European Nuclear Safety Regulators Group

EU Peer Review Report of the Armenia Stress Tests

June 2016

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1 INTRODUCTION and BACKGROUND

On 11/03/2011, a magnitude 9.0 earthquake struck some 80 km off Japan's Tohoku coast. The ensuing tsunami triggered core melt of three reactors at the Fukushima Dai-ichi Nuclear Power Plant (NPP).

While Fukushima is not the world's worst nuclear accident, history has shown that each major nuclear accident (Three Mile Island (USA, 1979), Chernobyl (Soviet Union, 1986)) has caused a re-examination of the risks of nuclear power on both national and international levels leading to implementation of additional safety improvement measures.

Although the technical challenges are different with each accident, the analysis of the Fukushima accident reveals already quite substantial, well-known and recurring technical issues: natural phenomena of critical nature not being considered, faulty design, insufficient backup systems, failure to introduce safety improvements to operating reactors, human error, inadequate contingency plans, confusion in the response to a severe accident and poor communications. These points are clearly described in the International Atomic Energy Agency (IAEA) Comprehensive report on Fukushima published in September 20151.

Specifically, Fukushima has shown that well-known lessons learned from accidents decades ago have not been fully addressed by the entire nuclear industry and in some cases not sufficiently enforced by regulators, even in a nation that was assumed to have a high standard of safety. In Fukushima's aftermath came a vigorous reassessment of the safe use of nuclear energy worldwide, firstly because it was a severe accident, and secondly because it occurred in a nation that was previously assumed to have a high standard of nuclear safety and technical expertise.

Regarding the European Union (EU), as stated in the Communication on a Nuclear Illustrative Programme (PINC)2 published in April 2015, "Nuclear energy is part of the energy mix of half of the EU Member States. In those countries that chose to use it, nuclear has a role to play in ensuring the security of electricity supply. (…) There are 129 nuclear power reactors in operation in 14 Member States, with a total capacity of 120 GWe and an average age close to 30 years. New build projects are envisaged in 10 Member States, with four reactors already under construction in Finland, France and Slovakia."

Therefore, ensuring nuclear safety is of utmost importance to the EU and its citizens. The costs of a nuclear accident, especially if it would happen in a densely populated region, could be so large that it could be potentially ruinous to the affected national economies. It is therefore essential for the society and the economy to avoid the occurrence of any nuclear accident in a Member State of the EU, by ensuring the highest possible standards of nuclear safety and quality of regulatory oversight.

The same applies of course to Armenia, which strongly relies on nuclear energy for a sizable fraction of its total electricity production.

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[1] https://www.iaea.org/newscenter/news/iaea-releases-director-generals-report-on-fukushima-daiichi-accident

[2] https://ec.europa.eu/energy/en/news/commission-presents-nuclear-illustrative-programme

2 EU – STRESS TESTS AND FOLLOW-UP

2.1 Mandate

Against the background of Fukushima and based upon a mandate given by the European Council at its meeting on 24-25/03/2011, the European Commission (EC) – together with the **European Nuclear Safety Regulators Group** (**ENSREG**) – launched in 2011 EU-wide comprehensive risk and safety re-assessments of all EU NPPs (hereinafter referred to as **"Stress Tests" (STs)**).

The request of the European Council defined that the STs had to be performed first at national level and to be complemented by a European **Peer Review (PR)**.

2.2 Methodology

The European Council invited the EC and ENSREG to develop the scope and modalities for the STs with the support of the **Western European Nuclear Regulators' Association (WENRA).** WENRA drafted the preliminary stress tests specifications. Consensus on these specifications, the so-called **"EU-STs specifications"**, was achieved by ENSREG and the EC on 24/05/2011[3].

The specifications for the PR of these EU-STs as well as a working paper on the transparency aspects of the STs[4] were agreed later at the 11/10/2011 ENSREG meeting.

The EU-STs specifications, which were the basis of the safety track of the stress tests, defined three main areas (topics) to be assessed: extreme natural events (earthquake, flooding, extreme weather conditions), response of the plants to prolonged loss of electric power and/or loss of the ultimate heat sink (irrespective of the initiating cause) and severe accident management.

The assessments were organised in three phases:

- Self assessments by nuclear licensees. Licensees were asked to submit STs reports covering all their facilities to the national regulators
- National review of the self assessments. The National regulator reviewed the ST reports supplied by the licensees and prepared a **National Report (NR**);
- European PR of NRs.

2.3 Invitation to neighbouring countries to take part in the EU-STs

On 23 June 2011 a meeting took place with Commissioner Oettinger, Deputy Ministers of Energy and senior representatives of the Ministries of Energy and national authorities responsible for nuclear energy of the Republic of Armenia (RA), Republic of Belarus, Republic of Croatia, Russian Federation, Swiss Confederation, Republic of Turkey and Ukraine with the aim to invite these counties to take part in the EU STs and to improve the safety of their nuclear installations. As an outcome of this the participating counties, in cooperation with the EU:

- Confirm their willingness to undertake on a voluntary basis comprehensive risk and safety assessments ('stress tests'), taking into account the specifications agreed by the European Commission and the European Nuclear Safety Regulators Group (ENSREG) on 24 May 2011. The need for a consistent approach towards nuclear safety by all countries making use of nuclear energy is reinforced by today's shared vision that highlights the potential cross-border nature of nuclear accidents;

[3] http://ec.europa.eu/energy/nuclear/safety/doc/20110525_eu_stress_tests_specifications.pdf

[4] http://www.ensreg.eu/node/349/

- Agree to commit nuclear operators to self-assessments of their nuclear power plants, as well as to invite national regulatory bodies to present national reports, and to make use of a transparent peer-review system enhancing credibility and accountability of the comprehensive risk and safety assessments;
- Agree to engage on a multilateral level and with the IAEA a discussion for a strong and common safety standards as well as international peer reviews.

Two countries **Switzerland and Ukraine** directly participated to the full process of the STs with the other EU countries in 2012 and to the National Action Plan (NAcP) peer reviews in 2013 and 2015.

Some neighbouring countries like **Armenia,** Belarus and Turkey expressed their interest to follow the same peer review process but were not ready to join and to submit immediately a report. The EC has always indicated its willingness to support the peer review process in collaboration with ENSREG when the country will be ready.

2.4 Participation and responsibilities

It was the first time that such a multilateral exercise covering over 140 reactors in all the 15 EU Member States having at that time **Nuclear Power Plants (NPPs)** with an operating license as well as in 2 EU Neighbouring Countries (Switzerland and Ukraine) was initiated.

While ENSREG and the EC developed the scope and the specification of the STs, the re-assessment of safety of NPPs was under the responsibility of the nuclear licensees and the competent national regulators. The PR process was organised to allow all of the participating countries to verify the findings and in this way to contribute to the harmonisation of the high level of nuclear safety across the EU. The whole ST including its PR was a voluntary activity, because in accordance with the EU legislation[5] the responsibility for nuclear safety is the responsibility of the member states.

2.5 The peer review process

In order to provide an objective assessment of the work done at national level and to maximise coherence, National ST reports were subjected to a multinational peer review process. The review work was done by about 90 nuclear safety experts from EU Member States, Switzerland, Ukraine and from the EC. The process was additionally accompanied by about 20 observers from third countries (Croatia, USA, Japan) and the IAEA.

The peer review process was organised in three phases:

Desktop review

The PR started with a desktop review of the NRs. Each of the reviewers had access to all of the NRs and could generate written questions addressed to national regulators.

Additionally, a dedicated website was established to allow the public to pose the questions on the NRs. A lot of questions were raised. The questions were forwarded to the competent national regulators and then considered during the PR process.

[5] COUNCIL DIRECTIVE 2009/71/EURATOM of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations - Article 6

<u>Topical reviews</u>

Following the desktop review, all peer reviewers met in Luxembourg to undertaken the topical review that lasted for two weeks. The review process was structured in line with the three technical topics of the stress tests: natural hazards, loss of safety systems and severe accident management (one dedicated PR group for each topic). Each of the 17 participating countries subjected to the PR made a presentation on the national findings on each of the three topics, presented answers to written questions as well as answered additional questions asked during the presentations. Finally, the results of the reviews undertaken by each topical group were joined in a draft report for each country.

<u>Country reviews</u>

In the third step, each country subjected to the peer review was visited by a team of eight peer reviewers for three or four days. Discussions were held in order to obtain answers and clarifications (e.g. on the level of a NPP) to the questions left open after the topical review as well as clarification on other important issues. One NPP site, selected by the Peer Review Team (PRT), was visited in each country. The total number of reactor units on the sites visited during the originally scheduled visits in March 2012 was 43 (approximately 30% of all the units in operation). Reports drafted during the topical reviews were completed using additional information obtained during the visits. The national regulator had the opportunity to review and comment on the report but the final decision in respect to the country report belonged to the PR team. The findings in the country reports were reflected in the overall Peer Review Board report to ENSREG[6], which endorsed it on 26 April 2012.

Additional visits were performed to eight reactor sites by the PRTs in September 2012, in order to gain additional insight on different reactor types, to discuss implementation of the identified improvements and in order to alleviate concerns relating to installations in areas bordering other Member States. Thus, all operating reactor types in Europe have been visited by peer reviewers.

2.6 Follow-up

While the STs confirmed the high standards of nuclear safety in the EU, the reports also identified a number of improvements that could enhance safety. To ensure an appropriate follow-up, Member States developed NAcPs for the implementation of the identified recommendations.

NAcPs were subject to the EU level peer review process. The 1st NAcP peer review workshop was organised by ENSREG in April 2013. The workshop:

- Identified specific country actions and timescales for actions to improve nuclear safety in nuclear reactors
- Highlighted the importance of the principle of "Defence-in-Depth" whereby the safety of nuclear plants is assured in the case of an accident by a number of independent layers of safety actions
- Recognized the importance of Periodic Safety Reviews (PSR) for continuous improvement in the field of nuclear safety
- Highlighted the need to maintain "containment integrity" (ensure that the reactor containment building does not allow the release of radioactivity) under severe accident conditions

- Committed to present an updated NAcP report by December 2014 with a follow-up peer review workshop in April 2015

The 2nd NAcP peer review workshop took place in April 2015 discussed the updated NAcPs and the measures undertaken to improve the safety of nuclear power plants as well as changes in the schedules since the first reports. During the 2nd Workshop, special attention was devoted to the technical basis for any changes to the safety improvement measures proposed as well as the review of studies and analyses identified and completed since the 1st Workshop.

2.7 Transparency and public involvement

In its meeting on 24-25 March 2011, the European Council mandated that the outcome of the STs and the information on any subsequent selected safety improvement measures to be provided to the public. Therefore, from the very beginning full transparency was a key issue of the EU-STs and its follow-up activities. The possibility to become involved, by raising questions on the NRs and later the NAcPs and to have public access to all reports of the reviews conducted is the best illustration of the extent of transparency achieved.

Several public meetings took also place in 2012 to present the process of the Stress Tests and the major outcomes.

Details regarding the transparency process are available in the document "Transparency of "Stress Tests" – Transparency aspects in the implementation, reporting and follow-up of the “stress tests”” (http://www.ensreg.eu/node/349/).

All reports, including the licensee reports, NRs and NAcP are accessible to the public on the ENSREG website. (http://www.ensreg.eu/EU-Stress-Tests)

2.8 Nuclear safety – EU legislative framework

In addition to the STs-process, the mandate from the European Council included the request to the EC to *"review the existing legal and regulatory framework for the safety of nuclear installations"* and to *"propose by the end of 2011 any improvements that may be necessary"*.

In line with this mandate, the EU legislative framework has been significantly strengthened in the past five years: a Council Directive for the responsible and safe management of spent fuel and radioactive waste was adopted in 2011, a new Directive establishing Basic Safety Standards to protect the health of workers and the general public against dangers arising from ionising radiation in 2013 and an amended Nuclear Safety Directive in 2014. Altogether, this represents the most advanced legally binding and enforceable regional legal framework for nuclear safety and radiation protection in the world.

With the amendment to the Nuclear Safety Directive, adopted by the Council in 2014, Europe significantly enhanced its legislation and its leadership in nuclear safety. Ambitious EU-wide safety objectives for all types of nuclear installations have been introduced, with the aim of reducing the risk of accidents and avoiding large radioactive releases. These EU-wide safety objectives will have a global impact via the “Vienna Declaration” on the Convention of Nuclear safety, adopted in 2015.

3 ARMENIA – CURRENT STATUS and STs PROCESS

3.1 The nuclear power plant in Armenia

The Metsamor Nuclear Power Plant (MNPP), referred to as the **Armenian Nuclear Power Plant (ANPP),** is located in the western part of the Ararat Valley, 10 km northeast of the regional centre of Armavir, 28 kilometres west of Yerevan and 16 km from the border with Turkey. The site is surrounded by mountains from the north and northwest, from the east and south by the Zangu irrigation channel. The site is located about 934 m above sea level.

The ANPP consists of two identical units with VVER-440 (V-270) reactors with a thermal output of 1375 MWt each. VVER stands for “Water-Water Energetic Reactors”. The VVER-440s are pressurized water cooled and water moderated reactors of the first generation.

ANPP was developed in 1969 on the basis of the existing VVER-440 (V-230) design, with special modifications to accommodate the high seismicity at the ANPP site. The ANPP was the first plant in the Soviet Union built in an area of high seismic activity. The site seismicity (magnitude 8 according to Medvedev–Sponheuer–Karnik (MSK)-64 scale, see more in Chapter 5) required design improvements not only related with the enhancement of the resistance of the structures of the plant, but also the implementation of additional safety systems (emergency seismic pump, industrial antiseismic protection system etc.). The design of structures, in particular in terms of supports and bracing, is significantly different from the design of a V-230 plant. Therefore, the Armenian VVER 440 got the new model designation “V-270”.

The VVER-440 units have been conceived as twin units, in a mirroring spatial arrangement. A part of the equipment and the systems is common for both units. Among the common parts are the reactor hall, spent fuel transport infrastructure, radioactive waste handling, receipt, storage and transport of fresh fuel, vent stack, access to controlled area, demineralized water treatment system, service water system, and diesel generator building.

The primary circuit of each unit has six loops, two isolation valves in each loop and horizontal steam generators with a large volume of water on the secondary side of the steam generators. The reactor installations of each unit are located in separate confinements within the reactor building.

Unit 1 of the ANPP was commissioned in December 1976 and Unit 2 in January 1980. Soon after the Spitak earthquake, on 7 December 1988, both units were shut down. Due to severe shortages of power and the inability to assure imports of gas or oil, in 1993 the Armenian Government decided to restart the plant. After a comprehensive assessments and necessary back fitting measures, Unit 2 was restarted again in late 1995. By a decision of the regulator, Unit 2 is allowed to operate at a maximum power level of 407.5 MWe or 92% of the rated power. The Unit 1 never restarted and it has been used as a source of spare parts for Unit 2. In the meantime, some of the systems of Unit 1 are decommissioned with the support provided by the EC’s Instrument for Nuclear Safety Cooperation (INSC). The original main control room for of the Unit 1 is housing a full scope simulator (provided from Bohunice V-1 NPP in Slovakia, and adjusted to ANPP specifics under an INSC project) and its cooling pond is used to store spent nuclear fuel of Unit 2.

The restart activities of ANPP Unit 2 were implemented in accordance with the RA Government Decree № 474 as of 05.10.1994. The concept for the ANPP restart included the overhaul of Unit 2, implementation of the priority safety upgrades and implementation of safety upgrades. ANPP was restarted after 6.5 years of shutdown.

Decisions regarding future operation of plants

Information related to the future plans on operation of ANPP is missing in the stress-test reports (NR and licensee report). In the responses to the written questions of the PRT it was stated, that ANPP had started the process required for obtaining permission for Long Term Operation (LTO) from the Armenian Nuclear Regulatory Authority (ANRA). The details of the current status of this initiative and expected schedule of future steps were clarified during the entrance meeting in Armenia. The situation is as follows. In 2012 ANPP submitted to ANRA an application for Life Time Extension (LTE) and ANRA issued the requirements for LTE (Governmental Decree N1085-N). The first stage of the LTE process, i.e. a feasibility analysis and ANPP investigation process, started in 2014. The temporary permissions will be granted for operation for the period from 2016 to the end of 2018. An updated Safety Analysis Report (SAR) complying with current requirements of Government Decree N2013-N will be submitted to ANRA in 2018 and the final decision on license for operation is planned to be issued by ANRA in the beginning of 2021.

3.2 Nuclear stress tests in Armenia in compliance with the European STs process

Similar to the EU the Armenian Government requested a re-assessment of the safety of ANPP, to cope with extreme challenges. In June 2011, the **Armenian Nuclear Regulatory Authority (ANRA)** issued a request to the ANPP to conduct an in-depth reassessment of the safety of ANPP in the light of the Fukushima accident (stress-tests). It was a clear request from ANRA to the ANPP to comply, as closely as possible with the European ST process, keeping in mind the framework (e.g. the ST process not performed at the same time as the other EU countries, only one NPP in operation, lack of analytical capacities, etc.).

Through the INSC, the EC provided financial support for two projects (INSC A1.01/11 and A3.01/11), to assist ANPP to carry out the self-assessment and ANRA to undertake the review and the preparation of the National report. ANPP was supported by Tractebel, an EU company with experience in NPP safety re-assessments and ANRA by Risk Audit, an EU Technical Support Organization (TSO) with experience (drawing from its founders GRS and IRSN) in reviewing NPP reports and developing NRs within the ST framework.

Based on the findings of the safety re-assessment by ANPP, which were documented in its ST report, in July 2015 ANRA developed its NR: *"National Report Stress Test for Armenian Nuclear Power Plant"*. In addition to the safety improvements derived on the basis of the report of ANPP, ANRA proposed additional safety improvement measures that are all documented in the NR.

3.3 Mandate to perform a PR for the Armenian STs

In August 2015, ANRA submitted to the EC's Directorate-General for Energy its NR for the EU PR. The Revision 1 of this NR "*National Report Stress Test for Armenian Nuclear Power Plant"* issued on 17/03/2016 has been the basis for the PR.

The objective of the EU-PR of the Armenian ST was to **promote continuous nuclear safety improvements** in Armenia, by providing an international, independent and complementary assessment to ensure that no important issues have been overlooked on any of the topics within the scope of the ST. It shall give information to the national regulator and to the licensee for consideration of further improvements or good practices that have been identified during the PR of the NR.

