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OPEN PARTIAL AGREEMENT ON THE PREVENTION OF, PROTECTION AGAINST AND ORGANISATION OF RELIEF IN MAJOR NATURAL AND TECHNOLOGICAL DISASTERS

International Conference

Twenty Years after the Chernobyl Accident.

Future Outlook

Kyiv, Ukraine, April 24-26, 2006

CONCLUSIONS AND RECOMMENDATIONS

ORGANIZERS OF THE CONFERENCE

Government of Ukraine

in co-operation with:

Government of the Republic of Belarus

Government of the Russian Federation

European Commission

International Atomic Energy Agency

World Health Organization

United Nation Development Programme

Council of Europe

European Centre of Technological Safety

International Charitable Fund « Ukraine 3000 »

Institute of Radiation Protection and Nuclear Safety, France

Society for Technical and Nuclear Safety GRS, Germany

1. Introduction

These Conclusions and Recommendations of the International Conference "Twenty Years after the Chernobyl accident. Future Outlook ", held in Kiev on April 24-26, 2006, are based on :

- Conclusions of the Chernobyl Forum, 6-7 September 2005, Vienna, Austria;
- Conclusions of the International Conference “Chernobyl 20 years after: Local and regional authorities facing catastrophes”, Slavutych (Ukraine), 2 – 4 March 2006;
- Conclusions of the International Conference on the occasion of the 20th Anniversary of the Catastrophe at the Chernobyl Nuclear Power Plant held in Minsk and Gomel, Belarus, April 19-21, 2006;
- Executive Summary of the International Conference Fifteen Years after the Chernobyl Accident: Lessons Learned, Kyiv, Ukraine, April , 2001; as well as
- the conclusions of other international conferences; the material provided in the national and invited reports and the session conclusions of this Conference.

The Conference recommends that these Conclusions and Recommendations be used for future decision-making.

The Conference is being held to mark the 20th anniversary of the Chernobyl accident. The accident had major social, political, economic, health and environmental impacts both in the immediately affected countries and beyond. Despite the passage of two decades, considerable resources continue to be allocated to addressing the legacy of the accident, in particular the continuing management and socio-economic regeneration of contaminated settlements and ensuring the long term safety of the damaged reactor and its surroundings. On a more positive note, the accident acted as an important global stimulus to further improve nuclear safety and radiation protection, in particular in the area of emergency preparedness and response.

The purpose of the Conference is to review, consolidate and share the vast experience gained over the past two decades in responding to and managing the diverse and continuing impacts of the Chernobyl accident. A further objective will be to look forwards to identify what still needs to be done to further mitigate the continuing impacts of the accident and whether new policy initiatives are warranted, regionally or internationally. The main Conference outcome will be a world better prepared to manage any future nuclear accident or radiological emergency.

Based on a common understanding of the causes and consequences of the accident, as well as the efficiency of the response, the Conference has determined the main lessons learned from the Chernobyl catastrophe and has drawn the following conclusions and recommendations.

2. Background

On 26 April 1986, the most serious accident in the history of the nuclear industry occurred at Unit 4 of the Chernobyl nuclear power plant in the former Ukrainian Republic of the Union of Soviet Socialist Republics, near the present borders of Belarus, the Russian Federation and Ukraine.

The Chernobyl accident was the result of an inherently unsafe reactor design combined with serious deficiencies in "safety culture". The reactor was insufficiently safely constructed. Additionally, the operators were not informed of all design weaknesses. The test conditions were not approved under nuclear safety aspects. Finally the operators did not comply with operational procedures. Only the combination of these factors provoked the worst nuclear accident in which the reactor was totally destroyed within a few seconds.

Major releases of radionuclides from unit 4 of the Chernobyl reactor continued for ten days following the April 26 explosion. These included radioactive gases, condensed aerosols and a large amount of fuel particles. The total release of radioactive substances was about 14 Ebq [1], including 1.8 EBq of iodine-131, 0.085 EBq of ^{137}Cs, 0.01 EBq of 90Sr and 0.003 EBq of plutonium radioisotopes. The noble gases contributed about 50% of the total release.

More than 200,000 square kilometres of Europe received levels of ^{137}Cs above 37 kBq m^{-2}. Over 70 percent of this area was in the three most affected countries, Belarus, Russia and Ukraine. The deposition was extremely varied, as it was enhanced in areas where it was raining when the contaminated air masses passed. Most of the strontium and plutonium radioisotopes were deposited within 100 km of the destroyed reactor due to larger particle sizes.

Many of the most significant radionuclides had short physical half-lives. Thus, most of the radionuclides released by the accident have decayed away. The releases of radioactive iodines caused great concern immediately after the accident. For the decades to come ^{137}Cs will continue to be of greatest importance, with secondary attention to ^{90}Sr. Over the longer term (hundreds to thousands of years) the plutonium isotopes and americium-241 will remain, although at levels not significant radiologically.

Radionuclides deposited most heavily on open surfaces in urban areas, such as lawns, parks, streets, roads, town squares, building roofs and walls. Under dry conditions, trees, bushes, lawns and roofs initially had the highest levels, whereas under wet conditions horizontal surfaces, such as soil plots and lawns, received the highest levels. Enhanced ^{137}Cs concentrations were found around houses where the rain had transported the radioactive material from the roofs to the ground.

The deposition in urban areas in the nearest city of Pripyat and surrounding settlements could have initially given rise to a substantial external dose. However, this was to a large extent averted by the timely evacuation of residents. The deposition of radioactive material in other urban areas has resulted in various levels of radiation exposure to people in subsequent years and continues to this day at lower levels.

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[1] 1 EBq = 10^{18} Bq (Becquerel).

At present, in most of the settlements subjected to radioactive contamination as a result of Chernobyl, the air dose rate above solid surfaces has returned to the background level predating the accident.

The territories contaminated as a result of the accident have been intensively monitored and studied for two decades and the behaviour of the main contaminants, caesium and strontium, is well understood. A wide range of effective countermeasures has been established and implemented by the respective Governments to maintain radiation and contamination levels below national standards.

In the early months after the accident, the levels of radioactivity of agricultural plants and plant-consuming animals were dominated by surface deposits of radionuclides. The deposition of radioiodine caused the most immediate concern, but the problem was confined to the first two months after the accident because of fast decay of the most important isotope, ^{131}I.

