Considering Fukushima lessons for the Budapest Research Reactor

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Abstract. Hungary participated in the stress test process of the nuclear power plants according to the specification laid down by the European Commission. In the mirror of experiences of the Fukushima Dai-ichi NPP accident the stress tests were meant to re-examine the design basis and the margins against beyond design basis events for NPPs including analysis of cliff-edge effects. In particular, the loss of heat sink, loss of external power and emergency power were assessed and the potential instruments for coping with severe accidents and emergency preparedness were put in the objective. The stress tests took place as a single, extra effort for the nuclear power plants, about which the licensees and the regulatory body summarized the results in national reports. The results were then reviewed by European expert teams including on-site examinations, workshops and review meetings. The conclusions were compiled in a National Action Plan. Concerning research reactors there have not been no such a single European effort. The methodology, however, could be applied to these facilities (and other fuel cycle facilities), at least concerning the assessment phase of the stress tests. Regarding the Budapest Research Reactor, the occasion to carry out the assessment came with the imminent Periodic Safety Review (PSR) that was due in 2012. In addition to the Hungarian legal requirements, the HAEA's practice is to issue a regulatory guideline to aid how to carry out the actual PSR of the facilities. In this case a separate chapter was dedicated to the post-Fukushima safety review of the Budapest Research Reactor where a short specification was provided on the contents of the assessment. The licensee then followed the instructions and performed the analyses according to the guidance of the regulator, which were finally assessed and approved at the end of the PSR process by the HAEA. The overall conclusion was that it did not reveal the need for any immediate action.
The paper summarizes the stress test methodology followed in Hungary, the PSR requirements for research reactors including the post-Fukushima chapter added in 2012, the analyses results and the conclusions of the Licensee and the corresponding HAEA assessments.

1. Introduction

1.1. The Hungarian Nuclear Programme

The Hungarian Nuclear Programme consists of a nuclear power plant, two research reactors, a spent fuel interim storage facility and two low and medium level waste storage and disposal facility.
The four units of the Paks Nuclear Power Plant is of Russian design, commissioned in the 80s and are now entering the extended license period.
The Budapest Research Reactor was commissioned in 1959. Its history is summarized below.
The Training Reactor of the Budapest University of Technology and Economics was commissioned in 1971; it is a pool type reactor of 100 kW thermal power. It was designed and constructed by Hungary; it uses Soviet design fuel (EK10) of 10% enrichment. It passed its third periodic safety review in 2017 based on which it received an operating license until 2027.
The Spent Fuel Interim Storage Facility located next to the NPP was commissioned in 1997 to receive the spent fuel of Paks NPP for an interim storage of 50 years. Before that the spent fuel was transported back to Russia. The dry storage type facility can be extended on a modular manner as spent fuel is generated and transported from the plant.
The Radioactive Waste Treatment and Disposal Facility is meant to dispose the institutional wastes from the industrial, medical, scientific, agricultural, etc, applications. It is a near

surface disposal facility commissioned in 1971, it is now undergoing a safety improvement programme which foresees the reconditioning of the waste.
The National Radioactive Waste Repository is designed to receive the low and intermediate waste of the NPP. The geological disposal takes place at a depth of a few hundred meters. The facility was commissioned in 2008.

1.2. Regulatory oversight

In Hungary the use of atomic energy is governed by the Atomic Act of 1996, under which a set of governmental decrees and other regulations specify the conditions of the use. The Hungarian Atomic Energy Authority (HAEA) established in 1991 is responsible for the oversight of the safe use of atomic energy. The scope of oversight incorporates nuclear safety and security of peaceful use as well as radiation protection from 2016. In terms of type of applications the HAEA oversees the nuclear facilities, radioactive waste storage and disposal facilities as well as all users of nuclear and other radioactive material and ionizing radiation.
The HAEA issues licenses for the various stages of use, inspects the compliance with the regulations, reviews and assesses the safety and security performance on a regular basis and enforce the compliance should any breach of the regulations take place.