3.4 Peer Review Team (PRT)

Beginning of 2016, the EC's Directorate-General for Energy asked ENSREG to seek nominations to form an EU-PRT of experts who, together with the EC, would develop the practical arrangements for the PR, define the scope of the work as well as organisational issues and later on perform the desktop review and the PR mission to Armenia.

Based on proposals by ENSREG Members, the EC selected the team of experts. It comprised 1 Team Leader, 1 deputy Team Leader, 1 Rapporteur, 3 experts for Topic 1 (Extreme external initiating events), 2 experts for Topic 2 (safety functions and design issues) and 2 Experts for Topic 3 (Severe Accident Management).

The team was composed of 8 experts coming from EU member states and by 2 representatives from the EC.

The Team Leader was from an EU Member State and the Rapporteur from the EC.

3.5 Independence

The PR has been performed in an independent manner by the selected experts in the PRT

- being experienced in such type of exercises,
- drawing from information sources provided by a variety of different stakeholders (Regulator, Licensee, Non-governmental Organizations (NGOs), Scientific Community, Industry, etc.) supplementing the basic object of the EU-PR, i.e. the final Armenian NR[7] .

3.6 Questions of the PRT to the Armenian NR

The EU-PRT started to work on 02/03/2016, with a desktop review of the Armenian NR. Each member of the PRT had access to the NR as well as to the report of the license holder, the so-called "Stress Test Self-Assessment Report of the Armenian NPP", and was asked to develop written questions that were submitted to ANRA on 28th April 2016. In total, **around 200 written questions** were prepared by the PRT. To all of these questions ANRA prepared written answers by end of May.

The questions and the answers have been published on the ENSREG website[8].

The questions were structured according to the three topical areas of the ST:

- **Topic 1: Impact from extreme natural hazards** (80 questions),
- **Topic 2: Loss of safety systems** (64 questions), and
- **Topic 3: Severe accident management** (43 questions).

[7] http://www.ensreg.eu/sites/default/files/national_report_armenia.pdf

[8] http://www.ensreg.eu/document/entire-written-questions-prt-answers

3.7 Armenian peer review process - timescale

The main activities and timeframe of this peer review exercise were the following:

- Armenian NR transmitted to the EC in August 2015
- Request to ENSREG Members to nominate experts for the PR in Armenia was sent on 28 January 2016
- Armenian NR transmitted to ENSREG Members: 10 February 2016.
- **EU PRT established** by EC, based on ENSREG Members proposals: **02 March 2016**
- Desktop review of the Armenian NR by the PRT (from 02 March to 28 April). A template for the questions was provided to the PRT by the EC on 31 March 2016. All questions were sent to the EC by 28 April 2016 using the template provided.
- **A one-day pre-meeting** of the PRT was organized in **Luxembourg on 28 April 2016** to ensure an optimal preparation for the country visit to Armenia in June. A phone conference with the ANRA was organized in the frame of this meeting.
- **Questions** prepared by the PRT were compiled by the rapporteur and **sent to ANRA on 29 April 2016**.
- **Written replies from ANRA** were provided in four batches, all of which were received by EC before **31 May 2015**.
- The PRT members assigned on each technical topic jointly developed the 1st draft of the corresponding chapters of the EU-PR report by 31 May. These drafts were later updated based on the replies to the questions provided.
- A first entire draft of the EU-PR report assembled by the Rapporteur was sent to ANRA on 15 June 2016, to give ANRA the opportunity to comment on the draft. The same day a pre-meeting took place at the ANRA premises. Following the same principles as in the PRs in the EU, ANRA was informed that the final decision in respect to the EU-PR report rest with the PRT.
- **The country visit of the PRT (Country Review) to Armenia** took place **from 20 to 24 June 2016** (including a 1 day visit of ANPP on 22 June).
- At the end of the Country Review, the PRT organized the Exit Meeting where the preliminary EU-PR results were presented to ANRA
- An executive summary of the EU Peer Review report presenting the process and the main results was transmitted to ANRA and published on the ENSREG Website on 6 July 2016[9].
- The same day a press release was published by the EC Delegation in Yerevan
- The final **EU-PR report**, in which the accuracy of facts has been confirmed in discussions with ANRA, was finalized **within two months after the visit.**

[9] http://www.ensreg.eu/document/armenia-stress-tests-peer-review-20-24-june-2016

3.8 Transparency and public involvement

Being aware that full transparency, combined with the opportunity for public involvement, would significantly contribute to the STs being recognised by all stakeholders, particularly by the public, as a trustworthy reference in order to better understand the status and prospects of nuclear safety, the EC ensured that the EU-PR of the Armenian STs was guided from the beginning by the principles of openness and transparency similar to those applied to the STs and follow-up processes in Europe.

ANRA was informed about the EU transparency objectives and requirements and advised on how it might engage the public by organizing a structured and comprehensive information process.

Transparency was further ensured by quickly publishing key background and communication documents – in agreement with the information provider and also on its direct request– on a dedicated EU-PR project website[10].

The goal of all these activities was to inform all stakeholders concerned as objectively and comprehensively as possible as well as to collect the views from all stakeholders on the key nuclear safety related issues being dealt with in the course of the PR.

The **public consultation was launched** by employing a web-based tool that involved placing the Armenian NR on the ENSREG web site and opening the facility for raising questions by the public (http://www.ensreg.eu/document/armenia-national-stress-test-report-open-public-consultation). The NR was made available as well on the ANRA Website (http://www.anra.am/index.aspx). Questions could be sent to a special ENSREG e-mail address (ener-ensreg@ec.europa.eu) or to ANRA by mail or phone (info@anra.am or phone +37410564014). The consultations were opened for one month (02/05/2016 to 31/05/2016) comparable to the EU-ST arrangements.

No questions were received by ANRA or through the ENSREG Website.

3.9 PR report

The **main outcome of this peer review exercise** is this **"EU-PR report"**. The structure of this EU-PR report is similar to the structure of the reports published for the countries which participated to the EU STs in 2012. According to the 2012 ST template the report covers the following topics:

- General Quality of national report and national assessment
- Plant assessment relative to earthquake, flooding and other extreme weather conditions. Because of the special geophysical situation of the site of ANPP volcanism hazards are evaluated additionally.
- Plant assessment relative to loss of electrical power and loss of ultimate heat sink
- Plant assessment relative to Severe Accident Management

The EU-PR report presents further potential improvements or good practices that have been identified during the review exercise performed in Armenia in a view to ensure continuous safety improvement.

[10] http://www.ensreg.eu/

4 GENERAL QUALITY OF NATIONAL REPORT AND NATIONAL ASSESSMENTS

4.1 Compliance of the national report with the topics defined in the EU stress tests specifications

Regarding Topic 1 the NR addresses all hazards (earthquake, flooding, extreme weather) which were identified as important external initiating events in the EU Stress Tests. Upon the request of the PRT volcanic hazards were added to the hazards under consideration. This request was raised after the completion of the NR. ANRA therefore provided access to a volcanic hazard assessment study, which was finalized in 2011[11].

Regarding Topic 2, the NR in general complies with the EU-ST specifications in terms of topics considered. The aspects related to a loss of electrical power supply are described for the ANPP as requested, assuming the subsequent loss of all equipment up to the scenario of total Station Blackout (SBO). Additional devices for a partial power supply applicable beyond the defined SBO are mentioned. Loss of Ultimate Heat Sink (UHS) is covered in general together with the combination of loss of power supply and UHS. For both topics, core cooling as well as Spent Fuel Pool (SFP) cooling are addressed, including necessary measures on how to improve the robustness of the ANPP.

Regarding Topic 3 the overall compliance is good. NR followed the EU STs specification for the content.

4.2 Adequacy of the information supplied, consistency with the EU stress tests specifications

Information provided in the NR with respect to the initiating events (earthquake, flooding, extreme weather) is regarded adequate. Open issues and questions that arisose from the desk-top review of the NR were clarified by 80 written replies received from ANRA to questions raised by the PRT about topic 1.

Volcanic hazards are detailed in a separate report, which provides a comprehensive analysis of volcanic hazards for the siting of a new NPP. However, no information on the robustness and protection concept of the existing ANPP with respect to volcanic phenomena was available during the desk-top review.

Regarding Topic 2, the NR is largely consistent with the guidance provided by ENSREG. It should be noted however that, although the NR in general provides a lot of information, the information related to some specific elements were sometimes difficult to understand but these different points were clarified during the country visit. The unique composition of safety relevant systems not known from other NPPs with the same general type of reactor is sometimes presented in a sparse manner. In some cases the information from the ST's report were complemented with information available in the report of the licensee. In particular, schemes and figures illustrating the structure of the power supply system and safety relevant systems are sometimes not available in the NR.

In several sections of the NR the provided text does not comply with the subtitle. It was clarified during the entrance meeting that the respective information was corrected.

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[11] Connor et al., 2011. Volcanic Hazard Assessment of the Armenia Nuclear Power Plant Site, `Final Report.

4.3 Adequacy of the assessment of compliance of the plants with their current licensing/safety case basis for the events within the scope of the stress tests

Protection measures against external hazards (earthquake, flooding and extreme weather) were redefined reflecting the site specific hazard re-assessments. The compliance of the plant with these measures was demonstrated by probabilistic and deterministic safety assessment methods. The NR identifies one case of noncompliance of the plant with the current design bases for external hazards which concerns the robustness of the BZOV tanks (demineralized water tanks) against low temperature.

Regarding topic 2, no cases of non-compliance of the plant with the current design bases have been identified for SBO and loss of UHS. In addition, programs for back fitting measures to enhance the technical level for nuclear safety were mentioned in chapter 1 of the NR. Statements about the compliance of the ANPP with its current licensing basis were not included in the NR.

Regarding Topic 3, statements about compliance of ANPP with its current licensing basis were not included in the NR. Only planned or ongoing activities to be able to cope in the future with severe accidents are mentioned in the respective chapters. The situation was clarified during the country visit.

4.4 Adequacy of the assessment of the robustness of the plants: situations taken into account to evaluate margins

Regarding earthquake, a seismic margin analysis has been performed showing that protection is ensured for the current design basis.

Regarding flooding, the main issues were addressed. Plant vulnerabilities beyond the design basis against rainfall have been identified. The rainfall intensity associated to these cliff-edge effects has not been defined so far. Regarding extreme weather, margins of key safety-related Structures, Systems and Components (SSCs) beyond the design bases have been assessed for all relevant hazards.

Regarding Topic 2, the main issues were addressed. Statements about time-to-cliff-edge effects were included, sufficient information on how those times were determined was provided during the country visit. A detailed check of the results was not performed by PRT.

Regarding Topic 3, the main issues were addressed and statements about time-to-cliff-edge effects (i.e. the time between the incident occurs and the start of core heating up beyond maximum acceptable value and failure of the reactor vessel) were included. But only limited information of how these times were determined is provided in the NR. The situation was clarified during the country visit.

4.5 Regulatory treatment applied to the actions and conclusions presented in NR

4.5.1 General aspects

In its official message addressed to ANPP dated 10 June 2011 ANRA requested to undertake the analyses necessary to re-assess safety in line with the requirements of the EU ST specifications.

On the basis of the analysis performed within the STs, ANPP identified a series of measures to increase safety margins. Those were specifically scrutinised by ANRA and additional safety measures were identified, as documented in the NR, in particular:

- To obtain experimental evidence of Main Circulation Pump (MCP) seals tightness after 24 hours of loss of cooling,
- To provide mobile pumps for Essential Service Water System (ESWS) make-up from Circulation Water Channel and to modernize the Spray System including implementation of interlocks to reduce the risk of deep sub-atmospheric pressure and to reduce oxygen inflow from outside.

ANPP included the complete list of measures with the implementation schedule in its safety upgrade programme that was submitted to ANRA in April 2016. As a result of the review ANRA made comments that need to be taken into account by the ANPP prior to ANRA approval of the programme.

4.5.2 Periodic Safety Review (PSR)

One of the main outcomes of the European peer review[12] was the positive contribution of PSRs as an efficient tool to maintain and improve the safety and robustness of plants. In the frame of PSRs, it is recommended to re-evaluate natural hazards and relevant plant provisions as often as appropriate but at least every 10 years.

The Article 20 of the Law of the RA for the safe utilisation of atomic energy for peaceful purposes stipulates that the operating organisation carries out periodical safety assessments of the object to ascertain its compatibility with the most recent safety requirements. This means the Armenian Atomic Law requires the conduct of PSRs.

However, up to now no PSRs have been performed according to IAEA standards.

The ANPP design documentation did not include Safety Analysis Reports (SARs). The operational license MTSH-002-2011 was granted in 2011 just after a comprehensive safety review and assessment had been done.

In accordance with the RA Government Decree № 1085-N as of 23.08.2012 on approval of the requirements to extension of the lifetime (expiring in 2016) of ANPP unit No 2 operation, the license holder shall update the safety analysis report and submit it to the regulatory authority with the most safety relevant parts in 2016 (operation lifetime for SSC Class 1 and 2) and the complete report by 2018. In this context activities in respect to periodic safety reviews are planned as well.

A comparison with the IAEA "Periodic Safety Review for Nuclear Power Plants" SSG-25 shows that currently all safety factors will be covered to some extent. Particularly, reviews of the safety factors 1, 2, 5-14 are required to get an operation licence (RA Government decree 400-N as of 24 March 2005 on approval of licensing procedure and license form on operation of nuclear installations), and reviews of the safety factors 3, 4 are required by LTE requirements (RA Government decree 1085-N as of 23 August 2012 on approval of the requirements on the life time extension for ANPP Unit 2).

[12] EU Stress Test Peer Review Report of 26/04/2012 - http://www.ensreg.eu/node/407

5 PLANT(S) ASSESSMENT RELATIVE TO EARTHQUAKES, FLOODING AND OTHER EXTREME WEATHER CONDITIONS

Introductory Remark: ***The seismotectonic and volcanic hazards are much higher in Armenia than in most of the European countries which subjected their NPPs to the EU-Stress Tests. Therefore, the PRT considers proper treatment of these hazards as being of crucial importance for nuclear safety in Armenia.***

5.1 Description of present situation of plants in country with respect to earthquake

5.1.1 Design Basis Earthquake (DBE)

5.1.1.1 Regulatory basis for safety assessment and regulatory oversight

The design and siting of the ANPP started in the former Soviet Union in the period between 1966 and 1972. The NR states that during this period no specific regulations for the seismic design of NPPs were in force. The design, however, included a categorization of the SSCs into three seismic classes and the design of selected SSCs for seismic demands.

In 1979 the former Soviet Union issued the Temporal Standard for Design of NPPs in Seismic Regions VSN-15-78 which was replaced by the Seismic Design Standard PNAE G-5-006-87 in 1987. The later standard was adopted as the basis of seismic safety reviews performed between 1989 and 1995 in preparation of the re-commissioning of ANPP unit 2 after the 1988 Spitak earthquake.

The NR provides no information about the current legal and regulatory framework in Armenia with respect to seismotectonic hazards. During the country visit it was explained that no formal national regulation currently exists. It was further explained that seismic safety evaluations are based on the IAEA guide 1997[13]. This document was approved by ANPP, ANRA and the Armenian Government in 1999. It is regarded as the legal basis for ANRA's regulatory activities.

5.1.1.2 Derivation of DBE

Values for DBE for the ANPP are specified as follows:

1977 DBE (?): I_{MSK} = 8° (~ PGA = 0.2g)

In 1985 two specific seismic safety values were defined for the site based on the Standard VSN-15-78: the so-called Design Basis Earthquake "PZ" with a non-exceedance probability 10^{-2} per year, and the so-called Maximum Design Earthquake "MRZ" with a non-exceedance probability of 10^{-4} per year and with the following Peak Ground Accelerations (PGAs).

1985 PZ: PGA = 0.1 g

1985 MRZ: PGA = 0.2 g

[13] IAEA, 1997. Project ARM/9/002 and IAEA/RU-5869: Seismic Safety Re-Evaluation Programme for the Armenian Nuclear Power Plant Unit 2 (Republic of Armenia)

After the plant shut down subsequent to the 1988 Spitak earthquake a deterministic hazard assessment was carried out in 1993-1995. According to the NR the Armenian Government subsequently decided "to increase the seismic design level up to the value that corresponds to the 84th percentile".

1995 DBE: No value stated in the NR.

In 2006 a Probabilistic Seismic Hazard Analysis (PSHA) derived the following horizontal PGA values for the DBE (non-exceedance probability 10^{-4} per year):

2006 DBE: PGA_H = 0.28 g (mean hazard value)

2006 DBE: PGA_H = 0.32 g (85th percentile)

The currently valid seismic design basis has subsequently been selected as:

PGA_H = 0.35 (Review Level Earthquake – RLE)

The value was recommended as the result of a mission conducted by IAEA in May/June 1995.

In 2010 a PSHA was completed for the construction of a new power unit of the ANPP (Arakelyan et al., 2010). This study revealed the following values for PGA_H:

2010 DBE (SL-2): PGA_H = 0.32 g (mean hazard value)

2010 DBE (SL-2): PGA_H = 0.42 g (85th percentile)

During the country visit ANRA explained that the value of PGA_H = 0.42 g has not been adopted as an updated design basis yet.

Secondary earthquake effects, such as seismically-triggered landslides, ground subsidence/ground heave, and ground settlement that pose potential hazards to the sites have been screened out by physical impossibility. It is explained that the soil below ANPP was investigated by up to 0.4 km deep boreholes to derive geotechnical data. Due to these data secondary hazards such as ground settlement, liquefaction etc. are screened out.

Internal flooding as an indirect effect of earthquakes is addressed.

5.1.1.3 Main requirements applied to this specific area

National and regulatory requirements for seismic safety are not specified in the available documents.

SSCs important to safety are said to be seismically qualified for the design basis earthquake PGA of 0.35 g. The robustness of the SSCs is demonstrated by the seismic design. It is said that from the very beginning the V-270 type reactor was seismically resistant up to 0.4 g and that pressurizer and steam generators were also designed to cope with a PGA of 0.4 g.

A Safe Shutdown Equipment List (SSEL) comprising of 29 systems and 2589 individual Structures, Systems and Components (SSCs) was established and reviewed by IAEA in 2007. These SSCs were subjected to a seismic evaluation and upgrading programme as defined in the IAEA guidance 1997.

