REPUBLIC OF SLOVENIA
MINISTRY OF THE ENVIRONMENT AND SPATIAL PLANNING
SLOVENIAN NUCLEAR SAFETY ADMINISTRATION

UPDATE OF THE SLOVENIAN POST-FUKUSHIMA ACTION PLAN

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Prepared by the **Slovenian Nuclear Safety Administration**

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Summary

This report describes the conclusion of the follow-up on the Slovenian stress test National Action Plan (NAcP). Implementation of the Krško NPP's Safety Upgrade Programme (SUP) improvements is nearing its end. All of the original SUP improvements have been completed by the end of 2021. The report gives some details about each SUP improvement.

The SUP improvements have drastically decreased risk and improved the robustness of the Krško NPP. This is best seen from the PSA results, where core damage frequency has been reduced by around 75%. With SUP implementation unfiltered releases are reduced by about 70% mainly due to the filtering effect of the passive containment filtering vent system (PCFVS) and additional preventive DEC A systems, such as Alternate safety injection system (ASI), Alternate auxiliary feedwater system (AAF) and Alternate heat removal system (ARHR).

In addition to the originally planned SUP improvements, the Krško NPP implemented additional improvements as part of SUP Rev.3 [7], such as installing high temperature RCP seals and constructing the spent fuel dry storage (SFDS).

The second part of the Slovenian NAcP form the so called "soft" improvements. These relate to legislation changes, improvements in emergency response, performing special inspections, developing PSA, inviting peer review missions, improving safety culture, etc. Although, most of the original actions have been implemented, the SNSA sees these actions as never-ending, as most of them repeat in time with new knowledge and new possibilities for improvements. Such actions form the basis for continuous improvement of the nuclear and radiation safety.

Introduction

Immediately after the Fukushima Daiichi accident in March 2011 both Slovenian Nuclear Safety Administration (SNSA) and the Krško Nuclear Power Plant (the only nuclear power plant in Slovenia) started working on analyses and possible improvements of Krško NPP's safety.

Already in June 2011 the Krško NPP started acquiring mobile equipment (pumps, compressors, diesel generators, etc.), installing quick connection points and preparing procedures for use of this equipment. This was done with already prepared analysis based on the NEI B.5.b requirements [1] (later supplemented by NEI 12-06 [2]) endorsed by the NRC. In September 2011 the SNSA ordered the Krško power plant to analyse and propose design improvements that would further reduce the risk of severe accidents and mitigate their possible consequences. The licensee prepared a thorough analysis of possible improvements together with risk reduction analysis [3]. Based on that the plant proposed a programme of safety improvements, the so called Krško NPP's Safety Upgrade Programme (SUP) [4], which was reviewed and approved by the SNSA in February 2012.

In the meantime, the SNSA and Krško NPP also cooperated in the European Stress tests process of reviewing the safety of European nuclear power plants. This process resulted in the forming of national action plans reports (NAcP), which were based, as suggested by the ENSREG Secretariat, on the ENSREG compilation of recommendations and suggestions [5] as well as 2nd Extraordinary Meeting of the Contracting Parties to the Convention of Nuclear Safety topic and summary report (CNS EOM) [6].

The Slovenian NAcP is comprised of two parts. The first part is the "hardcore improvements" part based on the Krško NPP's SUP. This part is a major part of Slovenian NAcP and it covers the main recommendations and suggestions described in the ENSREG compilation of recommendations and suggestions [5] as well as CNS EOM reports [6]. These are the physical improvements of the Krško NPP design with a goal to strengthen the plant's robustness against natural hazards, possible multiple (common cause) failures, and improve severe accident management.

Later, the Krško NPP's SUP was revised several times, mostly for rescheduling, but also for substantive changes. For the preparation of the third revision in 2017 [7], the new legislation on the design was taken into account, which already included requirements of the new 2014 WENRA Safety Reference Levels [8], as well as WENRA Report on Safety of new NPP designs [9]. This new revision of the SUP was supplemented to include additional improvements, such as installation of new high RCP temperature seals and construction of the spent fuel dry storage (SFDS).

