This Section summarises the major safety related modifications that have been implemented in the Ignalina NPP. This encompasses the important structural and procedural modifications implemented after the occurrence of the Chernobyl incident and the ongoing and projected modifications whose purpose is to bring the INPP safety criteria up to western safety standards.

13.1 POST-CHERNOBYL MODIFICATIONS

After the Chernobyl accident, technical and organizational changes were prepared and implemented in order to improve the operational safety of all NPP's with RBMK reactors. These changes had the following objectives:

- reduce the positive steam reactivity coefficient to less then 1 β,
- redesign control rods in order to increase the prompt shut-down reactivity,
- install programs designed to calculate the effective reactivity reserves and to display the results at the operator's panel,
- eliminate the possibility of disconnecting the emergency protection system when the reactor is at power,
- modify technical specifications re pump operation to ensure that even at low power a sub-cooling margin is maintained at the reactor inlet.

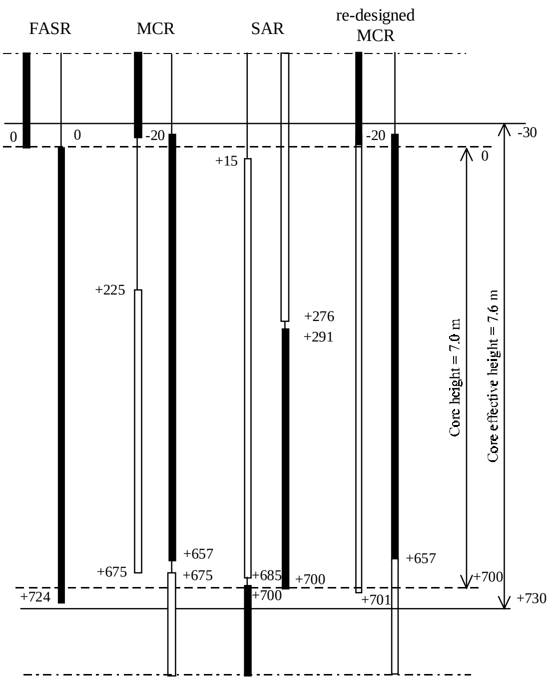

Fig. 13.1 Redesign of the RBMK-1500 manual control rods [62] (all dimension are in cm)

The reduction of the positive steam reactivity coefficient at the Ignalina NPP, from +4.5β to +1β, was achieved by installing from no less than 52 additional absorber rods in the core, and increasing the effective reactivity reserve to from 53 to 58 manual control rods. In addition, replacement fuel enrichment has been increased to 2.4 %.

The increase in emergency protection system effectiveness was achieved by three independent means [54]. In the first modification the old type of absorber rods were replaced by a re-designed type, in which the water column in the bottom part of the CPS channel has been eliminated (Fig. 13.1).

Secondly, the modernization of the CPS rods servodrive increased their speed of insertion into the core. This allowed a reduction of the insertion time from 18 seconds to 14 seconds. When these changes were implemented, the prompt effectiveness of the emergency protection system reached 0.9 β/s, which is about 8 times higher than the value before the Chernobyl accident.

The third stage of increasing the control and protection system effectiveness was to install a new design of the fast-acting scram rod in all the operating RBMK reactors. This new design eliminated the water which used to slow down the rod movement. The channel walls are now cooled by a thin film of water, while the rod moves in a gaseous environment.

The new design was tested at the Ignalina and St. Petersburg NPPs in 1987-88. Fig. 13.2 [54] shows that as the 24 FAS rods are fully inserted in less than 2.5 s, achieving more than 2β of negative reactivity (left diagram). The diagram on the right shows the reduction in power when the FAS rods are inserted.