5.1.1.4 Technical background for requirement, safety assessment and regulatory oversight (Deterministic approach, PSA, Operational Experience Feedback)

Assessments of the fault capability hazard included geological, geophysical and paleoseismolotical studies in the site vicinity (<5 km from the site). The investigations are said to exclude the existence of capable faults in this area.

The latest assessment of vibratory ground motion hazard is based on PSHAs which were performed in 2006 (for the existing ANPP) and 2010[14] (for the siting of a new NPP). The PSHA 2010 was performed by Noratom Consortium involving foreign organizations and leading national experts. The programme was executed under supervision of an expert and quality control panel.

In the latter study the PRT noted two issues which are regarded important for the reliability of the hazard results:

(1) PSHA results are highly sensitive to the chosen maximum earthquake magnitudes (M_{max}). In the PSHA 2010 the ANPP site is contained by a source zone for which a maximum magnitude of M_{max} = 5.5 is assumed while for all other source zones M_{max} is > 6. The value of M_{max} = 5.5 appears unreasonably low when compared to the other source zones and international seismic hazard studies covering the same region (e.g., the EC project "Seismic Hazard Harmonization in Europe" - SHARE).

(2) Hazard deaggreagation in the PSHA 2010 shows that the main contribution to seismic hazard derives from nearby earthquakes with magnitudes 5 < Mw < 6.5 which are associated with the fault sources Sardarapat (SaF, 12 km distance), North West Fault (NWF) and Yerewan fault (YeF, 16 km distance or less). Further, the Garni fault (GF), Igdir fault (IgF) and Gaylatu-North Tebris fault (GSF) are found to contribute significantly to the ground motion hazard at 10^{-2} per year exceedance probability. The correct assessment of these faults is therefore of prime importance.

The addressed issues were discussed with leading Armenian experts during the country visit. The PRT consequently accepts the assumptions of the 2010 PSHA as sufficient for characterizing the hazard of the existing ANPP. The issues raised above should, however, be clarified in order to obtain a reliable basis for regulatory decisions.

The PRT appreciates the analysis of hazard combinations of earthquake with external flooding and extreme temperature. Analyses were performed in the framework of a Fault Sequence Analysis (FSA) in cooperation with IAEA and NRSC.

5.1.1.5 Periodic safety reviews (regularly and/or recently reviewed)

Previous seismic hazard assessments, the identification of the SSEL, and the seismic qualification and upgrading of SSCs have been accomplished with participation of IAEA and other international organisations. The actions were partly reviewed by international experts and IAEA.

In respect to the PSR process, more details are available in chapter 4.5.2

[14] Arakelyan et al., 2010. Seismic hazard assessment for the construction site of a new power unit of the Armenian NPP. WP 5. Probabilistic Seismic Hazard Assessment, Draft Report Ver. 1

5.1.1.6 Conclusions on adequacy of design basis

Defining the design seismic basis by a DBE with a non-exceedance probability of 10^{-4} per year is in agreement with current international praxis, IAEA guidelines and the WENRA (2014) Safety Reference Levels.

The PRT notes that the currently valid seismic design basis value of PGA_H = 0.35 g is superseded by the PSHA 2011 which identified a hazard level of PGA_H = 0.42 g. It is consequently suggested that ANRA should consider adopting 0.42 g as an updated DBE for the existing ANPP.

In the case that ANRA decides for an update of the DBE, qualification and upgrade requirements should be applied in a timely manner taking due account of the hazard re-evaluation.

The PRT stresses that the reliable assessment of maximum magnitudes and the seismic capacity of capable faults in the site vicinity/near region is of crucial importance for any future hazard re-evaluation. The issue requires careful paleoseismological examination of key input parameters such as fault lengths/fault areas; fault geometry, possible fault segmentation, and fault slip rates. Such activities may deem necessary for the development of DBE requirements.

5.1.1.7 Compliance of plant(s) with current requirements for design basis

The Armenian Nuclear Regulatory Authority is of the view that ANPP fulfils the design basis requirements of a ground acceleration of 0.35 g.

Inspection of all SSCs included in the SSEL during a plant walkdown in 2007 resulted in the identification of numerous upgrading measures which are listed in the reports by Vibroseism 2008 and 2012[15]. According to these reports the robustness of SSCs was established by direct testing, computational methods and indirect methods including verifications by plant walkdowns in 2000 and 2007. Upgrades were supported by IAEA Experts (Project N ARM9022-84188). Procedures and upgrading measures are summarized in the two Vibroseism reports which were made available to the PRT.

During the country visit ANPP explained that all of the upgrading measures identified in 2008 (i.e., 446 easy fix measures, 29 not so easy fix measures, and 26 measures requiring testing and computation) have been resolved. The implementation of the measures has been confirmed by ANRA.

The seismic withstand of the SSCs constituting the systems of the SSEL are expressed in terms of High Confidence Low Probability of Failure (HCLPF) values determined for the design basis ground motion and the median of the 1% probability of failure determined from the 85^{th} percentile.

According to the NR the lowest HCLPF values for the 29 systems included in the SSEL were derived for the spray system (HCLPF 0.38 g), main steam pipeline system (0.39 g), the Steam Generator (SG) feedwater system (0.40 g), the SG blowdown system (0.42 g) and the pressurizer system (0.43 g). These values indicate that only small margins exist above the design basis requirements of 0.35 g for HCLPF values determined from 85^{th} percentile of 1% probability of failure (i.e., for conservative design basis requirements). Other SSCs of the SSEL have higher margins.

[15] CKTI Vibroseism, 2008. Detailed Plant Seismic Walkdown of the Armenian NPP – Unit 2. Report No. Rep01.ARM9014-89032S.

CKTI Vibroseism, 2012. Seismic Qualification of Safety Related Systems and Equipment Armenian NPP – Unit 2. Report No. Rep21.ARM9022-84188.

The seismic capacities of the ANPP main building and other civil structures were analysed by computational methods. Analyses revealed a HCLPF value of PGA_H = 0.44 g for the Emergency Diesel Generator (EDG) building and higher values for the other buildings.

A possible failure of the EDG building could lead to a common cause failure of all EDGs and the "Additional emergency cooling system" (DAR), which is regarded as a cliff edge effect.

The HCLPF value for containment integrity is 0.49 g. Containment integrity is limited by the robustness of containment wall penetrations for piping. The HCLPF value for the "massive box part of the reactor compartment" is 0.98 g. It is concluded from these values that containment integrity is ensured for Beyond Design Basis (BDB) loads up to PGA = 0.74 g (all values for 1% probability of failure 85th percentile).

SSCs required for SFP cooling are qualified for the DBE.

The exceedance of a ground shaking level of 50 cm/s² triggers an automatic reactor trip and a number of additional measures (interruption of crane and refuelling actions, valve closure etc.) and post-event inspections.

The seismic upgrades between 2006 and 2015 led to a significant increase of seismic safety. According to the NR a Probabilistic Safety Assessment (PSA) model completed prior to the upgrading programme revealed a contribution of seismic hazards to the Core Damage Frequency (CDF) of 1.04 x 10^{-4} per year[16]. The updated Seismic Probabilistic Risk Assessment (SPSA) 2015 reveals that upgrades reduced the contribution of seismic hazard to the total CDF to 1.39 x 10^{-5}.

According to the NR the firefighting system of the ANPP is not qualified for DBE loads. This may significantly impair the mitigation of hazards such as internal fire and explosion initiated by earthquake. The protection concept can therefore claim availability of the system neither for design basis accidents nor for design extension conditions.

The PRT notes that the lowest HCLPF values listed in the NR (spray system HCLPF 0.38 g, main steam pipeline system 0.39 g, the SG feedwater system 0.40 g) are slightly below the hazard values which were determined by the PSHA 2011 (0.42 g for a non-exceedance probability of 10^{-4} per year). The PRT stresses the importance of timely retro-fitting measures that may become necessary should ANRA adopt 0.42 g as an updated design basis.

5.1.2 Assessment of robustness of plants beyond the design basis

5.1.2.1 Approach used for safety margins assessment

The assessment of safety margins used a Seismic Margin Assessment methodology based on the determination of HCLPF values. HCLPFs were identified by a Conservative Deterministic Failure Margin (CDFM) approach. It is explained that HCPLF values refer to the 50th percentile of 1% probability of failure under DBE loads (i.e., a non-exceedance probability of 10^{-4} per annum). The BDB assessment therefore relies on less conservative methods than those applied to design basis requirements. This procedure is generally in line with the WENRA (2014) Reference Levels.

[16] The NR only refers to this outdated study. The results of the updated PSA which reflect the seismic upgrading program were supplied during the country visit and are not included in the NR.

5.1.2.2 Main results on safety margins and cliff edge effects

The margin analyses using this less conservative approach show a seismic resistance of ANPP of 0.47 g, which corresponds to a recurrence frequency of 10^{-5} per year according to the PSHA 2011.

In the NR no cliff edge effects have been identified.

5.1.2.3 Strong safety features and areas for safety improvement identified in the process

ANRA has initiated a series of seismic hazard assessments using both, deterministic and probabilistic approaches to determine the site hazard. It further started a continued process to (i) identify SSCs which need to be seismically qualified to maintain the fundamental safety functions during and after an earthquake, (ii) comprehensive assessments of the robustness of these SSCs, and (iii) programs to upgrade SSCs, which were identified as being not sufficiently qualified. Seismic walkdowns that complement the use of other methods are implemented.

The sum of these programmes constitutes a process of continuous improvements as required by the WENRA (2014) Reference Levels. The PRT appreciates these efforts and encourages the continuation and, if possible, extension of this good practice.

The seismic protection concept has been complemented by the implementation of a permanent seismic monitoring and alarm system. The exceedance of a pre-defined ground shaking level triggers automated and human action following procedures which are already implemented. The information provided by monitoring systems further enables the licensee to make an informed judgement of the event.

In case of NPP site isolation, it is a commendable practice that the licensee has the capability and competences to locally analyse information provided by the monitoring system.

5.1.2.4 Possible measures to increase robustness

The PRT suggests that ANRA should consider adopting the hazard value of 0.42 g derived from the PSHA 2011 as an updated DBE for the existing ANPP. In case of its acceptance the safety demonstration shall be updated accordingly.

The PRT further suggests reviewing the seismic robustness of all SSCs, mobile equipment, and buildings housing such SSCs or used as storages for mobile equipment, which are required for crisis management in cases of Design Basis (DB) and BDB accidents.

Particular attention should be given to the upgrade of the fire extinguishing system which is currently not seismically resistant. Such a program is envisaged in the ANPP Action Plan. The PRT supports this measure.

The seismic resistance of the EDG building was discussed during the ANPP site visit. The PRT stresses the importance of the reliability of the HCLPF assessment for this building (0.44 g) as its failure during an earthquake would lead to a common cause failure of all EDGs and DAR and a cliff edge effect. The PRT recommends to ANRA to re-assess the computational results considering current status of the concrete wall panels and their anchoring.

Strengthening of the fire brigade building is planned to start 2016 or early in 2017. Meanwhile fire trucks are kept outside the building.

A number of additional upgrading measures (revising SPSA, upgrade of seismic monitoring system, assessment of firefighting system, etc.) are listed in the ANPP Action Plan which will be submitted to ANRA in 2016. These measures are supported by the PRT.

The PRT suggests continuing seismic walkdowns as a regular conformity check including the inspection of SSCs that may damage other equipment upon their failure during a seismic event. Walkdowns should also identify SSCs that are necessary for BDB accident management and crisis management.

5.1.2.5 Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

The NR lists a number of measures which were already identified by ANRA to increase seismic robustness. These include performing an updated seismic PSA and the evaluation of the seismic margin of the seismic monitoring system and its upgrade (if necessary) for BDB ground motion.

5.1.3 Peer review conclusions and recommendations specific to this area

Due to the seismotectonic situation of Armenia and the past experiences with severe earthquakes such as the 1988 Spitak earthquake, particular emphasis should be put on seismic safety.

In the past, ANRA and ANPP have undertaken continued efforts to ensure and improve the seismic safety of the ANPP. This process of continuous improvements is appreciated and the PRT encourages ANRA to proceed with it.

Past and current seismic safety evaluations follow the IAEA guide 1997 which is regarded as the basis for ANRA's regulatory activities. Comprehensive national regulatory requirements for seismic safety (as well as other hazards) are currently not available and should be developed considering the WENRA (2014) Reference Levels to strengthen the regulatory position and oversight.

In accordance with the IAEA guide 1997 several seismic hazard reviews and upgrades of SSCs important to safety have been conducted. Today a DBE of PGA_H = 0.35 g for the occurrence probability of 10^{-4} per year is applied. Adequate protection appears to be in place with respect to this currently valid DBE. Conservative evaluations of the seismic capacity of SSCs included in the SSEL reveal HCLPF values higher than 0.38 g.

To further strengthen the seismic robustness of the ANPP the PRT recommends to:

- upgrade the fire extinguishing system which is currently not seismically resistant;
- ANRA should verify that seismic protection of the EDG building is sufficient and that computational analyses account for the current status;
- review the seismic robustness of all SSCs, mobile equipment, and buildings housing such SSCs or used as storages for mobile equipment required for crisis management for DB and BDB evens;
- continue seismic walkdowns as a regular conformity check including the inspection of SSCs that may damage other equipment upon their failure during a seismic event;
- summarize all measures which are currently envisaged or planned by ANPP and/or ANRA in a National Action Plan giving priority to important measures and linking all actions to fixed time schedules.

The PRT expresses reservations on the reliability of the current design basis value of PGA_H = 0.35 g for the non-exceedance probability of 10^{-4} year. Reservations are due to the PSHA 2010 which revealed a hazard level of PGA_H = 0.42 g for the occurrence probability of 10^{-4} per year. This value shall be considered as an updated ANPP design basis for planning and implementing the improvement measures. SSCs important to safety shall be upgraded to this level.

The PRT further suggests complementing the 2011 PSHA by (i) the review of the maximum magnitude M_{max} values which are regarded to be underestimated when compared to other recent seismic hazard assessments[17], and (ii) the detailed investigation of the active faults close to the site[18] using extended paleoseismological techniques.

5.2 Description of present situation of plants in country with respect to flood

5.2.1 Design Basis Flood (DBF)

5.2.1.1 Regulatory basis for safety assessment and regulatory oversight (national requirements, international standards, licensing basis already used by another country…)

The regulatory basis for flooding (codes, guides and standards applied in Armenia for the flood evaluation and design) is not detailed in the NR. The report mentions that the design basis for the amount of rainfall was calculated based on Soviet standards (SNiP).

New requirements for flooding hazards were set in the Governmental Decision of Armenia 1411N of 8th November 2012 addressing the design safety basis for the new Armenian NPP. However, these requirements are not applied to the existing ANPP.

Requirements for the SAR for the existing ANPP were set in force in 2002. Updated SAR requirements should be decided by the Armenian Government in the near future.

5.2.1.2 Derivation of DBF

The concept of the DBF is not strictly used at ANPP. The NR states that during the design of ANPP, flooding of the site was not considered as an essential hazard; therefore the design basis flood was not properly evaluated.

ANPP siting has used the “dry site” concept. It is situated on the northern slope of the Ararat Valley at a site which slopes 1.5 to 5.0 % southward towards the valley. All streams and water basins existing near the plant site (Araks River, Sevdzhur River and Aknalich Lake) are located more than 50 m lower than the elevation of the plant site. As a result most of the flooding hazards detailed in WENRA (2015)[19] are screened out by physical impossibility.

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[17] E.g., the European SHARE Project; Pegasos Refinement Project (seismic hazard assessment of Swiss NPPs)

[18] The PSHA 2010 includes hazard disaggregations showing that fault sources near the site are the main contributors to ground motion hazard. These are the Sardarapat (SaF), North West Fault (NWF) and Yerewan fault (YeF), and to a lesser extent the Garni fault (GF), Igdir fault (IgF) and Gaylatu-NorthTebris fault (GSF).

[19] WENRA, 2015. Guidance Document Issue T: Natural Hazards, Head Document. 18th February 2015.

Flooding of the plant site seems realistic only in 3 scenarios, which are further assessed:

- ***Heavy rainfall (flash flood).*** The design basis rainfall for ANPP (buildings of reactor installation including spent fuel pools) was set to 145 l/sec/ha during 5 minutes (~4.35 mm) and 65 l/sec/ha during 20 minutes (~7.8 mm). These values correspond to a return period of 1 year only.

  Drainage of rain water from the plant site is organized by the sewer system which consists of a network of underground piping. The design basis amount of rainfall water leads to a flow design basis for the ANPP sewer system of 1200 m^3/h.

- ***Mudflow.*** As the site is located on the northern slope of the Ararat Valley, mudflows from the slope of the volcano could be considered as a potential flooding source. However, topography is favourable for by-passing the plant site. Volcanic hills with low slopes north of the site are regarded to be incapable for releasing intense mudflows. On the north-western part a mountain canal for disposal of possible mud flows is in place. The site is further protected by about 2 m high concrete walls fencing the site. Analysis for mudflows will be performed by 2017.

  The assessments of mudflow hazards are apparently based on engineering judgment. Simulations or calculations proving protection against mudflows are apparently not available.

- ***Outlet canal overflow or breach.*** The breach of the outlet channel was not considered in the original design basis of ANPP. The design of the outlet channel has been recently modified to include a special spill zone which should ensure that overflowing water bypasses the Diesel Generator Station (DGS). The plant visit allowed confirming that the spill zone, considering the local topography, should allow avoiding flooding of the DGS building from the outlet channel or from the cooling towers.

5.2.1.3 Technical background for requirement, safety assessment and regulatory oversight (Deterministic approach, PSA, Operational Experience Feedback)

No information about the technical background of the design basis (SNiP) is available.

Taking into account the location of the site the flooding due to nearby river or lake overflow is excluded by using the dry site concept.

Analyses of external flooding hazards have been mainly performed during design stage and later in the frame of external hazard PSA implementation. In addition, after the Fukushima accident a complementary analysis of plant robustness has been performed to find out the external event combination which could lead to undesirable after effect by using the FSA method and a tool developed by the IAEA. This is regarded as good practice.

