The Extraordinary Safety Review and Safety Improvements of the Krško NPP

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ABSTRACT

Before the March 2011 accident in the Fukushima-Daiichi nuclear power plant there was not enough attention dedicated to managing severe accidents that would be caused by rare external hazards in the nuclear industry in general, since it was believed that such events are practically impossible and that they would not cause such unimaginable devastation. The accident in Japan represents a major milestone in the development of nuclear industry after which events with minimal probability but large consequences also have to be considered in the design of protective and mitigative measures. The start of this era is also represented by the European stress tests which started immediately after the Fukushima event. The purpose of stress tests was to evaluate how are the European NPPs designed and prepared against the extreme external events such that have occurred in Japan, to identify potential edge effects as well as to propose possible improvements. The Slovenian Nuclear Safety Administration (SNSA) issued a series of decisions with which it required from the plant to implement the Stress tests and to further investigate and analyze the additional possible upgrades of the plant’s safety, especially in the area of severe accident management and emergency preparedness. This article presents the Slovenian response on Fukushima event and the response on ENSREG initiative focusing on the implementation of stress tests, safety reviews and related safety improvements in Slovenia and the Slovenian only nuclear generating station, the Krško NPP. In the paper the stress test process itself is presented, the decisions of the regulatory body, the supporting analyses that were prepared by the plant itself or by the technical support organizations, as well as the stress test results. Also some major planned improvements, which were demanded in parallel by the SNSA, are presented.

1 INTRODUCTION

The Fukushima accident caused a major reaction from the world’s nuclear industry as well as the regulatory authorities. The first response by SNSA was oriented towards gathering of information and preparing explanations for the public in Slovenia. The emergency response team of SNSA was activated on Saturday, 12 March 2011 and remained active for several
weeks. During the first two weeks of the accident the SNSA was present in media daily and has achieved reputation of the trustful source of information.

In parallel the actions have started to introduce improvements into the Krško NPP in Slovenia based on the first lessons learned. During the next months a number of ideas were created both by the operator of the plant and by the regulatory body. In this paper it is described how these new ideas were implemented.

2 ACTIVITIES IN PROGRESS BEFORE THE FUKUSHIMA ACCIDENT

Some particularly activities related to NPP Krško safety upgrades were started before the Fukushima accident. Based on the results of the first periodic safety review (PSR) process the Krško NPP was implementing two significant safety upgrades:

- Installation of the third independent diesel generator with a safety bus, which can be connected to both existing safety buses. The new generator was installed during 2012 refueling outage and has significant impact on plant seismic risk and is reducing the total Core Damage Frequency (CDF) for around 35%,

- Increasing the level of the dikes upstream of the site on the left bank of the Sava river and of the tributary Potočnica to improve the flood protection. By that the plant is protected against the newly determined probable maximum flood (PMF) with the return frequency of the order of 1 million years. The dikes were heightened in the spring 2012.

In the meantime the second periodic safety review is underway in the framework of which the plant’s design and operation will be compared against the newest standards and best industry practice.

3 IMPROVEMENTS BY THE OPERATOR IMMEDIATELY AFTER THE FUKUSHIMA ACCIDENT

Immediately after the Fukushima event the Krško NPP started performing its first preliminary analysis of its preparedness and possible improvements. It has followed the WANO SOER-2011-2 requirements. By May 2011 they were ready to introduce several quick improvements and have applied to the SNSA with a set of modifications with which special quick connection points would be installed that would provide quick access to the plant’s most important systems and through which the operators could provide additional cooling water and power supplies with portable or mobile equipment. Also the plant acquired several pieces of mobile equipment, such as portable and mobile diesel generators, portable and submersible pumps, portable air compressors and transformers. The SNSA has quickly reviewed proposed modifications and was happy to approve them. By the end of June 2011 most of them were already implemented.