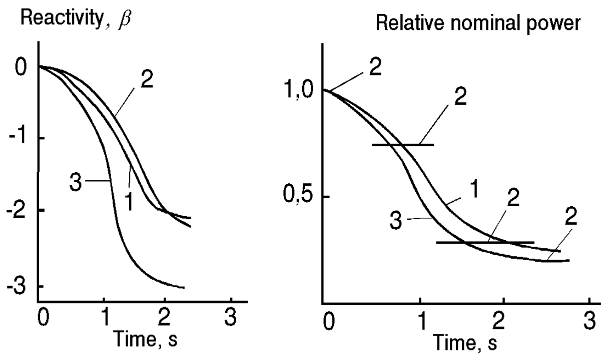

Fig. 13.2 Fast-acting scram system test, at reactor power $N = 0.4N_{nom}$ [54]
1 - calculated, 2 - St. Petersburg NPP, 3 - Ignalina NPP

Besides the improvements mentioned above, several other important improvements were made which increased the CPS effectiveness:

- the number of shortened absorber rods was increased up to 40,
- automatic reactor shutdown was provided for when reactivity reserves fall below 30 manual control rods.

All of these mean to improve the neutronic characteristics of the reactor and increase the emergency protection system effectiveness and thus diminish the chances of an uncontrolled increase in reactor power.

13.2 MODIFICATION IMPLEMENTED DURING THE SAFETY IMPROVEMENT PROGRAM

As noted in previous Subsection significant safety improvements were done by the plant after Chernobyl accident. Efforts to upgrade the Ignalina NPP safety were accelerated when Lithuania assumed control of the plans in 1991. To meet the safe operation goal, the management of the Ignalina NPP together with the Lithuanian Ministry of Energy and assisted by Western experts prepared the Ignalina NPP Safety Improvement Program [22]. It was approved by VATESI in 1993. The objective of the safety upgrading program is to increase and maintain the Ignalina operational safety level until it is permanently closed. The program recognizes the need for better fire-protection system, procedures for proper documentation of plant equipment and improved reactor protection system.

Lithuania's original intention was to contribute about $5 million of its own funds to plant improvements. Because of general difficult economic situation within Lithuania, it was quite clear that part of the SIP could be realised only with technical as well as financial assistance from Western countries. For this reason, a Grant Agreement [83] was signed on February 10, 1994 in London between the Lithuanian Government, Ignalina NPP and the European Bank for Reconstruction and Development on behalf of the Nuclear Safety Account (NSA). This agreement is the first significant Western financial aid for an RBMK plant and is only a second such grant approved to help an eastern European nuclear power plant from NSA. The accord provides for a grant of 33 million ECU. The grant was to fund short term safety upgrades in support of the SIP being implemented at Ignalina plant. As part of the overall improvement program, the EBRD funds are to support 20 projects in three area:

- Operational Safety Improvements,
- Near-Term Technical Safety Improvements,
- Provision of Services.

Operational safety improvement and short-term safety improvement projects are listed in Table 13.1. At the present time fifteen of safety-related engineering projects sponsored from the NSA have been completed, others are under way. All in-service inspection equipment and special tools for maintenance have been delivered and the engineering studies, including seismic upgrading walkdown, are all complete. The ultrasonic In-Service Insperction (ISI) equipment for the reactor channels will provide important direct evidence of channel conditions. Site acceptance tests were successful. The ARKI Technical Documentation Management System has been in operation since February 1996. Since that time, utilization of the system has been extended and about forty additional users have been connected. The system currently contains more than 20,000 different documents. Hydrogen monitoring system on both units are now in service. All 24 safety valves have been delivered and were installed during 1996 outages. All 76 motor gate-valves have been delivered. Twelve at unit 2 and ten valves at unit 1 are in service. Fire protection improvements are now well advanced and visitors to the plant will see evidence of new fire resistant paint and fire dampers.

Radioactive release and environment monitoring equipment have been delivered to the Ignalina NPP. However, due to failure of the supplier company (SEA) assembling work has not started and design documentation as well as computer software have not been delivered. SEA has promised to take further action only in September of 1997. Main actions related to built full scope simulators are completed in October of 1997. Equipment for a trip system due to low flow in the GDH, low reactivity margin for unit 1 and cables for both units have been delivered. Similar equipment for unit 2 is already tested at the manufacturers sides. There is a necessity to do same changes in the design of the trip system. The most important changes are related with trip logic. The EBRD has approved changing of contract related trip logic. Seismic monitoring equipment has been delivered to the plant, but most the important problem is to get permission for construction of seismic stations at the territory of Lithuania, Belorus and Latvia. In accordance with working plans seismic stations in Lithuania should be mounted in 1997.

