely high in quantity, involving a large fraction of the radioactive product inventory existing in the reactor, and its duration was unexpectedly long, lasting for more than a week. This duration and the high altitude (about 1 km) reached by the release were largely due to the graphite fire which was very difficult to extinguish.

For these reasons and the concomitant frequent changes of wind direction during the release period, the area affected by the radioactive plume and the consequent deposition of radioactive substances on the ground was extremely large, encompassing the whole Northern hemisphere, although significant contamination outside the former Soviet Union was only experienced in part of Europe. The pattern of contamination on the ground and in food chains was, however, very uneven in some areas due to the influence of rainfall during the passage of the plume. This irregularity in the pattern of deposition was particularly pronounced at larger distances from the reactor site.

Reactions of national authorities

The scale and severity of the Chernobyl accident had not been foreseen and took most national authorities responsible for public health and emergency preparedness by surprise.

The intervention criteria and procedures existing in most countries were not adequate for dealing with an accident of such scale and provided little help in decision-making concerning the choice and adoption of protective measures. In addition, early in the course of the accident there was little information available and considerable political pressure, partially based on the public perception of the radiation danger, was being exerted on the decision-makers.

In these circumstances, cautious immediate actions were felt necessary and in many cases measures were introduced that tended to err, sometimes excessively so, on the side of prudence rather than being driven by informed scientific and expert judgement.

Within the territory of the former Soviet Union, short-term countermeasures were massive and, in general, reasonably timely and effective. However, difficulties emerged when the authorities tried to establish criteria for the management of the contaminated areas on the long term and the associated relocation of large groups of population. Various approaches were proposed and criteria were applied over the years. Eventually, criteria for population resettlement or relocation from contaminated areas were adopted in which radiation protection requirements and economic compensation considerations were intermingled. This was and continues to be a source of confusion and possible abuse.

The progressive spread of contamination at large distances from the accident site caused considerable concern in many countries outside the former Soviet Union and the reactions of the national authorities to this situation were extremely varied, ranging from a simple intensification of the normal environmental monitoring programmes, without adoption of specific countermeasures, to compulsory restrictions concerning the marketing and consumption of foodstuffs.

Apart from the objective differences of contamination levels and regulatory and public health systems between countries, one of the principal reasons for the variety of situations observed in the different countries stems from the different criteria adopted for the choice and application of intervention levels for the implementation of protective actions. These discrepancies were in some cases due to misinterpretation and misuse of international radiation protection guidelines, especially in the case of food contamination, and were further enhanced by the overwhelming role played in many cases by non-radiological factors, such as socioeconomic, political and psychological, in determining the countermeasures.

This situation caused concern and confusion among the public, perplexities among the experts and difficulties to national authorities, including problems of public credibility, as well as a waste of efforts and unnecessary economic losses. These problems were particularly felt in areas close to international borders due to different reactions of the authorities and media in bordering countries. However, all these issues were soon identified as an area where several lessons should be learned and international efforts were undertaken to harmonise criteria and approaches to emergency management.

Radiation dose estimates

Most of the population of the Northern hemisphere was exposed, to various degrees, to radiation from the Chernobyl accident. After several years of accumulation of dosimetric data from all available sources and dose reconstruction calculations based on environmental contamination data and mathematical models, it is now possible to arrive at a reasonable, although not highly accurate, assessment of the ranges of doses received by the various groups of population affected by the accident.

The main doses of concern are those to the thyroid due to external irradiation and inhalation and ingestion of radioactive iodine isotopes, and those to the whole body due to external irradiation from and ingestion of radioactive caesium isotopes. According to current estimates, the situation for the different exposed groups is the following:

* ***Evacuees*** - More than 100,000 persons were evacuated, mostly from the 30-km radius area around the accident site, during the first few weeks following the accident. These people received significant doses both to the whole body and the thyroid, although the distribution of those doses was very variable among them depending on their positions around the accident site and the delays of their evacuation.

Doses to the thyroid ranging from 70 millisieverts to adults up to about 1,000 millisieverts (*i.e.,* 1 sievert) to young children and an average individual dose of 15 millisieverts [mSv] to the whole body were estimated to have been absorbed by this population prior to their evacuation. Many of these people continued to be exposed, although to a lesser extent depending on the sites of their relocation, after their evacuation from the 30-km zone.