The second part of the Slovenian NAcP is the "soft improvements" part. These improvements were established based on additional documents reviewed by the SNSA, such as:

- US NRC's "Recommendations for Enhancing Reactor Safety in the 21st Century", The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident (SECY-11-0093) [10]
- US NRC's "Recommended Actions to be Taken Without Delay from the Near-Term Task Force Report" (SECY-11-0124) [11]
- US NRC's "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned" (SECY-11-0137) [12],
- The National Diet of Japan's "The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission" [13],

- "Das KKW Krško in Licht der Nuklear-Katastrophe von Fukushima" prepared by the University of Natural Resources and Life Sciences in Vienna [14],
- IAEA's Action Plan on Nuclear Safety [15], and
- ASME's report "Forging a New Nuclear Safety Construct" [16]

These improvements cover different topics, such as legislation improvements, emergency preparedness, additional special analysis, special inspections, peer review missions, probabilistic safety analysis, etc. Even though several actions of this "soft improvements" were implemented, this part of the NAcP comprises of actions that are subject to continuous improvement.

Status of the Slovenian NAcP

Part 1 – Hardcore improvements

The hardcore improvements part of the Slovenian NAcP are comprised of the Krško NPP's Safety Upgrade Programme (SUP), which was drawn up based on the "NPP Krško Analyses of Potential Safety Improvements" [3] required by the SNSA in September 2011.

No.	Action / activity	Area	Status	Finalization
1	SUP SUP comprises of a set of modifications/ improvements (see numbers 1.1 to 1.10) that were to be implemented in steps until the end of 2021.	SUP	implemented	2021
1.1	Safety upgrade of AC power supply	SUP, Phase II	implemented	2018
1.2	New pump for supplying SGs; in a bunkered building, with a dedicated water supply	SUP, Phase III	implemented	2021
1.3	Installation of alternative ultimate heat sink – revised into alternate long-term heat sink using SGs and underground well water (see 1.2)	SUP, Phase III	implemented	2021
1.4	Additional pump for injecting into the reactor primary system, in a bunkered building, with a dedicated (borated) water supply	SUP, Phase III	implemented	2021
1.5	Containment integrity safety upgrades including containment filtered vent systems and PARs	SUP, Phase I	implemented	2013
1.6	Establishment of emergency control room	SUP, Phase II	implemented	2019
1.7	Installation of fixed spray system around the SFP with provisions for quick connection from different sources of water.	SUP, Phase II	Implemented	2020
1.8	Mobile heat exchanger with provisions to quick connect to SFP	SUP, Phase II	implemented	2020
1.9	Flood protection upgrade (additional protection of nuclear island and bunkered buildings)	SUP, Phase II	implemented	2015
1.10	Establishment of new technical support centre and upgrade of existing operational support centre (emergency operating facilities)	SUP, Phase II	implemented	2021

Following are some details of each Krško NPP's SUP improvement.

Safety upgrade of AC power supply (1.1)

Within this action several improvements have been implemented, such as:

- strengthening of the third safety related 6.3 kV bus (MD3) - requalified for 0.6 g PGA
- procurement of an additional large mobile DG (2 MW), which can be quickly connected to the MD3 and thus support the DEC equipment (mostly the new SUP systems) in case of failure of the 3rd safety related DG
- installation of the 24hr battery for the emergency control room (ECR) and main I&C needed for preventing severe accidents
- installation of additional connection possibilities between DC trains
- DG3 island mode operation – possibility to disconnect all design basis power buses and loads in case of possible disruptions due to fires or other events. In this mode the 3rd safety DG powers only the ECR and DEC equipment.

2 MW diesel generator parked by the new BB2 building

The new BB2 building

The new bunkered building was erected on the Krško NPP site. It is designed to withstand extreme external hazards, such as extreme earthquakes, floods, winds, temperatures, aircraft crash, etc. As can be seen from the left picture below, two thirds of the building is underground. The BB2 holds two main new SUP systems, e.g., the alternate auxiliary feedwater (AAF) and the alternate safety injection system (ASI).