The radioiodine was rapidly absorbed into milk at a high rate leading to significant thyroid doses to people consuming milk, especially children in Belarus, Russia and Ukraine. In the rest of Europe increased levels of radioiodine in milk were observed in some southern areas, where dairy animals were already outdoors.

After the early phase of direct deposit, uptake of radionuclides through plant roots from soil became increasingly important. Radioisotopes of caesium (^{137}Cs and ^{134}Cs) were the nuclides which led to the largest problems, and even after decay of ^{134}Cs (half-life of 2.1 years) by the mid-1990s the levels of longer-lived ^{137}Cs in agricultural products from highly affected areas still may require environmental remediation. In addition, ^{90}Sr could cause problems in areas close to the reactor, but at greater distances its deposition levels were low. Other radionuclides such as plutonium isotopes and ^{241}Am did not cause real problems in agriculture, either because they were present at low deposition levels, or were poorly available for root uptake from soil.

In general, there was a substantial reduction in the transfer of radionuclides to vegetation and animals in intensive agricultural systems in the first few years after deposition, as would be expected due to weathering, physical decay, migration of radionuclides down the soil, reductions in bioavailability in soil and due to countermeasures.

The radiocaesium content in foodstuffs was influenced not only by deposition levels but also by types of ecosystem and soil as well as by management practices. The remaining persistent problems in the affected areas occur in extensive agricultural systems with soils with a high organic content and animals grazing in unimproved pastures that are not ploughed or fertilized. This particularly affects rural residents in the former Soviet Union who are commonly subsistence farmers with privately owned dairy cows.

In the long term ^{137}Cs in milk and meat and, to a lesser extent, ^{137}Cs in plant foods and crops remain the most important contributors to human internal dose. As ^{137}Cs activity concentration in both vegetable and animal foods has been decreasing very slowly during the last decade, the relative contribution of ^{137}Cs to internal dose will continue to dominate for decades to come. The importance of other long-lived radionuclides, ^{90}Sr, plutonium isotopes and ^{241}Am, in terms of the human dose will remain insignificant.

Currently, ^{137}Cs activity concentrations in agricultural food products produced in areas affected by the Chernobyl fallout are generally below national and international action levels. However, in some limited areas with high radionuclide contamination (parts of the Gomel and Mogilev regions in Belarus and the Bryansk region in Russia) or poor organic soils (the Zhytomir and

Rovno regions in the Ukraine) milk may still be produced with ^{137}Cs activity concentrations that exceed national action levels of 100 Bq per kilogram. In these areas countermeasures and environmental remediation may still be warranted.

Following the accident vegetation and animals in forests and mountain areas have shown particularly high uptake of radiocaesium, with the highest recorded ^{137}Cs levels found in forest food products. This is due to the persistent recycling of radiocaesium particularly in forest ecosystems.

Particularly high ^{137}Cs activity concentrations have been found in mushrooms, berries, and game, and these high levels have persisted for two decades. Thus, while the magnitude of human exposure through agricultural products has experienced a general decline, high levels of contamination of forest food products have continued and still exceed permissible levels in some countries. In some areas of Belarus, Russia and Ukraine, consumption of forest foods with ^{137}Cs dominates internal exposure. This can be expected to continue for several decades.

Therefore, the relative importance of forests in contributing to radiological exposures of the populations of several affected countries has increased with time. It will primarily be the combination of downward migration in the soil and the physical decay of ^{137}Cs that will contribute to any further slow long-term reduction in contamination of forest food products.

The high transfer of radiocaesium in the pathway lichen-to-reindeer meat-to-humans has been demonstrated again after the Chernobyl accident in the Arctic and sub-Arctic areas of Europe. The Chernobyl accident led to high levels of ^{137}Cs of reindeer meat in Finland, Norway, Russia and Sweden and caused significant difficulties for the indigenous Sami people.

Radioactive material from Chernobyl resulted in levels of radioactive material in surface water systems in areas close to the reactor site and in many other parts of Europe. The initial levels were due primarily to direct deposition of radionuclides on the surface of rivers and lakes, dominated by short-lived radionuclides (primarily ^{131}I). In the first few weeks after the accident, high activity concentrations in drinking water from the Kyiv Reservoir were of particular concern.

Levels in water bodies fell rapidly during the weeks after fallout through dilution, physical decay and absorption of radionuclides to catchment soils. Bed sediments are an important long-term sink for radioactivity.

While ^{137}Cs and ^{90}Sr levels in water and fish of rivers, open lakes and reservoirs are currently low, in some "closed" lakes with no outflowing streams in Belarus, Russia and Ukraine both water and fish will remain contaminated with ^{137}Cs for decades to come. For example, for some people living next to a "closed" Kozhanovskoe Lake in Russia, consumption of fish has dominated their total ^{137}Cs ingestion.

Owing to the large distance of the Black and Baltic Seas from Chernobyl, and the dilution in these systems, activity concentrations in sea water were much lower than in freshwater. The low water radionuclide levels combined with low bioaccumulation of radiocaesium in marine biota has led to ^{137}Cs levels in marine fish that are not of concern.

Soviet and, later, Commonwealth of Independent States (CIS) authorities introduced a wide range of short- and long-term countermeasures to mitigate the accident's negative consequences. The countermeasures involved huge human, financial and scientific resources.

Decontamination of settlements in contaminated regions of the USSR during the first years after the Chernobyl accident was successful in reducing the external dose when its implementation was preceded by proper remediation assessment.

The most effective agricultural countermeasures in the early phase were exclusion of contaminated pasture grasses from animal diets and rejection of milk based on radiation monitoring data. Feeding animals with "clean" fodder was effectively performed in some affected countries. However, these countermeasures were only partially effective in reducing radioiodine intake via milk because of the lack of timely information about the accident and necessary responses, particularly for private farmers.

The greatest long-term problem has been radiocaesium contamination of milk and meat. In the USSR and later in the CIS countries, this has been addressed by the treatment of land used for fodder crops, clean feeding and application of Cs-binders, such as Prussian blue, to animals that enabled most farming practices to continue in affected areas and resulted in a large dose reduction.

Application of agricultural countermeasures in the affected CIS countries substantially decreased since the middle of 1990s (to less extent in Belarus) because of economic problems. In a short time, this resulted in an increase of radionuclide content in plant and animal agricultural products.

In Western Europe, because of the high and prolonged uptake of radiocaesium in the affected extensive systems, a range of countermeasures are still being used for animal products from uplands and forests.

