ABSTRACT

As it was agreed in the ENSREG group, the Slovenian Nuclear Safety Administration (SNSA) prepared a complementary National Action Plan (NAcP) of improvements, which is based on the lessons learned from the Fukushima accident in March 2011. The Slovenian NAcP and the NAcPs of other nuclear countries of the European Union, as well as Switzerland and Ukraine were reviewed in the framework of NAcP peer review workshop organized by the ENSREG in April 2013.

The core of the Slovenian NAcP and post-Fukushima improvements in Slovenia represents the planned Krško nuclear power plant’s Safety Upgrade Program (SUP), which includes the installation of passive autocatalytic recombiners, containment filtered venting system, establishment of the emergency control room and relocation of the technical support centre (i.e. emergency control centre) into a bunkered and severe accident protected building, installation of alternative ultimate heat sink and additional pumps for injecting into steam generators, the reactor coolant system and spent fuel pool, all designed for the design extended conditions.

Beside the implementation of the Safety Upgrade Program the SNSA identified 11 additional actions that could further enhance nuclear safety in Slovenia, either indirectly by changing the legislation, hosting additional peer reviews, performing additional studies, or directly by improving the nuclear power plant and regulatory body processes, enhancing of emergency preparedness and nuclear safety infrastructure or improving the safety culture of both the operator and the regulatory body.

Most of the measures which are part of the Safety Upgrade Program will be implemented in medium term till 2016. The rest of the measures are scheduled until 2018.

Specific attention will be given to the description of design extension conditions, which will represent the design bases for the SUP system and structures.

1 INTRODUCTION

Post-Fukushima actions in Slovenia started immediately after the accident. While the Krško nuclear power plant (NPP) started implementing short-term improvements, the SNSA
issued a decision requiring from the plant to perform an extraordinary safety review in line with the ENSREG Stress Test specifications [1].

In addition the SNSA in September 2011 issued another decision 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 evaluation was finished in January 2012 [2]. The action plan [3], which shall be completely implemented within the SUP by the end of the year 2016, was reviewed and approved by the SNSA in February 2012.

After completion of the Stress Test process the SNSA started to review different post-Fukushima reports, analyses and reviews to determine whether additional long-term improvements are needed or possible. Based on this review the SNSA started preparing its post-Fukushima action plan [4].

In September 2012 the European Nuclear Safety Regulators Group (ENSREG) decided to perform another peer review process, this time to review the national post-Fukushima action plans (NAcP). The NAcP peer review was conducted between January and April 2013, with a closure workshop in Brussels that was held between 22nd and 26th of April 2013, at which also the final NAcP peer review summary report [5] was prepared.

2 THE NACP PREPARATION PROCESS

The core of the Slovenian NAcP and post-Fukushima improvements in Slovenia represents the planned Krško NPP’s SUP, which was ordered, reviewed and approved by the SNSA as it takes into account the Fukushima lessons learned, especially regarding the preparedness and response to extreme external hazards.

Since the SNSA followed the Fukushima accident very closely, it has decided to review additional post-Fukushima reports, analyses and reviews ([6], [7], [8], [9], [10] and [11]) prepared by different organizations with the purpose to learn and improve nuclear safety in Slovenia as much as possible.

The SNSA prepared the report for and took part in the 2nd Extraordinary Meeting of the Contracting Parties to the Convention of Nuclear Safety and later reviewed and discussed the meeting recommendations [12]. This review was followed by a review of ENSREG’s recommendations and suggestions [13], International Atomic Energy Agency’s (IAEA) Action Plan on Nuclear Safety [14], as well as American Society of Mechanical Engineers’ (ASME) report [15].

Each of identified recommendation from these reviews was analysed whether it is applicable for the Krško NPP, the SNSA or Slovenian nuclear safety infrastructure in general. Recommendations were screened on the basis of different reactor type (e.g. pressurized vs. boiling water reactor), site characteristics (e.g. river based site), whether the recommendation was already implemented in the plant/legislation/infrastructure, etc. In case the recommendation was not applicable for the NPP or Slovenia in general, it was appropriately commented. Otherwise the description of an action with which the recommendation will be implemented was given. At the end the repetitive or similar actions were grouped. Altogether 131 recommendations were identified and reviewed, and based on that 12 actions with additional 10 sub actions were extracted.

3 THE SLOVENIAN NACP

Following is the description of 12 actions of the Slovenian NAcP.
3.1 The Safety Upgrade Program

As mentioned earlier the SUP represents the core of the Slovenian post-Fukushima improvements. The main purpose of the SUP is to strengthen the preventive measures of the plant regarding the extreme external hazards, but also to provide additional mitigating measures and strategies in the case of severe accidents.