4 THE EU STRESS TEST PROCESS IN SLOVENIA

In Europe the European Commission immediately initiated the preparation of specifications for stress tests, which were to be executed in all European NPPs to raise the level of nuclear safety. SNSA took part in this process from the very beginning. The first meeting of all European nuclear stakeholders was held already on 15 March 2011 in Brussels, where the general agreement about the need for such Stress Tests was reached. One week later, on 21 March the EU Ministers of Energy have formally supported the idea, which was few days later endorsed by the EU Council.
On 22 March the members of WENRA met at their regular meeting, which was mainly devoted to the preparation of Stress Tests. At that meeting the first draft of the Stress Test methodology was drafted. The SNSA representative was member of the first drafting team. During the next weeks the draft Stress Test methodology was elaborated by the WENRA Working Group on reactor safety, where SNSA took active part. In the beginning of May the draft methodology was submitted to ENSREG, which held its regular meeting on 12 May. The meeting was chaired by Andrej Stritar, director of SNSA. The discussions were very dynamic and lasted about 20 hours in two days. At the end of the meeting the full consensus could not be reached, so the decision making was extended with the so called silent procedure. It lasted almost two more weeks to get the consensus with the EU Commissioner Oettinger. Finally, on 24 May 2011 the EU Stress Test methodology was made public [1]. It was expected from all EU nuclear countries to implement it until the end of the year 2011.

As SNSA was fully involved into the preparation of EU Stress Tests, we have decided not to request anything from the Krško NPP operator before the methodology was adopted. It was our intention from the first ideas about Stress Tests to fully implement in Slovenia whatever was agreed upon at EU level.

4.1 Implementation process of Stress Tests in Slovenia

Few days after the EU Stress Test methodology was announced the SNSA has issued a formal order (in legal terms it is called a decision), which has basically requested from the operator to implement EU Stress Tests for Krško NPP. Formally it was based on the provision in the Slovenian Nuclear Act which is giving power to the regulatory body to request the implementation of the extraordinary periodic safety review after some important triggering events like after major accident or after some major new circumstances on local or global level. The Fukushima accident was definitely such major new international circumstance that was a basis for the implementation of the special extraordinary periodic safety review in a form of EU Stress Tests.

Like envisaged in the specifications, the Krško NPP gave progress report to the SNSA until August 15, while final report [2] was prepared until the end of October 2011. Several additional analyses (e.g. evaluations of seismic and flooding margins, additional station blackout analyses to support the newest severe accident strategies, drain cycle of the batteries supplying power to the instrumentation of safety systems, water heat-up and evaporation rate in the spent fuel pool, evaluation of spent fuel pool criticality; these are described in more details in the following chapter) were performed by the operator and were reviewed and supported by technical support organizations with additional calculations where necessary. All the above was reviewed by the SNSA, open issues were cleared and the national report was adopted [3]. The fact that there is only one NPP in the country was once for the change a beneficial one for the SNSA. We did not have to spend too many efforts in summarising the reports of different operators, but the national report could very much rely on the report of the only operator.

After the national reports of member states were prepared by the end of 2011, they were subdued to peer reviews by teams of member states’ nuclear safety experts. The reviews were separated into so called horizontal and vertical reviews. In the framework of the horizontal review the individual chapters of the reports were reviewed (external events, loss of all power sources, loss of the ultimate heat sink and severe accident management provisions) and questions were put up for the individual countries. This was followed by the preparation of answers and country presentations in the common Luxembourg meeting.
SNSA was able to delegate only two of their staff members into the Peer Review teams intensively reviewing other national reports during January 2012 and later working as a team throughout two weeks in February 2012 in Luxemburg. Later the same SNSA team members took part also in several country visits. During the Peer Review process a larger number of SNSA employees were involved in presenting the work done in Slovenia to the Peer Review members both in Luxemburg and during the country visit of the Peer Review Team to Slovenia.

The second part of the review, the vertical one, was performed in each collaborating country. In Slovenia a team of 8 experts performed a detail review of still open issues, which also involved a walkdown in the Krško NPP. As a close up of the national review the team prepared a country report [4], which concluded that the Krško NPP is well designed against all credible and even some very unlikely external threats at the site.

4.2 Stress test results

This chapter summarises the results of the analyses and results performed by the operator and approved by the SNSA, more details can be found elsewhere [3]. The stress test analysis was divided into three topics: External events, Loss of electrical power and loss of ultimate heat sink, and Severe accident management.

4.2.1 Topic 1 – External events

Earthquake

For the Earthquake subtopic (as well as for Flooding) a special analysis [5] was performed by the operator and later reviewed and recalculated with different code by a technical support organization.