1.3. Budapest Research Reactor

The Budapest Research Reactor (BRR) is a Soviet design and construction reactor, commissioned in 1959 and operated by the Hungarian Academy of Science Centre for Energy Research. It is a tank type reactor with beryllium reflector. Fuel is provided by Russia (VVER-SM). All the HEU fuel (enrichment: 36%) was repatriated to Russia by 2012, currently the reactor uses only LEU fuel. The reactor has undergone two major refurbishments that resulted in a thermal power increase from 2 to 10 MW and significant safety improvements. The latter one took place between 1986 and 1990 and covered the replacement of all equipment except for the civil structures. The reactor received the operation license in 1993 which is of unlimited duration but subject to Periodic Safety Reviews taking place every ten years. Currently the reactor has operating license until 2023.
The reactor serves high neutron flux for the Budapest Neutron Center [www.bnc.hu] that is the owner of the scientific experiments and equipment around the reactor. It is used for material testing purposes (e.g. reactor materials), activation analysis, neutron scattering and diffraction, radiography and tomography, gamma spectroscopy, x-rey fluorescence etc. It has also a cold neutron source. There are altogether 60 vertical irradiation channels, 8 radial and 2 tangential beams. Isotope production is also among the most important tasks.
The Centre for Energy Research, supported by the operation of the BRR is the focal point in Hungary for research in nuclear energy and nuclear safety.

2. Post-Fukushima Stress Tests in Hungary

After the severe nuclear accident in Fukushima in 2011 the European Council decided to carry out an integrated risk and safety review of the nuclear power plants in the European Union. The European Nuclear Safety Regulators Group (ENSREG) elaborated the methodology [1] for the reviews that were implemented in all European Union and some neighboring countries. The process was called European Stress Tests after a methodology established for the bank sector for extreme financial scenarios. In Hungary the review process was officially renamed to Targeted Safety Re-Assessment (TSR) [2]. The reassessment was completed in 2011 and a

national report [3] summarized the results for Paks NPP, as in the case of all other countries participating the Stress Test process.
The reassessment basically focused on the following items:

- issues corresponding to earthquake and flooding and other external natural hazard factors: on the one hand the design basis of the plant had to be reviewed, while the margins beyond the design bases had to be assessed on the other hand taking into account the potential for cliff-edge effects;
- loss of electric power supply and loss of ultimate heat sink or combination of those: what margins exist from the aspect of maintaining safety functions, what timeframes and which tools are available to recover the situation;
- severe accident management: what organizational preparedness and tool sets are available during an extreme natural disaster and when more than one unit is affected

There was an international peer review component of the reassessment process consisting of three steps: 1. expert teams were formed to review the national reports, then 2. dedicated missions visited the countries and the plants to better understand the situation and finally 3. a national review was done in the 3 topics above, when the results had to be presented to expert teams. Based on the results the countries were required to develop a National Action Plan [4], which were then also subject of an international peer review. In addition workshops were organized to share the results with the progress. The National Action Plan of Hungary is regularly updated since [5] and the tasks are approaching to full completion by the end of 2018.

3. Using post-Fukushima experience for the Budapest Research Reactor

Concerning research reactors there has not been such a single European effort to review nuclear safety. The methodology, however, could be applied to these facilities (and other fuel cycle facilities), at least concerning the assessment phase of the stress tests. Regarding the Budapest Research Reactor, the occasion to carry out the assessment came with the Periodic Safety Review that was due in 2012.

3.1 Periodic Safety Review of nuclear facilities

In Hungary all nuclear facilities are obliged by the Act on Atomic Energy [6] to carry out a Periodic Safety Review together with the nuclear safety authority every 10 years. The purpose is to reassess the nuclear safety of the facility, compliance with licensing basis and the level of risk. The licensee shall perform its own review and develop and execute a programme based on the review results to implement safety improvement measures aimed at the elimination or mitigation of the risk factors revealed by the review. The licensee shall submit to the nuclear safety authority a Periodic Safety Review Report summarizing the findings and decided actions.

