Experience with Safety Reviews of Slovenian Research Reactor by PSR and IAEA INSARR Missions and the Stress Tests for the Krško NPP

Tomaž Nemec

Slovenian Nuclear Safety Administration, Litostrojska 54, SI-1000 Ljubljana, Slovenia

Corresponding author: tomaz.nemec@gov.si

Abstract.
The TRIGA Mark II research reactor of the »Jožef Stefan« Institute in Slovenia started its operation in 1966. The operational experience of the reactor and performance indicators reflect safe and stable operation. The first safety review of the reactor was done in 1992 by IAEA INSARR mission. In 2002 the new Ionizing Radiation Protection and Nuclear Safety Act introduced a requirement for nuclear facilities to perform Periodic Safety Reviews (PSR) which is a prerequisite for extension of facility's operating license. The PSR requirements were defined in 2009 in a new regulation Rules on operational safety of radiation and nuclear facilities. The operator of the TRIGA research reactor performed the PSR from 2011 to 2014. The PSR summary report confirmed that the reactor can safely operate for a further 10 years. In 2012, the second IAEA INSARR mission of the TRIGA research reactor was carried out. The INSARR Follow up mission in 2015 confirmed that the operator is making significant progress with recommendations implementation and included some additional recommendations. In 2011, after the Fukushima accident, the EU countries performed the stress tests. The Krško NPP prepared a Safety upgrade program to resolve stress tests findings and to upgrade the plant design to Design extension conditions.

1. Introduction

The TRIGA Mark II research reactor of the »Jožef Stefan« Institute (JSI) was constructed in 1963-1966 as a joint project of the IAEA, US DOE and the Government of the Yugoslavia (Figure 1). The reactor started its operation in 1966 and is located close to Ljubljana, the capital of Slovenia. The reactor operates with steady state power of 250 kWt. In 1992 the reactor reconstruction provided capability for pulse mode operation with pulses up to 1 GWt. During 51 years of its operation the research reactor was utilized for research in activation analysis and neutron radiography, isotope production, training of personnel and Krško NPP operators, education of university students, validation of computer codes and nuclear data etc. The operational experience of the reactor and performance indicators reflect safe and stable operation of the reactor without emergencies or events of safety significance [1].

FIG. 1 The Ljubljana TRIGA Mark II research reactor [1].

The TRIGA research reactor had several safety reviews during its operation what is presented in Figure 2 together with other important milestones in reactor's operational history. The first periodic safety review was performed in years 2011-2014 [2]. International safety reviews were carried out by the IAEA with first INSARR mission in 1992 and a second one in 2012, as well as an INSARR follow up mission in 2015 [3, 4, 5]. The scope and results of these safety reviews are briefly presented in this paper.

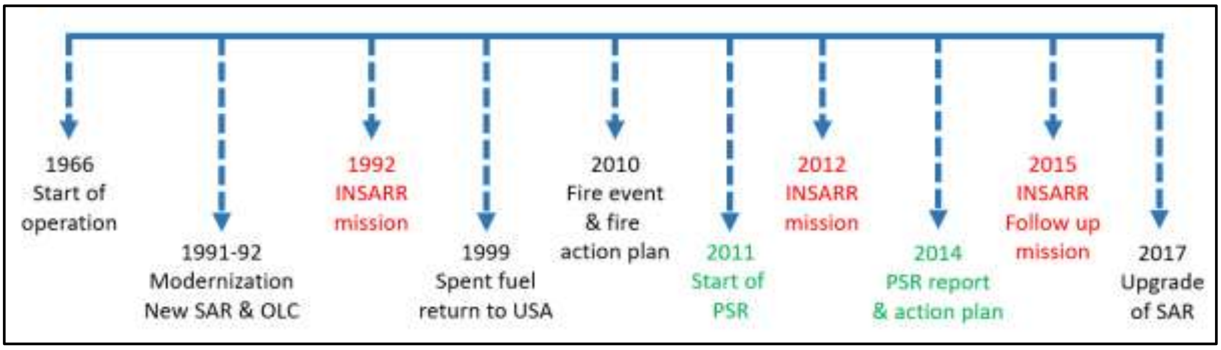

FIG. 2 The timeline of the TRIGA reactor operation and safety upgrades.