The response of the natural environment to the accident was a complex interaction between radiation dose and radiosensitivities of the different plants and animals. Both individual and population effects caused by radiation-induced cell death have been observed in biota inside the Exclusion Zone as follows:

- Increased mortality of coniferous plants, soil invertebrates and mammals; and
- Reproductive losses in plants and animals.

No adverse radiation-induced effect has been reported in plants and animals exposed to a cumulative dose of less than 0.3 Gy during the first month after the accident.

Following the natural reduction of exposure levels due to radionuclide decay and migration, biological populations have been recovering from acute radiation effects. As soon as by the next growing season following the accident, population viability of plants and animals had substantially recovered as a result of the combined effects of reproduction and immigration from less affected areas. A few years were needed for recovery from major radiation-induced adverse effects in plants and animals.

Genetic effects of radiation, in both somatic and germ cells, have been observed in plants and animals of the exclusion zone during the first few years after the Chernobyl accident. Both in the exclusion zone, and beyond, different cytogenetic anomalies attributable to radiation continue to be reported from experimental studies performed on plants and animals. Whether the observed cytogenetic anomalies in somatic cells have any detrimental biological significance is not known.

The recovery of affected biota in the exclusion zone has been facilitated by the removal of human activities, e.g., termination of agricultural and industrial activities. As a result, populations of many plants and animals have eventually expanded, and the present environmental conditions have had a positive impact on the biota in the Exclusion Zone. Indeed, the Exclusion Zone has paradoxically become a unique sanctuary for biodiversity.

The accidental destruction of Chernobyl's Unit 4 reactor generated extensive spread of radioactive material and a large amount of radioactive waste in the Unit, at the plant site and in the surrounding area. Construction of the Shelter between May and November 1986, aiming at environmental containment of the damaged reactor, reduced radiation levels on-site and prevented further release of radionuclides off-site.

The Shelter was erected in a short period under conditions of severe radiation exposure to personnel. Measures taken to save construction time led to imperfections in the Shelter as well as to lack of comprehensive data on the stability of the damaged Unit 4 structures. In addition, structural elements of the Shelter have degraded due to moisture-induced corrosion during the nearly two decades since it was erected. The main potential hazard of the Shelter is a possible collapse of its top structures and release of radioactive dust into the environment.

To avoid the potential collapse of the Shelter, measures are planned to strengthen unstable structures. In addition, a New Safe Confinement (NSC) that should provide more than 100 years service life is planned as a cover over the existing Shelter. The construction of the NSC is expected to allow for the dismantlement of the current Shelter, removal of highly radioactive Fuel Containing Mass (FCM) from Unit 4, and eventual decommissioning of the damaged reactor.

In the course of remediation activities both at the Chernobyl nuclear power plant site and in its vicinity, large volumes of radioactive waste were generated and placed in temporary near-surface waste storage and disposal facilities. trench and landfill facilities were created from 1986 to 1987 in the Exclusion Zone at distances of 0.5 to 15 km from the reactor site with the intention to avoid the spread of dust, reduce the radiation levels, and enable better working conditions at Unit 4 and in its surroundings. These facilities were established without proper design documentation and engineered barriers and do not meet contemporary waste disposal safety requirements.

During the years following the accident large resources were expended to provide a systematic analysis and an acceptable strategy for management of existing radioactive waste. However, to date a broadly accepted strategy for radioactive waste management at the Chernobyl power plant site and the Exclusion Zone, and especially for high-level and long-lived waste, has not yet been developed.

More radioactive waste is potentially expected to be generated in Ukraine in the years to come during NSC construction, possible Shelter dismantling, FCM removal and decommissioning of Unit 4. This waste should be properly disposed of.

The overall plan for the long-term development of the Exclusion Zone in Ukraine is to recover the affected areas, redefine the Exclusion Zone, and make the less affected areas available for limited use by the public. This will require well defined administrative controls on the nature of activities that may be performed in the particular areas. In some of them, restriction of food crops planting and cattle grazing, and use of only clean feed for cattle still may be needed for decades to come for radiological reasons. Accordingly, these resettled areas are best suited for an industrial use rather than an agricultural or residential area.

The future of the Exclusion Zone for the next hundred years and more is envisaged to be associated with the following activities:

- Construction and operation of the NSC and relevant engineering infrastructure;

- De-fuelling, decommissioning and dismantling of Units 1, 2 and 3 of the nuclear power plant and the Shelter;
- Construction of facilities for processing and management of radioactive waste, in particular a deep geological repository for high-activity and long-lived radioactive material;
- Development of natural reserves in the area that remains closed to human habitation; and
- Maintenance of environmental monitoring and research activities.

The problem of the impact of Chernobyl disaster after-effects on health is of a many-sided nature and is connected with a radiation factor as well as with a whole range of factors of non-radiation character, the main of which are stress and deterioration of living conditions as a result of the collapse of the Soviet Union.

The diagnose of radiation sickness was confirmed with 134 participants involved in repair works, out of which 28 persons, exposed to high doses of radiation, died in 1986. Among those who survived 19 persons died from different reasons within the period from 1987 to 2004.

The radiation-caused cataract can be the second possible deterministic effect that could be found with the people exposed to relatively high radiation doses. Under this category fall the participants of repair works who suffered acute form of radiation sickness or persons exposed in 1986 to radiation doses exceeding the established annual level of 250 mSv as well as a certain part of evacuated population.

The radiation-caused thyroiditis should also be treated as a deterministic effect that may develop under exposure of the thyroid gland to high radiation doses to radionuclids of iodine.

In 4-5 years after the disaster there was registered a trustworthy growth of incidences among the younger children and teenagers exposed to iodine radionuclids, in particular to iodine-131. Over the past 20 years there were found nearly 5 thousand cases of thyroid gland cancer in Belarus, Russia and Ukraine among persons under 18 years old who were exposed to iodine-131. The levels of prevalence exceed the pre-disaster values ten, and in certain regions, hundred times.

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3. Environment

Radiation levels in the environment have decreased by a factor of several hundred since 1986 due to natural processes (radioactive decay, migration of radionuclides) and countermeasures. Therefore, much of the land that was initially contaminated can now be used with little or no restrictions or remedial measures. However, in the Chernobyl Exclusion Zone and in more limited areas of Belarus, Ukraine and the Russian Federation, some restrictions on land use will need to continue for decades to come.