Concept of the BB2

BB2 with 2 MW DG and transformer in front

Alternate auxiliary feedwater system, AAF (1.2)

New auxiliary feedwater pump was installed in a new bunkered building (the BB2) for supplying long term cooling water through the plant's SGs. The system includes a dedicated 1500 m^3 tank

of demineralized water, with possibilities for replenishment from either demineralized water system or an underground water well.

The new AAF pump

AAF tank (view from above)

Alternate safety injection system, ASI (1.4)

Similarly, the ASI system includes a new safety injection pump installed in the BB2 for injecting into the reactor primary system. Likewise, the ASI includes a dedicated 1500 m^3 tank of borated water, also with a possibility for replenishment from other sources (including underground water well).

The ASI pump

ASI tank during construction

In addition to the new ASI system, the Krško NPP also installed the new train of the residual heat removal system (ARHR) capable of ensuring long-term reactor and containment cooling in case of multiple loss of design basis systems, such as residual heat removal system, component cooling system, containment spray system and containment cooling system. This new ARHR system can cool the reactor and containment using different sources of cooling water (e.g., component cooling or the river water).

The ARHR pump

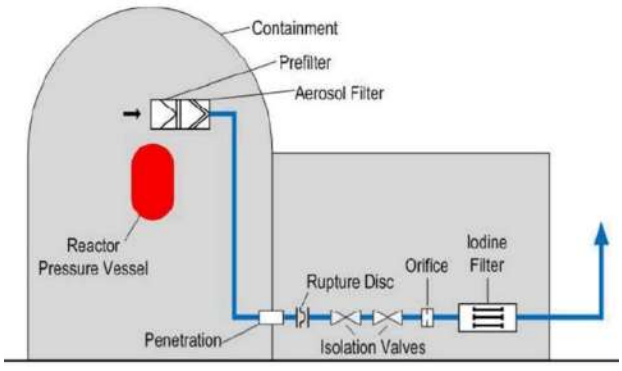
ARHR heat exchanger

Containment filtered vent system and Passive autocatalytic recombiners (1.5)

For the mitigation of severe accident consequences, the Passive Autocatalytic Recombiners (PARs) and Passive containment filtered vent system were installed. The PAR system is comprised of 20 PARs designed for severe accident conditions (in addition to two design basis PARs), capable of protecting the containment against combustible gases' threats.

PARs in the containment building

The Passive containment filtered vent system (PCFVS) is a dry type consisting of aerosol and iodine filters. The system is "passive", not requiring any electrical power or manual operations from the operator. In addition, it can also be operated remotely from the ECR, or locally by manual activation.



Concept of the Krško NPP's CFVS

CFVS' vent pipe (the first pipe right from centre)

Establishment of the emergency control room (ECR) (1.6)

A new emergency control room was installed in a bunkered building (the BB1), which gives operators additional reactor control means in the case of extreme external hazards, such as extreme earthquake, winds, aircraft crash, or need for main control room evacuation (e.g., MCR fire). In addition, the ECR is protected against possible radioactivity releases on site in the case of a severe accident.

The ECR has the needed I&C capabilities for safely shutting down the plant and bringing it to hot and/or cold shutdown state. It is powered from the third safety related bus (MD3), which can also be connected to two safety related buses, or a large (2 MW) mobile diesel generator, if the third safety DG is unavailable. From the ECR also all the new SUP systems can be controlled.

The emergency control room

Within the installation of the ECR, also additional train of safety related instrumentation was installed. This includes 107 new instrumentation channels powered from the third safety bus needed for safely shutting down the reactor and enabling the long-term cooling of the power plant. 20 of these new instrumentation channels are needed in case of severe accident management and are thus qualified for severe accident conditions.

One of the new transmitters

DEC transfer panel

Alternate cooling of the spent fuel pool – fixed spray system (1.7)

A fixed spray system was installed around the spent fuel pool (SFP) with provisions for quick connection from different sources of water. This system can replenish the SFP water in case of SFP boiling but can also remove residual spent fuel elements heat in case of a large leak from the pool.

Fixed spray system around the SFP

Alternate cooling of the spent fuel pool - mobile heat exchanger (1.8)

A trailer with a pump and a heat exchanger was acquired that can be quick connected to the SFP. This mobile heat exchanger can use several means of cooling water (including river water) and can thus ensure long-term cooling of the spent fuel elements.

