The Transition Facility programme
for Nuclear Safety for Lithuania

Implementation of the Second Diverse Shutdown System at the INPP Unit 2: Review and Licensing of the System

Transition Facility Project No. 2004/016-925-05-01

Funded by the European Union

The present publication has been prepared within the framework of the Transition Facility programme for Lithuania Project No. 2004/016-925-05-01

Support to VATESI during Review and Licensing of the New Servo Drives' Design and Commissioning at Ignalina Nuclear Power Plant Unit 2

Vilnius, 2007

Contents

1. Foreword

The safety of Ignalina Nuclear Power Plant (INPP) Unit 2 has been upgraded by installing a second diverse shutdown system (DSS). Unit 2 has two entirely separate and different shutdown systems which protect the reactor from the scenarios of accidents during which it would not be safely scrammed. It implies that in case of an emergency situation and a concurrent failure of one system, the other system is sure to shut down the reactor and prevent any harm to the public and environment.

The safety and effectiveness of two shutdown systems is assured by skilled work of the INPP personnel, the INPP contractors and rigorous regulation by the Lithuanian State nuclear regulatory authority VATESI. VATESI's regulatory work during licensing process of the new system implementation was supported by an international Review Team of independent experts from France, Germany, Sweden, United Kingdom and the United States. VATESI Technical Support Organisations (TSOs) from Lithuania also took an active part in these activities.

Two different projects, both funded by the European Commission, to support VATESI during DSS licensing were implemented. The first project, entitled ***TSO Support to VATESI during Review and Licensing of the Diverse Shutdown System (DSS) at Ignalina NPP Unit 2*** was implemented in a period between years 2000 and 2004, whereas implementation of the second project ***Support to VATESI during Review and Licensing of the New Servo Drives' Design and Commissioning at Ignalina NPP Unit 2*** commenced in 2005 and lasted until 2007.

The following paragraphs of this brochure will provide basic understanding on DSS implementation and licensing aspects.

2. Background

Ignalina Nuclear Power Plant (INPP) is the only nuclear installation in Lithuania. INPP is located in the north-eastern part of Lithuania, at the vicinity of the borders with Latvia and Belarus. It is comprised of two RBMK-1500 reactors (Russian acronym for "Channel-type Large Power Reactor"). The power plant was built as a part of the Soviet Union's North-West Unified Power System. The first unit of INPP was put into commission at the end of 1983, the second unit – in August 1987. Their design lifespan was projected out to 2014-2017, accordingly. A total of four units were originally planned to be built on the INPP site. Construction of Unit 3 was terminated in 1988 because of the staunch political pressure, construction of the forth unit had never been commenced. Presently, Unit 2 is in operation and power production mode, Unit 1 was permanently shut down in December 2004.

RBMK-1500 reactors of the INPP have their own design peculiarities. INPP owns a number of unique features, which place it between 2nd and 3rd generation of reactors.

Both reactors have one circuit, two cooling loops; fuel clusters are loaded into individual channels. The neutron spectrum is thermalized by a massive graphite moderator block. Refuelling is performed during reactor operation, a low-enriched nuclear fuel is used.

Ignalina NPP belongs to the category of boiling water channel-type reactors. The reactor cooling water, when passing through the core, is subjected to boiling and is partially evaporated. The steam-water mixture then continues to drum-separators, the elevation of which is greater than that of the reactor. Here the water settles, while the steam proceeds to the turbines. The remaining steam beyond the turbines is condensed in the condenser, and the condensate is returned via deaerator by the feedwater pumps to the water of the same drum-separators. The coolant is returned by main circulation pumps to the core, where part of it is converted to steam over again.

This fundamental heat cycle is identical to the Boiling Water Reactor (BWR) cycle widely used throughout the world, and is similar to the thermal cycle of power plants using the carbon-hydrogen fuel. However, compared to BWRs used in Western power plants, INPP and other plants with the RBMK-type reactors have a number of their unique features.

The accident in Chernobyl had revealed severe deficiencies in the shutdown function of the RBMK reactors with regard to speed, efficiency and reliability of the then shutdown system.

The international review of the Ignalina Safety Analysis Report (1995-1997) provided: "The apparent lack of effective inherent safety features in RBMK reactors leads to one high priority recommendation that a second fast acting, independent and fully diverse reactor shutdown system needs to be installed". Defence against accidents involving failure of scram was defined as a high priority by the authors and reviewers of the Safety Analysis Report for Ignalina Unit 1. Therefore, it was included in the scope of the "Safety Improvement Programme No. 2" for Ignalina.