Following the Fukushima Daiichi nuclear accident in 2011, the ENSREG defined the scope of stress tests for all nuclear power plants in EU [6]. In Slovenia, the stress tests were performed for the Krško Nuclear Power Plant (NPP), which is the only NPP in Slovenia.

2. Safety upgrades and safety reviews of TRIGA research reactor prior to 2011

2.1 Reconstruction of TRIGA research reactor

In 1990, the program for reconstruction of the reactor was prepared, since most of the instrumentation was outdated after 24 years of operation. The reconstruction took almost two years and comprised of replacement of reactor control board, all electrical connections, some radiation monitors, some core components. New physical protection for reactor areas was installed. A storage for spent fuel elements was also constructed. The reactor reconstruction also provided capability for pulse mode operation with pulses up to 1 GWt.

In parallel, a new comprehensive Safety analysis report (SAR) was prepared that included changes to safety analysis and operating limits and conditions (OLC) because of reactor reconstruction. The reactor commissioning program was performed according to the SNSA decision and the SNSA also requested an IAEA INSARR mission to review results of reactor physics test and the new SAR and OLC. The SNSA approved the new SAR and issued a new operating license in 1992.

2.1 Safety review by IAEA INSARR mission

The first safety review of the reactor was done in March 1992 after completion of its reconstruction. The IAEA INSARR mission [3] reviewed the areas of nuclear safety and radiation protection and provided a list of 16 recommendations for improvements of reactor design, operation and its safety relevant documentation. In Table I the scope of the mission is presented. One mission recommendation was to include in the SAR an explicit mention in the safety analysis of the impact of the external events. Some examples of other recommendations are to develop of procedures for operators, to determine criteria for event reporting to the regulatory body, and some recommendations for emergency preparedness. The mission recommended that a separate SAR should be prepared for hot cell facility (later it was merged with the reactor) and radioactive waste storage facility (that was transferred to the Agency for radwaste management). The mission also recognized four good practices of the operator.

Relevant for the assessment of severe accidents is the statement in the INSARR mission report chapter on Safety Analysis: *"An analysis was carried out where the release of all volatile fission products from the core was postulated without considering how such a release can occur. The consequence of this worst case accident have been analyzed and found to be acceptable"*. Furthermore, relevant for the extreme natural hazards assessment, the INSARR report states that *"explicit analysis for external events has not been performed"*. However, at the time of SAR preparation, there was already some limited assessment of facility robustness to the natural hazard, such as an expert opinion on seismic safety of the reactor hall.

TABLE I: Scope of IAEA INSARR mission, 1992 [3].

Nuclear Safety		**Radiation Protection**	
Regulatory Supervision	Records and reports	Regulatory Authority	Radioisotope Production Laboratory
Organization, Management and Training	Experiments and Modifications	Organization of Radiation Protection at the Research Reactor Centre	Radioactive Waste Storage Facility
Safety Analysis	Security	Ventilation and Fixed Radiation Monitors	Public Dose Control
Operating Instructions and Procedures	Quality Assurance	Radiation Protection Practices	Emergency Planning and Preparedness
Maintenance, Testing and Inspections	Conduct of Operations		

2.2 Reactor operational events related to hazards

In 2008, the adjacent hot cell facility was merged with the TRIGA research reactor into a single nuclear facility and the TRIGA reactor SAR was amended with a separate chapter on the hot cell, including the relevant safety analysis and the OLC. The hot cell facility was used for research, as temporary storage of radioactive material and for processing of radioactive waste prior to be accepted into the Central interim storage facility Brinje. During one of such radioactive waste processing campaigns a fire occurred, which caused local spread of contamination to a room of hot cell facility and to the ventilation system. There were no radioactive releases to the environment or radiological consequences to the staff who extinguished the fire. The event was rated as level 1 on the INES scale [7].