The Safety Improvement Project is not restricted to the safety upgrading project at Ignalina NPP. It encompasses also the NSA-funded Safety Improvement Program, in addition, the Ignalina NPP has ongoing bilateral cooperative projects with Sweden, USA, Germany, UK, France, Belgium, Italy, Switzerland, Canada, Finland and Japan. Sweden is especially active in Lithuania. Geographically the two RBMK reactors at Ignalina NPP are the closest RBMK plants to Sweden. This makes Ignalina NPP a natural focus-point for Swedish interests. The most important technical safety projects implemented by Swedish assistance encompass fire protection equipment, including improved alarms, sprinklers and fire isolating partitions in various plant locations. Sweden has provided modern inspection equipment, including cutting equipment which has been used for the installation of a pressure relief pipe from the reactor cavity to the accident confinement system. The object of the latter project is to enhance the pressure relief

Table 13.1 EBRD funded safety improvement projects at Ignalina NPP

Item	Project	Supplier	Contract value, MECU
A-1.1	Steam separator and primary circuit visual inspection equipment	GES Alsthom (UK)	0.70
A-1.2	Ultrasonic in-service inspection equipment for steam separator, pipes, etc.	Force Institute (Denmark)	0.60
A-1.3	Ultrasonic in-service inspection equipment for reactor channel	MAN Energie (Germany)	1.42
A-1.4	Radiographic inspection equipment	ABB-TRC (Sweden)	0.13
A-2.1	Special tools for maintenance	Furmanite Int. (UK)	0.43
A-2.3	Seal rings for fuel channels	Advanced Products (USA)	0.24
A-4	Radioactive release and environment monitoring	SEA (Italy)	1.72
A-5	Design documentation upgrading	IVO (Finland)	0.52
A-6	Full scope simulator	Atlas (Germany)	5.49
B-1.1/3	Engineering study of additional shutdown and protection systems	AEA Technology (UK)	0.63
B-1.2/5	Low flow and low reactivity margin reactor trip systems	Westinghouse (USA)	6.36
B-1.4	Upgrading for the TITAN system	SAIC (USA)	0.4
B-2.2a	Seismic upgrading (walkdown)	ISMES (Italy)	0.4
B-2.2b	Seismic upgrading (equipment)	-	1.37
B-2.4	Hydrogen monitoring system	Electrowat (Switzerland)	1.45
B-3.1a	Safety valves	Sebim (France)	2.68
B-3.1b	Motor gate valves	FIAT-AVIO (Italy)	2.25
B-5	Fire protection equipment	SVT Brandshutz (Germany)	2.71
		Total	29.18

capacity of the reactor cavity. This was achieved by using remotely controlled equipment to cut out a 600 mm penetration into the cavity and install piping leading to the ACS. As a result, the reactor cavity is now able to withstand multiple ruptures of 3 up to 9 pressure tubes. Other Swedish assistance projects include NDT testing, development and implementation of the plant quality assurance system, physical security and communications system upgrades. The Ignalina NPP has signed an agreement worth $2million with Swedish International Project Nuclear Safety and the US Department of Energy to install a new computer network and database system to improve plant safety and productivity. The contracts cover computer hardware, software, and training for the reliability maintenance management system/configuration management process at Ignalina plant. The USA will purchase the computer hardware and training for plant personnel, while Sweden will purchase computer software. The new system will monitor the state of the plant and warn operators of any irregularities. It will also link up the plant‘s seven existing databases, which currently operate independently of each other. Symptom-based emergency operating instructions is under development and will be finished at the end of 1997 in cooperation between Ignalina NPP and Pacific Northwest National Laboratory.