The rainfall design basis has been established using a probabilistic approach. At the time of the initial design, a return period of 1 year only was used. However, recent calculations showed that the sewer capacity could cope with a rainfall corresponding to an occurrence probability of 10^{-4} per year, as recommended by the EU Stress Tests conclusions and WENRA (2014). Data from long-term records (since 1920) have been used to define the climate characteristics in the area of the ANPP site. These records come from meteorological stations and monitoring stations of the Armenian Department of Hydrometeorology within a radius of 40 km around the ANPP site.

5.2.1.4 Conclusions on adequacy of design basis

The NR states that during the design of ANPP flooding of the site was not considered as an essential hazard; therefore DBF was not properly evaluated.

The rainfall design basis (1 year return period) value which was based on SNiP is not consistent with current international standards, however recent calculations showed that the sewer capacity could cope with a rainfall corresponding to a frequency of 10^{-4} per year, as recommended by the EU Stress Tests conclusions.

The scenario of the mudflow needs still to be investigated.

5.2.1.5 Compliance of plant(s) with current requirements for design basis

For ensuring the operability of SSCs that are needed for achieving and maintaining the safe shutdown state, regular testing, examinations and inspections are performed at the ANPP. Periodic surveillance tests and maintenance allows to assure operability of the systems and to monitor performance of components.

The SSCs of the plant are categorized based on their safety significance. The graded approach is used for systems surveillance test and maintenance. The general approach is that the systems which have a higher safety class are tested with higher periodicity than the lower safety class systems.

The NR states that no deviation from the licensing basis has been observed.

5.2.2 Assessment of robustness of plants beyond the design basis

5.2.2.1 Approach used for safety margins assessment

Analyses of external flooding were mainly performed in the frame of an external hazard PSA corresponding to a frequency of 10^{-4} per year. But the margin of the design beyond this value has not been assessed yet.

The main plant vulnerabilities against rainfall have been analysed using the following conservative assumptions:

- Loss of offsite power (LOOP) due to heavy rainfall;
- Failure of Turbine Hall (TH) and DGS drainage system pump was assumed; no credit was given to staff actions to recover functionality;
- Penetration of water from TH to the boron compartment through doors leakiness with enough capacity to flood both boron compartments.

The rainfall intensity needed to create the abovementioned conditions has not been defined so far.

5.2.2.2 Main results on safety margins and cliff edge effects

In the frame of ANPP external events PSA study the sewer system was re-assessed for 286 l/sec/ha which corresponds to the DBF with a return period of 10,000 years. The analysis showed that the sewer system has enough margin to prevent site flooding even in case of a rainfall of 286 l/sec/ha.

The analysis identified the following potential vulnerabilities:

- Water propagation from TH to the boron compartments through cable tunnels and/or non-water proof doors. This flooding scenario could lead to flooding of the boron compartment 1, inoperability of diesel driven pumps, and finally reactor core damage. The time window to implement recovery actions is regarded to be large. During the site visit it was shown that this potential water pathway had been permanently sealed.

- Reaching the water level of about 45 cm in the DGS basement area can be considered as cliff edge effect leading to potential Diesel Generator (DG) failure. It was further explained that the DGs basement sumps are equipped with a drainage system. These drainage pumps are however not safety classified or seismically resistant, and not on safety buses. Though the likelihood of a flooding of the basement is regarded low, considering the significant consequences of this scenario on safety), the PRT recommends considering improving the volumetric protection of the DGS basement against flooding. The PRT also suggests considering improving the DGS basement drainage system to ensure it can function adequately in all scenarios for which the EDGs or the DAR are needed (LOOP, earthquake…).

The rainfall intensity (and the associated occurrence frequency) that would lead to exceedance of the drainage system capacity has not been assessed yet, but this analysis is included in the list of further ANPP actions.

5.2.2.3 Strong safety features and areas for safety improvement identified in the process

The selection of the ANPP site according to the "dry site" concept is a robust passive safety feature preventing external flooding from most sources of water.

Areas for potential improvements include improving the robustness of safety related buildings against water ingress (volumetric protection), improving the reliability of the drainage system of the DGS basement, and the provision of adequate mobile means. A number of further analyses needs to be completed (such as on the mudflow scenario).

5.2.2.4 Possible measures to increase robustness

The PRT suggests to consider assessing the rainfall intensity (and the associated occurrence frequency) that could exceed the drainage system capacity.

Areas for potential improvements include improving the robustness of safety related buildings against water ingress (volumetric protection).

The PRT suggests considering improving the DGS basement drainage system to ensure it can function adequately in all scenarios for which the EDGs or the DAR are needed (LOOP, earthquake…).

5.2.2.5 Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

The NR contains a list of nine measures to increase robustness which have partly been already implemented. For the remaining measures an implementation schedule has been established by ANPP and monitored by ANRA. The PRT acknowledges and supports these measures.

5.2.3 Peer review conclusions and recommendations specific to this area

The “dry site concept” and the site topography of the ANPP, which is located some 50 metres above the nearest fore-floods, adequately protects against most external water sources. This is regarded a strong safety feature.

During the initial design of ANPP, flooding of the site by extreme precipitation was not considered as an essential hazard; therefore DBF was not properly evaluated.

The rainfall design basis (1 year return period) value which was based on Russian Standard SNiP is not consistent with current international standards. However, recent calculations showed that the drainage system capacity could cope with a rainfall corresponding to a frequency 10^{-4} per year, as recommended by the EU Stress Tests conclusions.

The margins beyond the design basis rainfall have not been assessed yet. However, the main plant vulnerabilities against BDB rainfall have been identified (water ingress into the boron compartments and the DGS basements) and a list of possible safety improvement is under consideration. The PRT acknowledges and supports these measures.

Though the likelihood of a flooding of the basement is low, considering the significant consequences of this scenario (common mode failure for all EDGs and DAR), the PRT recommend to consider improving the volumetric protection of the DGS basement against flooding. The PRT also recommends considering improving the DGS basement drainage system to ensure it can function adequately in all scenarios for which the EDGs or the DAR are needed (LOOP, earthquake…). Areas for potential improvements also include the provision of adequate mobile devices. These measures would increase the robustness of the plant against external events, as recommended in the ENSREG Summary Report[20].

The PRT recommends completing timely the implementation of the measures to increase the robustness against flooding listed in the NR as well as the completion of the mudflow hazard analysis.

5.3 Description of present situation of plants in country with respect to extreme weather

5.3.1 Design Basis Extreme Weather

5.3.1.1 Regulatory basis for safety assessment and regulatory oversight (national requirements, international standards, licensing basis already used by another country…)

The design of the ANPP was carried out on the basis of Soviet construction norms and rules (SNiP standards). Several extreme weather hazards were originally not considered in Armenian NPP design. Currently valid regulatory standards are not detailed in the NR. During the country visit it is explained that requirements for meteorological hazards were set in the Governmental Decision of Armenia 1411N of 08 November 2012 addressing the design basis for the new NPP. However, these requirements are not applied to the existing ANPP. SAR requirements for the existing ANPP were set in force in 2002. The design bases will be updated to comply with 10-4/year frequency for all natural hazards.

5.3.1.2 Derivation of the design bases for extreme weather loads

The following parameters were taken into account in the design basis of ANPP units 1 and 2:

Max wind speed: 27 m/s frequency 2.0×10^{-1}

[20] EU Stress Test Peer Review Final Report of 25/04/2012

Max snow load:	80 kg/m^2	frequency 6.3 x 10^{-2}
Max temperature:	+42° C	frequency 1.0 x 10^{-2}
Min temperature:	- 40° C	frequency 1.0 x 10^{-4}

The following parameters were taken into account in the design basis of the Independent Spent Fuel Storage Installation (ISFSI):

Max wind speed:	160 m/s	frequency <1.0 x 10^{-7}
Max snow load:	10 kN/m²	frequency <1.0 x 10^{-7}
Max temperature:	+52°C	frequency <1.0 x 10^{-7}
Min temperature:	- 40°C	frequency 1.0 x 10^{-4}

Values corresponding to the severity of design basis events with non-exceedance probabilities of 10^{-4} per year are not provided in the NR. However, it is explained that hazard curves were calculated in frame of an external hazards PSA using probabilistic and deterministic methods. Accordingly, the wind speed for an annual occurrence probability of 10^{-4} is 41 m/s[21]. For critical scenarios detailed deterministic analyses were performed.

The concept of defining design bases for extreme weather based on design basis events[22] with occurrence probabilities of 10^{-4} per year is not strictly used at the ANPP.

5.3.1.3 Technical background for requirement, safety assessment and regulatory oversight

The technical background for justification of the original design bases (SNiP) is not explained in the NR.

The ANPP units and the ISFSI have different design bases for extreme weather. It is explained that the ISFSI was designed according to U.S. standard engineering designs in the 1990ies (NUHOMS-56H design). Correlated hazards and combinations of high frequency / low magnitude hazards were assessed by a FSA approach. According to the NR the study was performed in co-operation with IAEA.

The occurrence probabilities of the extreme weather loads listed in the previous chapter were derived from an external event PSA. The hazard assessments, however, did not lead to the formal definition of design bases for extreme weather phenomena.

Data from long-term records (since 1920) have been used to assess the climate characteristics in the area of the ANPP site. These records come from meteorological stations and monitoring stations of the Armenian Department of Hydrometeorology within a radius of 40 km around the ANPP site.

5.3.1.4 Conclusions on adequacy of design basis

The conclusions of the EU Stress Tests and the WENRA 2014 Safety Reference Levels require the definition of design basis events for exceedance frequencies not higher than 10^{-4} per year. Out of the design basis values listed in the NR for the ANPP, only the DB for low temperature fulfils this requirement. The DB values for the other hazards do not meet this exceedance frequency yet.

[21] Information obtained during the Country Visit.

[22] WENRA 2014, Safety Reference Levels for Existing Reactors, Issue T

However for a number of critical scenarios detailed deterministic analyses were performed for hazards with an equal or lower exceedance frequency than 10-4/year.

The NR does not contain information on other extreme values of meteorological phenomena or rare meteorological events[23] which might impair the safety of the ANPP. It is explained that a screening of meteorological hazards has been performed in the framework of the external hazards PSA and that other hazard were screened out on the basis of being incapable of posing a physical threat to the plant.

The PRT appreciates the consideration of external hazards combinations in the safety assessment of the ANPP. The effects of the concurrent hazards seismic-high temperature, seismic-low temperature, low temperature-snow load, and high wind-dust storm are addressed in the NR.

5.3.1.5 Compliance of plant(s) with current requirements for design basis

No information given in the national report.

However the NR mentions that the outlet pipes of BZOV tanks could freeze at -31.5° C and this seems not in line with the design bases of -40° C. ANPP took recently additional measures regarding this aspect but these measures have not been reviewed yet by ANRA.

5.3.2 Assessment of robustness of plants beyond the design basis

5.3.2.1 Approach used for safety margins assessment

The ANPP safety assessment report, the external hazards PSA and other sources have been used to re-evaluate external hazards and safety margins. A screening analysis was performed by ANPP within the external hazards PSA. It is said that this analysis allows concluding that the list of hazards considered in the design documentation is comprehensive, no other natural hazards are found significant for ANPP.

In the frame of external hazards PSA, hazards curves were identified for selected hazards and the frequencies of the design base parameters were evaluated.

5.3.2.2 Main results on safety margins and cliff edge effects

The NR gives the following information in respect to extreme weather conditions, consequences for ANPP, and existing margins:

- ***High wind (including wind pressure and dust concentration in the air).*** The external hazards PSA suggests that wind is not leading directly to serious effects on buildings. Wind speeds of 33 m/s were found to damage window glasses and open switchgears (e.g., equipment in the vicinity of turbine building windows could be damaged in case of glass break; missiles could affect open yard transformers leading to LOOP).

  Wind with 59 m/s (occurrence probability below 10^{-4} per year) could lead to a collapse of the ventilation stack and subsequent serious damage to the auxiliary building with boron preparation tanks.

[23] A list of meteorological hazards is included in: WENRA, 2015, Guidance Document Issue T: Natural Hazards.

Safety related buildings are explained to be resistant against wind speeds with occurrence probability below 10^{-4} per year.

Other types of wind impacts are a possible increase of dust concentration in the air and wind-induced missiles that could affect safety-related equipment. Increase of dust concentration in high wind (dust storm) has a probability to cause DG failure (1.7×10^{-4} per year). The same probability was found for LOOP due to high wind and dust storm.

- ***Snow loads.*** Calculations show that the building roofs of the ANPP have significantly higher capacities than the original design basis of ~0.8 kPa/m², which derived from Soviet SNiP standards):

Reactor building:	2.96 kPa/m²	frequency below 10^{-5} per year
Turbine building:	1.78 kPa/m²	frequency 3.57×10^{-5} per year
DG building:	2.74 kPa/m²	frequency below 10^{-5} per year

  The NR lists possible scenarios and fault trees associated with the collapses of the roofs of the reactor building, turbine hall, and DG building, as well as possible countermeasures to mitigate the effects

- ***Extreme temperatures.*** Both high and low temperatures could be challenging for ANPP safety. Due to the slow progression of these hazards sufficient mission time is available for the implementation of countermeasures.

- ***High temperatures.*** External equipment of some switchgear compartments could fail at air temperatures of 55-60°C occurring at a frequency of $<1.0 \times 10^{-7}$.

- ***Low temperatures.*** The most vulnerable SSCs of the ANPP in terms of low air temperatures are:

  - Freezing of outlet pipes of BZOV at -31.5° C (frequency 9.1×10^{-3} per year). This is not in line with the design bases for low temperatures (-40°C) and the PRT recommends to address this issue.
  - Deny of function of open switchgear at -45° C (frequency ~ 1.0×10^{-6} per year)
  - Main transformers minimal design temperature is -45°C (frequency ~ 1.0×10^{-6} per year)

  It is concluded that temperatures less than -45° C could lead to LOOP, unavailability of emergency cooldown system, and diesel driven pumps.

- ***Lightning.*** The NR states a lack of detailed analysis for lightning impact on ANPP.

The NR concludes that external hazards with occurrence probabilities > 10^{-7} per year as well as their combinations will not directly lead to core damage. However, most of the hazards may lead to LOOP and SBO. It is further concluded that these conditions can be resolved by using existing systems and procedures.

5.3.2.3 Strong safety features and areas for safety improvement identified in the process

The consideration of hazard combinations is regarded as a strong safety feature.

At the moment the robustness of the design does not allow to cover low temperature hazards corresponding to this frequency. It is stated that the ANPP design minimum temperature is -40°C. However, based on conservative calculations, adverse effects on BZOV appear at -31.5° C. The PRT recommends to consider improving the BZOV robustness against low temperature up to the Design Basis (-40°C). . ANPP took recently additional measures regarding this aspect but these measures have not been reviewed yet by ANRA.

Winds with an expected frequency of 1.7 x 10^{-4} per year would lead to SBO and corrective actions are needed to solve this.

The PRT suggests defining clear design basis requirements for meteorological hazards and hazard combinations, which are based on the severity of design basis events with non-exceedance probabilities of 10^{-4} per year as required by WENRA (2014) and suggested by the EU Stress Tests.

5.3.2.4 Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

The NR contains a list of seven measures to increase robustness which has partly been already implemented. For the remaining measures an implementation schedule has been established by ANPP and monitored by ANRA. The PRT acknowledges and supports these measures.

5.3.3 Peer review conclusions and recommendations specific to this area

Information about the design bases for some extreme weather conditions is provided. The design bases have been explained, however without clear technical background.

The design bases should cover hazards corresponding to a frequency of 10^{-4} per year or lower. At the moment this is not the case and some DB values correspond to design basis events with very high occurrence probabilities of 10^{-1} to 10^{-2}. Robustness of the plant for loads of events with occurrence probabilities of 10^{-4} per year is however demonstrated for all extreme weather hazards with the exception of wind and associated dust storm. This demonstration is currently not included in the SAR. For the Life Time Extension of ANPP Unit 2 it is planned to put the design basis requirements in the SAR in line with the internationally agreed values.

The PRT suggests defining clear design basis requirements for meteorological hazards and hazard combinations, which are based on the severity of design basis events with non-exceedance probabilities of 10^{-4} per year as required by WENRA (2014) and suggested by the EU Stress Tests. Design bases should be defined for all meteorological hazards which cannot be screened out based on being physically impossible or extremely unlikely with a high degree of confidence[24].

Design basis requirements should be anchored in binding regulatory documents.

After the Fukushima accident a complementary analysis of plant robustness has been performed to find out the external event combination which could lead to undesirable after effect by using the FSA method and a tool developed by the IAEA. This is regarded as good practice.

The robustness of the design does not allow covering high winds and low temperature hazards corresponding to the frequency of 10^{-4} per year. It is stated that the ANPP design minimum temperature is -40°C, however based on conservative calculations the adverse effects on BZOV appear at -31.5°C. The PRT recommends to consider improving the robustness of BZOV against low

[24] The PRT assumes that such a screening process has been performed in the course of the external hazard PSA.

temperature up to the DB (-40°C). Winds with an expected frequency of $1.7x10^{-4}$ per year would lead to SBO and corrective actions are needed to solve this.

Vulnerabilities have been identified in the NR. A number of possible corrective actions are under consideration of ANRA. The NR contains a list of seven measures to increase robustness which has partly been already implemented. For the remaining measures an implementation schedule will be established by ANPP and monitored by ANRA. The PRT acknowledges and supports these measures.

5.4 Volcanism

<u>Introductory Remark:</u> ***The ANPP site is located in an area of Quaternary and Holocene volcanism on the flanks of the Aragats volcano. Other volcanic centres include the historically active Ararat volcano 50 km from the site, and the volcanoes of the Shamiram plateau, adjacent to the ANPP site. The PRT therefore decided to include volcanic hazards in the review, although the hazard type was not covered by the EU-Stress Tests of European NPPs.***

5.4.1 Assessment of hazards and design basis

5.4.1.1 Derivation of the design basis

Design basis requirements for the ANPP have not been established for volcanic hazards. It appears that neither volcanic phenomena occurring near a volcanic centre (opening of vents, lava flows, pyroclastic flows, ballistic projectiles; applicable to the Aragats volcano and the volcanoes of the Shamiram plateau) nor effects extending to areas remote from the volcanic centres (ash clouds, tephra fallout; applicable to the Aragats volcano) have been considered during siting, construction and operation.

International standards for volcanic hazard assessment and the definition of design bases are set by the IAEA Safety Standard SSG-21.

5.4.1.2 Main requirements applied to this specific area

Design basis values for the ANPP have not been defined at the stage of siting and construction.

