NUCLEAR SAFETY ASPECTS

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From 1-3 April 1996 an International Forum "One Decade After Chernobyl: Nuclear Safety Aspects" was convened at the IAEA in Vienna, Austria. It was organized by the IAEA in co-operation with the UN Department of Humanitarian Affairs (UNDHA). The objective was to review the remedial measures taken since the Chernobyl accident to improve the safety of RBMK reactors and the Chernobyl containment structure (sarcophagus). The results were presented at the International Conference on Chernobyl held in the following week.

This article features excerpts of the conclusions of the Safety Forum related to the safety of Chernobyl-type reactors (RBMKs) and to conditions at the site of the Chernobyl plant itself.

Causes of the accident

The events which led to the accident in Unit 4 of the Chernobyl nuclear power plant on 26 April 1986 have been investigated by many teams of scientists over the past ten years. Although there are still some gaps in knowledge relating to details of some phenomena involved in the accident, the knowledge acquired is sufficient to identify the causes and to take effective measures to prevent a repetition of such an event.

From today's viewpoint the main causes of the accident can be summarized as follows:

- severe deficiencies in the reactor's physical design and in the design of the shutdown facilities;
- high positive void effect during operational conditions with high burn-up;
- positive scram effect under conditions of the reactor before the accident;
- failure to incorporate the operating reactivity margin (ORM) into reactor protection;
- lack of safety culture in the responsible organizations leading to the inability to remedy important weaknesses, even though they had been known long before the accident;
- an insufficiently reasoned and examined test programme with respect to technical safety;
- violation of operating procedures;
- operation and operating equipment imposing undue requirements on the responsible staff;
- insufficient protection against accidents beyond the design basis.

The safety of RBMKs

There is broad agreement that the original design of the RBMK core and shutdown system had severe deficiencies. This holds for all generations of RBMK plants. Between 1987 and 1991, a first stage of safety upgrading was performed for all RBMK units addressing the most serious problems in this area.

The void reactivity effect has been reduced by installing 80-90 additional absorbers and by increasing the operative reactivity margin up to 43-45 manual control rods, and by increasing the fuel enrichment to 2.4%.

The efficiency of the scram system has been increased by elimination of water columns; increasing the number of bottom control rods driven in the core together with the upper rods after trip signals; the speed of rod insertion; a new fast-acting shutdown system; and additional signals for the control and safety system.

Organization and operation has been strengthened by more frequent computation and display of the operative reactivity margin; and improved operating rules and procedures. Progress has also been achieved in further areas, such as installation of remote shutdown stations, non-destructive testing and training of personnel (simulator). The realization of these measures varies from plant to plant.

There remain issues beyond the scope of the first stage of upgrading which require further attention. These needs largely depend on the different stages of RBMK development.

There is no doubt that significant improvements were achieved regarding the safety deficiencies relevant for the Chernobyl accident. For other safety issues, safety upgrading is under way or planned. The realization of this second stage of upgrading continues to

Aerial view of the Chernobyl nuclear power plant. The sarcophagus (foreground) encases the unit destroyed in the accident.
(Credit: Mouchkin/IAEA)

encounter major financial difficulties. That may be characterized as an important if not the main current problem for RBMK safety.

Remaining problems of RBMKs. The analysis performed so far shows that, from a technical point of view, the known safety deficiencies of second and third generation RBMKs could be overcome in a way broadly consistent with the defense-in-depth concept. Many of the steps to be taken have been already defined and internationally agreed.

The practicability of backfitting first generation RBMKs raises further questions in addition to the issues relevant for the second and third generations of the plant. There have been significant doubts in Western countries about the feasibility and the cost effectiveness of backfits. However, from today's perspective it must be recognized that the existing upgrading programmes address most safety concerns. They include the backfitting of essential safety features such as control and protection systems, emergency core cooling systems, and partial confinement. It is evident that they will lead to significant improvements even if they will not always reproduce the technical solutions implemented in the new RBMK plants. Where "classical" approaches are difficult to implement, they often rely on "compensating solutions".

Particular problems at Chernobyl

Most of the above considerations on RBMK safety also hold for the Chernobyl plant. Nevertheless, the situation at Chernobyl is a particular one as there exists a range of site specific problems. These problems concern both the safety of the remaining units and the accident consequences.

Although there are plans to shut down the Chernobyl reactors in the near future, programmes for upgrading them, that have been agreed internationally, should be implemented to ensure safety during their remaining lifetime.

Overview of international activities on RBMK safety

In response to a request initiated by the former Soviet Union, the IAEA started a programme on the safety of RBMKs in 1992.* It aims at consolidating results of various national, bilateral, and multilateral activities and to establish international consensus on required safety improvements and related priorities. It assists both regulatory and operating organizations and provides a basis for technical and financial decisions.

A wide range of activities are covered, and since 1992, a number of reviews and assessments have been conducted. Smolensk-3 and Ignalina-2 have served as RBMK reference plants during the programme's first phase.

European Commission. An international RBMK consortium on the "Safety of Design Solutions and Operation of Nuclear Power Plants with RBMK Reactors" was established in 1991 under the auspices of the European Commission. Eight Western countries (Canada, Finland, France, Germany, Italy, Spain, Sweden, United Kingdom) and the three countries operating RBMKs (Lithuania, the Russian Federation, and Ukraine) have participated in the consortium. The following topical areas were studied: systems engineering and accident progression, control and protection systems, core physics, external events, engineering quality, operating experience, human factors, regulatory interface and probabilistic safety assessment (PSA).

More than 300 recommendations for safety improvements have been made. Many of these had been previously recognized by designers and operators and already acted upon while others are important new recommendations.

