Lessons not Learned from the Fukushima Accident

Risks of the European NPPs

10 years later

Study commissioned by Greenpeace

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Content

1 INTRODUCTION

The March 2011 accident at the Fukushima Dai-ichi nuclear power plant proved that it was not justified to exclude highly unlikely accidents from happening. In a prompt reaction to this catastrophic accident, the European Council concluded in March 2011 that the safety of all EU nuclear plants should be reviewed on the basis of a comprehensive and transparent risk and safety assessment ("stress tests"). The EU Nuclear Safety Regulators Group (ENSREG) took over this task. (WENISCH 2012)

However, two month later the scope of the EU stress tests was reduced: The EU stress tests were defined as a targeted reassessment of the safety margins of nuclear power plants developed by ENSREG, with contributions from the European Commission. The EU stress tests comprised three topics:

1. The response of a nuclear power plant when facing different extreme situations (earthquakes, floods and extreme weather events, and the combination of events),
2. Capabilities to cope with consequences of loss of power (Station Black-out – SBO) and loss of heat removal via Ultimate Heat Sink (UHS),
3. Capabilities to prevent major radioactive emissions in case of a severe accident: the Severe Accident Management (SAM).

The stress tests revealed a number of shortcomings regarding the plants´ capability to withstand several external hazards and the lack of possibilities to cope with the consequences. By the end of 2012, the national regulators had provided National Action Plans (NAcPs) to remedy the identified shortcomings during the EU stress tests process.

By 31 December 2014, each country was obliged to update its original NAcP to reflect developments since its issue and the current status of the measures and their implementation. The updated NAcPs have been published on the ENSREG website. Since 2015, some countries have released several updates and some countries have not released any updates of their NAcPs.

By assessing eleven nuclear power plants in nine countries, we want to answer the question of lessons learned from Fukushima. This study[1] looked for each plant into the recommendations made by the ENSREG team and how they have been implemented until now, whether they will be realized or delayed or simply ignored. It also sheds light on the issue of safety culture and the determination of the responsible nuclear authorities to enforce it**.** At the same time "good practices" are not discussed, because the ENSREG reports described them in detail. This study presents the weaknesses and omissions and focuses on the hard facts of the nuclear safety level achieved after completion of the stress tests. These evaluations do nott intend to be exhaustive, but the findings contribute to a more comprehensive understanding of the risk of nuclear power plants in Europe.

Scope of the Stress tests

It is important to understand that the EU stress tests could not take into account all key safety issues such as the capability to prevent accidents – the scope of these tests was not designed to deliver a comprehensive risk assessment. Too many factors were not taken into account – most importantly ageing, obsolescence of the design, safety culture and vulnerability against terror attacks. Thus it is important to underline that the EU stress tests cannot be understood as a comprehensive safety check of the NPP in Europe. (WENISCH 2012)

To show a more complete picture of the safety respectively risk of the NPPs, examples of further safety and security issues are presented. Reference is also made to the topics briefly described below.

[1]This study based on three studies already performed on this topic (WENISCH 2012; BECKER 2013, 2015).

WENRA Safety Reference Level

One of the objectives of Western European Nuclear Regulators Association (WENRA) is the development of a harmonized approach to nuclear safety and regulation in Europe. A significant contribution to this objective was the publication of a report on harmonization of reactor safety in WENRA countries in 2006. This report addressed the nuclear power plants in operation, and it included “Safety Reference Levels”, which reflected expected practices to be implemented in the WENRA countries. The RLs were updated in 2007 and again in 2008.

In 2014, WENRA published a revised version of the RLs for existing reactors developed by the Reactor Harmonisation Working Group (RHWG). The objective of the revision was to take into account lessons learned of the TEPCO Fukushima Daiichi accident. (WENRA RHWG 2014a)

A major update of the RLs was the revision of Issue F "Design Extension of Existing Reactors" introducing the concept of Design Extension Conditions (DEC). Occurrence of conditions more complex and/or more severe than those postulated as design basis accidents (DBA) shall be investigated as Design Extension Conditions (DEC) so that any reasonably practicable measures to improve the safety of a plant are identified and implemented (RL F1.1). RL F1.2 defines two categories of DEC: DEC A for which prevention of severe fuel damage in the core or in the spent fuel storage can be achieved; and DEC B with postulated severe fuel damage.