The SNSA requested to the operator to perform root cause analysis of the event and to prepare corrective actions based on the analysis findings that will prevent a recurrence of such event. Based on the results of its root cause analysis, the JSI performed several improvements including administrative restrictions and conditions aimed to prevent fire events, installation of active fire protection system in the facility premises, revision of the emergency response plan and procedures for use in case of emergency including fire events. The SNSA prepared its own independent analysis of the event and proposed additional corrective actions both for the operator and the regulatory body.

2.3. Requirements by new nuclear safety regulations

In 2002, the new Ionizing Radiation Protection and Nuclear Safety Act [8] introduced a requirement for nuclear and radiation facilities to perform Periodic Safety Reviews (PSR). The completion of the PSR is also a prerequisite for extension of facility's operating license.

The PSR requirements and description of the review process were defined in 2009 in a new regulation JV9, Rules on operational safety of radiation and nuclear facilities [9]. This new regulation was prepared based on WENRA Reactor safety reference levels from 2008 (listed in table II).

TABLE II: WENRA Safety Reference Levels [10].

Safety Reference Levels, Issues A to T	
A - Safety Policy	K - Maintenance, In-Service Inspection and Functional Testing
B - Operating Organisation	LM - Emergency Operating Procedures and Severe Accident Management Guidelines
C - Management System	N - Contents and Updating of Safety Analysis Report (SAR)
D - Training and Authorization of NPP Staff (Jobs with Safety Importance)	O - Probabilistic Safety Analysis (PSA)
E - Design Basis Envelope for Existing Reactors	P - Periodic Safety Review (PSR)
F - Design Extension of Existing Reactors	Q - Plant Modifications
G - Safety Classification of Structures, Systems and Components	R - On-site Emergency Preparedness
H - Operational Limits and Conditions (OLCs)	S - Protection against Internal Fires
I - Ageing Management	
J - System for Investigation of Events and Operational Experience Feedback	*WENRA SRL (2014) added a new issue* T - Natural Hazards

WENRA (Western European Nuclear Regulators Association) [11] is an organization that started in 1999 as cooperation of regulators for nuclear safety in EU countries and Switzerland. Later it was extended also to new members outside of the EU and currently WENRA includes also observers from other continents. The WENRA Reactor safety reference levels were prepared with joint work by regulatory bodies as a harmonization process of regulatory regimes of individual countries participating in WENRA. The SNSA issued also a practical guideline PS 1.01 on the contents and scope of a PSR for radiation or nuclear facility that was based on IAEA standard [12]. The operator of the TRIGA reactor started to implement these new requirements within two processes: its first periodic safety review (2011-2014) and with preparation of a new revision of SAR (2011-2017).

3. The Post-Fukushima safety reviews and safety improvements

In 2011, the Fukushima accident occurred and this changed the perspective to the nuclear safety requirements for nuclear facilities. The EU countries performed stress tests of nuclear power plants (and some also did that for research reactors and other fuel cycle facilities). The IAEA revised its requirements and guides [13] to incorporate lessons learned from Fukushima. The WENRA prepared new safety reference levels for existing NPPs in 2014 [10] as an update in relation to lessons learned from TEPCO Fukushima Dai-ichi accident. The SNSA included these new requirements into amended nuclear safety law in 2015 and new revisions of regulations in 2016 [8, 9, 14]. All these information, new requirements and approach of stress tests had some impact on the safety reviews that were performed at the TRIGA reactor in the period after 2011.

3.1 Periodic safety review

The operator of the TRIGA research reactor prepared the PSR program in 2011 [2] based on the PSR scope defined in the SNSA guideline PS 1.01 but with some differences according to graded approach. The review of Probabilistic safety analysis was not included in the PSR scope since the TRIGA reactor is not legally required by regulations JV5 and JV9 to perform such analyses. The PSR program defined in its scope a total of 14 safety factors to be reviewed (as presented in Table III) and on the SNSA request the JSI included in the PSR program the review of reactor's preliminary decommissioning plan and the role of the reactor safety committee.