World Association of Nuclear Operators (WANO). In 1992 an International User's Group for Soviet-Built Reactors identified common requirements to improve RBMK safety. They include measures already implemented or fully developed for implementation and those yet to be implemented.

European Bank for Reconstruction and Development (EBRD). By the end of 1995, fourteen countries and the European Union had pledged to the 245 MECU Nuclear Safety Account (NSA).

Assistance to the Ignalina plant includes in-service inspection equipment, a full-scope simulator, fire protection, and the preparation of a Safety Analysis Report.

Assistance to the Leningrad RBMK relates to a safety improvement programme with provision of equipment like that for Ignalina.

The NSA Chernobyl Project focuses on short-term safety improvements to Unit 3 including in-service inspection, neutron flux instrumentation, and the hydrogen monitoring system.

Funding is also being provided for decommissioning facilities, namely a low- and intermediate-level liquid radwaste treatment plant and a spent fuel storage facility.

Bilateral programmes. ***Sweden and Lithuania.*** This programme includes support to the regulatory body VATESI, co-operation between the Swedish Nuclear Industry and Ignalina plant, and various technical projects. Main areas where assistance is being provided relate to the legal framework (review of the Lithuanian Energy Law), development of the regulatory system, material inspection, management, and organization, and a PSA level-1 study (of the Barselina plant).

Main technical projects cover areas such as fire protection, enhancement of the relief capacity from the reactor cavity, enhancement of the ALS system, storage capacity of spent fuel, waste compaction, improvement of the plant's physical protection, and upgrading the communications system.

Russia and Canada, France, Germany, Japan, Italy, Sweden, Switzerland, UK, USA. Bilateral programmes with Russia include those related to: development of symptom-based emergency operating procedures (USA); fire protection; fuel channel sealing plugs; instrumentation and control improvements; in-service inspection; leak detection system (Japan); metallurgical analysis; probabilistic safety assessment; quality assurance; thermal hydraulic and neutronic codes.

Outlook. It is generally agreed that the results from international assistance have increased confidence that the major shortcomings and the required safety improvements of RBMK reactors have been identified.

The plant-specific status of implementation of safety improvements varies considerably. Therefore a major effort is still required to complete plant-specific safety analyses and to implement the required safety improvements.

*An overview of this Programme was published in the *IAEA Bulletin*, Volume 38, No. 1 (March 1996).

For the consequences of the accident, concerns focus on the sarcophagus built around the destroyed reactor, on the radioactive material contained inside the sarcophagus, and on the radioactive material buried on the site.

The sarcophagus. The possible instability of the sarcophagus is a significant problem. The concern is mostly related to the fact that essential supports of the main construction had to be built by remote control without fixings such as welding and bolt connections. As a consequence, there is considerable uncertainty regarding the resistance to potential internal and external impacts. This relates above all to the withstanding of loads due to external burden or impact, such as loads due to wind, snow, or earthquake, for example. There is broad agreement that the risk of a partial or total collapse during the initially projected design lifetime of the sarcophagus of about 30 years is not negligible if no countermeasures are taken.

Even in the worst case of a complete collapse, widespread effects are not to be expected. Nevertheless, the stabilization of the sarcophagus is an issue of high priority.

Water entering the sarcophagus is another significant safety issue. The presence of water stimulates the disintegration of fuel masses into dust and degradation of building structures by corrosion, and can increase the reactivity of fuel masses. Regarding the risk of groundwater contamination, the existence of water in the sarcophagus bears some risk in the long term. However, this risk is assumed to be much smaller than that from contact of water with the radioactive material buried in the ground outside the sarcophagus.

Possibilities of recriticality have been widely investigated. It has been found that the sarcophagus is currently safe from a criticality point of view. Nevertheless, it cannot completely be excluded that there exist configurations of fuel masses inside the sarcophagus which could reach a critical state when in contact with water. However, even if this could lead to significant radiation fields inside the sarcophagus, neither large off-site releases nor mechanical effects would have to be apprehended in such an event. The impact on the operating personnel of the other units should also be clarified.

Another specific issue for the Chernobyl plant is the possible implications for safety of the proximity of the sarcophagus and the destroyed reactor to the adjoining operating Unit 3. The risks are generally assumed to be low; however, the issue needs further investigation. (Note: Opinions differ widely about the significance of the risk of an accident in Chernobyl Unit 3 caused by a collapse of the sarcophagus. More detailed investigations of this issue are required.)

Other site-specific problems

Further site-specific problems relate to the contamination, in particular to the radioactive material buried at the site. The type and extent of the contamination are well known by measurements. Although the local dose rate is considerably high, most areas are accessible. The provisional depositories of highly radioactive material, such as nuclear fuel ejected out of the reactor during the accident, however, represent an obstacle for construction and reconstruction measures. Furthermore, radioactive substances get into the groundwater there. At present the contamination is still low. In the long term there is, however, a considerable risk, and an orderly disposal of the provisional depositories is absolutely required.

Step-by-step site restoration

Given the scale of the problems to be solved at Chernobyl, it is evident that major long-term efforts are needed. The stability of the sarcophagus must be ensured, the destroyed reactor permanently secured, the wastes disposed of, and the site reconstructed. This will require substantial resources.

There is a broad agreement that these problems call for an integrated approach divided into suitable steps. This approach should be based on realistic targets which take into account the radiological conditions at the site and appropriate safety and waste disposal priorities. It should begin with a stabilization of the existing sarcophagus. That stabilization could significantly reduce the risk of a collapse of the shelter and provide time for a careful reflection and planning of further measures, such as the construction of a new encasement and waste management. This would include the recovery or partial recovery of fuel masses inside the sarcophagus, and the disposal of radioactive material buried on the site. ❒