On the basis of the Periodic Safety Review Report the nuclear safety authority may revoke or limit the validity of the operation license. The resolution of the authority may also set new conditions or obligations for the operation. The authority also orders for implementation of necessary safety improvement measures and approves any deviation identified.

The detailed requirements on the PSR are described in the Nuclear Safety Code (NSC) [7], where a minimum list of the scope is also provided. According to the expectations the practice of the facility shall also be compared to the best international practices, the results of science and technology and the operating experience of the past period shall also be reviewed. The safety significance of the deviations identified during the review shall be evaluated and this should be the basis for the improvement actions.

The scope of the review should be the broadest possible and in general the evaluation of changes of the plant conditions should take place and all the results should be documented in the Final Safety Analysis Report, as necessary. As part of the review a main item is the reassessment of external and internal hazards.

The NSC also requires the authority to publish a guideline in order to facilitate the review process.

3.2. Guidelines on Periodic Safety Review of the Budapest Research Rector

In the practice of the HAEA separate guidelines are published for all PSRs of each facility. Concerning the PSR of the Budapest Research Reactor in 2012 the guideline [8] was sent to the licensee in the beginning of February 2012. The reference time of the PSR was fixed to 31 December 2011, while the period to be reviewed was set to 2002 March to 2012 March in order to be adjusted to the campaigns of the reactor. The guideline contains detailed expectations on the PSR volumes foreseen by the NSC.

The guideline tells that in Volume 3 Safety Analysis of the PSR there should be a separate chapter on the review of severe accident analysis in the mirror of the Post-Fukushima targeted safety reassessments with the below structure. In addition all piece of experiences of the accident should be reviewed if being relevant for the Budapest Research Reactor.

- Analysis of potential for occurrence of the most severe events (key events) based on the Fukushima experience;
- Causes of occurrence of key elements should be analyzed;
- Possible prevention and response to key events should be described;
- Consequences if the prevention of or response to key events are unsuccessful should be described.
- On-site management of the consequences of key events should be described.

An attachment to Volume 3 should be prepared with the following structure:

F1. Potential external causes of occurrence of key events
F1.1 Assessment of external causes of key events
F1.2 Earthquake
F1.3 Loss of cooling of active core due to external and internal causes
F1.4 Other extreme environmental effects
F2. Possible methods of prevention and/or response to key events
F2.1 General issues of prevention and response methods
F2.2 Specific issues of prevention and response methods
F3. Possible consequences of uncontrolled key events
F4. Management of consequences of key events
F4.1 General issues of severe accident management
F4.2 General issues of severe accident management
F5. Possible actions to improve management of severe accident situations

3.3. Conclusions of the PSR of the BRR on Fukushima experience

Chapter 3 of the Periodic Safety Review of the Budapest Research Reactor [9] contains the description how the safety analyses of the facility were reviewed, the main attributes of the analyses included in the Final Safety Analysis Report [10]
Budapest Research Reactor was designed based on the defense in depth concept, accordingly it has systems to prevent deviations from normal operation, to prevent an event to initiate an accident and to respond to accidents and reach a stable final state.

Safety analysis of the Budapest Research Reactor

Accident analyses also cover beyond design basis and severe accident cases. A safety objective for the reactor is to prevent the dry out of the whole active core via the design of the reactor and the primary circuit and the temperature and pressure conditions. The safety systems of the reactor are protected against single failure in accordance with the nuclear safety requirements. The complete loss of them therefore is not required to be assumed during the safety analysis. In addition the design is such that if both trains of a redundant safety system become inoperable than a diverse system still can activate to fulfill the safety function. All event sequences with and without appropriate activation of the safety systems were analyzed. The facts that the cases when both safety trains are lost were also analyzed and that all event sequences were followed by calculation mean a very conservative approach. Because of being extremely conservative, it was not assumed for the deterministic analysis that more than two safety systems are lost. This case was only part of the PSA studies meant to develop the Emergency Response Plan.