The following data result from the assessments of volcanic hazards for the siting of a new NPP at the ANPP site. These assessments were completed in 2011[25]. The study clarified that the Aragats volcano, the Ararat volcano, and the volcanoes of the Shamiram plateau are “capable volcanoes” as defined by IAEA SSG-21.

Hazard assessment revealed the following frequencies for volcanic phenomena:

Formation of new vents less than 2 km from the ANPP site:

5.9×10^{-8} to 5.1×10^{-7} per year;

Pyroclastic flows:

2.1×10^{-7} to 1.9×10^{-6} per year;

Tephra fallout exceeding 100 kg/m²:

[25] Connor et al., 2011. Volcanic Hazard Assessment of the Armenia Nuclear Power Plant Site, Final Report.

10^{-5} to 10^{-6} per year;

Volcanic ballistic projectiles:

3.6 to 2.4 x 10^{-6} per year;

Lava flows:

1 x 10^{-7} to 8.8 x 10^{-7} per year;

Other volcanic phenomena and effects (slope failures, debris flows, volcanic gases, atmospheric phenomena, hydrothermal systems) were screened out by their extreme unlikeliness. Vibratory ground motion hazard due to volcanic earthquakes is thought to be enveloped by the hazard resulting from tectonic earthquakes.

The PRT stresses that the hazards pyroclastic flows, lava flows, and new vent formation are considered an exclusion condition at the site selection stage by IAEA SSG-21.

The assessment concludes that tephra fallout during an eruption of the Ararat volcano is the most likely event threatening the ANPP site. The hazard assessment report concluded that the phenomenon "*should be considered when developing design bases for systems at the ANPP site.*"

5.4.1.3 Technical background for requirement, safety assessment and regulatory oversight (Deterministic approach, PSA, Operational Experience Feedback)

The NR and the additional information provided by ANRA do not contain information on the legal or regulatory basis for the assessment of volcanic hazards and the protection of the existing ANPP against such phenomena. The volcanic hazard assessment report 2011 addresses volcanic hazard analyses for the siting of a new nuclear installation at the ANPP site.

The authors of this report state that hazard assessment follows the guidelines IAEA SSG-21 for the identification, screening and calculation of potential hazards.

5.4.1.4 Periodic safety reviews (regularly and/or recently reviewed)

Periodic safety reviews for volcanic hazards are not implemented.

More details about PSR are provided in chapter 4.5.2

5.4.1.5 Conclusions on adequacy of design basis

The potential volcanic hazards in the site vicinity of the NPPs were analysed in a detailed hazard assessment study completed in 2011. Reviews of the report in 2010 and 2011 identified its high quality.

The study includes assessments of both, phenomena occurring near the volcanic centre (opening of new vents of monogenetic volcanoes in the site vicinity, pyroclastic flows, lava flows, ballistic projectiles, derived from the Aragats volcano and the volcanoes of the Shamiram plateau) and effects extending to areas remote from the volcanic centre (tephra fallout from eruptions of the Ararat volcano). Hazards were analysed based on geological data, probabilistic assessments and numerical simulations which correspond to current best praxis.

5.4.1.6 Compliance of plant(s) with current requirements for design basis

DBs for volcanic hazards have not been defined for the existing ANPP.

The PRT recommends implementing design bases for volcanic events on the basis of the hazard levels derived by the volcanic hazard assessment 2011. As a minimum, a design basis for tephra fallout, which was identified as the most likely volcanic hazard, should be implemented. During the country visit ANRA explained that the development of such requirements is currently ongoing.

5.4.2 Assessment of robustness of plants beyond the design basis

No assessments of the robustness of the ANPP with respect to volcanic hazards are available. The PRT suggests determining the capability of the plant to cope with tephra fallout and ballistic projectiles as a minimum.

5.4.2.1 Approach used for safety margins assessment

Safety margins with respect to volcanic hazards have not been identified.

5.4.2.2 Main results on safety margins and cliff edge effects

Pyroclastic flows from the Aragats volcano and the opening of new vents at the Shamiram plateau next to the site are beyond design basis events. Due to the nature of these processes a protection concept cannot be established.

Pyroclastic flows and opening of new vents are therefore cliff edge effects with a probability of occurrence which is determined by the expected frequency of pyroclastic flows (2.1×10^{-7} to 1.9×10^{-6} per year).

5.4.2.3 Strong safety features and areas for safety improvement identified in the process

No strong safety features could be identified.

5.4.2.4 Possible measures to increase robustness

The PRT recommends to:

- Establish design bases for ballistic projectiles and tephra fallout, i.e., those volcanic phenomena for which protection is possible. Some effects of tephra fallout (loading of structures, effects on ventilation) may be enveloped by protection against other hazards (snow load, protection against dust storms).
- ANPP to develop response plans/procedures to respond to potential volcanic activity at Ararat, Aragats, and the Shamiram plateau.
- Develop a monitoring of these capable volcanoes in the framework of the national civil protection programmes

The Volcanic Hazard Report 2011 arrived at similar recommendations saying: *"Should the decision be made that the ANPP site is acceptable, it is recommended that plans be developed to respond to potential volcanic activity at Ararat, Aragats, and the Shamiram plateau. IAEA guidelines further recommend the monitoring of capable volcanoes. Plans conforming to IAEA guidelines should be developed to monitor these volcanoes."*

5.4.2.5 Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

The PRT has no information on such measures or studies.

During the country visit ANRA explains that existing emergency plans will be supplemented for volcanic hazards.

5.4.3 Peer review conclusions and recommendations specific to this area

Volcanic hazards have not been considered during the siting and construction of the ANPP. Siting requirements and design basis requirements for different volcanic hazards were consequently not defined.

The ANPP site is located in the vicinity of three capable volcanoes which are currently not active. It is subjected to volcanic hazards such as pyroclastic density currents, lava flows, and opening of new vents, which are considered site exclusion conditions at the site selection stage by the IAEA[26] irrespective of their occurrence probability. Protection against these phenomena is not possible.

A screening and assessment of volcanic hazards for the ANPP site was only recently performed in the framework of the site evaluation process for a new NPP. Hazards were assessed in a comprehensive geological study which is based on a novel and scientifically sound database. The applied methods are regarded to conform to the current state of science and technology.

For new vent formation, pyroclastic flows and lava flows (all regarded site exclusion conditions at the design stage) probabilities of about 10^{-6} to 10^{-7} were identified in this study. The effects of these hazards cannot be mitigated by appropriate measures for design and operation. They are consequently cliff edges.

For tephra fallout and pyroclastic projectiles probabilities of about 10^{-5} to 10^{-6} per year were derived. The development of a protection concept for the existing NPP for these hazards appears feasible.

In order to increase the safety of the existing NPP the PRT recommends to:

- Establish design bases for those volcanic phenomena for which protection is possible;
- Develop plans to respond to potential volcanic activity at Ararat, Aragats, and the Shamiram plateau;
- Develop a monitoring of these capable volcanoes in the framework of the national civil protection programmes.

The assessment of the suitability of the ANPP for new nuclear installations is not a topic of the current Peer Review. The PRT, however, strongly recommends to base future decisions on the guidance provided by IAEA SSG-21.

[26] Site exclusion criteria are listed in Table 1 of IAEA SSG-21.

6 PLANT(S) ASSESSMENT RELATIVE TO LOSS OF ELECTRICAL POWER AND LOSS OF ULTIMATE HEAT SINK

6.1 Description of present situation of plants in the country

6.1.1 Regulatory basis for safety assessment and regulatory oversight (national requirements, international standards, licensing basis already used by another country)

The ANPP reactors belong to the first generation of the Soviet-type Pressurized Water Reactors (PWRs), designed in the early sixties, before the first nuclear safety regulation (OPB-73) was developed and published. The safety concept was based on design rules and standards effective at the time of the design and construction of these plants, basically industrial codes, standards and rules, which were applied to conventional thermal power plants and other industrial facilities in the Soviet Union.

No further statements concerning national and international standards and norms effective by the time of the units' construction were made in the NR.

In the early nineties in the framework of an IAEA project on safety assessment of VVER-440/230 units this type of reactor was investigated, safety deficits identified and safety enhancements for accommodation to comparable international technical standards were defined. The results were stipulated in the IAEA TECDOC-640 of February 1992 *"Ranking of Safety Issues for WWER model 230 Nuclear Power Plants"*. This TECDOC served as one of the basis for the backfitting prior to the re-start of the ANPP unit 2 in 1995. According to the report of the licensee, these measures were described in detail in the Unit's SAR, Chapter 1.2.

In 2002 the national *"Requirements for format and content of the safety analysis report of the Armenian NPP Unit 2"* were enacted. SAR is based on IAEA guide. However the structure is slightly changed and the chapters Commissioning and Decommission are excluded. Instead a new chapter is added "Safety deficiencies and modernization program".

To describe the safety status of unit 2, in 2009 a SAR named "Safety analysis report of the ANPP Unit No. 2" was compiled which is based on this requirement. Based on this report ANRA issued an operation license to ANPP in 2011.

Today the legal framework for the utilization of nuclear power in Armenia is defined by the "Law on Safe Utilization of Atomic Energy for Peaceful Purposes (Atomic Law)" Law HO-285 25.03.1999. This act obliges ANRA to establish and implement the regulatory oversight for ANPP. Under the Act, ANRA develops drafts of relevant regulations that define safety requirements in Armenia and submits these documents to the Government for approval. Bases for regulations development are usually IAEA standards and fundamental as well as Russian and US NRC guides and regulatory documents.

ANRA can also enact Ministerial Acts that describes how to fulfil relevant safety requirements. In addition, for specific technically relevant issues, the regulations and standards of the country of origin of the technology (Russia, France, US) are used.

6.1.2 Main requirements applied to this specific area

Currently following Russian regulations were applied for power supply and heat sink.

- General regulations on ensuring safety of nuclear power plants OPB -88/97
- PNAE G-9-027-91 Rules for designing emergency power supply systems of nuclear power plants

6.1.3 Technical background for requirement, safety assessment and regulatory oversight (Deterministic approach, PSA, Operational Experience Feedback)

Nuclear safety oversight in Armenia is based traditionally on the deterministic concept. According to RA Government Decree 400-N from 24.03.2005 ANPP is required to perform a PSA level 1 before receiving license for operation. To comply with this requirement, in 2009 ANPP developed an all new SAR (see above). Starting in 2002, a PSA level 1 was developed limited to internal initiators. The PSA model was reviewed by an IAEA IPSART Mission of 2007. The PSA was expanded to include external events (flooding, fire, earthquakes), other operational states (shutdown and low power modes) and it is being adjusted to plant modification and changes (currently with the status of December 2010). Specific requirements to PSA level 1 are now under development (draft is ready and is in discussion phase).

The Atomic Law requires the full use of ANPP's own but also international operating experience (OPEX) for enhancing safety. The ANPP collects and analyses its own events in a systematic way since 2007. In this respect a data base with recording of events and analyses has been established.

6.1.4 Compliance of plants with current requirements

The NR does not contain a statement on the actual safety status of the NPP and a confirmation that the existing design complies with the current national regulations. In the discussion during the country visit ANRA explained based on the current license issued in 2011 that ANPP fulfils the current safety requirements (see details in chapter 6.1.3).

6.2 Assessment of robustness of plants

6.2.1 Approach used for safety margins assessment

The assessment of the robustness of the plant to cover the issues SBO and loss of UHS was conducted according to the requirements set in the EU-STs specifications from May 2011. For both cases the required levels of actions set in the specifications were considered and assessed. Actions and countermeasures were described and safety margins defined as well as cliff edge effects and related time periods up to their occurrence expressed.

The approach is based on a detailed assessment of technical and administrative measures that enable the plant to cope with the consequences of a failure of power supply (SBO) and UHS. This includes losses of power from the national grid, after the reactor scram and an immediate or subsequent failure of the alternative power supplies. For the loss of UHS, an assessment of the sufficiency of residual heat removal from the reactor to avoid a core damage event was undertaken.

6.2.2 Main results on safety margins and cliff edge effects

Loss of off-site power (LOOP)

Off-site Power Supply Features

ANPP is connected to the National grid by five power lines of 220 kV and six power lines of 110 kV. The junctions are realized by five nodal transformer substations. The transmission lines at both voltage levels are connected by bus bars to the respective 220 kV and 110 kV outdoor switchyards. Both switchyards can be connected to an auto-transformer. Power from the national grid is transmitted by two main transformers. The station power supply transformers are arranged as „tapped transformers“ to bus bars at 6 kV / 0.4 kV.

In the case of a failure of the national grid, there is a possibility of a separate, independent emergency off-site-power supply via a direct 110 kV transmission line from the Hydroelectric Power Plant (HPP) „Argel“. Argel is located in a distance of nearly 40 km from ANPP. This power supply would be available if the hydroelectric plant as well as the direct power lines to ANPP are operable. *Neither the plant nor the transmission lines are safety classified or seismically proved.*

Completely filled Akhparin reservoir ensures operation of one turbine of the Argel HPP with full power of 56 MW for 60 hours and the daily – storage reservoir ensures operation for 2.5 hours.

The coordination of actions among the ANPP, the HPP Argel and the RA power grid dispatcher is regulated by the dispatcher interaction procedure "Grid operator interaction with facilities”. There is a direct link between the dispatcher, HPP Argel and ANPP.

On site power supply

At ANPP there is a “graded” backup power supply system for safety relevant consumers. It encompasses a redundant EDGs system (consisting of 4 DGs organized in two trains, each being capable of supplying all the emergency loads of the respective train) to supply all safety relevant consumers of category II, a single „emergency cooling“ diesel to supply selectively consumers of category II (Class (category) II emergency power supply system is designed to provide electric power for Class II essential consumers both in normal operation and in case of the loss of the outside power supply), as well as batteries supporting the uninterruptible power supply to category I consumers (the first group - AC and DC loads which do not allow power supply breaks for more than fractions of a second in any operating mode including one of complete loss of AC voltage from basic and standby preferred power transformers (de-energizing mode) and do require mandatory power supply availability after reactor scram operation).

The tanks within the DG building can be refilled from the site diesel storage tank. This diesel tank holds enough fuel for 7 days of EDGs operation (four EDGs running at full nominal power). However, the site diesel tank is not seismically qualified and the refilling pump is not powered from reliable power supply. Therefore, it is not considered as a reliable source of diesel fuel in case of loss of off-site power.

The cooling of the EDGs is normally conducted by Essential Service Water System (ESWS). The DGs of emergency power supply system are able to start without availability of ESWS pumps. After the start and connection to the 6kV bus-bars, by start-up program two of the trains of the ESWS are put in operation which switches on two ESWS pumps in each train.

Ventilation of diesel-generator station rooms is designed to remove heat emitted by the operating equipment in the building and to provide normal conditions for equipment operation.

In case of blackout two parallel EDGs are automatically started and connected to each 6kV bus.

It is possible to put EDGs in operation manually. Appropriative instructions exist at ANPP.

The emergency power supply system as the ordinary back-up system consists of ***two independent trains***. Each train consists of:

- Two EDGs of 1500 kW each;
- Power bus bar systems 6 kV and 0.4 kV
- Transformers 6/0.4 kV

Power supply to the consumers of Category II is provided via two separate auxiliary 6 kV bus bars. There, each 6 kV section supplies respective redundant consumers that jointly belong to one safety train. The output of one EDG of 1500 kW is sufficient to supply one 6 kV bus bar. Each of the 4 DGs could be connected to each of the 6 kV bus bars. Thus, the operability of at least one redundancy in all safety relevant systems is given, if at least one EDG is in operation.

Station Blackout (SBO)

The EU-STs specifications define the SBO as a loss of all permanently-installed AC power sources on and off site. In the case of ANPP, it is the loss of the external grid and all four EDGs.

Second Emergency Cooling (SEC) system (an independent DG with related equipment)

In the case of a SBO a separate diesel generator (DAR) of 1500 kW (DAR cooled by "technical non-safety qualified" water system or by diesel driven pumps if the system is not available), a respective transformer with outdoor switchboard and outdoor transformer substation as well as additional cables to individual consumers are available. DAR has to be put in operation manually by the operating personnel. There is existing instruction which specifies how consumers should be connected. The selection of consumers is dependent from the emergency situation. Usually in first order the ESWS pumps are connected. Performed tests showed that average time to connect consumers is about 30 min. The switching-on of the all respective consumers to the DAR emergency power supply can take up to ***60 min***. Depending on the accident sequence; the swiftness of the switch-on is decisive. The decision which safety loads are to be supplied depends on the state of the plant, the priority of the consumer and the information about re-establishing of the emergency power supply by EDGs or by the normal in-house power supply.

DAR system cables are already placed in the same compartment as the consumers to be connected with corresponding markings. The cables are tested every 10 days according to existing procedures.

Batteries for DC power supply

The battery system provides the uninterruptible power supply to the safety-relevant consumers of Category I. The system consists of two independent trains of 100% capacity. Each train includes:

- Seismic resistant batteries with a capacity of 1500 Ah;
- Two reversible motor generators , one is operating, the other in reserve;
- Two thyristor devices for reserve activation;
- Section 0.4 kV;

- DC panel and
- Rectifier for battery charging/discharging

The batteries are charged

- In normal power operation of ANPP – via turbine generators and respective in-house transformers,
- For shutdown/startup of the facility – via off-site supply from the national grid by redundant reserve transformers and
- In case of LOOP – via EDG for the consumers of Category II.
- In the case of SBO and a loss of SEC there is no possibility to recharge the batteries.

After the Fukushima NPP accident, the duration of power supply was assessed for the batteries feeding Class I DC and AC consumers without recharge. Calculations made with conservative assumptions showed that the duration of the power supply from the batteries is 7 hours.

If the batteries are completely drained before power is restored then all control at ANPP such as level measurement in SGs will be lost. However, SG water inventory could be maintained by the diesel auxiliary feed water system, and decay heat removed through SG Safety Valve (SV). Operator will manually control mass flow rate of auxiliary feed water diesel-pump to maintain pressure in primary side at nominal level.

DG for security system of ANPP can be used for charging of batteries. This is a temporary solution until mobile DG will be available.