Very important is also Issue T “Natural Hazards” of the updated RL 2014.

WENRA RHWG (2020a) reports on the implementation of the revised RLs in the national regulatory frameworks of WENRA countries.

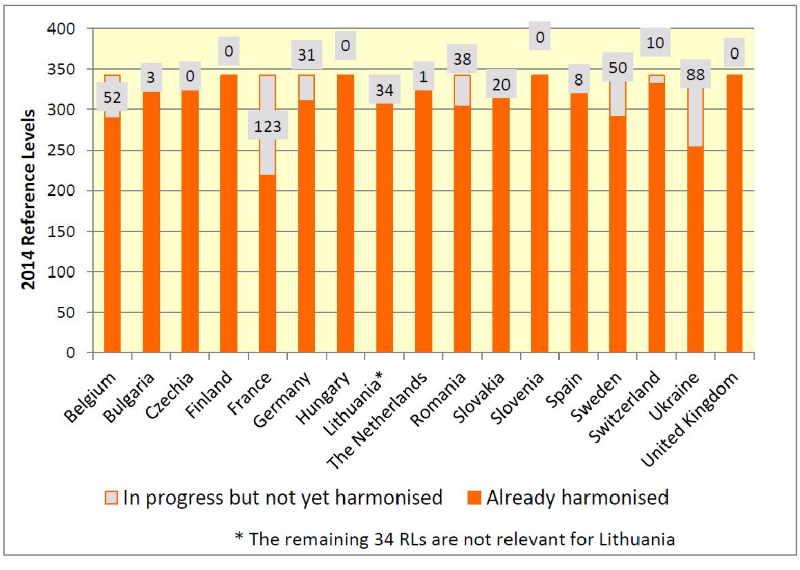


Figure 3: Reported status of implementation of 2014 RL in 2020 (WENRA RHWG 2020a)

If the Reference Levels, which reflect the safety requirements learned from the accident in Fukushima, are not implemented in the regulations, the operators are not obliged to retrofit the plants accordingly. The plant is then considered "safe" in the respective country because it meets the outdated safety requirements in the regulations.

Topical Review of Ageing Management

The Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM (EU 2014) has been carried out in 2017. The first TPR focused on the Overall Ageing Management Programmes and four thematic areas: electrical cables, concealed pipework, reactor pressure vessels and calandria, and concrete containment structures. All participating countries made a self-assessment and reported results in their National Assessment Reports. In the course of the TPR, national results have been evaluated through the peer review process, complementing the national assessments. The review identified generic findings, namely good practices and expectations to enhance ageing management (ENSREG 2018):

- Good practice is an aspect of ageing management which is considered to go beyond what is required in meeting the appropriate international standard.
- TPR expected level of performance for ageing management is the level of performance that should be reached to ensure consistent and acceptable management of ageing throughout Europe.

IAEA Safety Reviews

The purpose of an IAEA Operational Safety Review Team (OSART) of international experts visit is to review operating practices. OSART missions in general review performance in the following areas: Management, organization and administration; training and qualification; operations; maintenance; technical support; operational experience feedback; radiation protection; chemistry; emergency planning and preparedness; severe accident management.

Another IAEA Peer Review is also important in regard of LTO: A Safety Aspects of Long-Term Operation (SALTO) peer review is a comprehensive safety review addressing strategy and key elements for the safe LTO of nuclear power plants. SALTO missions complement IAEA Operational Safety Review Team (OSART) missions. SALTO peer reviews can be carried out at any time during the lifetime of a nuclear power plant, though according to the IAEA the most suitable time lies within the last 10 years of the plant's originally foreseen operating period. The peer review addresses the strategy and key elements of long-term operation (LTO) and ageing management programs.

It is good practice that different IAEA Peer Review Missions take place regularly. The resulting recommendation and suggestions should be realized in a timely manner. It is very important that the whole procedure will be performed in a transparent procedure.