* ***"Liquidators"*** - Hundreds of thousands of workers, estimated to amount up to 800,000 and including a large number of military personnel, were involved in the emergency actions on the site during the accident and the subsequent clean-up operations which lasted for a few years. These workers were called "liquidators".

A restricted number, of the order of 400, including plant staff, firemen and medical aid personnel, were on the site during the accident and its immediate aftermath and received very high doses from a variety of sources and exposure pathways. Among them were all those who developed acute radiation syndrome and required emergency medical treatment. The doses to these people ranged from a few grays to well above 10 grays to the whole body from external irradiation and comparable or even higher internal doses, in particular to the thyroid, from incorporation of radionuclides. A number of scientists, who periodically performed technical actions inside the destroyed reactor area during several years, accumulated over time doses of similar magnitude.

The largest group of liquidators participated in clean-up operations for variable durations over a number of years after the accident. Although they were not operating anymore in emergency conditions and were submitted to controls and dose limitations, they received significant doses ranging from tens to hundreds of millisieverts.

⋆***People living in contaminated areas of the former Soviet Union -*** About 270,000 people continue to live in contaminated areas with radiocaesium deposition levels in excess of 555 kilobecquerels per square metre [kBq/m2], where protection measures still continue to be required. Thyroid doses, due mainly to the consumption of cow's milk contaminated with radioiodine, were delivered during the first few weeks after the accident; children in the Gomel region of Belarus appear to have received the highest thyroid doses with a range from negligible levels up to 40 sieverts and an average of about 1 sievert for children aged 0 to 7. Because of the control of foodstuffs in those areas, most of the radiation exposure since the summer of 1986 is due to external irradiation from the radiocaesium activity deposited on the ground; the whole-body doses for the 1986-89-time period are estimated to range from 5 to 250 mSv with an average of 40 mSv.

⋆***Populations outside the former Soviet Union -*** The radioactive materials of a volatile nature (such as iodine and caesium) that were released during the accident spread throughout the entire Northern hemisphere. The doses received by populations outside the former Soviet Union are relatively low, and show large differences from one country to another depending mainly upon whether rainfall occurred during the passage of the radioactive cloud. These doses range from a lower extreme of a few microsieverts or tens of microsieverts outside Europe, to an upper extreme of 1 or 2 mSv in some European countries. The latter value is of the same order as the annual individual exposure from natural background radiation.

Health impact

The health impact of the Chernobyl accident can be described in terms of acute health effects (death, severe health impairment), late health effects (cancers) and psychological effects liable to affect health.

1. The acute health effects occurred among the plant personnel and the persons who intervened in the emergency phase to fight fires, provide medical aid and immediate clean-up operations. A total of 31 persons died as a consequence of the accident, and about 140 persons suffered various degrees of radiation sickness and health impairment. No members of the general public suffered these kinds of effects.
2. As far as the late health effects are concerned, namely the possible increase of cancer incidence, in the decade following the accident there has been a real and significant increase of carcinomas of the thyroid among the children living in the contaminated regions of the former Soviet Union, which should be attributed to the accident until proved otherwise. There might also be some increase of thyroid cancers among the adults living in those regions. From the observed trend of this increase of thyroid cancers it is expected that the peak has not yet been reached and that this kind of cancer will still continue for some time to show an excess above its natural rate in the area.

On the other hand, the scientific and medical observation of the population has not revealed any increase in other cancers, as well as in leukaemia, congenital abnormalities, adverse pregnancy outcomes or any other radiation induced disease that could be attributed to the Chernobyl accident. This observation applies to the whole general population, both within and outside the former Soviet Union. Large scientific and epidemiological research programmes, some of them sponsored by international organisations such as the WHO and the EC, are being conducted to provide further insight into possible future health effects. However, the population dose estimates generally accepted tend to indicate that, with the exception of thyroid disease, it is unlikely that the exposure would lead to discernible radiation effects in the general population above the background of natural incidence of the same diseases. In the case of the liquidators this forecast should be taken with some caution.