Auxiliary feed water system

In the case of a SBO and loss of DAR, there is another technical solution to provide, for a limited time, heat removal from the primary circuit via the secondary circuit by steam relief and the emergency feed of the steam generators from the auxiliary feed water system. The system consists of the auxiliary feed water diesel-pump as well as of feeder tanks BZOV-1 and 2 each with 500 m^3 demineralized water. During the discussion ANPP stated that in 2015 possibility to supply water to BZOV tanks from fire trucks was added. The same way possibility to supply fuel to auxiliary feed water diesel-pump from external sources was added.

In the above described scenario, the integrity of the reactor coolant pump seals is important, because due to the failure of the seals a loss of primary cooling water may occur. The tightness of the reactor cooling pump seals has been experimentally confirmed for 24 hours. It is planned by ANPP in the frame of an action plan to confirm the seal tightness for longer times by preforming additional tests.

<u>Time margins until „Cliff Edge Effects“</u>

For various LOOP scenarios, the availability of specific systems to prevent a core damage accident demonstrates time margins within which a sufficient core cooling as well as cooling of the spent fuel pool of units 1 and 2 can be maintained.

With the assumption that after a LOOP, one emergency cooling train with two EDGs is available, of which one EDG is sufficient to power the emergency cooling train. In a case that there is a no possibility of re-filling the tank of the EDG (25 m^3 diesel fuel), one EDG would operate for 55 h. The availability of the site diesel tank, which is not seismically designed, would increase this time up to 660 h.

Should by then neither the re-filling of the EDG tanks or the operation of DAR be possible, nor the re-establishment of off-site power supply, the emergency makeup of the SGs using the diesel operated pump would be necessary. In such a case, cooling via the secondary side for at least 24 h can be provided, limited to the availability of the fuel for the diesel pump and the water of the 2 demineralized water storage tanks with capacity of 500 m^3.

As a special characteristic of VVER 440 reactors (that is common to all models, in a case of a total loss of water supply (caused by a SBO, loss of DAR and unavailability of the diesel pump) the heat removal from the reactor could be accomplished by natural circulation on the primary side and the heat removal from the SGs by steam release to the atmosphere via BRU-A (steam relief valves). If no water supply to the SGs is available, there is a window of about 5 hours during which the reactor could be cooled by evaporating water available in SGs.

After the secondary side heat removal is terminated, the decay heat of the nuclear fuel in the reactor can still be removed by evaporation of the coolant and release via the pressurizer safety valves. But in this case after about 4 hours the water level will reach and then fall below the top of the fuel assemblies, which then will be an initiation of fuel damage (cliff edge). This means that the loss of integrity of fuel elements would occur about 9 h after the initiation of the station blackout (EDGs and DAR DG not available) sequence and if availability of auxiliary feed water diesel-driven pump will be not taken into account.

Depending on the operability of equipment on site, the start of the fuel damage is being delayed. If the auxiliary feed water diesel-driven pump is operational but no refuelling is possible, it adds 24 hours. If there is a possibility to add diesel fuel, then the pump will continue to operate, but the critical issue becomes the availability of water. The water inventory in both tanks BOZV-1 and 2 (total of 1000 m^3) will be exhausted (without a re-fill) in 169 hours.

If a SBO combined with a loss of the EDGs, DAR DG and SGs auxiliary feed water system with diesel-driven pump happens during a shutdown of the reactor with open pressure vessel, the inventory of the reactor pressure vessel begins to boil after 4 hours. This stops the natural convection in the primary circuit and the heat transfer to the secondary circuit and the steam generators. 5.5 hours later the coolant will evaporate to the level of the hot leg nozzles and after overall 18 h fuel damage begins. However if SGs auxiliary feed water system with diesel-driven pump is operational even without refuelling, it allows to have additional 24 hours.

For the fuel in the SFP, the critical event scenario is a complete discharge of the reactor core into SFP-2. In case of a SBO and failure of the DAR, due to the evaporation of water of SFP-2 after about 33 hours, a rapid oxidation of the cladding of the fuel rods will start. This will lead to hydrogen release and mechanical failure of fuel cladding.

Loss of ultimate heat-sink (UHS)

Heat sink for normal operation

During normal power operation, the heat-sinks are the cooling towers. With the inlet/outlet channels, they create a cooling loop. Connected to this loop are condensers of both the turbines and also the condensers and heat exchangers of the Coolant System of Normal Operation (CSNO) which cools down the primary and the secondary circuit after operational shutdown. For the heat removal from the spent fuel pools and for the containment cooling in normal operation the heat sinks are the spray ponds of the ESWS.

To compensate the evaporation-caused and leakage-caused loss of water from operational heat-sinks, the water makeup is provided from the BTV tank which - via the pumping station NTB – feeds the condensers and heat exchangers of CSNO as well as the ESWS spray ponds. Then the water from CSNO is supplied to the outlet channel of the cooling towers, to serve as the operational makeup feed. There is also a possibility to supply the cooling tower system directly from the BTV tank.

The water inventory in the BTV tank and the water supply of both heat-sinks is provided by two external raw-water sources – from the river "Sevdjur" and from an artificial water pond („Prud") over respective pump stations. Additionally there are three deep wells in the vicinity of the site and it is planned to build additional nine wells. When completed this would complement the different water sources on the site.

Loss of primary UHS

For the ANPP the initial scenario for the loss of primary UHS are the losses of cooling towers and the CSNO. Considering the EU-STs specifications, losses of external water supply from "Sevdjur" and "Prud" are considered as well

Cooling towers and CSNO

In a scenario where the cooling towers and CSNO are lost (primary UHS losses) the heat removal from the reactor core, spent fuel pools (and containment) can be accomplished by several systems acting as alternate UHS. A leading role in this context plays the ESWS.

In a first step the core cooling is accomplished via the primary and secondary circuit, by the secondary High Pressure Emergency Cooling System (ASN), which feeds steam generators, where heat is removed by steaming out through the Safety Valves (BRU-A). An additional possibility is the second circuit emergency cooling system (Low Pressure Emergency Cooling System: AKN), which, in a closed circuit, removes the heat from the secondary circuit. The condensers and heat exchangers of this system are cooled by ESWS, and the heat is released to the atmosphere via the ESWS spray ponds. The ESWS is also the heat sink for the SFPs, as well as the containment.

In terms of robustness, it is noted that the ESWS is designed with 2 x 100% redundancy. Each train contains 3 pumps and 1 spray pond. A third spray pond serves for both lines as a reserve for emergency situations. The ESWS is designed to comply with single failure criteria, its trains are independent and each ESWS train is supplied from a respective train of the emergency power supply (EDG). The availability of the water in the system is monitored. There is a possibility to replenish from "Sevdjur" and "Prud".

Loss of raw water supply

If water supply from both external sources „Sevdjur“ and „Prud“ is interrupted or if the BTV tank and/or the NTV pumps are not available, the water supply to the ESWS spray ponds could be obtained from the outlet channel of the cooling tower system. This could be accomplished via the ESWS the makeup reserve pumping station or via the diesel pump.

<u>Loss of alternate UHS (ESWS and spray ponds)</u>

Should none of the redundant ESWS trains and spray ponds be available, neither due to loss of water inventory nor due to other failures of the ESWS, the heat removal from the core can be realized via primary and secondary circuit with the heat relief over BRU-A into the atmosphere, in a similar fashion as with the losses of the main UHS (above). Water losses from the steam generators can be compensated with the help of the High Pressure Emergency Cooling System ASN and Low Pressure Emergency Cooling System AKN. For this, the necessary water reserve is available in both tanks BZOV-3 and 4. In addition to these possibilities, for a limited time, heat removal from the primary circuit via the secondary circuit by steam relief and the emergency feed of the steam generators from the auxiliary feed water system is possible. The system comprises the diesel-operated pump (DNP SG) and feeder tanks BZOV-1 and 2 each with 500 m^3 demineralized water.

<u>Loss of UHS with SBO</u>

ESWS operable

In a case of a SBO, there is a possibility to provide power to safety consumers from the SEC system. One pump of either of the two ESWS trains will be supplied by the DAR DG. The water supply to compensate the operational losses of the respective ESWS spray pond can be realized from the outlet channel of the cooling tower system by the “diesel pump station”.

ESWS not operable

Complete, immediate and long term loss of operability of both ESWS trains is covered by the SBO analysis discussed above.

<u>Time margins until „Cliff Edge Effects“</u>

Loss of primary and alternate UHS

In the case of a loss of the cooling towers and the CSNO, cooling of the safety-relevant consumers can be maintained via the ESWS, if the water supply from the external sources „Sevjur“ and „Prud“ is provided.

If the feed water supply from the external sources is not possible, then the supply of the ESWS - to compensate the evaporation losses from the spray ponds - could be accomplished from the outlet of the cooling tower system. The amount of water available is such that the supply could last for about 30 days.

If losses from the ESWS cannot be compensated, within about 72 hours the water level will drop to the point that the ESWS operation would cease. This will result in a failure to provide cooling to safety relevant consumers.

Maintaining of the heat removal from the core after a complete failure of ESWS can be ensured, by feed and bleed of the secondary circuit, for 16 days. The makeup for the steam generators would be ensured by the emergency feed water pumps with water from 2 deaerators with a volume of 120 m³ each. The water will be pumped into the secondary circuit, by the high-pressure emergency pumps, which are connected to both tanks BZOV -3 and 4 (of 500 m³ each) and via the auxiliary feed water system with a diesel-operated pump (DNP SG) with the connected reserve tanks BZOV-1 and 2 (of 500 m³ each).

Therefore, the critical scenario for the core damage in case of loss of UHS is the loss of the ESWS, with the core cooling solely via steam generators' feed and bleed. The time to core damage in this scenario is 16 days. It shall be noted that there are safety relevant systems supported by the ESWS (e.g. EDGs), which would also be lost.

In the case of a total loss of ESWS and resulting loss of SFP-cooling, the only alternate is the recirculation of a part of the water inventory in the SFP-2 via the boron reserve tanks using SFP-make-up pumps. In the case of a complete core being downloaded into the SFP-2, in such a recirculation mode, it would take 3.3 days to increases the temperature of the cooling water of the SFP from (operational) 60°C to 80°C. It should be checked, whether a reliable operation is possible in this regime, because of potential cavitation of the recirculation pumps.

Loss of ultimate heat sink with SBO and loss of SEC

In the case of a complete failure of all power sources and therefore – of all heat sinks – solely the diesel-operated pump of the auxiliary feed water system already mentioned in the section SBO would be available for the emergency feed water supply of the steam generators. The processes and timeframes already mentioned in „cliff edge effect“ SBO and necessary for the core and SFP cooling would come up also in this scenario.

6.2.3 Strong safety features and areas for safety improvement identified in the process

In most cases, the SBO is the ultimate cause for the loss of the UHS. This will lead to the inoperability of various systems and as a consequence to fuel damage in the reactor and the SFPs. Therefore the enhancement of the reliability of power supply and/or alternative power sources is of particular importance. The main areas for safety improvements linked to LOOP, SBO and loss of UHS are the following:

- ANPP have no diverse power sources (all emergency power are same type EDGs);
- The seismically qualified diesel fuel tank capacity does not allow the operation of EDGs up to 72 h, without any additional action;
- The EDGs are cooled by the ESWS, in case of interruption of ESWS refiling after 72 hours EDGs will be lost;
- In the case of a loss of the complete ordinary back-up power source (all 4 EDGs), there is no possibility to recharge the batteries for the uninterruptable power supply for Category I consumers;
- In the case of SBO there is no possibility for cooling the SFPs.

6.2.4 Possible measures to increase robustness

Following the completion of the assessment, ANPP identified a series of measures that would increase safety and robustness. Upon its review of the report of the licensee but also based on some other sources and information ANRA decided on some additional safety measures to enhance the robustness against LOOP with SBO and loss of UHS. ANRA considers the actions and measures as listed below as appropriate and necessary to enhance precautions against impacts of external initiating events and to increase the safety level of the ANPP in general such as:

1. *Implement additional measures to assure longer operation time of batteries during SBO including:*
   - *Provision of mobile DGs for charging batteries during SBO,*
   - *Develop and implement additional measures to extend the operating time of reversible motor generators in an inverter mode that will lead to increase the time to provide Instrumentation and Control(I&C) AC power supply,*
   - *Replace all reversible motor generators with modern inverters with less energy losses,*
   - *Implement a new electrical scheme for charging batteries from DAR system and/or the portable diesel generators.*
2. *Assure long term heat removal from Unit №1 and 2 SFPs in case of SBO:*
   - *Implement two new separate lines for make-up of the coolant inventory in the SFPs from a mobile source (e.g. fire pumps or diesel pumps) and external water sources for SFPs emergency cooling.*
3. *Increase the reliability of provision for availability of fuel for EDGs or foresee measures to install additional fuel capacity in terms of seismically qualified and reliable fuel tanks.*
4. *For activation of the alternate emergency power supply system (DAR) manual actions are needed and activation can take up to 1 hour. Implement analysis of circuit diagram for consumers power supply (from DAR). Develop and implement activities aimed at minimizing personnel manual actions to activate the DAR system.*
5. *Implement Diesel Generator Load Sequencer program for "cold" shutdown and refuelling modes.*
6. *Assure MCP seals long-term (more than 24 hours) operation in case of cooling failure.*
7. *Perform additional calculations in order to demonstrate sufficient effectiveness of the SGs emergency feed water diesel pump for modes of reactor (cold shutdown, refueling, closed reactor, open reactor).*
8. *Implement autonomous alternative means for make-up of SGs 1-6 of the Unit 2.*
9. *Provide for mobile pumps for ESWS make-up from the Circulation Water Channel.*
10. *Develop and implement additional measures to use a large reserve of service water in the inlet and outlet channels, as an alternative heat sink.*

6.2.5 Measures (including further studies) already decided or implemented by operators and/or required for follow-up by regulators

As indicated in Chapter 6.2.4, the regulatory body proposed a variety of measures to be implemented for enhancing the robustness of the ANPP against LOOP, SBO and loss of UHS. Beyond that, neither information are contained in the NR whether this list is mandatory to be realised by the license holder nor whether a programme or a time schedule for implementing some or all mentioned provisions exist or is under realisation. During the visit the PRT was informed that in connection to the safety enhancement programme, ANPP developed a list of measures which was sent to ANRA for review and approval.

6.3 Peer review conclusions and recommendations specific to this area

Based on the criteria in the EU STs specifications, an assessment was carried out, whether the systems and components of the ANPP are appropriate to cope with the requirement “sufficient heat removal from the reactor core or the stored fuel elements in the spent fuel pools” in the case of SBO or loss of UHS.

The VVER-440 reactors of ANPP belong to the so called “Generation I” reactor types. Nevertheless, the reactor type VVER-440, here as VVER-440 (V-270), possesses design features leading to a “sedate” operational as well as accidental behaviour. The design has some safety merits not found in most other types of PWR in operation.

The core has a low specific heat production with respect to the fuel weight. Another remarkable safety feature of the VVER-440 plant design is the large volume of cooling water compared to its core power. The length of the reactor pressure vessel below the nozzles for the cold and warm section of the primary coolant pipes is twice of the core length. The primary circuit has six loops with isolating valves and horizontal SGs. This existing coolant inventory is a valuable buffer that gives time for corrective actions in abnormal events where the balance between heat production and coolant supply has been lost.

The NR indicates that a comprehensive safety analysis in the light of the Fukushima accident applying the EU STs criteria has been performed by the licensee of the ANPP. It can be stated, that a graded defence system exists, with measures which are pertinent in general to make ANPP resistant in the case of the events considered in chapter 5 of the NR. There are different actions planned to extend the available time for heat removal from the core and the SFP, without need for any external action or support.

Nevertheless ANPP is located in a geographic region with high external hazards especially in respect to earthquake. Due to this fact it is an indispensable prerequisite for the reliable function of the SSCs necessary for the measures discussed above, that these SSCs, flowpaths and the buildings housing those assure integrity and in respect to their safety relevant active parts keep operational in case of such events. This is in particular relevant for the water storage facilities, including inlet and outlet channel and the spray ponds for the ESWS and the connected pipes, to assure water supply for the alternate UHS in case of loss of the primary UHS.

In respect to the power supply, the PRT recommends the implementation of the intended improvements of safety systems necessary to cope with the postulated events. The PRT recommends especially strengthening the fuel supply of the EDGs. The PRT also recommends considering addressing the lack of diversity of the EDGs and DAR DG (same type, same building same age), the ability for recharging the batteries and the assurance for cooling the SFP of the unit 2.

It is further recommended that the improvement measures to increase the safety for LOOP, SBO and loss of UHS, proposed by the licensee and amended by the regulator are declared as mandatory and as such documented in the National Action Plan, with confirmed schedule for their implementation.

7 PLANT(S) ASSESSMENT RELATIVE TO SEVERE ACCIDENT MANAGEMENT

7.1 Description of present situation of nuclear power plants in Armenia

7.1.1 Regulatory basis for safety assessment and regulatory oversight (national requirements, international standards, licensing basis already used by another country)

In accordance to the Armenian Atomic law, the IAEA safety standards have to be applied with the purpose to bring the safety level of atomic energy utilization in compliance with the international criteria.

According to the RA Government decree № 709-A as of 04.06.2013, Safety standards coming from Russian or IAEA sources such as IAEA «safety standards on Safety of nuclear power plants: design-SSR-2/1 » and in particular the part related to Severe Accident Management are made legally applicable in Armenia.

According to IAEA SSR-2/1, "*a set of design extension conditions shall be derived on the basis of engineering judgement, deterministic assessments and probabilistic assessments for the purpose of further improving the safety of the nuclear power plant by enhancing the plant's capabilities to withstand, without unacceptable radiological consequences, accidents that are either more severe than design basis accidents or that involve additional failures. These design extension conditions shall be used to identify the additional accident scenarios to be addressed in the design and to plan practicable provisions for the prevention of such accidents or mitigation of their consequences if they do occur.*"

On top of that, the list of technical measures for the ANPP Unit №2 safety improvement for 2006÷2016 was used by ANPP to develop its safety enhancement programme as requested by the terms and conditions of operation licence provided by ANRA in 2011. This modernisation program was regularly reviewed and updated since 2011.

Provision of emergency response with required missing resources (equipment, including individual protection means, special clothes, tools and accessories, spare parts and repair materials, decontamination and sanitary treatment means, etc.) is implemented from the State reserve of the RA, in compliance with "Regulation plan of state reserve in nuclear and/or radiation accident at ANPP".

7.1.2 Main requirements applied to this specific area

Information related to requirements on Severe Accident Management (SAM) is missing in the stress-test reports (NR and ANPP report).