The Nuclear Threat Initiative (NTI)

The Nuclear Threat Initiative (NTI), a US NGO, ranks measures taken by countries to reduce the risk of sabotage in its Nuclear Security Index. The index ranks countries based on a range of nuclear security measures by analyzing factors such as government policy and regulation. It does not conduct direct observations of security measures at individual sites. (NTI 2020)

For the first time, the 2016 NTI Index assesses nuclear security conditions related to the protection of nuclear facilities against acts of sabotage. This ranking includes in 2020 47 countries where an act of sabotage against a nuclear facility could result in a significant radiological release similar in scale to the release in Japan in 2011 when a tsunami hit the Fukushima Daiichi Nuclear Power Plant. The sabotage ranking also found that although some states have been taking steps to protect their nuclear facilities from cyber-attacks, many are still unprepared to deal with cyber-attacks that might lead to sabotage. In the NTI Index scores of 0 and 100 represent the lowest or highest possible score, respectively; as measured by the NTI Index criteria. More details about the scores of the specific countries are given in the specific chapters.

A threat of terrorist attacks must also be taken into account for an overall assessment of the existing risks posed by a nuclear power plant. It should be noted that the risks for old nuclear power plants are particularly high due to the existing design deficits.

2 ALMARAZ, SPAIN

The nuclear power plant Almaraz comprises two Westinghouse three-loop pressurised water reactors (PWR). Almaraz 1 with a net capacity of 1011 MWe and started commercial operation in 1983, Almaraz 2 (1006 MWe) in 1984.

The site is located on the left bank of the Arrocampo brook reservoir, 180 km west-southwest of Madrid. The NPP is situated about 100 km from the border to Portugal. Upstream from the site is the dam – Valdecañas –, halfway down the course of the River Tagus.

In March 2019 the owners – Iberdola, Endesa and Naturgy – announced that they intend to request a license renewal until November 2027 and 2028 for the units 1&2 respectively. The license for extended operational time was granted in May 2020.

2.1 Spanish National Action Plan (NAcP)

To implement all the Stress Test results in the Spanish nuclear power plants, the Spanish Nuclear Safety Council, Consejo de Seguridad Nuclear (CSN) issued a binding complementary technical instruction (ITC-STs) for each of the licensees. The ITC-STs sets an implementation schedule which is divided into three periods: short, medium and long-term, i.e. periods ending in the years 2012, 2014 and 2016 respectively. The 2012 Spanish National Action Plan (NAcP) was set up to structure the necessary upgrade measures. It contains 39 actions to be taken: five "generic requirements", 25 "improvement implementations" and nine cases for which "additional analysis" is needed. (CNS 2012)

The 2014 updated NAcP announced a delay in the evaluation of the earthquake and flooding hazards and in the implementation of the containment filter venting system. (CSN 2014)

The ENSREG Peer Review Team considered the implementation schedule for the planned improvements as being appropriate, but highly demanding in terms of completing the necessary upgrades. They recommended reinforcing the Spanish nuclear regulator CSN's technical assessment of human resources. The regulator announced its plan to ask the Spanish Government for increased funding to properly manage human resources. However, the CSN increased the number of staff only for three years (2011-2014) to reinforce the capacity for a timely evaluation of the issues raised by the Fukushima accident.

The ENSREG Rapporteurs' report of the 2015 workshop noted that *"By the end of 2014 practically all the planned analyses have been completed by the licensees, but in many cases the review by CSN is not completed yet. In these cases where the analysis results are still being reviewed by the regulator, the related modifications are being implemented – or even finished – by the licensees"*. This is remarkable. Even more remarkable is CSN's reply: Since they constitute a safety improvement most of the design modifications carried out as a result of the stress test didn't need the explicit approval by CSN and the Ministry of Energy, Tourism and Digital Agenda (Minetad). **This is a very unusual approach the nuclear safety authority decided to take. The regulator should review the measures proposed by the operator to reduce existing safety deficiencies. As the operator of the nuclear power plant is of course interested in keeping the costs of retrofitting low, it is possible that the required safety level will not be achieved.**CSN explained, that due to the safety relevance of three of the major improvements (Containment Filtered Venting System, Passive Autocatalytic Recombines and Alternative Emergency Management Centre), the CSN decided to perform a complete authorization process for these three cases.

In December 2017, the second and last update of the NAcP was published. (CNS 2017)

2.2 Weaknesses identified by the Spanish Stress Tests the NAcP should remedy

An update of the **seismic risk assessment** is requested by the CSN. The ENSREG Peer Review Team suggested the incorporation of geological and paleo-seismological data to characterize relevant active faults.

