SNSA SURVEILLANCE OVER THE AGEING EFFECTS AND ABILITY FOR LONG TERM OPERATION AT THE KRŠKO NPP

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Abstract

The Krško NPP, the only NPP in Slovenia, is a two-loop pressurized water reactor of Westinghouse design. For this reason and also because of former weak domestic legislation in some areas the licensee strictly follows the U.S. nuclear requirements. A new "Act on Protection Against Ionizing Radiation and Nuclear Safety" has introduced additional requirements in accordance with the European practice. As a result the first PSR was performed and confirmed that the plant is still as safe as it was originally intended. An approved PSR report by the SNSA is a condition for renewing the operation license of the Slovenian nuclear facilities for the next ten years' period.

Numerous additional SNSA's activities for deeper insight into the plant activities and equipment status have been introduced. Regular inspections are performed about twice a week. During plant outages a team of the SNSA's inspectors is strengthen by the experts from the Nuclear Safety department. Additional supervision during outages covers mainly performance of plant modifications, maintenance, equipment inspection and surveillance testing.

Significant progress has been done in the field of review and assessment of important plant programmes. In 2005 and 2006 Environmental Qualification, Ageing Management and Maintenance Rule Programme had been reviewed. Findings were discussed with plant managers and most of the SNSA's findings were taken into account.

In order to obtain deeper insight into the status of the plant equipment, the software for monitoring the condition of the plant SSCs and the procedure governing its use have been developed. The software provides monitoring of transients important for fatigue evaluation and the status of safety important plant SSCs. An additional way to for monitoring the status of plant SSCs is a database for tracking the corrective work orders issued by the plant, which was introduced in 2005.

1. Introduction

The Slovenian Nuclear Safety Administration (SNSA), as a regulatory body in the area of nuclear and radiation safety, performs inspection and licensing processes in the area of radiation and nuclear safety, development of regulatory infrastructure, review and assessment, analyses of operational events and experience, preparation of reports on nuclear safety in Slovenia etc.

The first SNSA's priority is supervision over the nuclear safety at The Krško Nuclear Power Plant, the only nuclear NPP in Slovenia. The SNSA's staff comprises 47 permanent employees and is organized into six divisions. Divisions of Nuclear Safety and Inspection are

directly responsible for supervision of the Krško NPP. The SNSA carries out its surveillance responsibilities with a combination of inspections, scrutiny of documents, approval of plant modifications, and regular monitoring and evaluation of the station's performance.

The Krško NPP is a Westinghouse two-loop pressurized water reactor with originally installed capacity of 632 MWe net electrical output power. Its construction started in 1974, full power was reached in 1982, and the first full year of commercial operation was in 1983. From then the plant has constantly been modernized. The modernization resulted not only in the improved safety, but the output power was also increased. In 2000 steam generators were replaced and the power was uprated to 707/676 MWe (gross electrical power/net electrical power). During the outage in 2006 the low pressure turbines were replaced and the nominal output power reached 727/696 MWe. The basic safety features of the plant are typical for a two-loop Westinghouse plant. However, during its lifetime the Krško NPP updates Safety Analysis Report (SAR) in a regular basis, as is the case in the U.S. (vendor country of the Krško NPP). The Probabilistic Safety Analysis (PSA) was performed and since then the Krško NPP maintains a living PSA that is regularly internally reviewed. The Regulatory Compliance Programme (RCP), that reviews the plant compliance with the U.S. NRC requests, is an ongoing programme at the Krško NPP. Additionally, the Krško NPP hosted many international missions like OSART, ASSET, ICISA, IPPARS, IPERS, IPSART and RAMP.

In spite of having the plant with such a living updated programme in accordance with the U.S. requirements, a new "Act on Protection Against Ionizing Radiation and Nuclear Safety" [1], which was accepted in 2002, introduced additional requirements in accordance with the European practice. Periodic Safety Review (PSR) was introduced and identified a number of recommendations to further enhance the plant's safety. Among others a development of an Ageing Management and the Environmental Qualification Programme, which are directly connected to the plant's life management, were recommended.

In Europe, the PSR is a widely accepted approach to reassess nuclear safety at nuclear power plants. Period of an operation's license is based on a 10-years successfully performed PSR in many countries. Meeting the requirements of a new Slovenian legislation, this is a case in Slovenia as well.