In the responses to the written questions of the PRT, the following information has been provided: "Legislative requirements to perform analyses of severe accidents are specified in Chapter 3 of "Requirements on the structure and content on ANPP Unit 2 SAR" approved by RA Government Decree N2013-N at 21.11.2002".

According to this decree, the requirements on the structure and content on ANPP Unit 2 SAR approved by RA Government Decree N2013-N of 21.11.2002 SAR should include Beyond Design Basis Accident (BDBA) analysis. It is necessary to present main objectives of BDBA analysis, including:

- Defining causes of Design Basis Accidents (DBAs) developing into BDBAs;
- Developing technical and organizational measures aimed at preventing occurrence of causes of BDBAs;
- Obtaining data required for developing BDBAs management.

For justification of BDBA analysis and management activities, the following is required:

- Develop and substantiate the list of BDBAs that are subject to analysis;
- BDBA analysis methodology;
- Provide the results of BDBA analysis;

Define main activities to prevent and mitigate BDBA consequences, including similar accident management activities.

Furthermore, during the country visit it was clarified that requirements on SAM were already present in OPB-88/97 where it is stipulated that ANPP should elaborate and issue guidelines and manuals determining personnel actions on ensuring safety under Design Basis Accidents (DBA) and BDBA.

7.1.3 Technical background for requirement, safety assessment and regulatory oversight

Requirements for performing safety assessments of ANPP in accordance with the IAEA documents, including the development of a SAR, are defined in the Armenian Act on Safe Utilization of Atomic Energy for Peaceful Purposes. Specific requirements related to the format and content of the SAR are defined by the Government Decree № 2013-N as of 21.11.2002 decree issued in 2002 (Requirements for format and content of the safety analysis report of the Armenian NPP Unit 2). Based on this decree a SAR complying with these requirements was developed in 2008. According to the NR this SAR contains the results of the deterministic and probabilistic safety analysis, including sufficient information for adequate understanding of the current unit design, the safety concept and the identified technical and organizational measures to ensure safety of the plant.

The third version of the PSA Level 1 is available reflecting plant configuration as of December 2010. PSA level 1 covers situations with power from 50% to 100% which corresponds to the operational states with operating turbine generators. The PSA considers internal events, fires and external hazards. The activities for expanding the scope of the PSA models for internal initiating events to low power and shutdown modes and to perform Level 2 PSA are ongoing.

The List of technical measures for the ANPP Unit №2 safety improvement for 2006÷2016 was used by ANPP to develop its safety enhancement programme as requested by the terms and conditions of the operation licence provided by ANRA in 2011. This safety enhancement program was regularly reviewed and updated since 2011 and in April 2016 an updated version was submitted to ANRA for review and approval.

The list includes besides others the development and introduction of symptom-oriented Emergency Operating Procedures (EOPs) for full-power and shut-down reactor states, analyses of severe accidents, development of Severe Accident Management Guidelines (SAMGs), as well as various hardware modification related to SAM. The development and/or implementation of these measures is in progress.

7.1.4 Periodic safety reviews (regularly and/or recently reviewed)

According to the information provided during the country visit to the PRT, the requirements of Government Decree N2013-N on SAR content (see chapter 7.1.2 for details) related to BDBA include also accident scenarios with core melt and definition of main activities aiming at prevention and mitigation of BDBA consequences, including similar accident management activities. Therefore it can be stated that SAM aspects are covered by existing SAR, which has been regularly reviewed by ANRA. The next revision of SAR complying with Government Decree N2013-N will be submitted to ANRA in 2018.

With support of various international experts in 2014 ANRA started a process aiming at development of new requirements on SAR. The technical part of these new requirements is ready and issue of the respective governmental decree is expected during 2017. The process of new requirements development is communicated to ANPP. The future revision of SAR complying with the new requirements shall be submitted to ANRA in 2021.

More information in respect to the PSR process is available in chapter 4.5.2

7.1.5 Compliance of plants with current requirements (national requirements)

Since the decision to restart the ANPP Unit 2 in 1993 and its restart in 1995, the process of continuous improvement of nuclear safety and modernization of ANPP has been taken place and is still on-going. The main binding document for the process at this stage was a living document which has been extended to a program on safety enhancement of the Armenian NPP Unit 2. This living document includes the list of measures, associated schedule, justification, necessary financial means and sources taking into account the suggestions and recommendations of the IAEA OSART mission in 2011.

One of the main IAEA OSART recommendations was related to develop a comprehensive Severe Accident Management Program which is currently under development.

7.2 Assessment of robustness of plants

7.2.1 Adequacy of present organizations, operational and design provisions

Organization and arrangements of the licensee to manage accidents

The NPP operation is continuously performed by the shift crews consisting of 7 to 9 members (depending on the plant state) and assisted by the radiation protection agents, the fire brigade and the site security. As soon as an emergency situation is identified, the Internal Emergency Plan (IEP) is activated, the Emergency Response Team (ERT) is formed, and stand-by crews can be called to be available on-site within 15 minutes to 1 hour, whenever requested. The ERT is technically directed by the Plant Chief Engineer and supervised by the Plant Director. The ERT includes a technical support team divided in several groups (analytical and technical) and in total consist of 34 people. They are organised in 3 shifts.

On top of that totally 400 technical people are also organised in 3 shifts and available, also 200 people working for the fire brigade and site security are available.

The Main Control Room (MCR) is the basic working place of the operators, during normal and accidental situations. Use of the Back-up Control Panel (BCP) accessible from the turbine hall is foreseen for situations, when habitability of MCR will be lost or the reactor and/or safety systems cannot be controlled from the MCR. However, full operation of the BCP has not been assured yet due to improvements still needed regarding habitability. The site is equipped with a sheltered Main Crisis Centre (MCC) which is a basic working place of the ERT. The MCC is provided with power supply systems, ventilation system and external air filtering equipment, water supply and sewage system, heating system and tanks of emergency water reserve. For a long stay it is not equipped with a kitchen with food supply. The location of sanitary equipment (showers and toilet units) does not seem to be optimal, since it is between the double entrance doors thus not directly accessible. This MCC is also not equipped with any personal protective equipment or measures like personal dosimeters or dose-rate meters.

There is no radioactivity monitoring available. Activities to eliminate this deficiency are in progress. In case the MCC becomes inhabitable or inaccessible, the Back-up Crisis Centre (BCC) located in Yerevan, i.e. about 28 km from the site, will be used as a working place of the ERT for managing activities defined in the IEP.

In the MCC the main plant parameters important for safety are available through a dedicated connection (optical cable partially underground); however reliability of the connection in case of seismic events is not confirmed. These parameters are also available in the crisis centre of ANRA in Yerevan (the steps to improve the reliability of data transmission have been initiated) and will be in the future also available in the BCC.

Initial and periodic refresher trainings of every person involved in the IEP are assured. These include also emergency drills, simulating real emergencies including core melt scenarios. Operating personnel is involved in monthly emergency trainings to be ready for taking measures in non-standard situations. The whole training plan will be revised after the planned update of the existing EOPs and introduction of SAMGs. The staff of the ERT will be extended by the personnel of the Technical Support Centre.

There are several agreements for supporting the ANPP staff by external contractors in case of emergency. Analytical, recommendatory, engineering, as well as logistical support to the ANPP is available through its cooperation with the Regional Crisis Centre (RCC) of World Association of Nuclear Operators Moscow Centre (WANO MC) VVER NPPs. At national level, functions and duties of various authorities of Armenia involved in population protection in nuclear and/or radiation accidents at ANPP are specified in the External Emergency Plan, issued as a governmental decree in 2005.

All the above mentioned arrangements and provisions are mainly related to DBAs and are not fully adequate for coping with more severe situations.

There are three types of exercises organised:

- 3 times a year, exercises at ANPP level only
- Once a year, an exercise involving also ANRA and relevant national organisations
- Once every three years a large exercise at national level plus WANO MC crisis centre

During the country visit the following list of the major emergency exercises performed at country level after Fukushima accident was provided to PRT:

- 12.11.2012 Earthquake, SBO for 12 hours, SG diesel driven pump failure for 12 hours, fuel damage in reactor core up to 20%.
- 27.03.2013 Earthquake, SBO, multiple failures (TG-3 fire, 2 SG-5 Primary to secondary leak, LOCA 40mm, ESWS failure, DWST piping failure, loss of demineralized water inventory in Chemistry Department, outlet channel rupture that leads to reduction of water level by 0.5 m/hour), fuel damage in reactor core up to 20%.
- 17.06.2014 Strong north-west wind. Spurious opening and failure to close PRZ SV. Power grid collapse. Earthquake. Short circuit and fire on both busbars of reliable power supply category II from DG. Fuel damage in the reactor core up to 10%.
- 22.06.2015 Earthquake over intensity 9 according to MSK-64. SBO. Leak from spent fuel storage pools of Unit 1 and Unit 2. Fuel damage in spent fuel storage pools.

These exercises are covering all important aspects related to Fukushima lessons learned.

Procedures and guidelines for accident management

At present, the accident management of the ANPP Unit №2 is solely based on the existing event based EOPs, which have the main objective to restore core cooling. They include both, procedures for BDA and BDBA. However, only full power operation is covered by the existing EOPs. Low power and shutdown states are not included there. EOPs for SFPs of both units are also missing. Development of symptom oriented EOPs and SAMGs for full power is proceeding. SAMGs for shutdown states will be considered in the future revision.

Hardware provisions for severe accident management

Most of the hardware provisions are currently still only under development.

Provisions already available at the ANPP site, originally not dedicated for severe accident management but with a potential to be used for, are the following:

- various resources of fuel for DGs (for operation of DGs from 27 hours to 14 days),

  There is one emergency diesel tank at ANPP site. The emergency diesel tank holds enough fuel for 7 days of EDGs operation (four EDGs running at full nominal power). In case of LOOP one train of EDG (two DGs) is operated. It means that one train can operate 27 hours+14 days
- resource of borated water (800 + 800 m^3) to be used for primary circuit and/or SFP (*tanks of borated water of both units can be used*) injections,
- resource of demineralized water (2000 m^3) to be used for SGs feeding during more than 15 days,
- electrical batteries supplying electrical power to vital equipment during at least 7-8 hours,
- Containment Spray System (CSS) reducing containment pressure and preventing or at least limiting opening of containment pressure relief valves/flaps, thus reducing the leak rate, however current CSS capacity and availability during severe accident are limited;
- instrumentation systems for monitoring 6 of 7 key plant parameters (core temperature, pressure in the primary circuit, water level in SGs, pressure in the containment, water level in the containment sumps and dose rates on the site), but their full implementation in the Post

Accident Monitoring System (PAMS) and assessment of survivability in severe accident and BDBA conditions is still needed;

- communication and information systems for internal (a radio-station with back-up batteries available several hours also in case of SBO, internal phones with back-up batteries for 24 hours, mobile phones for 2 hours of active communication or 8 hours in stand-by mode), and external communication (radio-relay communication from ANPP to Armatom Institute and to the Ministry of Territorial Administration and Emergency Situations running on own batteries for 4 hours and a high-frequency and radio-relay communication from ANPP to Energy Grid central Control Service, belonging to the 1st category reliable power supply of the equipment thus charged from DGs and batteries).

Evaluation of factors that may impede accident management

Several factors which may impede accident management have been identified by the licensee and the Armenian regulator. An extensive destruction of infrastructure around the ANPP may hinder accessibility of the site. Local equipment consisting of various pieces of specific machinery (e. g. 2 bulldozers, 2 excavators, a motor grader, 6 special fire trucks, etc.) is foreseen to recover the ANPP site accessibility. An external support, e. g. from the army, can be requested as well. Based on information provided, loss of communication system availability after 24 hours of SBO event has to be considered.

Possible restrictions of habitability of MCR, BCP and MCC and of radioactivity monitoring, caused by excessive radioactive dose rate or contamination, have been indicated and correction measures are being implemented.

Influence of some other factors should be further investigated. Unavailability of power supply sources during severe accident has to be taken into account in the frame of developing and implementation of SAM. Survivability of instrumentation needed for SAM must be proved for thermal-hydraulic and radiation conditions in the severe accident domain.

Accident management for events in the spent fuel pools

The SFPs of both units (i.e. the operating and permanently shut-downed one) are located in the common reactor hall, outside the containment. Procedures and guidelines to manage accidents with fuel melting in the SFPs are not available so far. Implementation of SFP guidance is expected in the future revision of ANPP Unit №2 SAMGs.

7.2.2 Margins, cliff edge effects and areas for improvements

The analysis of the SBO scenario showed the key role of the diesel driven pump for the steam generator emergency feedwater system. If this system is available there is a large time margin (169 hours, i.e. 7 days) between reactor shutdown and core heating up (calculated with RELAP 5 Mod 3.2). Any alternative device which is able to fill in water into steam generators would result in the prolongation of time between reactor shutdown and the start of core degradation.

The existing measures at ANPP allow increasing the time margin between reactor shutdown and start of core heat-up in case of SBO. Without possibility to re-fill diesel fuel to extend the operation time of the diesel driven pump of the auxiliary feedwater system core heat-up will start after 33 hours in case of SBO and time margin between reactor shutdown and failure of the reactor vessel is about 39 hours.

In the worst case of a SBO scenario, when the diesel driven pump for SG feedwater supply is not available from the beginning, the time margin between reactor shutdown and start of core heating up beyond maximum acceptable value was, depending on the initial reactor power, shortened to 6-11 hours. For a long lasting SBO scenario and the current operating power (92% of the nominal one), the time margin between reactor shutdown and failure of the reactor vessel is about 15 hours (calculated with MELCOR 1.8.6).

Timely depressurization of the reactor by the safety valve of the pressurizer will be included in the SAMGs, to avoid various negative aspects related to a possible vessel failure at high pressure (damage of the containment pressure relief valves or containment rupture).

Strong points, good practices

The existing co-operation with the RCC of WANO MC through which engineering and logistical support might be arranged can be indicated as an important measure supporting experience and training for dealing with emergency situation and for development and implementation of accident management.

There are numerous planned or on-going improvements identified as results of various international missions (mostly organized or supported by IAEA) and/or identified by the licensee and the regulatory authority as an outcome of the stress tests. These improvements show competence and awareness within ANPP and ANRA of the problems associated with severe accident management.

Weak points, deficiencies (areas for improvements)

Adequacy of the existing management measures for various phases of an accident scenario with a loss of core cooling function was assessed in the Armenian STs and reported in the NR.

The development of a complete set of symptom oriented EOPs is almost completed and development of SAMGs is currently in its final stage but for the moment ANPP is still relying only on event oriented EOPs.

Various severe accident management improvements have been proposed. But in most cases only an evaluation is planned or has been started so far, it is not clear which measure finally will be considered as feasible and selected for implementation, and what schedule or time frame for implementation can be expected.

7.2.3 Possible measures to increase robustness

Upgrading of the plants since the original design

Various safety re-assessments followed by implementation of some safety improvements were introduced to ANPP through its life time. Some were initiated after a major fire at ANPP in 1982, some after the Chernobyl accident in 1986 and others in relation to the restart of the unit 2 in 1995. A comprehensive list of technical measures aimed to improve the design level of safety, reliability and operating culture of the ANPP Unit №2 was implemented between 1996÷2012. Some of the measures are related to accident management. Examples of the most important ones are listed below:

- Replacement of pressurizer safety valve to improve the reliability of valves and the possibility to implement the feed and bleed procedure,
- Installation of equipment to detect primary to secondary leaks on the basis of the nitrogen-16 principle,
- Installation of an equipment diagnostic system at the ANPP, according to the leak-before-break concept ,
- Replacement of the obsolete radiation monitoring system,
- Implementation of a new system of ventilation, air conditioning and emergency filtration for the MCR, and a control room protection against flying objects,
- Establishment of a back-up control panel
- I&C implementation for post-accident monitoring at the ANPP Unit 2.

Ongoing upgrading programmes in the area of accident management

Based on the results of deterministic and probabilistic safety analyses, as well as operating experience, the concept of modernization of the units with the purpose to significantly improve their safety has been developed. Currently, implementation of the identified technical measures summarised in the safety enhancement program (see chapter 7.1.3) is in progress. Some of the measures are related to accident management including beyond design basis and severe accidents.

There are measures focusing on upgrading and modernization of the hardware of the plant. These measures will allow either to expand the list of design basis accidents or to improve the capacity and/or reliability of the specific I&C and safety systems, or to cope with specific severe accident phenomena. The most significant hardware modifications are as follows:

- Installation of the new low pressure emergency core cooling system,
- Reconstruction of the spray system,
- Modernization of the in-core monitoring system,
- Installation of the system for monitoring presence of hydrogen generated in emergency situations,
- Installation of hydrogen recombiners.

There are also measures focusing on development of a relevant analytical base and improvement of operational documentation. The most significant measures of this nature are described hereafter.

Symptom based Emergency Operating Procedures (EOPs)

Development of a full set of EOPs (at full power and for shutdown states) based on Westinghouse Owners Group Emergency Response Guidelines (WOG ERG) is under way. The project is supported by the US Department of Energy with Pacific North National Laboratories and Argonne National Laboratories and by Ukrainian experts for specific VVER-440/270 aspects.

EOPs for shutdown mode were completed and have been verified and validated in 2015. EOPs for shutdown mode were submitted to ANRA for review in 2015. By end of 2016 it is expected that the final ANRA decision will be issued regarding this set of EOPs. EOPs for SFP are almost finalised and are expected to be submitted to ANRA by September 2016.

EOPs for power mode were completed and have been verified and validated in April 2016. It is expected that ANPP will submit EOPs for power mode to ANRA in August 2016.

Severe Accident Management Guidelines (SAMG)

The development of SAMGs was recommended by IAEA mission in 2009. In the framework of the Comprehensive Modernization Program for ANPP-2, one task has been devoted to severe accident analysis aiming, among others, to support the development of SAMGs. It has been recommended to develop the complete list of potential severe accidents, to perform the analysis of these accidents and to develop the guidelines for accident management accordingly. The generic WOG SAMGs are adapted to VVER-440/270. The adaptation for ANPP Unit №2 is performed by Armatom Institute with support of the US Department of Energy. The first draft of some of the procedures is currently available. The objective was the implementation of SAMGs at full power for ANPP by the end of 2015. In the responses to the written questions of the PRT it was clarified, that development of SAMGs is still running, their validation is planned by August 2016 and thus SAMGs are expected to be finalized by the end of 2016. Currently the guidelines are reviewed based on the updated Analytical Justification Documents provided recently by ANPP Analytical Team. During July 2016 the final verification of the guidelines and their Technical Basis Documents must be performed at ANPP. Before mid-August the validation plan and validation scenarios must be prepared.