TABLE III: Scope of Periodic Safety Review (PSR) of the TRIGA reactor [2].

Safety Factors	
Plant design	Use of experience from other plants and research findings
Actual condition of structures, systems and components (SSCs) important to safety	Organization and the management system
Equipment qualification	Safety culture
Ageing	Procedures
Deterministic safety analysis	Human factors
Hazard analysis	Emergency planning
Safety performance	Radiological impact on the environment

The PSR was performed in the period from 2011 to 2014 and topical reports with findings and conclusions were issued for every safety factor as required by the regulation JV9. The PSR summary report assembled together all the findings and determined the corrective actions. In the PSR report the global assessment of safety was included and the conclusions were that the reactor can safely operate for a period of further 10 years with condition that the PSR action plan has to be completed in next 5 years. As required by the regulation JV9, the PSR report was reviewed by independent expert on nuclear and radiation safety which concluded that the report is acceptable. The SNSA approved the PSR report and by this fulfilled the precondition for operating license extension until the next PSR (10 years). The SNSA decision also determined that PSR action plan has to be completed in the next 5 years.

Altogether, in the PSR there were 100 PSR findings in 14 safety factors, and these findings were joined in case of similarity, so 85 actions for improvements were defined [2]. Several findings were from the safety factors of Deterministic safety analysis, Hazard analysis, Safety management system and Procedures. Most of the findings were based on noncompliance with new regulatory requirements or new revisions of IAEA standards. Resulting corrective actions required revision of the SAR, including assessment and analysis of internal and external hazards to the facility. Other examples are preparation of new programs according to regulations (e.g. for aging management and equipment qualification) and update of preliminary decommissioning program.

3.2 IAEA INSARR mission and follow up mission

In 2012, the IAEA INSARR mission of the TRIGA research reactor [4] was performed while the PSR process was in course. Altogether 14 safety areas were reviewed (as shown in Table IV) and several recommendations and suggestions were issued that were implemented in the SAR, operating procedures and update of analyses, emergency plan or radiation protection. An important example is recommendation to improve the reactor fire safety, based on the fire event in 2010, and this action was then implemented in 2014. Several recommendations dealt with management and responsibilities of reactor manager and reactor safety committee. The mission identified as a good practice that a PSR for the research reactor has to be performed every 10 years with the objective and scope similar to the nuclear power plants; at the time the PSR was performed in parallel with the INSARR mission.

The SNSA performed annual inspections to review the progress in implementation of recommendations and suggestions. Those actions that included modifications and required changing of the SAR were also approved by the SNSA decision and were incorporated into the new revision of the SAR.

TABLE IV: Scope of IAEA INSARR mission, 2012 [4].

Safety Aspects of the Reactor Operation	
Regulatory Supervision	Conduct of operations
Operating organization and reactor management	Maintenance, periodic testing and inspection
Safety committee	Utilization and modifications
Training and qualification of operating personnel	Operational radiation protection and waste management programme
Safety Analysis Report (SAR)	Emergency planning
Safety Analysis	Quality assurance programme
Operational Limits and Conditions (OLCs)	Decommissioning plan

The INSARR Follow up mission in 2015 [5] confirmed that the operator is making significant progress with implementation of actions. An important recommendation that was issued to the Government of Slovenia to provide the funds needed for safe operation of the reactor and for a full time employment of the reactor manager was not implemented yet. The mission concluded that this recommendation should be fully implemented without further delay. The mission report included also some additional recommendations and suggestions. Examples are the design basis of water filter in the ventilation system, procedures for core changes and procedures for response in case of electrical supply loss.

The INSARR Follow up mission's suggestion was to perform a safety reassessment of the reactor according to the IAEA methodology [15]. The operator commented that the reactor potential hazard is low so that off-site consequences are considerably low in extreme accidental situations.