Furthermore, the SNSA has introduced series of additional activities which provide more direct contact of the SNSA experts with plant activities and contribute to deeper insight into status of plant's equipment. In the paper the main SNSA's activities to survey status of ageing management and suitability for long term operation at the Krško NPP are presented.

2. Periodic Safety Review

After the NPP's Krško modernization project in 2000 (including steam generators replacement, reactor power increase), the need for conducting a PSR of the Krško NPP has been clearly recognized by both, the NPP Krško management and the SNSA. The PSR was highly desirable, both in the light of current trends in the safety oversight practices and because of many benefits it is capable to provide. The Krško NPP PSR's objectives encompass three main criteria or goals:

- confirmation that the plant is as safe as originally intended,

- determination of any structures, systems or components that could limit the life of the plant in the foreseeable future and
- plant's comparison with modern safety standards to identify where the improvements would be beneficial at justifiable costs.

The first PSR programme, which started in 2001, comprised a systematic review of an operation of the NPP Krško, including changes as a result of modernization of the facility and is in accordance with the IAEA Safety Guide "Periodic Safety Review of Operational Nuclear Power Plants" No. 50-SG-012 and with European practice "Periodic Safety Review of Nuclear Power Plants in EC Member States, Finland, Sweden and Switzerland" EUR 15555 EN. The basic review factors are: Operational Experience, Safety Assessment and Analyses, Environmental Qualification and Ageing Management, Safety Culture, Emergency Planning, Environmental Impact and Radioactive Waste, Compliance with License Requirements and Prioritization.

The first NPP Krško's PSR was approved in 2005 and confirmed that the plant is as safe as it was originally intended and that there are no structures, systems, components, which could limit the life of the plant in the next ten years. This review has not revealed any major safety issue, nevertheless it has identified a number of recommendations to enhance further safety of the plant. The PSR's Action Plan contains 124 actions which are grouped in 13 areas:

- Ageing management
- NEK plant specific EOP supporting activities
- Krško individual plant examination, external events supporting activities
- Krško plant specific mechanical analyses closure activities
- Krško operational problems closure activities
- Krško IAEA RAMP mission recommendations closure activities
- Accident analysis closure activities
- Krško standard technical specifications closure activities
- Krško regulatory compliance programme closure activities
- Potential maintenance problems closure activities
- Potential environmental qualification problems closure activities
- Potential design problems closure activities
- Potential seismic design problems closure activities

Most of the actions will be completed by the end of 2008 while whole PSR's Action Plan must be completed by the end of 2010. The second PSR must be submitted to the SNSA by the end of 2013 as a proof that the plant will safely operate for the next 10 years.

The PSR programme is described in detail in new "Regulation on Assurance of Operational Safety of Nuclear and Radiation Facilities" (Regulation JV9, draft version) in accordance with the IAEA Safety Standards Series No. NS-G-2.10 "Periodic Safety Review of Nuclear Power Plants Safety Guide" [2]. Successfully performed PSR as described in Regulation JV9 provides to a regulatory body a good insight into suitability of the plant for a long term operation since basic elements of PLIM such an Ageing Management, Equipment Qualification, Maintenance, Testing, Equipment Inspection, Modifications, etc. are constituent parts of the PSR.

3. SNSA's inspections

The SNSA does not have resident inspectors on site. Inspectors, who are based at their headquarters in Ljubljana about 100 km from the plant, visit the facility about twice a week. Yearly, there are about 100 inspections performed on site during non-outage years and there is an additional daily presence during outages. Regular inspections cover the following main topics:

1. plant operation
2. maintenance, surveillance testing and equipment inspection
3. personnel training
4. radiological monitoring
5. emergency preparedness

Information on the condition of safety related equipment which are essential for plant's long term operation, is gained through monitoring and presence at the plant's activities in the areas of maintenance, surveillance testing and equipment inspection. The following activities in these areas are performed by the SNSA inspectors:

- supervision of on-line maintenance
- periodic presence at regular monthly tests of emergency diesel generators
- periodic presence at surveillance testing of safety equipment (emergency core cooling system, auxiliary feedwater system)
- review of results of surveillance testing
- review of in-service inspection reports
- supervision of spare parts suitability in storehouse

During the plant's outages even stricter inspections on plant's staff and subcontractors work are performed. Beside regular supervision by the SNSA's inspectors, an additional supervision is performed by the SNSA's experts from the Nuclear Safety department. An additional supervision during plant outages covers the following areas:

- performance of plant modifications
- maintenance and equipment inspection
- surveillance testing
- outage activities related to plant programmes
- plant pre-outage activities and outage phases
- evaluation of eventual abnormal events during outage

Table 1 shows main tasks at the Krško NPP which are planned to be supervised by the SNSA during the outage in October 2007.