SFP mobile heat exchanger

Connection points on the outside of SFP building

Flood protection upgrade (1.9)

The purpose of the additional flood protection is to protect the Krško NPP against extremely improbable combination of rare extreme floods (e.g., 10,000 – year flood) and strong earthquakes (e.g., 1000 – year earthquake), which could cause the breach of the flood protection dikes. Additional flood protection of the nuclear island and bunkered buildings was installed in a form of flood protection doors and sheet pile walls.

Examples of flood protection doors (outside and inside)

Sheet pile wall around DG3 cooling fans

New emergency operating facilities (1.10)

There are two emergency operating facilities at the Krško NPP site: technical support centre (TSC) for the team managing accident response, and operational support centre (OSC), which ensures long-term habitability of the emergency operating crew on the NPP site in case of an accident.

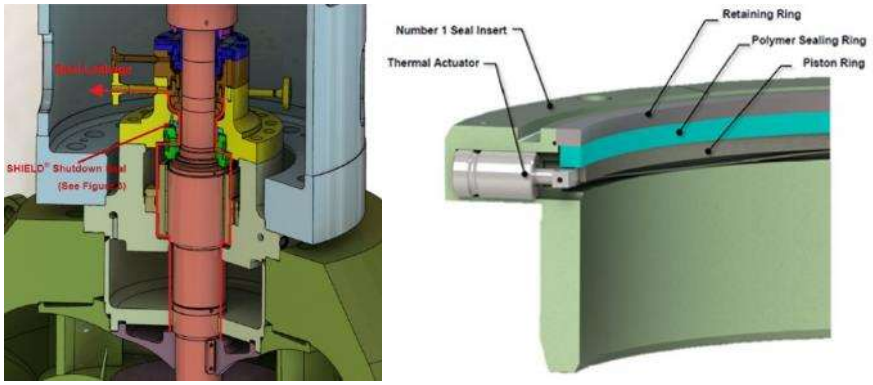
Both facilities were upgraded within the SUP. The new TSC was established in the new bunkered building (BB1), which gives long term protection against possible radioactive releases on site, as well as other external hazards. The old OSC was upgraded to include better protection against onsite releases, as well as extreme external hazards. It includes new ventilation system and a dedicated emergency power system to ensure long-term habitability of the emergency operating crew.

The new TSC in the BB1 building

Upgraded OSC

Installation of reactor coolant pump high temperature seals

In addition to originally planned improvements, the Krško NPP implemented one more design enhancement, that is the installation of reactor coolant pump (RCP) high temperature seals. This modification complements original first stage RCP seal package with Westinghouse High Temperature Seals. In case of loss of RCP seal cooling (such as with a station blackout (SBO) scenario), these new seals passively activate to limit the seal leakage to negligible levels. As such they greatly reduce the possibility of a SBO scenario developing into a small LOCA.



The high temperature seal design installed at the Krško NPP's RCPs

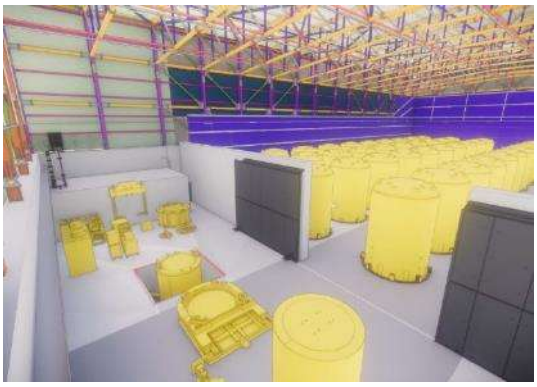
Spent fuel dry storage

Based on NAcP requirement (Action 12), a feasibility study of the options for further safer storage of the Krško NPP's spent fuel has been carried out. The option of the dry storage of

spent fuel was selected. By agreement, the construction of a new spent fuel dry storage (SFDS) at the NPP Krško site was added to the original SUP.

The new storage building will provide dry spent fuel storage in 70 casks with each cask containing 37 spent fuel assemblies (FA). The SFDS will provide passive cooling of FA and is designed to withstand extreme external hazards, such as extreme earthquakes, extreme floods, extreme winds, aircraft crash, etc. The storage capacity is sufficient to store FA from the Krško NPP up to prolonged operation of 60 years.