In 1997 the International Atomic Energy Agency (IAEA) had included this requirement in their RBMK Safety Issue edition as an issue of the highest priority.

To ensure that the DSS in RBMK meets modern nuclear safety requirements, TACIS project was started in 1998 for the selection of the preferable option for the DSS. The following organizations proposed their options of the diverse shutdown system and its components:

- AECL, Canada, and AEA Technology, UK
- Paul Scherrer Institute, Switzerland, (PSI) in conjunction with the Kurchatov Institute
- Ignalina NPP
- RDIPE, the RBMK designer.

As a result of this project, the option developed by RDIPE and Ignalina NPP was selected as a basis for the implementation at INPP.

3. Purpose and Organisation of the Projects

The first Review project – ***TSO Support to VATESI during Review and Licensing of the Diverse Shutdown System (DSS) at Ignalina NPP Unit 2*** – under Phare support was a major undertaking. It ran during the stage of preparation of regulatory requirements and technical specifications and then in parallel with INPP's development of the DSS during the design and implementation. The DSS was designed and installed by INPP's contractor Data Systems and Solutions.

The main objective of the review project was to provide technical support to VATESI and to ensure that the development project provided a satisfactory outcome in terms of safety improvement.

The project was managed by the Swedish International Project Nuclear Safety (SIP) who has contracted work with the European Commission as part of the Phare programme. SIP as a contractor has sub-contracted Serco Assurance (former AEA Technology plc), GRS, IRSN (former IPSN), ITECHA and the Lithuanian Energy Institute (LEI). The SIP team included experts from TAKO and from KTH.

In addition to the work under the EC Phare contract, Review Team members from ESRT (and Scientech Inc. until October 2001) from the USA participated in the review under separate funding from US NRC. The US team members were integrated into the Review Team effort.

At an early stage of the work proceeding the Phare contract, a Project Office was established at VATESI office, manned by a Lithuanian consultant. From the time of contract start the office was integrated into the project. The office provided VATESI with project management support in administration of the DSS review. The office supported VATESI in organisational, reporting and document control capabilities necessary to interface between VATESI, INPP and the technical review experts.

In November 2005 a second project under the Transition Facility Programme was started, it was entitled Support to VATESI during the Review and Licensing of the New Servo Drives Design and Commissioning at INPP Unit 2.

Following accession of Lithuania to the European Union on 1 May 2004 this project was not directly funded by the European Commission, but via Lithuanian Central Project Management Agency, established by the Ministry of Finance of Lithuania.

This project aimed to support VATESI in two main activities:

- review and licensing during the early operation of INPP Unit 2 at full power with the DSS;
- review and licensing of the design and installation of the new diverse servo-drives[1].

[1] *Servo drives control the movement of some of the absorber rods that control the nuclear reaction. They make the rods quickly descend into the shut-down reactor in an emergency situation and also help to control the power of the reactor at normal operation.*

The Servo-drive review project was performed by a team of experts from France (IRSN), Germany (GRS), Lithuania (ITECHA), Sweden (TAKO) and the UK (Serco Assurance) led by RISKAUDIT IRSN/GRS International. One of the selection criteria for this team was that it had to be familiar with the LI/TS/15 project. Accordingly, the Review Team for the Servo-drive review project was a subset of the Review Team of the earlier project.

Diverse Shutdown System implementation and licensing chronology

Year	Event
1993–1994	International "RBMK Safety Review, Phase 1", EU Phare project, provide: "An additional shutdown system capable of providing short and long-term sub-criticality has to be developed and implemented in order to reduce the probability of events with failure of reactor shutdown".
1994–1997	Safety Analysis Report (SAR) for Ignalina NPP including independent Review Safety Report (RSR). RSR Conclusion: "The apparent lack of effective inherent safety features in RBMK reactors leads to one high priority recommendation that a second fast acting, independent and fully diverse reactor shutdown system (DSS) needs to be installed". Supported by SAR authors. DSS included in the scope of ***Safety Improvement Programme No. 2*** for Ignalina.
1998	Selection of Preferred Option of DSS.
1999	Iterative review of Technical Specifications for the tendering process. Workshop at VATESI on the DSS for selection of Preferred Option. DSS Project Office established at VATESI (bilateral program).
2000	Preparation of Requirements for DSS design and safety justification. Technical meeting at Winfrith (UK) on DSS technical specifications and requirements issues. Signed Phare project LI/TS/15 "Support to VATESI during Review and Licensing of implementation of DSS at INPP unit 2". Support provided by: GRS (Germany), IRSN (IPSN) (France), LEI, ITECHA (Lithuania), ESRT LLC (SCIENTECH) (USA), Serco Assurance (AEA-T) (UK), SIP (Sweden).
2001	Review of Feasibility Study of DSS without splitting the Control and Protection System Cooling Circuit and without Cluster Control Rods. Review of Tender Technical Specifications (Proposed Option). Review of DSS implementation plan. VATESI issue the Requirements for safety justification of Second Diverse Shut Down System implementation at INPP Unit 2. VATESI approve the Technical Specification (Proposed Option).