Environmental monitoring and research

1. There is a requirement for continuing, albeit more limited and targeted, monitoring of the environment in these areas, especially for ^{137}Cs and, to a lesser extent, ^{90}Sr, in particular:

   - to validate the efficacy and continuing need for countermeasures, by comparison of actual and predicted levels of human exposure and of radionuclides in foods
   - for public reassurance, by providing timely and reliable information on the levels of radionuclides in commercial, privately produced and natural (mushrooms, game, freshwater fish from closed lakes, berries, etc) foodstuffs and the variation in these levels with time
   - there is no longer a need for extensive monitoring of foodstuffs or people (ie, by whole body counting, use of personal dosimeters); rather, monitoring should focus on areas where foodstuff contamination or individual exposures are, or are expected to be, highest (ie, resulting from high levels of deposition, high transfer of caesium or the particular habits or diets of individuals).
   - the scale and frequency of monitoring can be progressively reduced over time as the levels of contamination will only change slowly

Remediation and countermeasures

Agriculture

2. The system of countermeasures that has been developed and applied in the contaminated areas has resulted in large decreases in both the exposure of the population and the production of contaminated foodstuffs
3. The most efficient agricultural countermeasures are: clean feeding of animals and *in-vivo* monitoring before slaughter; administration of Prussian Blue to cattle; and enhanced use of mineral fertilisers in crop production. Radical improvement of pastures and grasslands, as well as draining of wet peaty areas, have also proved effective
4. In areas with poor soils (i.e., sandy, peaty), where the transfer of caesium to plants is high, the continued use of agricultural countermeasures is likely to remain effective and justified in the longer term
5. More attention should be given to managing the production of milk by private farms in several hundred settlements and by about 50 intensive farms in Belarus, the Russian Federation and Ukraine where radionuclide concentrations still exceed national standards
6. Priority should continue to be given to countermeasures concerned with fodder production and animal husbandry as consumption of milk remains the major contributor to internal exposure
7. Given the ever declining levels of contamination and exposure, the classification of Chernobyl-affected zones should be periodically reviewed to determine whether the existing controls remain optimal and/or whether land currently restricted can be returned to more productive use

Forests, aquatic environments and natural produce

8. Technologically based countermeasures, such as the use of machinery and/or chemical treatments to alter the distribution or transfer of caesium, are not practicable for application on a large scale to forests

9. Restricting the collection of natural food products and the hunting of wild animals (e.g., game, berries, mushrooms, fish from ‘closed lakes’) will continue to be needed, in some cases for several decades, in those areas where the levels of contamination exceed national standards

10. Advice on diet (e.g., reducing or avoiding consumption of highly contaminated natural foods) and simple procedures for food preparation and cooking (i.e., that reduce the level of caesium in consumed food) remains important for reducing internal exposures and should continue

11. Further countermeasures on surface waters (rivers, lakes, etc) are unlikely to be justified in relation to the reduction in dose achieved in consumed produce

General

12. All countermeasures should be subject to periodic review to ensure that they remain justified and optimal in the prevailing socio-economic, political and radiological situation; resources for countermeasures should increasingly be focused on areas where they will have greatest impact in terms of improved public health and social and economic well-being

13. The public (and the authorities) should be better informed about the prevailing levels of radiation risk, how these can be reduced through the use of countermeasures and/or changes in behaviour, and also be more involved in the processes of decision-making on the long term management and development of the contaminated areas

14. There is substantial diversity, nationally and internationally, in radiological criteria for the remediation of areas contaminated with radionuclides. The reasons for these differences should be better understood and, where appropriate and practicable, such differences should be minimised.

Chernobyl Exclusion Zone

15. A holistic and integrated strategy, capable of finding broad international support, for the long term management and rehabilitation of the Exclusion Zone (and supporting infrastructure external to the Zone, eg, Slavutich) should be developed. The following will comprise integral parts of an overall strategy or will be important considerations in its development:

    - an integrated waste management strategy and how it will be implemented should be developed as a matter of urgency for all installations and wastes in the Exclusion Zone. Particular emphasis needs to be given to the adequacy of current Ukranian legislation for this purpose and to the characterisation and classification of all wastes (in particular those containing transuranic elements) and the establishment of adequate infrastructures for their safe long-term management

    - a sound concept and strategy for the return of land in the Exclusion Zone to economic use should be developed, taking due account of the need for radiological and ecological safety and socio-economic constraints. Well-defined administrative controls will be needed on the nature of activities that may be performed. In some areas, prohibition of agriculture may be needed for many decades and these areas will be more suited for industrial use. In returning land to use, reliance should be placed on natural recovery processes supported by limited but focused human intervention where necessary

- an assessment should be made of the role of the Exclusion Zone as a barrier to the migration of radionuclides beyond its boundaries, of whether its role as a barrier needs strengthening and, if so, how this can be done including validation of any improvements made
- the monitoring system in the Exclusion Zone, including the "Shelter", needs to be improved and maintained, in particular its role in providing "early warning" of enhanced levels of radiation or contamination that may require remedial action. This will be especially important during the preparation and construction of the New Safe Containment (NSC) and soil removal
- human intervention will continue to be needed within the Zone irrespective of whether economic use is made of it, in particular to minimise the consequences (to those living outside the Zone) of forest fires, floods, outbreaks of plant and animal epidemics, etc, within the Zone and for the surveillance of existing installations

16. The Chernobyl Exclusion Zone has considerable research potential for: improving models of radionuclide transfer in the environment, in particular in less studied ecosystems (eg., role of fungi in forests); exploring new approaches for remediation; providing important input to the ongoing development of guidance on, and tools for, the protection of the environment from radiation. There would be merit in an internationally agreed strategy for making effective use of the unique features of the Exclusion Zone for research purposes

4. Health

Consequences for health

Here two types of health-related radiation effects are considered, namely: deterministic and stochastic.

Deterministic effect

1. The diagnose of radiation sickness was confirmed with 134 participants involved in repair works, out of which 28 persons, exposed to high doses of radiation, died in 1986. Among those who survived 19 persons died from different reasons within the period from 1987 to 2004. Not a single incidence of acute form of radiation sickness was registered among population, which testifies to the fact that exposed radiation doses were lower than the threshold level due to adequate radiation protection measures including evacuation and resettlement as well as a restricted amount of radionuclids entering human bodies via food chain.
2. The radiation-caused cataract can be the second possible deterministic effect that could be found with the people exposed to relatively high radiation doses. Under this category fall the participants of repair works who suffered acute form of radiation sickness or persons exposed in 1986 to radiation doses exceeding the established annual level of 250 mSv as well as a certain part of evacuated population. Existing medical statistics show the growth of cataract prevalence with the liquidators and with the population of Belarus and Ukraine; however, problems with differentiating diagnostics between the age- and radiation-caused

cataract as well as the lack of data on individual doses of exposure to rays by eye lens make it difficult to interpret the results.