Table 1. Main tasks at the Krško NPP to be supervised by the SNSA during outage in 2007

Plant modifications	• Replacement of moisture separator reheaters • Replacement of low pressure feedwater heaters • Replacement of reactor coolant pump motor • Replacement of chilled water system chillers • Repairing of turbine cross-under piping
Maintenance and equipment inspection	• Inspection of spent fuel integrity • SG sludge lancing • Revision of turbine driven auxiliary feedwater pump • Inspection of secondary pipelines • Revision of main generator

Surveillance testing	• Auxiliary feedwater full flow test • Containment integrated leak rate test • Safety injection full flow test
Outage activities related to plant programmes	• Control and limiting of corrosion at the Krško NPP • Steam generators programme • Reactivity Management Programme • Fuel Integrity Programme
Plant pre-outage activities and outage phases	• Refuelling • Planning of outage activities, risk and safety evaluation during shutdown

As a result of supervision of the plant's outage the SNSA afterwards publishes a report "Analysis of outage at the Krško NPP", which includes a list of planned SNSA activities aimed to further improve outage and on-line activities in the future and to eliminate deficiencies found out at the NPP during the outage.

4. Review and assessment of plant's documents

The SNSA has done a significant progress in the field of review and assessment of important plant programmes in the last few years. In 2005 and 2006 the following plant programmes were reviewed:

- Environmental Qualification Programme (EQ)
- Ageing Management Programme (AMP)
- Maintenance Rule Programme (MR)

Findings from the SNSA's review of plant programmes were discussed with plant managers and most of findings were taken into account by the plant's specialists. New Slovenian regulations are currently being developed and requirements in accordance with the IAEA and WENRA on ageing management, environmental qualification, maintenance, testing and other activities significant for plant life management are already included in draft versions.

4.1. Ageing Management Programme

As part of the first PSR at the Krško NPP, an Ageing Management Programme (AMP) has been initiated with the objective to determine whether ageing is being managed so that required safety margins are effectively maintained. The first phase (Scoping phase) of the AMP involves the development of the framework and scope of the programme, and provides an assessment of plant's current infrastructure and activities related to the ageing management.

The plant decided that the AMP will be similar in format and content to programmes defined by 10 CFR 54 "US License Renewal Rule" [3], which embodies a systematic and comprehensive approach to the ageing management of systems, structures and components (SSCs) important for safety, and is consistent with the principles of the IAEA guidelines on the implementation ageing management programmes for nuclear power plants.

The 10 CFR 54 process addresses the ageing management of passive, long-lived components, i.e. those that are not subject to routine maintenance or replacement. The ageing management

of active components, and routinely replaced passive components, is governed by the Maintenance Rule, which is addressed by a separate plant programme [4].
For the implementation of the requirements of 10 CFR 54 the NEI guideline NEI-95-10 [5] is used, which provides detailed methodology and criteria for the development of an AMP and has been endorsed by the NRC for use as the basis for license renewal applications.
The Krško NPP Ageing Management Programme involves the following elements:

- *Plant infrastructure assessment* comprises series of structured interviews with plant's staff from various disciplines and is aimed at identifying the plant's specific elements, such as databases, documents and plant programmes, which would provide the bases for developing the AMP at the plant.
- *Scoping of systems and structures* involves the application of scoping criteria to the plant systems in order to identify those which should be addressed by the AMP on the basis of their importance for safety. The scoping was performed separately for mechanical systems, electrical systems and civil structures.
- *Screening of components subject to Ageing Management Review (AMR)* addresses the mechanical, electrical and civil systems that were determined by the previous task as the scope of the AMP. The components in these systems are screened in order to determine which should be subject to Ageing Management Review (AMR), on the basis of being passive and long-lived.
- *Ageing Management Review (AMR)* addresses components identified by the scoping & screening tasks. All these components have to be precisely analyzed to determine whether all ageing mechanisms are adequately managed by the existing plant activities. The AMR will identify eventual need for improvement of existing plant programmes, procedures, inspecting technics or even a need for introduction of new activities or programmes.
- *Time-Limited Ageing Analysis (TLAA)* includes evaluation of the SSCs with time limited operation period on the basis of design requirements (for example 40 years, 36 EFPY, 400 cooldowns to hot shutdown…).
- *Database tools for supporting and maintaining the AMP* (LEX - extension process management system) includes the necessary functions and features for performing and reporting the AMR process and will be used as the platform to maintain the Krško NPP's Ageing Management Programme.