For earthquakes with Peak Ground Acceleration (PGA) below 0.60 g is considered that none of the success paths is affected. For earthquakes in the range of $0.60 \, \text{g} < \text{PGA} < 0.75 \, \text{g}$ structural failure of Condensate Storage Tank (CST) and/or Refuelling Water Storage Tank (RWST) is a credible consequence. At earthquakes interval in the range of $0.75 \, \text{g} < \text{PGA} < 1.0 \, \text{g}$, seismic failure of Emergency Diesel Generators (EDG) is considered likely. At seismic levels of approximately 1 g, a number of structures, systems and components are expected to fail, including CST, RWST, EDGs and Essential Service Water. Certain degradation of fuel assemblies’ geometry in the core is also expected. At such seismic levels also other safety systems, as well as larger structures are expected to fail (liquefaction cannot be excluded at such values of earthquake).

As for the containment integrity the late releases into the environment due to seismic events would be likely to occur in the PGA range of 0.8 g or higher. This estimate is dictated by the fact that core damage is considered likely at this range of seismic events. Seismic events at which early radioactivity releases into the environment would be likely to occur are considered to be of PGA significantly exceeding 1 g. For the spent fuel pool integrity it is considered that for earthquake levels up to, approximately, 0.9 g, it would not be challenged. At the end, it needs to be pointed out that seismic events with PGA higher than 0.8 g were estimated to be very rare events at the Krško NPP site. The return period for such an event is considered to be larger than 50,000 years.

Flooding

Plant building entrances and openings are constructed above the elevation of the 10,000-year flood. So the plant is safe for the occurrence of the design basis flood (DBF =
Plant is also protected against the probable maximum flood (PMF = 7081 m³/s). Flood wave caused by hydropower plants dam failures is not a threat to the Krško NPP since maximum flood wave would reach only the flow of 3700 m³/s what is much less than the design flood wave. In 2011 and 2012 the dikes upstream of the plant were upgraded and are now capable of protecting the plant to the flood flows beyond the probable maximum flood. It is worth noting that this improvement was initiated already years before the Fukushima accident.

The evaluation of external flooding margins at NPP was performed similarly as for earthquakes, by identification of “success paths” for a range of flooding events.

Flooding of the NPP plain would start around 11,000 m³/s and could lead to the core damage. The return period for such flood is more than 1 million years. This flow causing cliff edge effect is about 1.6 times higher than the PMF flow. The same margin analysis was performed for the containment integrity and the cliff edge effect was determined at the same flow of 11,000 m³/s.

**Extreme weather conditions**

These phenomena are very well analyzed and described in the plant’s Updated Safety Analysis Report as well as in the plant Probability Safety Analysis. Local meteorology is well known and taken into account in the design of the plant. The extreme weather phenomena that were taken into account include severe winds and tornadoes, drought and low river flow, extreme river temperatures, high and low air temperatures, snow and ice, rain, and storm, plus the combinations of events. Most of the design bases are based on at least 1,000-year period value or higher. With conditions exceeding design bases values the plant would shutdown but remain safe.

All above described events are bounded by the station blackout (SBO) and loss of ultimate heat sink (UHS) events. Thus same as for SBO and Loss of UHS the onsite available alternative equipment can be used (e.g. mobile diesel generators, gas heaters, etc.) if needed.

### 4.2.2 Topic 2 – Loss of electrical power and loss of ultimate heat sink

**Station blackout**

The Krško NPP is designed to maintain safe shutdown conditions in case of a SBO for 4 hours by removing the decay heat through both steam generators using the auxiliary feedwater (AFW) turbine driven pump. The decay heat removal by steam generators can be prolonged using alternative equipment. The batteries, which ensure power supply to 118 V instrumentation and control, also have capacity for a 4-hour SBO. Establishing alternative power supply from one of the provisioned portable diesels assures the long time availability (more than 72 hours) of DC batteries and of 118 V AC instrumentation power supply. If power supply can not be established, procedures instruct the operators to disconnect all non-essential DC loads, thus prolonging the availability of batteries to more than 13 hours. Minimum autonomy of the alternative equipment is 72 hours.