An important effect of the accident, which has a bearing on health, is the appearance of a widespread status of psychological stress in the populations affected. The severity of this phenomenon, which is mostly observed in the contaminated regions of the former Soviet Union, appears to reflect the public fears about the unknowns of radiation and its effects, as well as its mistrust towards public authorities and official experts, and is certainly made worse by the disruption of the social networks and traditional ways of life provoked by the accident and its long-term consequences.

Agricultural and environmental impacts

The impact of the accident on agricultural practices, food production and use and other aspects of the environment has been and continues to be much more widespread than the direct health impact on humans.

Several techniques of soil treatment and decontamination to reduce the accumulation of radioactivity in agricultural produce and cow's milk and meat have been experimented with positive results in some cases. Nevertheless, within the former Soviet Union large areas of agricultural land are still excluded from use and are expected to continue to be so for a long time. In a much larger area, although agricultural and dairy production activities are carried out, the food produced is subjected to strict controls and restrictions of distribution and use.

Similar problems of control and limitation of use, although of a much lower severity, were experienced in some countries of Europe outside the former Soviet Union, where agricultural and farm animal production were subjected to restrictions for variable durations after the accident. Most of these restrictions have been lifted several years ago. However, there are still today some areas in Europe where restrictions on slaughter and distribution of animals are in force. This concerns, for example, several hundreds of thousands of sheep in the United Kingdom and large numbers of sheep and reindeer in some Nordic countries.

A kind of environment where special problems were and continue to be experienced is the forest environment. Because of the high filtering characteristics of trees, deposition was often higher in forests than in other areas. An extreme case was the so-called "red forest" near to the Chernobyl site where the irradiation was so high as to kill the trees which had to be destroyed as radioactive waste. In more general terms, forests, being a source of timber, wild game, berries and mushrooms as well as a place for work and recreation, continue to be of concern in some areas and are expected to constitute a radiological problem for a long time.

Water bodies, such as rivers, lakes and reservoirs can be, if contaminated, an important source of human radiation exposure because of their uses for recreation, drinking and fishing. In the case of the Chernobyl accident this segment of the environment did not contribute significantly to the total radiation exposure of the population. It was estimated that the component of the individual and collective doses that can be attributed to the water bodies and their products did not exceed 1 or 2 percent of the total exposure resulting from the accident. The contamination of the water system has not posed a public health problem during the last decade; nevertheless, in view of the large quantities of radioactivity deposited in the catchment area of the system of water bodies in the contaminated regions around Chernobyl, there will continue to be for a long time a need for careful monitoring to ensure that washout from the catchment area will not contaminate drinking-water supplies.

Outside the former Soviet Union, no concerns were ever warranted for the levels of radioactivity in drinking water. On the other hand, there are lakes, particularly in Switzerland and the Nordic countries, where restrictions were necessary for the consumption of fish. These restrictions still exist in Sweden, for example, where thousands of lakes contain fish with a radioactivity content which is still higher than the limits established by the authorities for sale on the market.

Potential residual risks

Within seven months of the accident, the destroyed reactor was encased in a massive concrete structure, known as the "sarcophagus", to provide some form of confinement of the damaged nuclear fuel and destroyed equipment and reduce the likelihood of further releases of radioactivity to the environment. This structure was, however, not conceived as a permanent containment but rather as a provisional barrier pending the definition of a more radical solution for the elimination of the destroyed reactor and the safe disposal of the highly radioactive materials.

Nine years after its erection, the sarcophagus structure, although still generally sound, raises concern for its, long-term resistance and represents a standing potential risk. In particular, the roof of the structure presented for a long time numerous cracks with consequent impairment of leaktightness and penetration of large quantities of rain water which is now highly radioactive. This also creates conditions of high humidity producing corrosion of metallic structures which contribute to the support of the sarcophagus. Moreover, some massive concrete structures, damaged or dislodged by the reactor explosion, are unstable and their failure, due to further degradation or to external events, could provoke a collapse of the roof and part of the building.

According to various analyses, a number of potential accidental scenarios could be envisaged. They include a criticality excursion due to change of configuration of the melted nuclear fuel masses in the presence of water leaked from the roof, a resuspension of radioactive dusts provoked by the collapse of the enclosure and the long-term migration of radionuclides from the enclosure into the groundwater. The first two accident scenarios would result in the release of radionuclides into the atmosphere which would produce a new contamination of the surrounding area within a radius of several tens of kilometres. It is not expected, however, that such accidents could have serious radiological consequences at longer distances.