3. The radiation-caused thyroiditis should also be treated as a deterministic effect that may develop under exposure of the thyroid gland to high radiation doses to radionuclids of iodine. The wide scale reconstruction of radiation situation at the early stage of disaster and radiation doses exposed by a thyroid gland, conducted by a group of scientists from Belarus, Russia and Ukraine in cooperation with foreign experts, allowed to draw a conclusion that with some small groups of children the exposed radiation dose was 10 Gy and higher. In the aforesaid cases there could be seen evidence of certain temporary changes in thyroid gland functions; yet the radiation level was not high enough to cause the radiation thyroiditis.

Stochastic effects

Thyroid gland cancer

4. In 4-5 years after the disaster there was registered a trustworthy growth of incidences among the younger children and teenagers exposed to iodine radionuclids, in particular to iodine-131. Over the past 20 years there were found nearly 5 thousand cases of thyroid gland cancer in Belarus, Russia and Ukraine among persons under 18 years old who were exposed to iodine-131. The levels of prevalence exceed the pre-disaster values ten, and in certain regions, hundred times. A strong dependence was found between excessive prevalence and radiation doses absorbed by a thyroid gland. The group of higher risk consisted of children who were under 6 years old at the moment of disaster. The risk of acquiring the thyroid gland cancer is less with the increase of age at the moment of exposure to radiation.

5. The excessive incidence among the adults exposed to iodine-131 is registered in Belarus. With those who were born after the end of "iodine period" and were not exposed to iodine radionuclids while being in mother's uterus, the level of thyroid gland cancer incidence does not exceed usual values typical for specific regions.

6. In connection with an unprecedented growth of thyroid cancer there was established an effective system of early diagnostics, treatment and rehabilitation of patients in Belarus, Russia and Ukraine. The majority of cancer occurrences has been diagnosed at early stages, which increases the chances of favorable outcome of treatment. The complex treatment that includes a total thyroidectomy together with isotope diagnostics of completeness of thyroid tissue ablation and of presence of regional and distant metastases; courses of radio iodine therapy when treating metastases, suppressive therapy with L-thyroxin allowed to achieve the minimum level of mortality among the patients – nearly one percent mortality over 10 years after surgery. The system of individual rehabilitation of patients, namely the individual selection of doses of substitute therapy made it possible to bring the majority of patients back to their full-fledged and active life.

Leucosis

7. Leucosis, similarly to thyroid gland cancer, is also an indicator of radiation impact; the higher level of incidences can be seen with the children, the most vulnerable group, especially in 2-5 years time after the exposure.

8. Over the past 20 years there have not been registered any growth of leucosis prevalence among the children in Belarus, Russia and Ukraine which can be explained by a higher degree of attention to this problem as well as by a whole range of protective measures, namely temporary moving-out of children from the most contaminated areas from May to September 1986.

9. The participants of repair works (liquidators), who were exposed to considerable radiation doses, are a group of potential risk for developing leucosis. At the moment, according to the data of Russian medical and dosimetric register there was registered a two-fold increase of incidences of leucosis among the liquidators (excluding chronic lymphoid leucosis) who obtained the dose of 150 mGy.

10. The present-day internationally-conducted analytical and epidemiological studies will make it possible to clarify the risk of radiation-induced leucosis.

Other oncological diseases

11. A great number of studies on evaluation of incidences of oncological deceases among liquidators and population have been conducted in Belarus, Russia and Ukraine. The available data shows the growth of prevalence of certain types of cancer though there is still a lack of strong evidence on relation between the amount of incidences and doses of radiation.

12. It should also be kept in mind that a latent period (time from the moment of exposure to radiation till the moment of developing cancer), according to studies dedicated to the issue of after-effects of atomic bombings of Hiroshima and Nagasaki, lasts for 10-15 years and more; therefore, it is still early to assess the possible impact of Chernobyl radiation on oncological incidences. However, the following fact should be taken into account that people who were exposed to radiation at a younger age can bear a higher risk of developing cancer.

Hereditary diseases

13. The examination of descendants of those persons who were exposed to radiation during atomic bombings of Hiroshima and Nagasaki as well as children of the plant “Mayak” workers, who were as a result of their professional activity exposed to radiation doses about 10Sv, has not shown the increase of frequency of hereditary diseases.

14. After Chernobyl disaster the most comprehensive studies were conducted in Belarus; a register of hereditary diseases (that fully complied with international standards) had been kept there even before the disaster. These studies still have a descriptive character due to the lack of reliable assessments of individual radiation doses accumulated by pregnant women that gave birth to children with hereditary pathology

Cardiovascular system diseases

15. Over the recent years much interest was given to the study of incidences of cardiovascular system diseases (ischemia, cardiac infarction, cerebral hemorrhage) due to Japanese cohort data that indicates the relation between radiation and mortality rate from cardiovascular diseases.

16. There is also available data of a Russian medical and dosimetric register that confirms the growth of incidence risk and mortality rate among liquidators exposed to different doses of radiation.

17. The increase of incidences among liquidators and evacuated population was also recorded in Belarus and Ukraine but a relation with radiation doses has not been studied.

18. It is noteworthy that data on the level of incidences of cardiovascular diseases should be interpreted with special care due to possible impact of different non-radiation factors playing an important role in the development of the aforesaid diseases.

5. Recovery and development

1. Chernobyl demonstrated convincingly that the cost of ensuring the safety of nuclear facilities is considerably lower than that of dealing with the consequences of an accident. It is impossible to calculate an exact figure for the costs of the Chernobyl accident, but it is clear that the direct costs (for construction of the shelter, creation of the exclusion zone, resettlement of affected populations, health care, monitoring of the environment, and creation of technologies to produce “clean” food) to Belarus, the Russian Federation and Ukraine, as well as the many other countries affected, amounted to tens of billions of dollars. Globally, the indirect costs (in lost economic production and increased energy costs, among others) are estimated at hundreds of billions of dollars. This huge and lasting economic burden is one of the most important consequences of the accident.