The construction of the SFDS is still ongoing. The dry storage building and all the necessary infrastructure is expected to be completed in the second half of 2022.

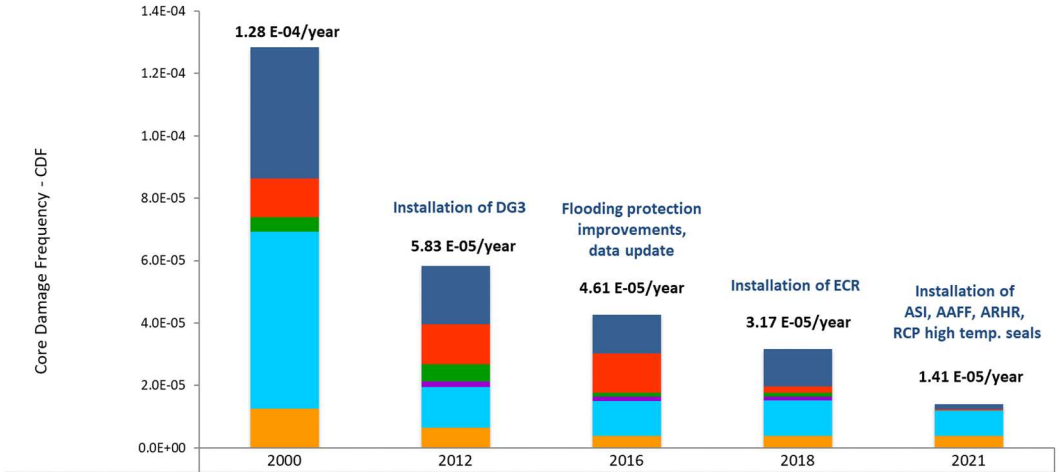


Concept of the Krško NPP's SFDS

Current status of the SFDS

SUP's impact on the Krško NPP's safety

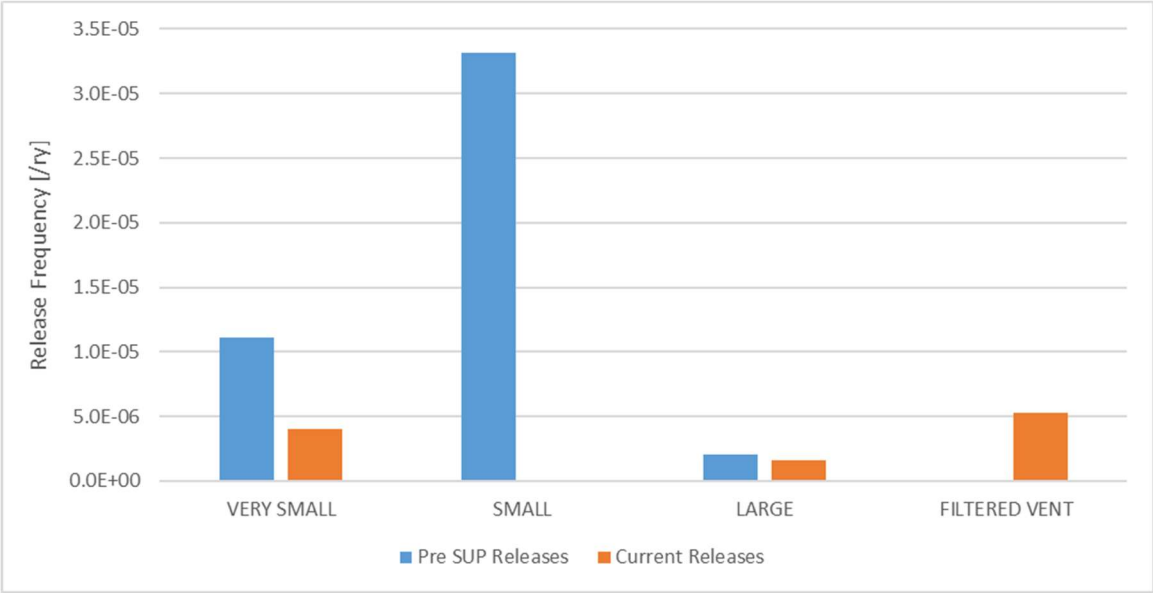
SUP improvements represent great enhancement of the robustness and safety of the Krško NPP, which can best be seen with the impact on the Krško NPP's PSA results. As can be seen from the PSA results on the pictures below, the risks from all categories of initiating events have been greatly reduced, especially of the internal hazards, such as internal initiating events, internal fires, floods, and high energy line breaks (HELB). Likewise, risks from external hazards have been further reduced.