Year	Event
2002	Safety justification and review of the existing servo drives. Schedule approved by VATESI for installation of new diverse servo drives. Completion date – September 2006. July 1 - Contract signed by the INPP on installation of the DSS at Unit 2 with Data Systems & Solutions (UK). Review or the DSS preliminary Safety Justification Report. The extension of PHARE project on supporting VATESI in licensing of DSS.
2003	Production of DSS components begins. Review of Interim Safety Justification. Approval of Technical specifications for new servo drives. A review of Lines-of-Defense assessment of DSS actuators aimed at substantiating operation of the existing CPS drives into the group of AZ/BSM drives after electronic part of DSS is installed and until new servo drives are installed in 2006. DSS Factory Acceptance Tests (FAT) in Gateshead, UK. Review of documents related to DSS testing during FAT and implementation of corrective measures.
2004	Review of Final Safety Justification for DSS and related documentation. Inspection of DSS installation at the INPP. Review of installation, tests and commissioning of DSS. VATESI request of a continued support after the completion of LI/TS/15 to cover period up to the end of installation, commissioning and trial operation of the DSS. Issue of order for modification of the existing Control and Protection System (CPS). Approval of Technological Reglament for the INPP Unit 2 operation. Approval of DSS Site Acceptance Test (SAT) Program. VATESI issue of permission for conducting trial commercial testing of emergency protection sets 1 and 2 and fast power reduction system. Final LI/TS/15 project meeting at VATESI to discuss relevant technical issues and to finalise the work of the project. Issue of the final LI/TS/15 report
2005	Review of the revised Final Safety Justification for the INPP DSS. GRS and Serco Assurance support to VATESI provided under bilateral German and the UK assistance programmes. INPP submits preliminary safety justification of servo drives of AZ/BSM system to VATESI for approval. Specialists from VATESI and TSOs take part in the factory acceptance testing of the main sample of servo drive of AZ/BSM system at the factory in Pilsen (the Czech Republic). VATESI signs an agreement with the Central Project Management Agency and Riskaudit within the framework of EU Transition Facility project regarding support to VATESI in assessing and licensing the design of new servo drives and their commissioning at the INPP Unit 2. Participating organizations: GRS, IRSN, Serco Assurance, Tako, Itecha.

Year	Event
2006	Review of improvements to DSS ('*Reactor protection by the 1st set of the AZ system at Unit 2 of INPP on low flow through the group distribution header*'). Review of the results of the commissioning tests described in the Final Safety Justification for the DSS. Review of the Final Safety Justification for INPP Diverse Shutdown System, Accident Analysis. Review of the Final Safety Justification for the New Servo Drives of the INPP Diverse Shutdown System". Issues concerning Failure Modes and Effects Analysis (FMEA), Reliability analysis, Modifications, Quality Assurance discussed during the meeting at VATESI in August. Review report on multiple failures of power supply units of output relay devices of the DSS. Issue of permission for installation of 25 new servo drives for the AZ/BSM control rods.
2007	Review of updated versions of Volumes 1 and 3 of the FSJ for the new servo drives, information on the operation of the first 25 servo drives installed during the outage of 2006 and the responses of INPP to the comments of the Review Team on the FSJ as of September 2006. August – VATESI issued the permission for installation the 24 new servo drives for the AZ/BSM control rods. 13-14 September – Final project meeting "Support to VATESI during Review and Licensing of the New Servo Drives' Design and Commissioning" held at VATESI.