The main benefit of the SUP is its set of the Design Extension Conditions (DEC), based on which the SUP systems, structures and components will be designed and built. DEC represent more stringent design requirements, which will assure that the SUP equipment is still available and operable even when the design basis systems have failed for reasons of extreme external events.

The Krško NPP’s DEC are derived on the basis of engineering judgment, deterministic and probabilistic assessments. They are defined for the set of following events:

- **earthquake**, extended design condition seismic value is 0.6 g Peak Ground Acceleration (PGA), which is twice the design basis Safe Shutdown Earthquake (SSE) value (0.3 g PGA),
- **flooding**, new maximum flood level is 157.53 m (above sea level), while existing flood protection dikes protect the plant up to the flood that corresponds to 157.10 m. Existing flood protection dikes protect the plant against the Probable Maximum Flood (PMF), i.e. 7,081 m$^3$/s with additional safety margin,
- **combination of earthquake and flooding**, the simultaneous occurrence of PMF and earthquake, which causes flood protection dikes to be destroyed,
- **combination of earthquake and fire**, fire caused by DEC earthquake,
- **external low and high temperatures**, air temperatures with a return period of 10,000 years,
- **aircraft crash accident**, crash of a large commercial aircraft at the maximum landing velocity, and
- **fire**, fire due to DEC aircraft crash.

All SUP systems, structures and components will be designed and constructed in accordance with the DEC.

In the Table 1 below all SUP improvements are given with a short description of the improvement, division by the function (preventive or mitigative), and planned time schedule for the implementation.

Table 1: The Krško NPP’s SUP improvements

<table>
<thead>
<tr>
<th>No. of NAcP action</th>
<th>Modification / improvement / equipment procurement</th>
<th>Description</th>
<th>For prevention and/or mitigation</th>
<th>Scheduled finish</th>
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</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Safety upgrade of AC supply</td>
<td>Within this action several modifications/upgrades will be performed on the AC power supply, including modification of alternative supply of non-safety related buses, requalification of 3rd 6.3 kV safety related bus, upgrade of connection between 400 V safety related bus (for charging batteries) and mobile diesel generators,…</td>
<td>prevention</td>
<td>2015</td>
</tr>
<tr>
<td>1.2</td>
<td>Additional high pressure pump for feeding steam</td>
<td>Additional high pressure pump for feeding SGs in the separated bunkered (2×SSE and PMF flood protected) building with dedicated source of water</td>
<td>prevention</td>
<td>2015</td>
</tr>
<tr>
<td>No. of NAcP action</td>
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<tr>
<td>generators (SG)</td>
<td>for 8 hours with provisions to refill from different water sources</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1.3</td>
<td>Installation of alternative ultimate heat sink</td>
<td>Alternative ultimate heat sink (2×SSE and PMF flood protected) will consist of a large pool of water and associated piping and pumps that will provide heat sink by cooling the steam generators and the component cooling water for cooling the plant safety systems via existing heat exchanger. Alternative ultimate heat sink will provide source of cooling water for 30 days with a possibility of pool refill with groundwater from several deep wells located at the NPP site and nearby.</td>
<td>prevention</td>
<td>2015</td>
</tr>
<tr>
<td>1.4</td>
<td>Additional pumps (low and high pressure, as well as a special pump for seal injection) Installation of additional pressurizer relief valves</td>
<td>Additional pumps (high and low pressure) for RCS injection, for spraying (pressure control) and flooding the containment (preventing core concrete interaction in case of failed reactor pressure vessel), for injecting water into the Spent Fuel Pool (SFP) through a new SFP spray system. Also a special high pressure pump for seal injection will be installed. All these pumps will be installed in the separated bunkered (2×SSE and PMF flood protected) building with dedicated source of borated water for 8 hours with provisions to refill from different water sources. In addition new severe accident pressurizer relief valves will be installed.</td>
<td>prevention (and mitigation)</td>
<td>2015</td>
</tr>
<tr>
<td>1.5</td>
<td>Containment integrity safety upgrades</td>
<td>Includes passive containment filtered venting system capable of depressurizing containment and filtering over 99.9% of volatile fission products and particulates (not including noble gasses), as well as the replacement of electric design basis recombiners with passive DEC auto-catalytic recombiners in the containment.</td>
<td>mitigation</td>
<td>2013</td>
</tr>
<tr>
<td>1.6</td>
<td>Establishment of emergency control room</td>
<td>Relocation and expansion of existing remote shutdown panels into a new emergency control room in the separate bunkered (2×SSE and PMF flood protected) building with all instrumentation and controls needed for safe shutdown of the plant and maintaining the safe shutdown conditions. Also a separate dedicated beyond design basis instrumentation and controls will be installed capable of monitoring and controlling both from the existing as well as the new emergency control room. The emergency control room will enable long term habitability of control room staff even during severe accidents (air filtering, radiation protection).</td>
<td>prevention (and mitigation)</td>
<td>2016</td>
</tr>
<tr>
<td>1.7</td>
<td>Installation of fixed sprays around the SFP</td>
<td>Installation of fixed sprays (2×SSE qualified) around the SFP with provisions for quick connection from different sources of water. Also the technology and material for quick filling of possible ruptures in SFP will be acquired.</td>
<td>prevention</td>
<td>2015</td>
</tr>
<tr>
<td>No. of NAcP action</td>
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<td>1.8</td>
<td>Mobile heat exchanger</td>
<td>Mobile heat exchanger (cooled by mobile equipment or air) with provisions to quick connect to SFP, containment sump or reactor coolant system</td>
<td>prevention (and mitigation)</td>
<td>2015</td>
</tr>
<tr>
<td>1.9</td>
<td>Flood protection upgrade</td>
<td>Nuclear island and the above-described newly installed equipment will be additionally flood protected against the failure of flood protection dikes or high river flows exceeding flood protection dikes by 0.4 m</td>
<td>prevention</td>
<td>2015</td>
</tr>
<tr>
<td>1.10</td>
<td>Establishment of new technical support center and upgrade of existing operational support center</td>
<td>Establishment of new technical support center in a bunkered building protected against extreme hazards (2xSSE and PMF flood, aircraft crash), severe accidents and radiation. Also the existing operational support center will be upgraded for the same conditions.</td>
<td>prevention (and mitigation)</td>
<td>2015</td>
</tr>
</tbody>
</table>