For the time being the first three phases of AMP at the Krško NPP have been completed. A whole programme is intended to be completed by the end of 2008. Within the scope of the SNSA's development project "Management of Ageing Effect at the Krško NPP" the Scoping and Screening project of the AMP was reviewed to find out if it meets all the requirements from the 10 CFR 54 and IAEA requirements. The review showed the following [6]:

- The Krško AMP fulfils all US acceptance criteria from the NUREG 1800 "Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants".
- The Krško AMP contains only passive SSCs therefore as such does not fulfil the IAEA requirements which require all safety important SSC to be within AMP.
- Together with the Maintenance Rule Programme [4] which is already implemented at the Krško NPP the IAEA requirement on AMP are fulfilled as well.
- A few inconsistencies were found in definition of a project's function of particular SSCs.
- Requirements of AMP have to be introduced into the Slovenian legislation.

4.2.Environmental Qualification Programme

The EQ Programme is one of a number of programmes intended to assure that common cause or common mode failures of components do not result in simultaneous failure of redundant safety systems. It provides the requirements and processes for development and execution of electric equipment environmental qualification activities at the Krško NPP in a documented and auditable manner and assigns departmental responsibility for implementation of those requirements.

The purpose of the EQ Programme is to demonstrate that essential electrical equipment, required to perform a safety function, is capable to perform this function during or following exposure to a harsh DBE environment and to ensure that it will perform this safety function at any time during the lifetime of the plant.

The EQ Programme and EQ procedures were assessed by the SNSA with the following purposes:

- to review the Slovenian nuclear legislation if it adequately covers the field of qualification of safety important SSCs to environmental conditions,
- to determine reconciliation of particular phases of EQ programme with the U.S regulation [7] and standards IEEE 323 [8],
- to verify the implementation of EQ programme requirements at the plant,
- to update the Slovenian legislation from the EQ area on the basis of foreign requirements (Finland, U.S) and international organizations (IAEA, WENRA).

Results of the review were the following [24]:

- current Slovenian nuclear legislation does not cover the field of qualification safety important equipment with regard to environmental conditions,
- there are a few discordances of the EQ Programme and procedures in relation to the requirements from 10 CFR 50.45 and IEEE 323 standards.

4.3.Programme on Reporting on Systems Status and Maintenance Effectiveness

With this programme the Krško NPP has implemented requirements from 10 CFR 50.65 "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants" (Maintenance Rule) [9]. NRC requirements are implemented by NEI guideline NUMARC 93-01 "Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants" [10].

In accordance with 10 CFR 50.65 criteria for safety-related SSC are established, proportional to their importance. On the basis of surveillance testing, maintenance activities and operation performance, the SSCs are sorted within the scope of the programme into 2 groups:

- (a)(2): effectiveness of these SSCs can be assured by the regular preventive maintenance
- (a)(1): SSCs what do not meet the established criteria and for which special goals have to be determined.

Clear criteria for transition between above mentioned groups are established as well. A result of a regular review of systems' status the "Collective reports on systems status" is issued on three-months basis. Currently 39 systems are included in these reports, showing the following data:

- indicator on status of particular system (green, yellow, orange, red),

- action plan for SSCs with red indicator - SSCs in group (a)(1),
- function failure within evaluation period,
- new problems with equipment within evaluation period,
- analyses and priorities.

The SNSA reviewed the Krško NPP "Programme on Reporting on Systems Status and Maintenance Effectiveness" [4] and found the following:

- all NRC requirements from 10 CFR 50.65 are met,
- implementation of the NRC's requirements is not entirely in accordance with the NEI's guideline. Selection of the SSCs which are to be within the scope of the programme meets the NEI's recommendations, but the difference exists in the definition of acceptance criteria and additional goals for the SSCs within the group (a)(1). The Krško NPP's criteria are much stricter than those from the NEI because they want to even improve the status of their systems, already in a very good condition.