Revision of safety analysis in the mirror of the Fukushima accident

The PSR covered the following items regarding the experience from the Fukushima-Daiichi accident:

- loss of ultimate heat sink,
- total loss of electric power supply (normal supply and emergency diesel generators),
- severe accidents,
- accidents during fuel element storage,
- severe accident management and emergency preparedness.

The cases were considered systematically one-by-one. Effect of physical properties of the reactor and its safety systems were reviewed on the examined processes. The results could be obtained much easier than for NPPs because of the difference in the size and the much simpler configuration of the safety systems.

Loss of ultimate heat sink

The ultimate heat sink of the BRR is the atmosphere via the primary heat exchanger and the secondary circuit. The atmosphere obviously cannot be lost, however loss of the regular path of the coolant was assumed. Decay heat is significant right after shutdown, which is to be removed

- via gravitational cooling,
- emergency pumps,

- gravitational tank.

The first case is a passive method, the pumps can be lost if the diesel generators are lost, while the third method needs an operator intervention (activation) but otherwise it is also a passive method.

After a shutdown cooling is performed via the passive gravitational system to prevent surface boiling of the most loaded fuel element portions. Later natural circulation and the free water surface of the reactor pressure vessel (and the surface of the vessels and pipelines) provide the cooling. This is required until 3 hours, after which local boiling could no more occur. Evaporation causes a coolant level decrease of 2.5 cm/h. The sprinkler system can make up the water after 32 hours of decrease (when the minimum limit of 80 cm is reached) during 2 hours of operation. The make-up water tank capacity is sufficient for 9 such make-up cycles.

Decay heat of the spent fuel is very low. The storage systems therefore do not need cooling. If the systems are intact, no intervention is needed. Since the fuel cladding is made of aluminum hydrogen production does not take place.

Safety systems of the BRR do not need water cooling, diesel generators have air cooling, so the loss of the ultimate heat sink even indirectly (i.e. through jeopardizing safety systems) cannot cause an issue.

Total loss of electric power supply

Total loss of electric power supply means loss of normal supply and loss of diesel generators. Electric supply of the BRR takes place from two directions. Loss of both of them at the same time could take place only in an extreme natural disaster. Switch from one to the other is a routine operation. Loss of both of them, however, is assumed in the accident analysis, but diesel generators in that case can cope with the situation.

Fail of diesel start up was examined during the PSR, since previously this was not documented in the FSAR [10]. Battery stations of the BRR can supply the connected systems for 24 hours. Electric supply is not required for the response even if the ultimate heat sink is lost. However in the case of a LOCA the refilling systems should operate (note: LOCA and loss of electric supply at the same time was not even assumed for the stress tests of the NPP), which need supply from the DGs and cannot be supplied from the batteries. According to the FSAR primary LOCAs are very improbable, because of the material of the pipelines (aluminum) and the low (hydrostatic) pressure within the pipelines. A break due to unknown cause should be assumed for the examination. It is strongly questionable if a large break LOCA is possible at all due to technological reasons or if an extreme event can lead to such a process. Further multiple failures need to be assumed in order to exclude the possibility to switch over to the communal water system or to the fire water system and to obtain a core melt scenario. These are very improbable scenarios.

Spent fuel storage does not need electric supply, thus loss of it will not cause a problem in this respect.

Severe accidents

Severe accidents from a technological reason can be practically excluded because of physical reasons and the configuration of safety systems (refilling systems, water seal of the reactor cavity, excludable pipe sections). In practice consequence mitigation type accident management is implemented via these systems.