3.3 New revision of TRIGA reactor SAR

The TRIGA reactor operator applied for approval of new SAR revision in 2011 that was prepared in new format. The information in the SAR was updated from the 1992 facility conditions and some changes were incorporated to fulfil new requirements of regulations from 2009, such as aging management program, operational experience program etc. However, the process of SAR review and approval took many years and it was completed only in 2017 by SNSA approval. During this time the SAR proposal was further extended with some of the actions from findings of 2012 INSARR mission and PSR findings. Examples are preparation of safety analysis for impact of experimental facilities on the facility and operating limits and conditions for impact of experiments on reactivity, irradiations in the reactor and use of materials in experiments. A thorough safety review of SAR by members of JSI reactor safety committee revealed some inconsistencies, such as the need to redefine operating limits for pulsing operation. For safety relevant modifications the regulation JV9 requires that operator's application be amended with an expert opinion of modification's impact to nuclear and radiation safety. Therefore, all changes to the chapters of safety analyses and operating limits and conditions as well as aging management program were reviewed by independent expert for nuclear and radiation safety and declared as acceptable.

4. Stress tests and safety upgrade of the Slovenian Krško NPP

In 2011, after the Fukushima accident, the EU countries performed the stress tests according to the ENSREG specifications [6]. The scope of the stress tests is presented in table V, extreme natural events had to be considered (an example is shown in Figure 3). The Slovenian Nuclear Safety Administration (SNSA), which is the Slovenian regulatory body, ordered the NPP operator to perform the stress tests based on legal requirement for special safety review as defined in the nuclear safety act and regulation JV9 [8, 9]. The technical support organization JSI, which is also the operating organization of the TRIGA research reactor, was also involved in the stress tests. The JSI made some beyond design basis analyses for postulated reactor and spent fuel pool accidents as support for the assessment of safety margins and cliff edge effects.

TABLE V: Technical scope of EU stress tests [6].

Initiating events		
Earthquake	Flooding	Extreme Weather Conditions
Consequence of loss of safety functions from any initiating event conceivable at the plant site		
Loss of electrical power, including station black out	Loss of the ultimate heat sink	Combination of both
Severe accident management issues		
Means to protect from and to manage loss of core cooling function	Means to protect from and to manage loss of cooling function in the fuel storage pool	Means to protect from and to manage loss of containment integrity

Based on the Krško NPP report the SNSA reviewed the safety of the NPP and prepared the national report on nuclear stress tests in December 2011 [16]. In 2012, an EU expert team performed a peer review to the countries involved in stress tests campaign, including Slovenia. The peer review team issued recommendation on the seismic design requirements for extreme earthquakes.

FIG. 3 Slovenian Krško NPP in 1990 during the worst flood in its history [16].

Based on new safety requirements for severe accidents from WENRA issue F [10] the operator prepared an assessment of plant performance for beyond design bases and severe accidents. The conclusions of this safety assessment, together with peer review team recommendation and findings of the stress tests were the basis for Krško NPP Safety upgrade program [17]. This Safety upgrade program shall upgrade the plant design to fulfil also Design extension conditions, as required by new regulations that were prepared according to new WENRA reference levels [10]. Examples of modifications from the Safety upgrade program included installation of passive autocatalytic recombiners, filtered containment venting system, upgrade of emergency centers and construction of a separate emergency control room, additional line of coolant injection into the reactor and the steam generators, improvements for cooling of the spent fuel pool, etc. The Safety upgrade program is a major investment in beyond design basis safety of the plant and it shall be concluded by 2021.