According to the 2017 NAcP, the ITCs should have suggested an update of the seismic hazards by 2013, but were issued as late as May 2015. The licensees are currently jointly performing the due analysis which is now scheduled for 2021.

The stress tests revealed that a seismic hazard assessment is necessary. However, it took the CNS four years to issue a new ITC which required this re-assessment. And the seismic hazard assessment is to be ready only in 2021 – 10 years after the Fukushima accident. Once the assessment is on the table, planning of the actual upgrade measures at the plants themselves can start; to complete the necessary modification at the plant will take several years.

As part of the stress tests, the Spanish licensees have analysed possible secondary effects of earthquakes. Significant improvements have been identified and scheduled for implementation by 31/12/2014 (A1and A2).

However, as mentioned above, the intensity of possible earthquakes hat not been assessed yet, therefore it is not possible to adequately evaluate secondary effects.

The site is located on the left bank of the Arrocampo brook reservoir; the Valdecañas dam is situated upstream (storage capacity 1146 hm^3). The stress tests revealed that the impact of external flooding caused by a Valdecañas dam break has not been sufficiently analyzed. CNS stated that the licensee's analysis of a postulated dam failure was not as strict as the dam emergency plans used in Spanish practice.The licensee was required to review its analyses. The dam break analysis was re-assessed to check against the dam emergency plans and to resolve the identified inconsistencies. The analysis was completed by 31/12/2012 (A3).

According to the 2017 NAcP, the revision and acceptance by the CSN of the analyses of dam rupture scenarios had undergone something of a delay due to the existing uncertainties, these having emerged during the review that was performed by the CSN. This issue was finally closed in 2016.

As suggested by the ENSREG Peer Review Team (S2), the adoption of a consistent approach for the return periods associated to heavy rain scenarios is planned. In this context, the implementation of the new WENRA Reference Levels for external events in the Spanish regulation should be finished in 2014.

According to the 2017 NAcP, the implementation of this action is still ongoing.

The threat of natural hazard events is highlighted in the framework of the European Stress Tests. However, the necessary evaluation of the hazards is not yet done, in particular because the specific regulations are lacking. Clearly it will take several years to implement the necessary back-fitting measures.

The stress tests revealed that the current spent fuel pool cooling and water make-up alternatives would not be available in a SBO situation, when the nuclear plant is cut off from external power supply, with the exception of the fire protection system – which however is not seismically resistant. The water starts boiling after 14.8 hours, once cooling is lost. The time calculated until boiling starts during the refuelling outage (all fuel assemblies stored in the pool) is only 5.4 hours. **But the stress tests report did not lead to more than the implementation of very limited measures.**

Some limited activities to prevent or to cope with SBO sequences have been completed: New equipment to cope with prolonged station black-out (SBO) to replace primary circuit inventory, to provide electrical supply for equipment and instrumentation and to ensure the availability of communications and lighting systems was implemented by 31/12/2014 (I4).

According to the 2017 NAcP, mobile equipment (pumps, electrical generators, etc.) allowing for quick connection to the fixed systems of the plants is implemented.

However, only mobile equipment was implemented to compensate design weaknesses. The mobile equipment is much cheaper, but the prevention of severe accidents depends on the action of the staff.

The ENSREG Peer Review Team had some doubts and recommended to verify the assumptions on time available for manual actions of the staff and recommended CSN to ask for clarification. Thus

CSN performed a detailed review of the analyses submitted by the licensees, in which they were required to explain the time available for each manual action, including the margin with respect to the appearance of cliff-edge situations. Analyses of the suitability of the human resources currently assigned to the Emergency Response Organisation were to be done. (I7).
The 2017 NAcP explained: Following a number of interactions between the CSN and the licensees, the licensee has developed specific methodologies taking into account the experiences made in the USA.
However, it remains unclear whether sufficient time will be available in reality.No prove exists that the necessary manual actions during accident sequences to prevent a core meltdown accident and the release of radioactive substances are practicable under all accident situations.

Possible improvements to reinforce the existing capacities of depressurizing the primary system and avoid possible high pressure core damage sequences were to be analysed (30/06/2013, I16).
According to the 2014 NAcP, the measure concerning the issue of high pressure core damage sequences *were completed. At the same time the NAcP mentioned that CSN continues its evaluation.*
High pressure core damage sequences are very dangerous, because very large radioactive releases are possible. Thus, risk reducing improvements need to be implemented.