Additional information was provided to PRT during the country visit. It was explained, that validation of SAMGs will be performed through table top exercises and SAMGs will be prepared for the current plant configuration. In Vessel Retention (IVR) strategy is under analyse, preparatory phase in collaboration with Gidropress.

The development of shutdown SAMG or SAMG for SFP is planned but development has not stared yet.

After issuing the final versions of guidelines the Accident Management personnel training materials must be prepared (foreseen to be completed by end of 2016).

SAMGs are expected to be implemented in 2017 (exact period depends on the schedule of personnel training).

Transition between EOPs to SAMGs has been considered during the EOP development project.

The Technical Support Centre will be located in the MCC. During an accident around 34 people are gathering in the MCC.

Training of staff for responding to emergency

The training performed in training centre on basic principles (emergency situation, evacuation of people, etc.) is done by the fire brigades.

Training on EOPs and SAMGs are conducted. Training material exists for EOPs. Training of staff has been already started by the NPP.

ANRA approves the training program also for EOPs and certifies the involved staff.

7.2.4 New initiatives from operators and others, and requirements or follow up actions (including further studies) from regulatory Authorities: modifications, further studies, decisions regarding operation of plants

Upgrading programmes initiated/accelerated after Fukushima

The development of symptom based EOPs and SAMGs was recommended and/or initiated already before the Fukushima accident, but their preparedness is delayed by a year or more comparing to the original objective.

Possible acceleration and/or a new initiative may include:

- Enhancement of the Emergency Core Cooling System to ensure long time operation and reliable compensation of the higher leak rate. Introduction of an alternative low pressure core cooling system with independent power supply and water sources (ongoing)
- Implementation of measurement of hydrogen concentration in the containment (in preparation)
- Comprehensive analysis of hydrogen generation and implementation of measures to reduce hydrogen explosion probability(expected in 2017)
- Modernization of the Spray System (2 times 2 pumps) including implementation of interlocks to reduce the risk of deep sub-atmospheric pressures and to reduce oxygen inflow from outside. It is recommended to foresee measures to supply spray system components using mobile DG equipment. This ongoing project is expected to be completed in 2017.

Further studies envisaged

The NR identified the lack of measures and technical tools for severe accident management. The successful development, completion and implementation of the SAMGs, mentioned in the previous sections, partially dependent on the results of the following studies:

- Comprehensive analysis of hydrogen generation and implementation of measures to reduce hydrogen explosion probability;
- Implementation of measurement of hydrogen concentration in the containment. A project for hydrogen monitoring system implementation and is underway (US DOE financing is anticipated). It is expected that the order for the system will be issued by the end of 2016;
- Feasibility study for adding alternative sprays with independent source of energy (using a diesel driven spray pump) and water (borated water storage tank of Unit №1); Requested by ANRA but has not started yet
- Feasibility study and development of measures to maintain the degraded fuel inside the reactor pressure vessel by external cooling of the vessel (In Vessel Retention); 1st steps for feasibility study initiated
- Further improvement of containment tightness; ongoing process and reinforcement of action foreseen during next long outages in 2017 and 2018
- A detailed analysis of the possibility of hydrogen accumulation in the rooms outside the containment;

All mentioned studies are already included in ANPP modernisation program (see chapter 7.1.3)

Decisions regarding future operation of plants

See chapter 3.1

7.3 Peer review conclusions and recommendations specific to this area

Despite of various programmes of international aid and support, the progress in SAM programme development and implementation is quite slow and delayed in respect to the original schedules. Various essential issues are unsolved.

In respect to SAM the current level of safety of ANPP is clearly lower than the EU average. However, this level will increase in near term due to the introduction of SAMGs expected in 2017. Only in the mid-term, with the implementation of the activities pursuant to "Stress Tests" recommendations, ANPP can reach an acceptable level.

Therefore the PRT highly recommends carrying out all planned activities in respect to SAM (hardware and procedures/guidelines) as soon as possible.

Regarding SAMGs the development and implementation of guidelines for shutdown states and SFP should be initiated and finalised.

Regarding hardware modifications the following aspects should be treated in priority:

- Enhancement of the Emergency Core Cooling System
- Containment tightness
- Hydrogen monitoring and control
- Improvement of the containment spray system

8 MAIN CONCLUSIONS OF THE PEER REVIEW TEAM

Introduction

In the aftermath of the Fukushima accident, the EU has been a world leader in carrying out "comprehensive risk and safety assessments" (so called **"Stress Tests" (STs)**) of all its nuclear power plants

From the very beginning the EU has invited interested non EU countries as well to cooperate and to take part in the ST exercise. As an outcome of the meeting on 23 June 2011 with Commissioner Oettinger, Deputy Ministers of Energy and senior representatives of the Ministries of Energy and national authorities responsible for nuclear energy of the Republic of Armenia, the Republic of Belarus, the Republic of Croatia, the Russian Federation, the Swiss Confederation, the Republic of Turkey and the Ukraine, in cooperation with the EU, confirmed their willingness to undertake on a voluntary basis comprehensive risk and safety assessments ('stress tests'), taking into account the specifications agreed by the European Commission and the **European Nuclear Safety Regulators Group (ENSREG)** on 24 May 2011.

At that time Armenia was not ready to take directly part in the EU Stress Tests process like Ukraine and Switzerland did. But with the support of two projects financed by the European Commission in the frame of the **Instrument for Nuclear Safety Cooperation (INSC),** the **Armenian Nuclear Power Plant (ANPP)** and the **Armenian Regulatory Authority (ANRA)** started to prepare their ST reports with the intention to perform thereafter an independent Peer Review process to assess them.

As a result, in August 2015, ANRA submitted its **National Report (NR)** on the STs of the ANPP to the Directorate-General for Energy of the European Commission for peer review. As a result of the desktop review of the NR, around 200 written questions were posted by the **Peer Review Team (PRT)** and were answered by ANRA/ANPP prior to the PRT's country visit. In addition ANRA and ANPP provided several specific reports related to initiating events.

Similarly to the arrangements during the EU STs, the most relevant information available on the PRT was published on the ENSREG Website[27].

The Peer review took place in Armenia from the 20th to the 24th June 2016. A team of 10 EU experts (8 from EU Member states which had been nominated by ENSREG members and 2 from the European Commission) were forming the PRT. During this visit, the willingness to share information and the great openness in all discussions of ANRA and ANPP representatives in particular during the visit to the nuclear power plant is to be especially highlighted.

Peer Review Team's general comments on the Armenian National Report

The NR complies with the EU STs specifications. It did not cover volcanic hazards. Due to the specific geological situation in Armenia the PRT decided to integrate the review of volcanic hazards in the scope of the peer review. Adequate information regarding this additional topic was provided during the peer review.

The NR identifies cliff edge effects and presents a series of safety improvement measures.

[27] http://www.ensreg.eu/armenia-stress-test

After the Fukushima accident, the programme on safety improvement measures has been revised by ANRA. At present, ANPP is in the process of implementing this programme.

Similarly to other first generation Nuclear Power Plants (NPPs) the original ANPP design basis did not include most of the modern requirements. Nevertheless, the criteria against which the safety assessment was performed during the recent licencing activities and within the STs reflect some of the new requirements. It is nevertheless recommended that ANRA considers formalizing the requirements according to the WENRA Reference Levels, in particular the one related to severe accidents.

ANPP has never been subject to a Periodic Safety Review (PSR) in full compliance with the IAEA standards. Some issues that were found during the STs might be expected to have been identified (and eventually rectified) through a comprehensive PSR, as it is recommended by ENSREG. The PRT recognises that the obligation for conducting a PSR is established in article 20 of the Armenian Atomic Act, and that the PSR is expected to be undertaken following the completion of the licencing process for the life time extension. Nevertheless the PRT recommends to define the scope of the future PSR in line with IAEA standards and to include the review of site related phenomena.

Topic 1: ASSESSMENT RELATIVE TO EARTHQUAKES, FLOODING AND OTHER EXTREME WEATHER CONDITIONS

The geological situation of Armenia is characterized by its location at the collision zone between the Arabic and Eurasian tectonic plates with high crustal deformation rates, abundant active faults, and numerous quaternary volcanoes. This geodynamic framework and the past experiences with numerous severe earthquakes such as the 1988 Spitak earthquake require putting particular emphasis on seismic safety.

In the past, ANPP and ANRA have undertaken continued efforts to ensure and improve the seismic safety of the ANPP. The PRT appreciates this process, which is in line with the WENRA (2014) requirement of continuous improvement, and encourages proceeding with it. It is suggested to base the process on a set of comprehensive national regulatory requirements for external hazards, which should be developed considering the WENRA (2014) Reference Levels.

With respect to the protection concept for the current seismic design basis of the ANPP it appears that adequate protection against Design Basis Earthquakes (DBEs) with a horizontal Peak Ground Acceleration (PGA_H) = 0.35 g is presently in place and that some margins are available. The PRT, however, expresses reservations on the reliability of the current design basis value of PGA_H = 0.35 g. These reservations are due to the Probabilistic Seismic Hazard Analysis (PSHA) 2011 which revealed a DBE of PGA_H = 0.42 g for the occurrence probability of 10^{-4} per year. This value shall be considered as an updated ANPP design basis for planning and implementing improvement measures. Structures, Systems and Components (SSCs) important to safety shall be upgraded to this level.

The PRT further suggests to complement the 2011 PSHA by (i) with a review of the maximum magnitude M_{max} values which are regarded to be underestimated when compared to other recent seismic hazard assessments, and (ii) detailed investigations of the active faults close to the site using integrated paleoseismological techniques.

In respect to flooding, the “dry site concept” adequately protects against most external water sources. This is regarded as a strong safety feature. The rainfall design basis (1 year return period) value, which was based on Russian Standard (SNiP), is not consistent with current international standards. However, recent calculations have shown that the drainage system capacity could cope with a rainfall corresponding to a frequency of 10^{-4} per year.

The PRT recommends to consider improving the volumetric protection of the Diesel Generator System (DGS) basement against flooding. The PRT also recommends to consider improving the DGS basement drainage system to ensure that it can function adequately in all scenarios for which the Emergency Diesel Generators (EDGs) or the additional emergency cooling system (DAR) are needed (Loss of off-site power (LOOP), earthquake). Areas for potential improvements also include the provision of adequate mobile devices.

The PRT suggests defining clear design basis requirements for meteorological hazards and hazard combinations, which are based on the severity of design basis events with non-exceedance probabilities of 10^{-4} per year. Design basis requirements should be anchored in binding regulatory documents.

The PRT recommends to consider improving the robustness of the Demineralised Water System (BZOV) against low temperature up to the design basis (-40°C).

Vulnerabilities have been identified for external flooding and for extreme weather conditions. A number of possible corrective actions are under consideration by ANRA. The NR contains a list of measures to increase robustness, which have been already partly implemented. For the remaining measures an implementation schedule has been established by ANPP and monitored by ANRA. The PRT acknowledges and supports these measures.

The ANPP site is located in the vicinity of three capable, but currently inactive volcanoes. The site is subject to the hazards of pyroclastic density currents, lava flows, and opening of new vents, which are considered site exclusion conditions at the site selection stage according to the IAEA SSG-21. A high-quality volcanic hazard study completed in 2011 identified probabilities of about 10^{-6} to 10^{-7} per year for the listed phenomena. Effects of these hazards cannot be mitigated and are consequently considered as cliff edges.

The 2011 study further determined the probability of tephra fallout and pyroclastic projectiles with about 10^{-5} to 10^{-6} per year. The development of a protection concept for the existing NPP for these hazards appears to be feasible.

In order to increase the safety of the existing NPP the PRT recommends to develop plans to respond to potential volcanic activity at Ararat, Aragats, and the Shamiram plateau, and to establish a monitoring of these volcanoes in the framework of national civil protection programmes.

Topic 2: ASSESSMENT RELATIVE TO LOSS OF ELECTRICAL POWER AND LOSS OF ULTIMATE HEAT SINK

The VVER-440 reactors of ANPP belong to the so called “Generation I” reactor types. Nevertheless, the reactor type VVER-440, here as VVER-440 (V-270), possesses design features leading to a “sedate” operational as well as accidental behaviour. The design has some safety merits not found in most other types of PWR in operation. A large coolant inventory provides a valuable time buffer for corrective actions in abnormal events, where the balance between residual heat production and coolant supply has been lost.

It can be stated, that in the cases of Station Blackout (SBO) or loss of Ultimate Heat Sink (UHS), a graded approach exists, with measures which are pertinent in general to make ANPP relatively resistant in the case of these events. There are different actions planned to extend the available time for heat removal from the core and the Spent Fuel Pool (SFP), without need for any external action or support.

Nevertheless ANPP is located in a geographic region with high external hazards especially in respect to earthquake. Due to this fact it is an indispensable prerequisite for the reliable function of the SSCs necessary for the measures discussed above, that the integrity of these SSCs, flowpaths and buildings can be ensured and that their safety relevant active parts can be kept operational in case of such events.

With respect to the power supply, the PRT recommends the implementation of the intended improvements of safety systems necessary to cope with postulated events. The PRT recommends especially strengthening the fuel supply for the EDGs. The PRT also recommends to consider addressing the lack of diversity of the EDGs and DAR DG (same type, same building, same age), the ability for recharging the batteries and the assurance for cooling the SFP of unit 2.

It is further recommended that the improvement measures to increase the safety for LOOP, SBO and loss of UHS, proposed by the licensee and amended by the regulator are declared as mandatory, with defined schedules for their implementation.

Topic 3: ASSESSMENT RELATIVE TO SEVERE ACCIDENT MANAGEMENT

Despite of various programmes of international aid and support, the progress in Severe Accident Management (SAM) programme development and implementation is quite slow and delayed with respect to the original schedules. Various essential issues are unsolved.

With respect to SAM the current level of safety of ANPP is clearly lower than the EU average. However, this level will increase in the near term due to the introduction of Severe Accident Management Guidelines (SAMGs) expected in 2017. Only in the mid-term, with the implementation of the activities pursuant to "Stress Tests" recommendations, ANPP can reach an acceptable level.

Therefore the PRT highly recommends carrying out all planned activities in respect to severe accident management (hardware and procedures/guidelines) as soon as possible.

Regarding SAMGs the development and implementation of guidelines for shutdown states and SFP should be initiated and finalised.

With respect to hardware modifications especially enhancements of the Emergency Core Cooling System, containment tightness, hydrogen monitoring and control as well as containment spray system should be treated in priority.

Future outlook

The PRT considers it as necessary that ANRA develops a National Action Plan containing all identified safety improvement measures and schedules for their implementation. It suggests that the safety measures identified, including the implementation schedules, are established as regulatory requirements. The PRT further recommends that the National Action Plan should be reviewed in the same way as the National Action Plans of European countries.

9 List of acronyms

AC	Alternating Current
ANPP	Armenian Nuclear Power Plant
ANRA	Armenian Nuclear Regulatory Authority
BCC	Back-up Crisis Centre
BCP	Back-up Control Panel
BDB	Beyond Design Basis
BDBA	Beyond Design Basis Accident
BZOV	Demineralised water tank
CDF	Core Damage Frequency
CDFM	Conservative Deterministic Failure Margin
CSNO	Coolant System of Normal Operation
CSS	Containment Spray System
DAR	Additional emergency cooling system
DB	Design Basis
DBA	Design Basis Accident
DBE	Design Basis Earthquake
DBF	Design Basis Flood
DC	Direct Current
DG	Diesel Generator
DGS	Diesel Generator Station
DOE	Department of Energy
EC	European Commission
EDG	Emergency Diesel Generator
ENSREG	European Nuclear Safety Regulators Group
EOP	Emergency Operating Procedure
ERG	Emergency Response Guidelines
ERT	Emergency Response Team
ESWS	Essential Service Water System
EU	European Union
FSA	Fault Sequence Analysis
g	standard value of the gravitational acceleration (9,81 m/s^2)
HCLPF	High Confidence Low Probability of Failure
HPP	Hydroelectric Power Plant
IEP	Internal Emergency Plan
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
INSC	Instrument for Nuclear Safety Cooperation
ISFSI	Independent Spent Fuel Storage Installation
LOCA	Loss of Coolant Accident
LOOP	Loss of Off-Site Power
LTE	Life Time Extension
LTO	Long Term Operation
MCC	Main Crisis Centre
MCP	Main Circulation Pump
MCR	Main Control Room

MNPP	Metsamor Nuclear Power Plant
MRZ	Russian abbreviation for the maximum design earthquake (~ Safe Shutdown)
MSK	Medvedev–Sponheuer–Karnik
NAcP	National Action Plan
NPP	Nuclear Power Plant
NR	(Stress Test) National Report
PAMS	Post Accident Monitoring System
PGA	Peak Ground Acceleration
PNAE	Russian nuclear standard
PR	Peer Review
PRT	Peer Review Team
PSA	Probabilistic Safety Assessment (also known as PRA)
PSHA	Probabilistic Seismic Hazard Analysis
PSR	Periodic Safety Review
PWR	Pressurised Water Reactor
PZ	Russian abbreviation for design earthquake
RA	Republic of Armenia
RCC	Regional Crisis Centre
RLE	Review Level Earthquake
SAM	Severe Accident Management
SAMG	Severe Accident Management Guideline
SAR	Safety Analysis Report
SBO	Station Blackout
SEC	Second Emergency Cooling
SFP	Spent Fuel Pool
SG	Steam Generator
SNiP	Russian civil code
SPSA	Seismic Probabilistic Risk Assessment
SSC	Structures, Systems and Components
SSEL	Safe Shutdown Equipment List
ST	Stress Test
TH	Turbine Hall
TSO	Technical Support Organization
UHS	Ultimate Heat Sink
US	United States
US NRC	United States Nuclear Regulatory Commission
VSN	Temporary Russian civil code
VVER	Water Water Energetic Reactor
WANO	World Association of Nuclear Operators
WANO MC	World Association of Nuclear Operators Moscow Centre
WENRA	Western European Nuclear Regulators Association
WOG ERG	Westinghouse Owners Group Emergency Response Guidelines