4. Activities and Results

Review Project for DSS implementation

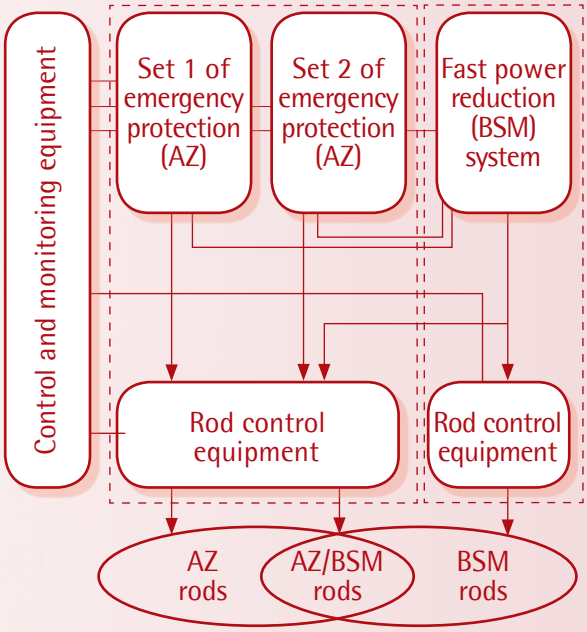
DSS implementation at the INPP Unit 2 was performed in two stages. The main project implementation of electronic part of the system was completed in mid-2004. Design, manufacturing and installation of 25 units of new drives were completed in 2006. The remaining 24 units were installed during the outage of year 2007.

INPP shutdown systems are shown in a figure (*see* figure **Shutdown systems of INPP Unit 2**). Review Team has proposed considerable iterations to the technical specifications and safety justification documentation produced by the DSS contractor in the first project and throughout counselled VATESI on appropriate responses to the NPP related to these submissions.

VATESI was assisted by the Review group while performing inspections of the manufacturing work at the contractor's factory and at the INPP. Several errors related to

implementation of the detailed design were uncovered in due course of inspections, some weaknesses in quality control were also underlined. Findings and observations of these inspections enabled to vouch for the DSS compliance with the nuclear safety requirements and technical specifications. Deficiencies were corrected by the contractor and the NPP and a fairly satisfactory outcome was achieved. Issues of high importance with regard to safety were fully resolved.

Shutdown systems of INPP Unit 2



It was judged that the final status of the DSS before the reactor start-up is satisfactory and a substantial improvement in the reliability of the scram function is demonstrated. This was the main aim of the DSS installation, as a response to the expected behaviour of reactors of the RBMK type in Anticipated Transients Without Scram (ATWS) scenario.

The reliability increased because of the overall system architecture. Two diverse and well-separated systems provide emergency protection. Each system has at least a three-fold redundancy, and good separation between the three redundant trains, at each level of the signal path. Adequate isolation of the signals is provided by qualified isolation devices such as relays and optical isolators. Considerable operating experience of the basic parts of the digital system (AZ 2nd set) is collected in other reactor types, and a large part of the analogue system (AZ 1st set) has a long successful operating experience in RBMK reactors, specifically in Ignalina NPP Units 1 and 2. This has provided basis for judgement that framework of this architecture and the qualification of the sub-systems and the overall system is fairly redundant and diversified.

New parts of the combined system that are closely interconnected in the 1st and 2nd set, or are common components relating to the actuation of absorber insertion (for example the ORDs and Servo Drives), were thoroughly examined in the review.

Detailed architecture of the system was also noted as complicated by the Review Team. This complexity subsequently may have resulted in difficulties in design, its analysis and evaluation. In other reactors of different type with second shutdown systems installed it was easier to demonstrate clear diversity and segregation, resulting in a very high estimated reliability. In case of Ignalina Unit 2, its DSS complexity required more efforts by the INPP staff, VATESI and the Review Team to reach the positive conclusion above.

The timeframe of the DSS review project was limited by the contract and ultimately by constraints of the disbursement schedule of the European Commission. The DSS implementation project was nearing its completion but not absolutely finished at the end of the review project (October 2004). At the end of the DSS review project the commissioning tests have been completed before start-up and the plant was ready to restart. The decision was taken that DSS operation should be closely monitored so in case of any divergence from the expected DSS performance it would be singled out and discussed with INPP.

A currently used servo drive of reactor control rods (left) and an AZ/BSM servo drive of the new design (right).

SD Project

The Servo Drive (SD) Review Project envisaged three fundamental aims.

The first aim was to complete some review activities left over from the first project. These included the review of the results of the commissioning tests of the DSS, making certain it had been installed correctly and was in full working order; and to review part of the Final Safety Justification for the DSS concerned with accident analysis.

The second aim of the servo drive project was to monitor and check on the early operation of the DSS and to review an improvement to the DSS so that it will operate correctly when the flow of coolant in the reactor falls below the specified value.