The reactor coolant inventory is controlled by depressurizing the primary system, manually isolating the letdown lines and by providing charging water with positive displacement pump powered by a mobile DG. For the spent fuel pool makeup water is established using portable fire pumps and alternative water sources available onsite.

**Loss of ultimate heat sink**

In case of loss of UHS the plant would be put in a “hot shutdown” condition; the heat removal is performed by the steam generators using AFW turbine driven pump and CST
inventory, or by alternative equipment and water sources available onsite. The loss of coolant
due to reactor coolant pump seal leakage is compensated with positive displacement pump
flow injection from the RWST.

For the spent fuel pool the heatup is same as with the SBO, thus foreseen actions are
similar/same as for the SBO. In case of losing the level of the spent fuel pool there would be
no criticality concern.

The Krško NPP can be in this condition for at least 7 days.

**Loss of ultimate heat sink with the station blackout**

The SBO for the NPP site with reactor in service represents the worst case scenario
(limiting case). Even in the case of the loss of UHS combined with a SBO, no cliff edge
effects have been identified for a period of more than 7 days, because usage of alternative
equipment assures reactor coolant inventory control and decay heat removal.

### 4.2.3 Topic 3 - Severe accident management

The accident response at plant level is covered by the Krško NPP Radiological
emergency response plan. It includes the Emergency Response Organization (ERO) covering
the Main Control Room and shift organization, a Technical Support Centre and Operational
Support Centre. The offsite structure of ERO, activated in case of a site or general emergency,
consists of the Emergency operations facility (EOF) and is located in Ljubljana. The EOF is
organized, equipped and located to carry out overall direction and coordination of the Krško
NPP’s emergency response, support to the Technical Support Centre and intervention
personnel, coordination with involved authorities, and evaluation of offsite radiological
consequences and recommendations of urgent protective measures for the population, public
information.

Accident management and corrective measures, individual emergency response actions
and the activities for maintaining emergency preparedness are dealt with in detail in different
types of Krško NPP procedures. The Emergency Operating Procedures aim at preventing core
damage. The overall objective of the Severe Accident Management Guidelines (SAMG) is to
terminate the severe accident condition. The SAMGs are plant specific and validated with a
full scope simulator as well as with emergency exercises. They cover also the spent fuel pool
accidents and are not power states’ dependent.

Emergency response training, activities are planned on annual basis within overall
Krško NPP annual training plan. The full-scope real time Krško NPP’s simulator serves as an
exercise’s scenario simulation tool for accidents.

All alternative equipment is located onsite. The Severe Accident Management
Equipment (SAME) is placed on safe locations to avoid impairments due to accidental
conditions. Fuel is stored onsite for mobile equipment in the quantities for at least first 72
hours. The SAME is also included in Krško NPP equipment data base as an Accident
Equipment system and is regularly tested and maintained in accordance to plant maintenance
procedures.

### 5 THE ADDITIONAL LONG TERM IMPROVEMENTS

During the summer of 2011 after the EU Stress Tests have already been initiated, the
SNSA has invested some more time into the study of potential additional improvements in the
NPP for protection against external events and the management of severe accidents. We have
in particular focused on transitional provisions in the Rules on radiation and nuclear safety
factors related to the application of severe accident management provisions to the existing nuclear power plants. About two years earlier when these Rules were adopted, the implementation of those provisions was connected with the potential extension of the operating life of the NPP. In simple words at the time of adoption of the Rules the severe accidents were considered to be of so low probability that the implementation of mitigation measures has been allowed to be delayed for several years. The Fukushima event has, however, shown that even the very low probability events are happening and that mitigation measures must be in place as soon as possible. After some open discussion with the operators we have eventually decided to overrule that transitional provision in our legislation. So, in September 2011 a second formal decision was issued to the operator requiring from the plant to reassess the severe accident management strategy, existing design measures and procedures and implement necessary safety improvements for prevention of severe accidents and mitigation of its consequences.

This reassessment was finished by the operator in January 2012. In preparation in addition to all available inputs related to major nuclear accidents also the results of the analysis of the intentional aircraft impact to the plant were taken into account.