5. Conclusions

The Ljubljana TRIGA reactor is a facility operating for over 50 years and at the time of construction the requirements of legislation and standards were not quite as they are at present. New requirements were developed also from experience of nuclear accidents, such as TMI, Chernobyl and Fukushima, and are much more stringent that were in 1966 when the TRIGA reactor started its operation. However, the reactor had upgraded its design and safety in campaigns such as reconstruction for pulsing operation and equipment modernization. Further improvements of reactor safety are currently being implemented based on PSR and INSARR mission action plans. The operating organization, the JSI, is also implementing the new requirements of legislation based on WENRA reference levels. For a small operating organization of the TRIGA reactor and its small operating budget, all these is a big burden. But instead of foreseen reactor shutdown planned for 2016 and decommissioning planned for 2019, the JSI decided to continue the reactor operation for many more years, as long as the Krško NPP would continue to operate (the aim is 2043). This demands continuous modernization and upgrade of safety of the reactor and also regular safety reviews of the facility conditions.

6. References

[1] Brochure 50 years of the reactor TRIGA, "Jožef Stefan" Institute, Ljubljana, 2016, http://www.rcp.ijs.si/ric/TRIGA50.pdf
[2] Sebastjan Rupnik, "Jožef Stefan" Institute, "Country presentation – Slovenia", Workshop on Establishing and Implementing a PSR Process for Research Reactors, 18-22 April 2016, IAEA, Vienna, Austria
[3] INSARR Mission to TRIGA Research Reactor, Ljubljana, Slovenia, 2-6 March 1992, www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/si/Porocila/PorocilaEU/insarr.pdf
[4] Report of the INSARR Mission to the Slovenia TRIGA Mark- II Research Reactor, Ljubljana, Slovenia, 12-16 November 2012, http://www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/si/Porocila/PorocilaEU/Porocilo_INSARR__16_Nov_12_final.pdf
[5] Report of the Follow-up INSARR Mission to the Slovenia TRIGA Mark- II Research Reactor, Ljubljana, Slovenia, 25-27 November 2015, http://www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/si/Porocila/NacionalnaPorocila/FUINSARR_Mission_Report.pdf
[6] Declaration of ENSREG - EU Stress Tests Specifications, 31 May 2011, http://www.ensreg.eu/sites/default/files/EU%20Stress%20tests%20specifications_1.pdf
[7] INES ERF 17 October 2010 "Fire in hot cell facility of the Ljubljana TRIGA reactor centre", SNSA, http://www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/si/INES/Final_ERF_OVC17-10-2010.htm
[8] Ionising Radiation Protection and Nuclear Safety Act, ZVISJV, 2002, last amendment 2015, http://www.ursjv.gov.si/en/legislation_and_documents/legislation_in_force/
[9] Rules on operational safety of radiation and nuclear facilities, JV9, 2009, last amendment 2016, http://www.ursjv.gov.si/en/legislation_and_documents/legislation_in_force/
[10] WENRA Safety Reference Levels for Existing Reactors, 24 September 2014, http://www.wenra.org/media/filer_public/2014/09/19/wenra_safety_reference_level_for_existing_reactors_september_2014.pdf
[11] WENRA, Western European Nuclear Regulators Association, http://www.wenra.org/
[12] "Periodic Safety Review of Operational Nuclear Power Plants", IAEA NS-G-2.10, 2003; and "Periodic Safety Review for Nuclear Power Plants", IAEA SSG-25, 2013, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1588_web.pdf
[13] IAEA Safety Standards for Research Reactors, www-ns.iaea.org/standards/documents/default.asp?s=11&l=90&sub=20&vw=0#sf
[14] Rules on radiation and nuclear safety factors, JV5, 2009, last amendment 2016, http://www.ursjv.gov.si/en/legislation_and_documents/legislation_in_force/
[15] "Safety Reassessment for Research Reactors in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant", IAEA Safety Report Series No. 80, 2014, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1615_web.pdf
[16] Slovenian National Report on Nuclear Stress Tests, Final Report, SNSA, December 2011, http://www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/si/Novice/Slovenian_Stress_Test_Final_Report.pdf
[17] Slovenian Post-Fukushima National Action Plan, SNSA, December 2012, http://www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/si/Porocila/NacionalnaPorocila/Slovenian_National_Post_Fukushima_Action_Plan_01.pdf