Analysis of critical instrumentation required for accident management, and guarantee of its operability under SBO and severe accident conditions was to be performed by 31/12/12 (I17).
According to the 2017 NAcP, the analyses have been completed and as, a result, the existing Severe Accident Mitigation Guidelines (SAMG) have been improved and include a list of the I&C features which are likely to remain available.
It is unacceptable that an instrumentation upgrade was avoided by presenting a list with instrumentation which is likely to remain available. However to cope with a severe accident situation, and to prevent the release of radioactive substances is nearly impossible without adequate instrumentation.

The 2017 NAcP concluded that most of the planned actions have been already implemented in the NPPs. The only point pending is the adaptation of the national regulation to the updated WENRA Reference Levels (issued in 2014) which is currently on-going. It is mentioned that reference level 4.2 (probability of exceedance of extreme natural events) of Issue T, is not yet implemented on the Spanish national regulation.
However, **the evaluation of the external hazard is of high importance: Adequate assessment of external hazards followed by adequate measures to achieve protection of nuclear power plants against these hazards was among the key lessons learned from Fukushima.**

2.3 Examples of further safety and security issues of Almaraz

In addition to the stress tests, and in a separate process, the CSN has initiated a program aimed at protecting the plants against serious external man-made events with severe safety impacts. But the actions requested by CSN focus on the “mitigation” of the consequences of these extreme situations and not on the prevention. The vulnerability of the units at Almaraz against air-plane crashes is as high as it is for old US reactors of this type. A crash of a large or a midsize airliner is very likely to cause a major damage of the reactor building. Such a crash – accidentally or deliberately – can result in a severe accident.

The spent fuel pools are located in buildings adjoining the reactor buildings. These buildings are simple industrial buildings. If the walls of a spent fuel pool were damaged, large amounts of radioactive material could be released. These buildings, however, are located at lower altitudes and therefore are not necessarily hit by a crashing aircraft. A US NRC report stated that “successful terrorist attacks on spent fuel pools, though difficult, are possible.” (CRS 2005). Once the pool is damaged and the water drained off the water starts to boil much earlier. The moment the fuel is exposed, the radiation shielding is completely lost. Intervention becomes already impossible, when 0.9 meter of water is covering the fuel, because of the high radiation dose rates. Recently discharged fuel would then reach the point when it starts burning in air (900 °C) and very severe radioactive releases start within hours. According to a recent U.S. study, about 75 percent (10-90 percent) percent of the caesium-137 inventory could be mobilized in the plume from the burning spent fuel pool. (HIPPEL 2016)

Unit 1 received the permission to operate at the new maximum power on 15 April 2010, unit 2 on 13 April 2011 – one month after the accident at the Fukushima Daiichi NPP. It was an increase of nearly 10% from the initial thermal capacity. **Power uprates** can cause unexpected failures in safety systems that could aggravate accident situations. Power uprates also accelerate the development of accidents, thereby decreasing intervention time needed to take action to minimize the accident. Furthermore, in case of a severe accident, the potential radioactive release is considerably higher. In addition, the increase in power accelerates the negative aging processes.

Ageing will become an increasingly relevant issue at the end of the fourth decade of operation. However, the aging management which was assessed in 2017 in the framework of the Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM showed deficiencies. The ageing management of the reactor pressure vessel (RPV) does not reach the level of safety expected in Europe by ENSREG: The periodic volumetric inspection is not performed for nickel base alloy penetrations to detect cracking at the earliest possible stage. Regarding the Non-destructive examination (NDE), the Peer Review Team also criticized that comprehensive NDE is not performed in the base material of the beltline region to detect defects. (ENSREG 2018)

An Operational Safety Review Team (OSART) mission took place in February 2018 and the Follow-up-mission in November 2019. The team proposed a number of improvements in operational safety. The most significant proposals included the following: The plant should improve the support, training and documented guidance for the Severe Accident Management Guidelines (SAMG) users in order to mitigate complex severe accident scenarios. (IAEA 2018b)The recommendation shows that despite all “improvements” after the stress tests the intervention of the operating team in case of a severe accident is still a safety issue.

The Nuclear Security Index 2020 shows Spain with a total score of 74 points ranked 22nd out of 47 countries. (NTI 2020) The score for the section “security and control measures” (55) is low. Of particular concern are the low scores for “cyber-security” (50) and “insider threat protection” (27). These low scores indicate weaknesses in the protection against those threats.