The third, the most important aim of the project was to review the design, safety justification, manufacture, installation and testing of the servo drives. The servo drives are novel devices to handle the movement of some of the absorber rods that control the nuclear reaction. They make the rods drop right in to shut down the reactor in an emergency and also help to control the power of the reactor during normal operation.

The review of the commissioning tests of the DSS revealed some non-compliances, which is to be expected at this stage. Appropriate recommendations were issued to make sure the commissioning tests included considerable portion of the equipment samples; and that non-compliances had been dealt with in a proper manner.

Recommendations submitted to DSS accident analysis part included a proposal to expand Final Safety Justification with more detailed information in order to demonstrate safety and to complete the table illustrating the preparedness of the shutdown system to operate in response to every possible reason for an emergency shutdown.

A review of documents to prove reliability and accuracy of DSS operation in case a flow of coolant in the reactor falls below the specified value was performed. Results of this review proved to be satisfactory.

The major objective of this project was to present iterative review of the Preliminary Safety Justification (PSJ) and Final Safety Justification (FSJ) for the diverse servo drives. This includes review of manufacturing, testing and design changes. The iterative review involved the production of five review reports including one recommending the modes of the FSJ completion. These reviews complemented the first draft PSJ, a later supplement and two drafts of the FSJ. Two Review Meetings were held between INPP, VATESI and the Review Team in February and August 2006.

The main issues discussed in the iterative review were:

- Assessing the number of shutdown rods that can fail to enter the reactor core so that the reactor still shuts down safely
- Demonstrating that the servo drive design is mature enough to be reliable

- Ensuring that all of the potential failures of the servo drives have been identified
- Numerical estimation of the reliability of the servo drives (probability of failure on demand) and whether it is possible to meet the target reliability of the design.

Conclusive remarks of the iterative review demonstrated that comments of the Review Team had been satisfactorily resolved.

In August 2007 VATESI and INPP resolved the outstanding issues on the basis of the new information provided by the plant. As an outcome, a final version of the FSJ will be issued that will be acceptable to VATESI. This will provide the basis for the safe operation of the servo drives during the remaining operation of the INPP Unit 2.

5. Conclusive Remarks and Recommendations

The DSS review project provided VATESI with continuous technical advice on submissions from INPP and supported them in many meetings with INPP and ensured that nuclear safety authority is fully able to act with full regulatory strength throughout the entire DSS project implementation. Upon acquiring this experience and specific training, VATESI and the Lithuanian TSOs have improved their capability to review, inspect and regulate large Control and Instrumentation projects.

On numerous occasions during the DSS design, development and realization, and especially at the specification stage, the review resulted in essential changes to the design. These improvements ensure that the DSS could be sufficiently diverse and have enough redundancy and shutdown capability. Therefore, it can be qualified as a diverse shutdown system giving a large improvement in scram reliability. Without these interventions it is arguable whether the system could have successfully and completely met its requirements.

Concurrently, VATESI monitors compliance with the recommendations presented in the review of the accident analysis in the DSS FSJ.

The performed review ensured that the large investment by the European Commission exceptionally beneficial, as an optimal increase in the shutdown reliability was successfully achieved.

At the final meeting of the second project VATESI and the Review Team agreed that the review process had been demanding to all parties involved. Many documents had to be studied in-depth to test the safety justifications. Numerous review comments were made and the responses were carefully examined. This resulted in improved safety of the DSS and the servo-drives and a demonstration of this improvement in a transparent mode.

The results achieved after having taken part in a detailed and exhaustive review of this complex installation enabled the staff of VATESI to solidify confidence in their role as a reliable regulator.

Members of the Review Group during a meeting at VATESI, September 2007.

6. Acknowledgments

This publication is prepared by the State Nuclear Power Safety Inspectorate (VATESI) of the Republic of Lithuania with valuable consultation and incorporating contributions of other institutions. Grateful acknowledgements are extended to:

- Central Project Management Agency, Lithuania
- GRS, Germany
- IRSN, France
- ITECHA, Lithuania
- RISKAUDIT, France
- SERCO Assurance, United Kingdom
- TAKO, Sweden

State Nuclear Power Safety Inspectorate (VATESI)
12 A. Goštauto str., LT-01108 Vilnius, Lithuania
Telephone: +370 5 262 41 41, fax: +370 5 261 44 87
E-mail: atom@vatesi.lt
Website: http://www.vatesi.lt

Published by Leidybos įmonė „Kriventa“
5-3 V. Pietario str., LT-03122 Vilnius, Lithuania
Tel./fax: +370 5 265 06 29
E-mail: kriventa@takas.lt, www.kriventa.lt