The so called “Program of safety upgrades” action plan [6] with planned modifications was carefully reviewed by the SNSA staff. It was concluded it is sufficiently comprehensive and no major additional potential improvements are missing. The action plan was approved and shall be implemented mainly during the refueling outages until the end of 2016. The planned modifications are as follows:

<table>
<thead>
<tr>
<th>Modification or equipment procurement</th>
<th>Schedule</th>
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<tbody>
<tr>
<td>Installation of the containment filtered venting system</td>
<td>2013</td>
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<tr>
<td>Installation of passive auto-catalytic hydrogen recombiners in the containment</td>
<td>2013</td>
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<tr>
<td>Additional high pressure pump for reactor coolant system injection, located in the bunkerised building</td>
<td>2015</td>
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<tr>
<td>Additional high pressure pump for feeding steam generators, also in the bunkerised building</td>
<td>2015</td>
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<tr>
<td>Additional low pressure pump for spraying and flooding the containment</td>
<td>2015</td>
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<tr>
<td>Installation of permanent sprays around the spent fuel pool</td>
<td>2015</td>
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<tr>
<td>Alternative air cooled ultimate heat sink with the new huge water storage</td>
<td>2016</td>
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<tr>
<td>Installation of a new emergency control room</td>
<td>2016</td>
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<tr>
<td>Installation of separate dedicated beyond design basis instrumentation and control</td>
<td>2016</td>
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<tr>
<td>Long term habitability of emergency control room and for support staff facility</td>
<td>2016</td>
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<tr>
<td>Mobile heat exchanger</td>
<td>2016</td>
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<tr>
<td>Acquiring the technology and material for quick filling of ruptures in spent fuel pool</td>
<td>2016</td>
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<tr>
<td>Additional flood protection of nuclear island and newly installed equipment</td>
<td>2016</td>
</tr>
<tr>
<td>Upgraded protection against extreme air temperatures</td>
<td>2016</td>
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6 POTENTIAL IMPROVEMENTS OF THE OFF-SITE EMERGENCY ARRANGEMENTS

In parallel with issues related to the operation and severe accident management in the NPP the SNSA is also involved into the nuclear emergency response on the national level. While the prime responsibility for the national nuclear and radiological accident emergency plan lies with the Slovenian Administration for Disaster Relief under the Ministry of Defense, the Slovenian Nuclear Safety Administration is the key administration responsible for preparation of any professional background for improvement of arrangements in the national emergency response plans. After studying the evolution of the Fukushima accident and
comparing it with the arrangements in the Slovenian national nuclear emergency response plan we have determined it would be wise to reassess the presumptions, which were the basis for the main solutions in the national plan. In particular, we thought it would be wise to check again what were the bases for definitions of emergency planning zones and the off-site protective measures. This was done decades ago during the construction of the NPP.

Therefore in January 2012 the SNSA issued the third formal decision regarding the Fukushima event, with which it requires from the Krško NPP to review the basis and assumptions for the Radiological Emergency Response Plan. This work should be finished by the end of 2012 and can not be presented in this paper. Any further actions related to off-site emergency planning will be based on the results and can not be predicted now.

7 CONCLUSION

Both the operator and the regulatory body in Slovenia have very seriously initiated improvements at Krško NPP after the Fukushima accident. This has included implementation of the EU Stress Tests as well as also other feasible actions that could prevent major damage to the environment and population after any external event. So far we believe we have done as much as it was reasonable achievable. However, we are continuing to monitor the developments at home and in the World and if any new ideas for improvements will emerge, we will seriously consider their implementation.

The process of stress tests together with a peer review of best European experts on nuclear safety has shown that the Krško NPP is well designed power plant with well developed design bases. With periodic safety reviews being performed regularly the plant’s design and safety is further improving taking into account the best industry’s practice, newest standards, operating experience as well as changes in the environment that may have impact on plant’s safety.

The Krško NPP has well developed SAMGs with Severe Accident Management strategies, which are regularly trained and tested also with the use of plant’s full-scope simulator. With the implementation of immediate post-Fukushima modifications the plant has prepared itself even for the most unlikely events. Additionally, the plant will further increase its safety and the safety of public with the implementation of the Program of safety upgrades, which is to be finished until the end of 2016.

REFERENCES