In 2020, Spain has not implemented all new WENRA Reference Level (RL) of 2014, eight RL are still missing in the Spanish regulations. (WENRA RHWG 2020a)

2.4 Conclusions

The stress tests revealed that a seismic hazard assessment conducted in line with state-of-the-art is necessary. However, it took the CNS four years to issue a new ITC which required this re-assessment. However, the seismic hazard assessment is to be ready only in 2021 - 10 years after the Fukushima accident. Once the assessment is on the table, the necessary modification of the plant will require several more years. Because the seismic hazard assessment is pending, the protection against earthquake is not assured yet.

The threat of natural hazard events is highlighted in the framework of the European Stress Tests. However, the necessary evaluation of the hazards is not yet done, in particular because the specific regulations are lacking. Clearly it will take years to implement the necessary back-fitting measures. Adequate assessment of external hazards followed by adequate protection of nuclear power plants against these hazards was among the key lessons learned from Fukushima.

Until the stress tests, the reactors of the Almaraz NPP did not have any accident management measures to assure containment integrity during a severe accident. Implementation of filtered venting systems as well as measures to prevent hydrogen explosion have been installed now. However, effective measures to prevent a severe accident are still lacking. Only mobile equipment (pumps, electrical generators, etc.) was deployed at the plant to compensate design weaknesses.

Especially worrisome is the fact that mobile equipment is presented as the solution to compensate deficiencies of the design reactors and the spent fuel pools. The EC/ENSREG highlighted as good practice the use of an additional layer of safety systems fully independent from the normal safety systems, located in areas well protected against external events, e.g. bunkered systems. Nevertheless, the Almaraz NPP relies heavily on mobile equipment and manual action of the staff. Apparently, it has not yet been proven that the necessary manual actions in accident sequences to prevent a core meltdown accident and the release of radioactive substances are practicable in any case.

An Operational Safety Review Team (OSART) 2018 found deficiencies in the Severe Accident Management Guidelines (SAMG). Despite all "improvements" after the stress tests the intervention of the staff in case of a severe accident is still a safety issue.

One of the most important "Lessons learned" from Fukushima was to understand the hazards posed by spent fuel pools. The hazard related to the Almaraz spent fuel pool was not considered earlier. The stress tests however led to a very limited implementation of measures only.

The scope of the measures is small compared to the low safety level of the Almaraz NPP, which is probably also due to the following facts: The ENSREG Rapporteurs stated in 2015 that in those cases, when the analytical results are still under review by CSN, the relevant changes should be implemented by the licensees; a rather astonishing recommendation. Even more astonishing is the Spanish nuclear regulator CSN's response: most of the design changes implemented as a result of the stress test did not require explicit approval, but rather represent a safety improvement. The correct approach of a regulator however would be a review of the measures proposed by the operator to reduce existing safety deficiencies and, if necessary, require additional measures.

The Almaraz reactors' vulnerability concerning air-plane crashes is as high as it is for old US reactors of this type. A crash of a large or a midsize airliner is very likely to cause a major damage of the reactor building. Such a crash – accidentally or deliberately – can result in a severe accident. The same is true for the spent fuel pool building. The spent fuel pools are located in buildings adjoining the reactor buildings. These buildings are simple industrial buildings. If the walls of a spent fuel pool were damaged, large amounts of radioactive material could be released.

More threats in terms of sabotage and attacks for the nuclear power plant exist for Almarez: The 2020 Nuclear Security Index shows Spain ranked 22nd out of 47 countries, with an overall score of 74 out of 100. This ranking includes 47 countries where an act of sabotage against a nuclear facility could result in a significant release of radioactivity, comparable in scale to the 2011 release in Japan. Of particular concern are the weaknesses identified in the protection against cyber-security and insider attacks.

Toward the end of the fourth decade of operation, ageing will become an increasingly relevant issue. However, the Topical Peer Review (TPR) as set out in the Directive 2014/87/EURATOM in 2017 revealed gaps of ageing management of the reactor pressure vessel (RPV) compared to the safety level expected by ENSREG for Europe.