Governance and public policy

2. Given the unprecedented scale of the accident, the response to it by the authorities was broadly satisfactory but not without flaws, in particular a failure to restrict the consumption of contaminated milk in some areas and to adequately inform those affected in the immediate aftermath of the accident. The latter left a legacy of mistrust in the authorities generally and, in particular, in official statements on radiation. This has greatly hindered effective communication with the public and the recovery process itself.

3. The persistent difficulties (from socio-economic and health viewpoints) in many of the contaminated settlements are a direct result of earlier failings and exemplify the importance of public participation, civic consultation, and transparent and open access to information the situation is to be improved. These considerations are equally important for the management of any future accident resulting in environmental contamination, nuclear or otherwise.

Government programmes and spending

4. Resettlement of several hundred thousand people, whether mandatory or voluntary, proved a traumatic experience, and those who remained in (or returned to) their homes have coped

better psychologically than those who were moved to other areas. This experience has implications for responding to any future accident, nuclear or otherwise.

5. The agricultural sector was the worst-hit area of the economy. Huge territories of agricultural land were removed from service, and timber production was halted in large areas of forest. Remediation measures have been developed to make farming safe, but the Chernobyl stigma hinders the sale of products from affected areas with more general socio-economic implications.

6. Given that natural recovery processes along with protection measures have resulted in a significant reduction of radiation levels. This is the basis for possiblerevisit the classification of zones with aim the future regional economy recovery. Areas with mild radiation levels can be made fit for adequate and even prosperous living with limited, cost-effective measures to reduce radiation exposure. The far smaller zones with higher levels of contamination require a different strategy focused on greater monitoring, provision of health and social services, and other assistance.

7. Government programmes need to be streamlined and budgets refocused, particularly in light of limited financial resources. Programmes should shift from those that create a victim and dependency mentality to those that support opportunity, promote local initiatives, involve the people and spur their confidence in shaping their destinies; the transition will not, however, be without difficulty and political risk. This overhaul of Chernobyl programming should aim to:

   - Target benefits. Resources should be re-targeted to assist people who have diagnosed health conditions or face true economic hardship. To ensure fairness, any overhaul in Chernobyl benefit provision should take place in line with a revamping of other benefit categories.
   - Discontinue resettlement programmes. For families who still under a legal right to relocation (as is the case in Ukraine), provide financial compensation.
   - Strengthen primary health care, including promotion of healthy lifestyles, access to and quality of reproductive health care, and provision of psychological support and diagnosis and treatment of mental diseases, especially depression.
   - Promote production of safe food. Continued efforts are needed to encourage the cultivation of agricultural products that can be grown safely, especially among small family farms.

Social and economic development

8. The negative impact of the Chernobyl accident was greatly exacerbated in the 1990s by economic turmoil caused by factors unrelated to radiation, in particular the collapse of the USSR. The quality of living standards, unemployment and poverty all worsened and agricultural regions, whether contaminated or not, were most vulnerable.

9. Chernobyl-affected regions face a higher poverty risk than on average in the three affected countries. Wages tend to be lower and unemployment higher, and the proportion of small and medium-sized enterprises is low. This is partly because many skilled and educated workers, especially younger ones, have left the region, and partly because the general business environment discourages entrepreneurship.

10. Communities in the contaminated areas suffer from a highly distorted demographic structure with an abnormally high percentage of elderly individuals. Aging populations

have local birth and death rates that differ considerably from the average, thereby affecting perceptions and heightening fears about health risks.

11. Anxiety over the effects of radiation on health has increased rather than diminished with the passage of time. Misconceptions and myths about the threat of radiation abound, promoting a paralysing fatalism among residents. While attributing a wide variety of medical complaints to Chernobyl, many residents of the affected areas neglect the role of personal behaviour in quality of health.

12. A sense of victimisation and dependency is widespread in the affected areaswith many viewing themselves as helpless, weak and lacking control over their future. A passive "culture of dependency" has taken root in many Chernobyl-affected communities.

13. New, innovative ways should be found for involving the affected populations in the actions devoted to amelioration of living conditions in contaminated territories. Information provision targeted to specific audiences, such as family mothers is needed, as well as trusted community sources providing useful advice to the people who live in areas where radiation exposure exists. Any new stakeholders involvement process should embrace a comprehensive approach to promoting healthy lifestyles, and not simply focus on radiation hazards.

14. Economic development aimed at restoring community self-sufficiency is key to improving living conditions, and should be at the centre of strategies to address the effects of Chernobyl. This aim should be pursued in a way that gives individuals and communities control over their own futures, as this approach is both efficient in terms of resources and crucial in overcoming the psychological and social effects of the accident. Central, regional and local governments need to cooperate to:

    - Improve the business climate, encourage investment and support private sector development. Appropriate national policies need to be supplemented by a proactive approach to stimulating economic development at the regional and local levels.
    - Support initiatives to promote inward investment, both domestic and international, at the regional level, to promote employment and create a positive image for the areas concerned. Build on experience of the local economic development agencies already functioning in the region to act as an interface with national and international development bodies and donors. Infrastructure should be developed to overcome the sense of exclusion experienced in affected communities.
    - encourage the creation and growth of small and medium-size enterprises in the affected areas and in the adjacent towns and cities using the whole range of business support techniques that have been tried and tested in other parts of the world.
    - Adapt examples of good practice in the three countries and abroad, including community based solutions such as credit unions and producer and consumer cooperatives, to the special circumstances that apply in the affected areas.
    - Promote the rebuilding of community structures to replace those lost in the process of evacuation and the economic turmoil of the 1990s. Initiatives designed to strengthen social interaction, particularly for the young, and promote community and economic leadership in towns and villages are needed to underpin sustainable recovery.

15. All Chernobyl recovery efforts should adhere to four general principles:

    - they should be addressed in the framework of a holistic view of the needs of the individuals and communities concerned and, increasingly, of the needs of society as a whole

- they must help individuals to take control of their own lives and communities to take control of their own futures, thereby moving away from a dependency culture
- they must make efficient use of resources by focusing on the most affected people and communities and taking account the limited budgetary resources at government disposal; priorities must be set
- international assistance should focus on development needs rather than humanitarian assistance, and be aligned with the far larger efforts made by local and national governments as well as the voluntary sector in the three countries.