13.3 NEW SAFETY IMPROVEMENT PROJECT

As described in Section 10, an in-depth safety assessment of the Ignalina NPP was undertaken in 1995-96 and as a result a plant-specific Safety Analysis Report was produced which will form the basis for decisions on future operation of Ignalina NPP. The SAR and RSR teams have identified safety issues, made many recommendations on necessary safety improvements in design, operation and safety culture. Implementation of all improvements will significantly increase the safety level of the Ignalina plant. The Ignalina Safety Panel holds the view that the most important safety issues in design and operation must be resolved without delay [84]. At the close 1997 these issues are as follows:

- The Ignalina NPP should introduced an appropriate management structure to ensure safe operation of the plant, efficient implementation of necessary safety improvements and adequate support of the licensing process.
- The safety case for the reactor control and protection system should be completed by the Ignalina NPP.
- The safety case for the accident confinement system should be provided by the plant.
- The safety case for the structural integrity of the reactor cooling system should be provided by the Ignalina NPP.
- A fire hazard analysis for all safety systems should be carried out by the plant.
- Ignalina NPP should develop and implement emergency operating procedures and provide an improved definition of the limits and conditions of safe operation.

Among the SAR’s recommendations is the desirability to install a second independent shutdown system at both units. This involves a significant hardware up-grade and could be expected to require about 3-4 years for completion. The Ignalina Safety Panel did not recommend the installation of such a system at unit 1 because is expected to be shut down in relatively near future. For unit 1 the development of an economic and speedy resolution of the control and protection system issue is required which will be able to provide an acceptable system for the remaining years of the operation before its closure. The projected longer life of unit 2 requires a more reliable solution. According the Panel, Lithuania must carry out an estimated about $120 million worth of safety improvements, which includes the installation of an independent shutdown system for unit 2.

To operate beyond June 30, 1998 unit 1 will have to be relicensed by VATESI. The operation of unit 1 beyond 1998 would depend on the results of the nuclear safety assessment, the cost of continued safety upgrades and energy situation in Lithuania. The Ignalina Safety Panel required substantial changes in the attitude of the regulator with regard to safety problems. VATESI must develop a regulatory regime for the licensing process and for monitoring of Ignalina NPP operation using bilateral and multilateral assistance.

As noted above, the SAR was initially conceived as a Western-style SAR, produced by the plant with help from Western experts. However, such a SAR would have consumed several times the resources budgeted for the in-depth safety assessment of Ignalina NPP. The scope was therefore defined as including assessment specific essential items. The intention was that it should take the form of a justification by of plant safety level in 1996, and the explanation of how the intended improvements will establish an acceptable safety level for remaining years of operation until plant closure. The objectives point out that the SAR is intended to aid VATESI in making a licensing decision, but it is not stated that the SAR will form the complete basis of the safety case prepared for licensing. The SAR is a major contribution to the licensing process currently being undertaken by Lithuanian regulatory body, VATESI. Some issues were not covered by the assessment and remain to be resolved between VATESI and Ignalina NPP. For this purpose the International Licensing Assistance Project was established. Its goal is to support VATESI during application of the SAR and RSR results in the licensing of the Ignalina NPP.

The Ignalina Safety Panel concludes that the measures defined by the Safety Improvement Program, partially funded from NSA, are in general supported by SAR and RSR results. However, the scope of these studies is not sufficient to resolve all licensing issues and continue operation. The ISP recognises the urgent need for and supports an integrated international assistance program that builds upon the Safety Improvement Program of Ignalina NPP and includes guidance to VATESI and its technical support organisations.

The ISP recommended that the Lithuanian Nuclear Safety Advisory Committee should monitor the follow-up process of the Ignalina Safety Assessment and provide necessary authority. The international component of the committee is broadened by inviting membership from the USA, France, and Japan in additional to the members from Sweden, Germany, UK, Finland and Ukraine.

The Lithuanian Government agreed that the recommendations of the ISP were extremely important for the enhancement of nuclear safety at the Ignalina NPP. The Government of the Republic of Lithuania also reported that they will ensure that the organizations within the country's nuclear energy sector will take all of the necessary actions and that the necessary resources would be made available.