As can be seen from the above table the SUP represents an action with 10 specific sub actions. During the review of post-Fukushima reports, analyses and reviews some recommendations were identified, that were some how related with the SUP improvements, but from detail description of the SUP improvements it could not be confirmed, whether certain issues would be covered. Thus from these recommendations that were not explicitly taken into account within the Krško NPP’ SUP the SNSA posed several tens of regulatory issues, which are to be solved within the licensing of the SUP improvements. Such issues are for example ventilation of the containment and SUP equipment, long-term recirculation of the primary coolant, migrating of hydrogen between different buildings, etc.

### 3.2 The legislation

SNSA plans to amend the legislation regarding nuclear and radiation safety. Several proposals for changes have already been identified, e.g. requirements regarding the use of advanced warning systems for external hazards (seismic, floods, severe winds…), requirements for probabilistic safety analysis for Level 3, emergency planning requirements for prolonged station black-out scenario in the areas of communications capability, training, exercises and equipment and facilities.

But even more legislation changes will be implemented based on the new revision of the Western European Nuclear Regulatory Association’s (WENRA) Reference Levels, which are now under preparation and are to be issued by the end of this year. These will include changes in the areas of design basis envelope for existing reactors, design extension conditions of existing reactors, emergency operating procedures and emergency preparedness, while majority of changes concern external hazards. Slovenian legislation is in compliance with WENRA Reference Levels since 2009 and SNSA will make sure that also all changes will be taken into account.

The SNSA plans to incorporate all legislation changes until the end of 2014.

### 3.3 Emergency response

In the area of emergency response several possibilities for improvements were identified. These include: ensuring provisions for off-site support in regard to long-term fuel
supply and also some additional pieces of mobile equipment for the case of widespread disruption of plant’s infrastructure, setting reference levels for importing food from contaminated areas, trans-border processing of goods and services, deciding on the approach / philosophy and associated limits and criterion to govern the remediation phase of the event, preparing national strategy regarding solutions for post-accident contamination and the treatment of potentially large volumes of contaminated water, enhancement of intervention personnel training, enhancing cooperation with neighbouring countries (especially Croatia) including mutual exercises, enhancing exercises by including all interface points (national, regional, municipal), performing longer term exercises for better reflection of the extreme events challenges, and incorporating failure of communication systems and radiation data availability into drill programs, and enhancement of national radiological monitoring system.

In this area extensive improvements are envisaged, thus the time frame for implementing these changes is until the end of 2016.

3.4 Inspection

Even though the SNSA inspection is already on a regular basis inspecting areas such as emergency preparedness, testing of severe accident management equipment, trainings of the operators and other NPP staff, the NAuCp foresees additional special inspections to be performed in the areas of external hazards protection equipment, full scale training events with emphasis on equipment deployment and transfer of additional fuel with limited number of staff, available and needed times, the capacity of (human and equipment) resources, as well as to inspect the capabilities to power communications equipment needed to communicate onsite and offsite during a prolonged station black-out.