	2000	2012	2016	2018	2021
Internal Initiating Events	4.20E-05	1.87E-05	1.24E-05	1.20E-05	1.81E-06
Internal Fire	1.25E-05	1.28E-05	1.26E-05	2.14E-06	3.53E-07
Internal Flooding	4.53E-06	5.61E-06	1.14E-06	1.13E-06	9.03E-09
High Energy Line Breaks		1.79E-06	1.36E-06	1.24E-06	2.82E-08
Seismic Events	5.67E-05	1.29E-05	1.12E-05	1.14E-05	8.04E-06
Other External Events	1.26E-05	6.50E-06	3.83E-06	3.83E-06	3.83E-06

Level 1 PSA results after implementation of the Krško NPP SUP [17]

Regarding the releases risk (level 2 PSA), with SUP implementation unfiltered releases are reduced by about 70% mainly due to the filtering effect of the passive containment filtering vent system (PCFVS) and additional preventive DEC A systems, such as ASI, AAF and ARHR.



Level 2 PSA results before and after implementation of the Krško NPP SUP [17 and 18]

Part 2 – Slovenian NAcP's "soft" improvements

As described in the introduction of the report, the Slovenian NAcP "soft" improvements were based on additional documents reviewed by the SNSA in the aftermath of Fukushima Daiichi accident.

The "soft" improvements included actions, such as:

- Revision of legislation (on Fukushima lessons learned, e.g., the 2014 WENRA SRLs).
- Emergency response improvements (e.g., supplementing the national radiological emergency response plan, preparing national strategy for nuclear and radiological accident, enhancing training of intervention personnel, trans-boundary arrangements and education of the public and media, enhancing cooperation with neighbouring countries (especially Croatia), including mutual exercises, enhancing emergency response exercises, and enhancing the national radiological monitoring system).
- Implementing special inspections at the Krško NPP on topics like external hazard protection equipment, mobile equipment (test and maintenance, procedures), power supply for communication systems in case of prolonged loss of AC, radiological protection in case of severe accidents (including equipment, procedures, mapping, staff training).
- Additional studies required regarding accident timing, including core melt, reactor pressure vessel failure, basemat melt-through, SFP fuel uncovery, etc., using different computer codes.
- Development of nuclear safety infrastructure (education, training, staffing, financing).
- Enhancing SNSA processes (e.g., improving SNSA's capability for evaluating defence-in-depth, enhancing staff training on severe accidents and SAMGs).
- Inviting IAEA peer review missions (EPREV, OSART, IRRS, RAMP)
- Upgrading the Emergency response data system (for transferring data about plant parameters in case of an emergency).
- Developing full scope PSA for Krško NPP (especially shutdown modes and spent fuel pool PSA).
- Improving and maintaining transparency (public discussion of safety issues), open and trustful relationship between regulators, operators and the public, enhancing safety culture at regulatory and operational organizations, develop methods to evaluate and detect degraded safety culture.
- Changing the national strategy on spent fuel to enable licensing of the spent fuel dry storage.

Most of the above actions were implemented, with a few of them still in progress (e.g., developing external hazard PSA for SFP). Anyhow, all of these actions are part of the continuous improvement process (for example, legislation is currently being revised again, to include some newest IAEA design requirements; in April 2022 the SNSA will again be reviewed by the IAEA IRRS mission, and then again in 10 years, etc.) and therefore are constantly being implemented, as there are always new ways to improve the processes that ensure and enhance nuclear and radiation safety.