The new Safety Improvement Program (SIP-2) of the Ignalina NPP [66] is based mainly on the recommendation of the Ignalina Safety Panel, Safety Analysis Report production and its independent review. The SIP-2 has been already developed and approved by the Lithuanian authorities. Experience of the first Safety Improvement Program and safety-related problems identified within Ignalina NPP were also taken into account. The SIP-2 will be continuously up-dated and revised annually and should be completed in three years (1997-1999). All activities within the new Safety Improvement Program are divided in three groups:

- Design modifications,
- Management and organization development,
- Safety Analyses.

Design modifications include system improvements for normal operation, such as feedwater regulation, development and implementation of hazard protection, accident prevention and mitigation measures. Management and organization development includes implementation of symptom-based operational procedures, system for maintenance and configuration management, Quality Assurance program and Safety Culture system. The new Safety Improvement Program includes the 6 most important safety measures recommended by the ISP to be resolved in short-term, safety problems to be resolved before licensing and safety issues to be resolved after licensing. The six safety issues needing immediate resolution are listed above. The other most important safety problems which should be resolved before licensing are as follows:

- Safety evaluation and stress analysis of operation with graphite - pressure tube gaps exhausted (gripped pressure tubes) and transient induced thermal stresses.
- Reactor trip and ECCS actuation based on the dP/dt signal in steam separator.
- Automatic actuation of ECCS on low flow in multiple channels connected to one GDH.
- Assessment of waterhammer effect on GDH check valves and connected pipelines.
- Justification of omission of an assessment of accidents at shut-down.
- Analysis of reactivity initiated events for core with new fuel design which is 2.4 % enriched and containing erbium burnable poison.

Among the long-term safety measurements the most important is the development and installation of a fully independent diverse shutdown system. Other important safety are as follows:

- Introduction of an early reactor trip and ECCS actuation for all break location in MCC and steam systems.
- Modifications to ensure ECCS is automatically injected to the unbreached reactor half.
- Improvement of redundancy and reliability of ECCS accumulator pressure control.
- Development of strategy for local flow degradation in intermediate and long term (ECCS injection management and depressurization).
- Improvements to drainage in steam separator compartments.
- Improvements of the reactor hall over-pressure protection.
- Improvements of fire protection systems, including fire load reduction, separation of fire compartments, installation of fire and smoke detectors and alarms.
- Development and implementation of the Equipment Qualification program for set of safety related electrical equipment.
- Analysis of hydrogen concentration in ACS compartments.
- Complete accident analysis in long term including accidents during reactor shut-down, internal areas events and external events.
- Evaluation of the impact of safety related component aging and Importance Analysis to identify components potentially contributing high risk.
- Partial ATWS analysis.
- Continue analysis of reactor pressure relief` system to determine margins.

All the tasks of the first Safety Improvement Program which were not completed have been included in the SIP-2. Among them are construction of the on-site interim spent fuel storage, development of cementation facility for spent ion exchange resins and others discussed in Subsection 3.2. Some new safety improvements proposed by the plant itself are included in the SIP-2, such as replacing of batteries and DC switch-gears at unit 2, implementation of safety panel at unit 2, development and installation of solid waste incinerator, upgrading of pipeline of SDV-D valves.

A special Project Organisation was established at the plant to implement the SIP-2 program. Project management and project staff have been appointed by the Director General of the Ignalina NPP and have been relieved from other duties in order to be able to devote their whole efforts to the Project. A Steering Group for the supervision of the Project composed of members from the plant and from external bodies has been established. Quality Assurance (QA) program for the Project which will be in line with general plant QA program has been developed and implemented. At the close of 1997 some specific project management actions have already been implemented by the plant in response to the SAR and RSR findings. Other changes are under way. These include continued development of management skills at all levels of the organisation, a Program for increasing Safety Culture awareness of all staff, combining with Safety Culture audits of individual parts of the plant organization, splitting-off of non-core activities of Ignalina NPP into separate independent companies during 1997-1998 activities, setting up of a new Department for Perspective Planning and introduction of a new efficient and transparent economy administration system that can serve as a management tool. The Department for Perspective Planning will be responsible for long-term planning, public and staff information, business development, management and organization development and governmental contacts.