However, extreme natural phenomena still may cause a severe accident. According to the FSAR [10] the extreme strong earthquake is the only hazard which can jeopardize the safety of the reactor by causing a loss of primary coolant and leading to severe accident. (Note: crash of a big aircraft and malevolent acts may also cause similar effects, but this was not required to be taken into account in the PSR). Effects of flooding and fire can be managed according to the FSAR. The reactor is designed to 0.15 g earthquake, safety shutdown could take place in this case and the reactor hall with the reactor and the pump house would remain intact. Automatic shutdown is set to even lower PGA values. For larger earthquakes the intactness of the reactor hall would be probably lost. Conclusions in terms of coping with earthquakes:

- core damage could be prevented if the reactor can be kept under water for at least 4 hours,
- core dry out will never cause complete core melt,

If damaged pipeline can be excluded or repaired then the water level can be retrieved for which the personnel are prepared: special repair methods are available that can be implemented within a timeframe not causing higher than allowed doses to the personnel. However an extreme earthquake

- may cause damage to the communal water lines which means that cooling cannot be provided,
- would damage the buildings and therefore decrease any containment function (filtering through the stack would not take place).

Even in this case the doses would not justify any off-site action, but the site should be evacuated.

Fuel storage accidents

As it was described above, cooling of the internal spent fuel storage is passive, the loss of ultimate sink is irrelevant, loss of electric power supply has no effect on cooling. The only critical phenomenon is the loss of coolant. According to the FSAR [10] this is excluded by the material selection, construction and realization of the internal storage.

Fuel melt should not be considered even if total loss of the coolant from the internal storage, at maximum some of the fuel elements would damage. The time for loss of the coolant is 1-1,5 hours. The personnel can intervene via activating the make-up water (passive) system and closing the valve of the outlet line. These actions can be executed in 40 minutes.

Regarding earthquakes the analysis showed that the structure of the storage will remain intact. Loss of coolant due to stronger earthquake cannot be excluded.

Regarding the external spent fuel store, the structure will remain intact even in the case of extreme earthquakes and due to the low decay heat the heat up would take place during a very long time after loss of coolant.

Severe accident management and emergency preparedness

SAM and emergency response actions are part of the operational programmes of the plant which mean that these are trained and exercised for the personnel as well as the necessary equipment is available. The planning basis of these arrangements was extreme situations including internal and external hazards as described in the FSAR [10].

Summary of PSR Volume 3

The review has demonstrated that the BRR is prepared for coping with the loss of ultimate heat sink, total loss of electric supply and managing severe accidents. Severe accidents are extremely improbable, only could occur due to extreme earthquakes or similar events. Since these events would damage the reactor building as well, there would be environmental impact, although just within the site area.

In conclusion, partly due to the physical properties and partly due to the former safety improvement actions the BRR had been prepared for similar event even before the Fukushima accident took place. Consequently no additional safety improvement action is necessary.

3.4. Regulatory conclusion regarding the post-Fukushima review of the BRR

The HAEA evaluated the assessments of the BRR in the frame of reviewing the PSR report of the licensee [11]. The conclusion tells that Volume 3 of the PSR report summarizes the analysis concepts, methods and actuality of the safety analysis. It does not really contain new elements apart from the Fukushima considerations. These supplementary examinations did not reveal any new hazards or safety vulnerability. The relevant FSAR chapters are still valid, therefore the conclusions of the licensee are acceptable for the existing analysis. Regarding the post-Fukushima parts, the Licensee's conclusions were accepted also taking into account a graded approach in relation to the depth of expectable analysis for the research reactor.

4. Summary

Hungary took part in the European Stress Tests process for nuclear power plants. The methodology downscaled to research reactors was applied to reassess the safety of the Budapest Research Reactor during the Periodic Safety Review carried out in 2012 and 2013. The results of the reassessment showed that the considerations from the Fukushima experience do not justify any additional safety improvement actions at the Budapest Research Reactor because either the extreme situations are not relevant for the facility or the reactor safety features are sufficient and appropriate to cope with such an accident phenomenon.

5. References

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