Conclusion

With this report the SNSA is concluding its follow-up on the stress test NAcP. Implementation of the Krško NPP's Safety Upgrade Programme (SUP) improvements is nearing its end. All of the original SUP improvements have been completed by the end of 2021. As it can be seen from the PSA results, the SUP improvements have drastically decreased risk and improved the robustness of the Krško NPP. In addition to the originally planned SUP improvements, the Krško NPP implemented a few more, such as replacing the RCP seals with the high temperature seals and constructing the spent fuel dry storage (SFDS). The latter is still ongoing, though the main designing and licensing, as well as construction of the main safety related structures is complete. The construction of the SFDS is to be completed in the second half of 2022.

The second part of the Slovenian NAcP form the so called "soft" improvements. These relate to legislation changes, improvements in emergency response, performing special inspections, developing PSA, inviting peer review missions, improving safety culture, etc. Although, most of the original actions have been implemented, the SNSA sees these actions as continuous actions, as most of them repeat in time with new knowledge and new possibilities for improvements. Such actions form the basis for continuous improvement of the nuclear and radiation safety.

Abbreviations

AAF	Alternate Auxiliary Feedwater System
ARHR	Alternate Residual Heat Removal System
ASI	Alternate Safety Injection System
BB1/2	Bunkered Building 1/2
CNS EOM	Convention on Nuclear Safety, 2nd Extraordinary Meeting
DEC	Design Extension Conditions
ECR	Emergency Control Room
EPREV	Emergency Preparedness Review
HELB	High Energy Line Breaks
IRRS	Integrated Regulatory Review Service
LOCA	Loss Of Coolant Accident
NAcP	National Action Plan
NEK	Nuklearna elektrarna Krško – Krško NPP
OSART	Operational Safety Review Team
OSC	Operational Support Centre
PAR	Passive Autocatalytic Recombiners
PCFVS	Passive Containment Filtered Vent System
PSA	Probabilistic Safety Assessment
RAMP	Review of Accident Management Program
RCP	Reactor Coolant Pump
SBO	Station Blackout
SFDS	Spent Fuel Dry Storage
SFP	Spent Fuel Pool
SNSA	Slovenian Nuclear Safety Administration
SUP	Safety Upgrade Programme
TSC	Technical Support Centre

References

[1] NEI 06-12, B.5.b Phase 2 & 3 Submittal Guideline, Rev.2, December 2006

[2] NEI 12-06, Diverse and flexible coping strategies (FLEX) implementation guide, Rev.4, April 2016

[3] NPP Krško Analyses of Potential Safety Improvements, NEK ESD-TR-09-11, NEK, January 2012

[4] Program nadgradnje varnosti NEK (Eng.: The Krško NPP Safety Upgrade Program), NEK, January 2012

[5] Compilation of recommendations and suggestions, ENSREG, July 2012

[6] 2nd Extraordinary Meeting of the Contracting Parties to the Convention of Nuclear Safety, topic and summary report (CNS EOM), August 2012, Vienna, Austria

[7] Program Nadgradnje Varnosti, Revision 3, January 2017

[8] WENRA Safety Reference Levels for Existing Reactors, 24th September 2014

[9] WENRA Report on Safety of new NPP designs, WENRA RHWG, March 2013

[10] US NRC's "Recommendations for Enhancing Reactor Safety in the 21st Century", The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident (SECY-11-0093)

[11] US NRC's "Recommended Actions to be Taken Without Delay from the Near-Term Task Force Report" (SECY-11-0124)

[12] US NRC's "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned" (SECY-11-0137)

[13] The National Diet of Japan's "The Official Report of the Fukushima Nuclear Accident Independent Investigation Commission"

[14] "Das KKW Krško in Licht der Nuklear-Katastrophe von Fukushima" prepared by the University of Natural Resources and Life Sciences in Vienna

[15] IAEA's Action Plan on Nuclear Safety

[16] ASME's report "Forging a New Nuclear Safety Construct"

[17] Letno poročilo verjetnostnih varnostnih analiz (PSA) za leto 2020/2021 (NEK Yearly PSA Report for 2020/2021)

[18] NEK ESD-TR-03/14, Rev.0, Update of PSA Model based on the Plant Modifications in Cycle 26, NEK 2014