Some of these special inspections have already been performed in 2013, while all special inspections shall be performed by the end of 2014.

3.5 Additional studies

The SNSA shall consider requiring the plant to perform additional studies regarding accident timing, including core melt, reactor pressure vessel failure, basemat melt-through, SFP fuel uncovery, etc., using different computer codes. Also SNSA will consider requiring additional studies regarding radiological protection equipment for severe accident response, analysis and identification of situations that would prevent performance of work for radiological reasons, the question of stress on staff behaviour including emotional, psychological and cultural aspects associated with emergency response and associated training and support. Time frame for the additional studies is by the end of 2017.

3.6 Nuclear safety infrastructure

Nuclear safety infrastructure in Slovenia needs more political support. Only in such environment the human resource capacity and competence across all organizations in the field of nuclear safety can be further developed. SNSA will organize a meeting in which this topic shall be brainstormed by all involved parties (the utility, the regulatory body, technical support organisations). Special action plan shall be prepared and executed to enhance political support to nuclear safety infrastructure. The deadline for implementation of this action is end of 2014.
3.7 SNSA processes enhancement

The SNSA will strive to increase its capabilities in the areas of evaluating the defence-in-depth and management of severe accidents. Due to the decreasing number of its staff, the SNSA will also try to reduce its involvement in the international meetings/groups. This action will be performed until the end of 2015.

3.8 Peer reviews

In the next years the SNSA will consider inviting several IAEA missions to review the organization, capacities and preparedness of the Krško NPP and the SNSA. By the end of 2017 the SNSA will invite a follow-up Integrated Regulatory Review Service (IRRS) mission, the Review of Accident Management Programmes (RAMP) mission, the Operational Safety Review Team (OSART) mission and Emergency Preparedness Review (EPREV) mission.

3.9 Emergency Response Data System

Severe accident plant parameters are being transferred to regulator premises within the Emergency Response Data System (ERDS). Yet, this system needs revision to include all needed severe accident parameters and to increase reliability and capacity of the system. The SNSA plans to revise the ERDS system by the end of 2014.

3.10 Probabilistic Safety Analysis

By the end of 2015 the goal is to have a full scope probabilistic safety analysis (PSA) for Level 1 and Level 2, for all modes of operation, including low power and shutdown. SNSA was also considering requiring the plant to perform a PSA for spent fuel pool, but the Krško NPP has already proactively started performing that analysis.

3.11 Safety culture

Even though the SNSA is continuously striving to improve “soft” areas such as transparency, public discussion of safety issues, openness and trustful relationship between regulator, operators and the public, as well as achieving high level of safety culture in the regulatory and operational organizations, additional attention to these areas shall be given until the end of 2014.

3.12 Long-term spent fuel strategy

Within the reassessment of severe accident management strategy and preparation of the SUP concept, the plant also conducted an analysis of alternative options for spent fuel management [16]. The results show that the best strategy would be storing the spent fuel in dry cask storage. Main advantages of this strategy are: reducing load to the spent fuel pool (static and dynamic loads), increasing free volume between fuel elements (smaller chance of re-criticality in case of spent fuel pool damage), and higher coolant/fuel rate (slower spent fuel heating up in case of severe accident). The dry cask storage should be in operation in 2016, 2018 the latest.
4 CONCLUSION

Operating a NPP requires a constant attention to the potential hazard that a NPP represents. That is why continuous investments are needed in the areas of staff education, maintenance of systems, structures and components, following the development of new standards, best practices and operating experience, as well as performing additional studies, which can give rise to needed improvements.

The Fukushima accident forced the global nuclear industry to pay special attention to extreme external events, as well as to the preparedness for beyond design basis events and severe accidents. As a response to the SNSA’ decision the Krško NPP prepared an extensive safety upgrade program, which will ensure the safety of the plant, its employees and general public even in the case of the most adverse external events. The SUP represents the integral solution for improving preventive abilities of the plant and establishing key mitigative measures in case of severe improvements.

The Slovenian NAcP is an integrated response of the Slovenian regulatory body and nuclear industry to the Fukushima accident. Its purpose is to improve nuclear safety with concrete measures on the plant itself (e.g., the SUP, special inspections), as well as indirectly by improving legislation and safety culture of both the regulatory body and the operator, by inviting foreign expert missions, etc. The ENSREG peer review final report appraised the Slovenian NAcP as a well structured and comprehensive program of improvements.

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