4.4.Corrosion/Erosion Monitoring Programme

At the Krško NPP a comprehensive Corrosion/Erosion Monitoring Programme (CEMS) [11] has been developed and implemented in accordance with EPRI recommendations. Between 70 and 80 critical locations from systems with two-phase flow are verified during plant's outages. As a result of implementation of the CEMS the Krško NPP systematically started to replace critical pipeline segments with new segments of better, to erosion more resistant material. Some other major modifications also result from the CEMS:

- replacement of Moisture Separator Reheaters,
- replacement of high and low Feedwater Heaters,
- repair of Turbine Crossunder Pipeline.

Implementation of this programme is supervised by the SNSA, with presence at outage activities, review of plant reports and by monitoring the results of SGs sludge lancing method.

5. Monitoring the condition of important plant SSC

A special way to control suitability for long term operation at the Krško NPP is a development project which the SNSA started in 2005, basically to improve knowledge in the ageing area and to set up a list of potential regulatory body activities in this area. The project consists of the following topics:

- Overview of regulatory requirements and practices from European countries and the USA,
- Theoretical basis of ageing processes,
- Review of the AMP at the Krško NPP,
- Development of the SNSA's procedure for supervision of ageing processes at the Krško NPP,
- Development of the software for monitoring the condition of SSCs at the Krško NPP.

The software for monitoring the condition of the plant SSC and the SNSA's procedure governing its use has been just completed. It provides two functions important for the SNSA to determine plant's suitability for future operation:

- monitoring of transients important for fatigue evaluation which are limited by components design in accordance with ASME Boiler & Pressure Vessel code, section III and are determined in the Krško NPP's Standard Technical Specifications [12]and Safety Analysis Report [13],

- monitoring of the status of safety important plant SSCs on the basis of data from surveillance testing, inspections and maintenance, received from the NPP. Trending, comparison with allowable values and alerts, review of corrective and preventive actions are possible.

At this moment, the software includes a number of transients defined in the plant's Standard Technical Specifications [12]. Data on these transients are obtained from plant's report "Review and Categorization of NPP Krško Transients or Operational Cycles" [11] which is regularly submitted to the SNSA. A review of these transients is given in Table 2.
The Krško NPP's Safety Analysis Report [13] includes much more extensive range of design transients which are divided into normal, upset, emergency, faulted and test conditions. The SNSA will gradually extend the range of transients of the software with transients from the SAR.
Table 2. The Krško NPP component cyclic and transient limits

Component	**Number of cycles**	**Cyclic or Transient Limit**	**Design Cycle or Transient**
Primary coolant system	200	Heatup cycles at $\leq$ 55.6°C/h	Heatup cycle T_{avg} from $\leq$ 93.3°C to $\geq$ 287.8°C
	200	Cooldown cycles at $\leq$ 55.6°C/h	Cooldown cycle T_{avg} from $\geq$ 287.8°C $\leq$ to 93.3°C
	200	Pressurizer cooldown cycles at $\leq$ 111.1°C/h	Pressurizer cooldown cycle temp. from $\geq$ 343.3°C to $\leq$ 93.3°C
	80	Loss of load cycles, without immediate turbine or reactor trip	$\geq$ 15% to 0% of rated thermal power (RTP)
	40	Loss of offsite A.C. electrical power	Loss of offsite A.C. electrical ESF Electrical System.
	80	Loss of flow in one reactor coolant loop	Loss of one reactor coolant pump
	400	Reactor trip cycles	100% to 0% of RTP
	10	Auxiliary spray actuation cycles	Spray water temperature differential $\geq$ 177.8°C
	10	Hydrostatic pressure tests	Pressurized to $\geq$ 218.4 kp/cm^2
	200	Leak tests	Pressurized to $\geq$ 174.7 kp/cm^2
Secondary coolant system	1	Large steam line break	Break with a 1300 cm^2 throat area
	10	Hydrostatic pressure tests	Pressurized to $\geq$ 94.9 kp/cm^2

The Figure 2 shows an evaluation of transients of reactor trip from 90-100% of RTP without cooldown. A cumulative curve of events number, project limit and annual number of events is given.