As far as the leaching of radionuclides from the fuel masses by the water in the enclosure and their migration into the groundwater are concerned, this phenomenon is expected to be very slow and it has been estimated that, for example, it will take 45 to 90 years for certain radionuclides such as strontium90 to migrate underground up to the Pripyat River catchment area. The expected radiological significance of this phenomenon is not known with certainty and a careful monitoring of the evolving situation of the groundwater will need to be carried out for a long time.

The accident recovery and clean-up operations have resulted in the production of very large quantities of radioactive wastes and contaminated equipment which are currently stored in about 800 sites within and outside the 30-km exclusion zone around the reactor. These wastes and equipment are partly buried in trenches and partly conserved in containers isolated from groundwater by clay or concrete screens. A large number of contaminated equipment, engines and vehicles are also stored in the open air.

All these wastes are a potential source of contamination of the groundwater which will require close monitoring until a safe disposal into an appropriate repository is implemented.

In general, it can be concluded that the sarcophagus and the proliferation of waste storage sites in the area constitute a series of potential sources of release of radioactivity that threatens the surrounding area. However, any such releases are expected to be very small in comparison with those from the Chernobyl accident in 1986 and their consequences would be limited to a relatively small area around the site. On the other hand, concerns have been expressed by some experts that a much more important release might occur if the collapse of the sarcophagus should induce damage in the Unit 3 of the Chernobyl power plant, which currently is still in operation.

In any event, initiatives have been taken internationally, and are currently underway, to study a technical solution leading to the elimination of these sources of residual risk on the site.

Lessons learned

The Chernobyl accident was very specific in nature and it should not be seen as a reference accident for future emergency planning purposes. However, it was very clear from the reactions of the public authorities in the various countries that they were not prepared to deal with an accident of this magnitude and that technical and/or organisational deficiencies existed in emergency planning and preparedness in almost all countries.

The lessons that could be learned from the Chernobyl accident were, therefore, numerous and encompassed all areas, including reactor safety and severe accident management, intervention criteria, emergency procedures, communication, medical treatment of irradiated persons, monitoring methods, radioecological processes, land and agricultural management, public information, etc.

However, the most important lesson learned was probably the understanding that a major nuclear accident has inevitable transboundary implications and its consequences could affect, directly or indirectly, many countries even at large distances from the accident site. This led to an extraordinary effort to expand and reinforce international co-operation in areas such as communication, harmonisation of emergency management criteria and co-ordination of protective actions. Major improvements were achieved in this decade and important international mechanisms of co-operation and information were established, such as the international conventions on early notification and assistance in case of a radiological accident, by the IAEA and the EC, the international nuclear emergency exercises (INEX) programme, by the NEA, the international accident severity scale (INES), by the IAEA and NEA and the international agreement on food contamination, by the FAO and WHO.

At the national level, the Chernobyl accident also stimulated authorities and experts to a radical review of their understanding of and attitude to radiation protection and nuclear emergency issues. This prompted many countries to establish nationwide emergency plans in addition to the existing structure of local emergency plans for individual nuclear facilities. In the scientific and technical area, besides providing new impetus to nuclear safety research, especially on the management of severe nuclear accidents, this new climate led to renewed efforts to expand knowledge on the harmful effects of radiation and their medical treatment and to revitalise radioecological research and environmental monitoring programmes. Substantial improvements were also achieved in the definition of criteria and methods for the information of the public, an aspect whose importance was particularly evident during the accident and its aftermath.

Conclusion

The history of the modern industrial world has been affected on many occasions by catastrophes comparable or even more severe than the Chernobyl accident. Nevertheless, this accident, due not only to its severity but especially to the presence of ionising radiation, had a significant impact on human society.

Not only it produced severe health consequences and physical, industrial and economic damage in the short term, but, also, its long-term consequences in terms of socio-economic disruption, psychological stress and damaged image of nuclear energy, are expected to be long standing.

However, the international community has demonstrated a remarkable ability to apprehend and treasure the lessons to be drawn from this event, so that it will be better prepared to cope with a challenge of this kind, if ever a severe nuclear accident should happen again.