16. Continued international assistance and co-operation is necessary to help national governments and regional and local stakeholders promote the social and economic recovery of affected communities and address health care needs, both those specific to Chernobyl and those affecting the general population. Effective co-ordination of international assistance and co-operation is vital, to ensure that limited resources are used efficiently and that recovery efforts are enacted in line with the latest scientific findings and the most efficient stakeholders involvement processes in view of decreasing the environmental, health, and socio-economic impacts of Chernobyl.

17. Exchange of experience should be encouraged, not only among the three most-affected countries but globally. In addition, the experience gained in the management of, and longer term recovery from, a nuclear accident should be shared with those responsible for post-crisis community development and economic recovery more generally.

6. The Safety Management and Institutional Development

1. The accident has shown the importance of strict compliance with basic safety principles for the design and operation of nuclear installations, of continuous safety assessments and the timely upgrading of installations to eliminate deviations, of remaining abreast of and incorporating best world practice and experience and of taking thorough account of the human factor.

2. Numerous improvements to nuclear safety and radiation protection have resulted from experience gained as a result of the Chernobyl accident. The accident acted as a catalyst, initiating important changes at national and international levels in nuclear safety principles, legislation, technology and practice. International cooperation on nuclear and radiation safety was broadened and fully incorporated the countries of the former Soviet block for the first time.

3. The accident has convincingly demonstrated that the cost of ensuring the safety of nuclear installations is considerably lower than that of dealing with accident consequences. Large-scale accidents may cause significant health and environmental impacts, as well as great social and economic damage to countries located in their area of influence. Direct and indirect damage amounting to hundreds of billions of US$ have been reported by Belarus, Russia and Ukraine as a result of the Chernobyl accident.

Improvements in Nuclear Safety and Security Legislation and Regulation

4. The Chernobyl accident prompted many actions to strengthen international and national legislation on nuclear safety. Several internationally binding conventions or protocols related to nuclear safety, emergency management, spent fuel and radioactive waste

management, liability, and the physical protection of nuclear material were developed and adopted.

5. As a direct response to the accident, two international Conventions were adopted in 1986. These are the Conventions on Early Notification of a Nuclear Accident and on Assistance in the Case of a Nuclear Accident or Radiological Emergency. Currently around 100 countries are party to them. Since 1986, the IAEA has operated an emergency centre to fulfil its obligations under the two Conventions.

6. The Convention on Nuclear Safety (CNS) was adopted in 1994 and ratified by all countries with nuclear power plants and by a further 25 countries without. An international nuclear safety regime was established under this Convention and the parties are obliged to follow nuclear safety principles based largely on the IAEA Safety Fundamentals "The Safe Operation of Nuclear Installations". Self-assessment reports on their safety status are made nationally and are peer reviewed at the triennial meetings of the CNS.

7. The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management was adopted in 1997. This promotes an effective nuclear safety culture worldwide through enhancing the safety in spent fuel and radioactive waste management and the parties are obliged to follow the safety principles of the IAEA Safety Fundamentals "Principles of Radioactive Waste Management". The underlying concepts of the Joint Convention and its implementation are broadly the same as those of the CNS.

8. Several other binding international legislation, mainly in the area of nuclear liability, have also been prepared.

9. A cadre of international Safety Standards, under the leadership of the IAEA, were developed and promulgated throughout the nuclear industry. These Standards have become accepted by the international community and are the basis for assessing safety acceptability in all areas (design, construction, operation, shutdown and decommissioning) and at all types of nuclear installations (nuclear power plants, research reactors, fuel cycle facilities).

10. Based on the experience of protecting the population after the Chernobyl accident, the ICRP recommended a single level criteria of intervention (ICRP-63, 1993). Later still, partially in response to long-term Chernobyl problems, the ICRP developed recommendations on the protection of the population in conditions of prolonged exposure (ICRP-82, 1999). In this last document, in developing the principle of optimization, new generalized radiological criteria were proposed for making decisions on the application of protection and rehabilitation measures. The ICRP recommendations are converted into IAEA safety standards.

11. Before the Chernobyl accident there were no international standards for permissible levels of radionuclides in food products. However, in response to the threat of internal exposure of the inhabitants of many European countries, by May 1986 in the USSR and the European Union, standards had been developed. In response to international demand, in 1989 the Codex Alimentarius Commission established guidelines on Levels for Radionuclides in Food for Use in International Trade (CAC, 1990). These guidelines are currently being updated.

12. The International Nuclear Safety Advisory Group (INSAG) emerged on the world stage as an authoritative body that could independently provide high level insights concerning issues of safety relevance at all nuclear installations. The group's report on The Chernobyl Accident (INSAG-1, updated as INSAG-7) set the precedence for providing sage counsel on all things related to nuclear safety.

13. After Chernobyl accident several immediate and continues actions were pursued at the national level to change and improve the national nuclear legislations. Especially the NIS and CEES had to replace most of their legislations and to develop own more democratic legislation to cope with the nuclear risk.

Improvements of international and national instruments

14. The World Association of Nuclear Operators (WANO) was created, in part to facilitate the exchange of experience between operating organizations. Every organization in the world that generates electricity from nuclear power plants is a voluntary member of WANO.

15. In order to facilitate communication with the public on the severity of nuclear accidents, the International Nuclear Event Scale INES was developed by the IAEA and the NEA and is currently applied by a large number of countries.

16. The open culture of sharing lessons learned is exemplified by operational experience feedback and peer reviews. WANO's peer reviews and the IAEA's safety review projects facilitate exchange amongst nuclear power operators and other nuclear installations to spread the best safety practices worldwide.

17. Creation and strengthening of independent powerful and competent national regulatory bodies is one of the most important improvements of nuclear safety instruments.

Improvements of RBMK reactor safety

18. Immediately after the accident a series of technological measures started to be implemented at all RBMK reactors, aiming to address within a short term the most critical safety deficiencies of the initial design of the RBMK. The main results of this period that lasted few years can be summarized as follows:

    - Significant reduction of the Positive Reactivity Coefficient
    - Improvements to the Shutdown System
    - Improvement of the Reactor Cavity Overpressure Protection
    - Increased Reliability of Core Cooling Systems
    - Improvement of the Instrumentation and Control Systems.

19. In the following period, plant specific modernisation programmes were developed for each RBMK unit with a specific schedule of implementation. The aim of the plant specific modernisation programmes was to substantially enhance the operation safety level of these reactors. Most of these programmes are currently still under way. Two of them, Ignalina 2 and Kursk 1, have been completely implemented. The Safety Analysis Reports of these two units after modernisation have been reviewed by international experts. The conclusions underline noticeable improvements in the different areas of operating safety: reactor systems, accident analysis, operating procedures, safety culture, etc. However few important points, in particular the confinement issue, are still remain open for further improvements.

Improvement of reactor decommissioning and waste management strategies

20. A consequence of the Chernobyl accident was a certain number of initiatives associated to the shutdown and the decommissioning of RBMK reactors. Actions have started in Ukraine (Chernobyl) and Lithuania (Ignalina) in this field.

21. A more general objective was to define the content of decommissioning plans and decommissioning projects, including other types of reactors, such as VVER reactors (in Armenia, Bulgaria, Slovakia…), in order to promote optimised decommissioning methods, allying industrial optimisation and safety considerations.

22. Taking into account the great amount of waste generated by NPP operation and during decommissioning and also the big amount of waste still to be characterized and conditioned, the implementation of a waste management strategy should be the prolongation of this work.

23. The related actions could be divided as follows:

- analysis of the status of radioactive waste management; examination of regulatory basis for radioactive waste management activity in force in the countries and adaptation to bring it in conformity with IAEA recommendations
- Detailed studies related to the status of waste production and management, including the following:
  - short description of facilities operated on the waste producing sites and analysis of the industrial activities that lead to radioactive waste generation
  - figures related to waste production (on an annual basis): current production and expected future production
  - waste inventory, including waste resulting from old practices and currently generated waste
  - identification of characteristics (physical and chemical) of existing waste (solid and liquid) stored on the sites, whatever their types of conditioning and packaging
  - description of the currently implemented waste treatment and storage methods on the selected sites and main characteristics of these methods.
- Definition of strategies for treating and conditioning the waste previously identified, based on a conceptual view of waste management relying on a need for homogenization and standardization of the methods. Such an approach should lead to a relatively small number of types of waste packages that would comply with Waste Acceptance Criteria and would thus be suitable (or deemed suitable) for ultimate disposal (near-surface or deep disposal). This should be based on a multi-criteria waste classification and on the evaluation of the status of the existing facilities and methodologies dedicated to waste treatment and waste packaging.
- Definition of the studies to be launched for the design of all the necessary types of disposal facilities, insisting upon the relevant parameters and requirements specific to these types of facilities

Chernobyl Site

24. The Shelter constructed urgently in severe radiation conditions remains the major potential source of nuclear and radiation risk. Its stabilisation and construction of new safe confinement for the destroyed Unit 4 remains first priority in order to provide for long-term isolation of fuel containing masses and the radioactive waste from the environment.

25. Future strategic tasks aiming at conversion of the Shelter in environmentally safe system are:

- Dismantling of unstable structures of the Shelter;
- Development and implementation of technologies for extraction and isolation of fuel containing mass and long-lived radioactive waste in order to create additional barrier for those dangerous materials;
- Creation of infrastructure and facilities for temporary controlled storage of fuel containing mass and long-lived radioactive waste;
- Justification and construction of geological waste disposal facility in the Chernobyl exclusion Zone or at neighbouring territories.

26. Before the Chernobyl accident, there was no experience in the world of treatment of such vast amount of radioactive materials created accidentally. Disposal of radioactive waste had been carried out in extreme conditions without proper justification of waste classification and recording of its amount and precise location, waste isolation technologies, etc.

27. Managing the radioactive waste from the Chernobyl accident is becoming a more pressing and topical problem as time goes on. Despite the established national programmes and international projects on radioactive waste management, there is still no realistically balanced and sound unified concept for radioactive waste management, which includes all stages from collection and processing to final disposal.

28. To take into account the Chernobyl's lessons in the field of radioactive waste management it is necessary:

- to finish inventory of all waste repositories including creation of national register of the radioactive waste and cadastre of repositories. In this connection the data should be obtained to substantiate decisions on the subsequent repositories utilization and, in case of need – to design technique of radioactive waste retrieval, conditioning, storage and disposal;
- to substantiate and make decisions concerning necessity and sequence of waste retrival out of a repository. These decisions should be made on the basis of comprehensive analysis of the long-term safety and assessment of repository influence on the environment. At that, the results of most common safety analysis should be taken into account, which should capture all kinds of radioactive waste management in the Chernobyl exclusion zone (ChEZ);
- to create in ChEZ borders the infrastructure (the National center) for treatment, conditioning, storage and disposal of the main types of Ukraine radioactive waste both of Chernobyl origin and those resulted from the national nuclear power facilities. For this purpose, by-turn, it is necessary: to develop and accept national strategy of the radioactive waste management, develop and accept corresponding national program, create the State fund to finance activities associated with radioactive waste management;
- in view of tasks concerning the above-mentioned infrastructure it is necessary to activate the works on substantiation and construction of geological disposal system for long-lived waste.

1. The accident has demonstrated the need to establish and support a high-level national emergency response system in case of man-made accidents.

2. The accident has demonstrated the danger of not bringing nuclear power under public control and has shown the need for open and objective dialogue with the public on all aspects of the safe use of nuclear energy.

3. The lack of objective and timely information to state authorities and the population about the accident at the Chernobyl nuclear power plant led to an inadequate response to its potential negative consequences on people's living conditions and health, and also created the preconditions for socio-psychological stress.

   - Transparency and broad and permanent access to information are crucial. International organizations, national governments, nuclear operators and plant managers have an obligation to provide honest and comprehensive information to the local communities of the areas concerned, the neighbouring populations and the international community. They must comply with this obligation both as a matter of routine and in times of crisis.
   - Citizens must be consulted and involved. Both at national level, in terms of major technological choices, and at local level, the populations concerned must be involved and consulted under procedures specific to each country. Such involvement is essential to create and sustain a culture of safety, which is the only credible defence in view of the scale of the risks and the potential cost of mistakes. It is also a prerequisite for implementing global security plans.
   - Exchange of experience should be encouraged. Many lessons have been learned from the negative consequences of the Chernobyl accident, and these should be shared more widely. Similarly, Chernobyl recovery efforts can benefit from global experiences in recovery from other disasters, both natural and man-made.

4. The adoption of legislative acts and legal documents has allowed a significant easing of the socio–psychological situation among clean-up workers and the affected population.