3 Mochovce, Slovak Republic

The Mochovce NPP comprises four pressurized water reactors (PWR) of the VVER 440/V213 type, two operating, and two units under construction. Mochovce 1&2 with a net capacity of 436 MWe and 469 MWe are in operation since 1998 and 2000 respectively.

The construction of the reactors Mochovce 3&4 was resumed in 2008 after a 16-year suspension. The units were expected to start up in 2012-2013. Due to construction delays, the start-up of Mochovce 3&4 was postponed several times.

The VVER 440/V213 is not equipped with a full pressure containment, which is a common feature of most pressurized water reactors. Mochovce NPP is situated 90 km north-east of Bratislava.

3.1 Slovak National Action Plan (NAcP)

The majority of tasks resulting from the NAcP are covered by the nuclear regulator ÚJD SR which issued decisions in the past and in particular after the completion of the Periodic Safety Review (PSR) in 2011. Based on the results, ÚJD SR issued the operational permit for subsequent 10 years of operation. Pre-Fukushima and post-Fukushima improvement programs are interlinked – to some extent they were carried out in parallel and dealt with the same topics.

The measures of the NAcP are divided into three groups: short-term (to be finished by 2013); medium-term (to be finished by 2015) and additional measures, which may result from analyses, defined by medium-term measures and shall be implemented after 2015. (UJD 2012, 2014)

Updates of the NAcP were published in December 2014, December 2017 and December 2019. According to the 2019 NAcP, the comprehensive activity - prevention of accidents initiated by natural hazards and limitation of their consequences – was not completed. (UJD 2019)

3.2 Weaknesses identified by the Slovak Stress Tests the NAcP should remedy

The protection against earthquakes is still a major issue for the NPP Mochovce: The original Design Basis Earthquake (DBE) assessments have been questioned and subsequently re-evaluated in several steps in accordance with the development of methodologies, data and safety requirements. A value of the peak ground acceleration (PGA) of 0.1 g was used during plant construction. After a re-assessment in 2003, the value was raised to 0.143 g. The Slovak nuclear regulator UJD SR (decision No. 100/2011) demanded seismic resistance at Mochovce 1&2 to be increased to the new value of 0.15g by 2018. The ENSREG Peer Review Team recommended considering prioritization of the seismic upgrading measures. The NAcP included this recommendation: The seismic reinforcement of structures with the highest priority was to be finished by 2015. The NAcP lists this activity as "prevention of accidents because of natural risks and limitation of their consequences". (ID 3)
According to the 2019 NAcP, in 2018 delays in the completion of seismic reinforcement were identified by UJD SR. The main reasons for the delay were in the inability of the contractors to provide the expected results using acceptable methodologies. The used methodologies for example do not included some steam pipelines and their impact on other components. During the early phase of the project several contractors were changed for different reasons (e.g. not providing the complete Safe Shutdown Equipment List (SSEL). The SSEL after an earthquake was finally developed during 2017 – 2018 by a group of contractors. The assessment of seismic capacity of SSC which are on the SSEL list is ongoing. Majority of SSC comply with the seismic capacity. In parallel to the assessment of seismic capacity of SSC, seismic reinforcement of buildings/structures has been completed. However, it is ongoing for the reactor building, also for the Diesel Generator Station, the Diesel oil system, the Nuclear auxiliary service building and the Electrical buildings. It is explained: taking into account the complexity of the project on seismic reinforcement UJD SR accepted the proposal of the licensee to reschedule the date for the completion of seismic reinforcement until 2022.
It has been known for a long time that significant improvements of the protection against earthquakes are required. Even 10 years after the accident in Fukushima, the seismic upgrade has not been completed. It turned out being a very difficult task because sufficient documentation of the existing components is missing. It cannot be excluded that sufficient earthquake protection will not be in place even when the ongoing upgrade measures will be completed.

The assessment of safety margins performed during the ENSREG Stress Tests indicate that a loss of containment integrity in Mochovce 1&2 is not expected to occur below PGA=0.2g. Since the plant's currently assessed PGA is 0.143, this value indicates a rather small safety margin as the Design Basis Earthquake (DBE). The reliability of the seismic hazard assessment is therefore highly important. However, the reliability of the currently assumed seismic hazard has not been proven yet.

Seismic hazard assessment of the Mochovce site has been extensively discussed at the Slovak-Austrian Expert Workshop on site seismicity and seismic design in context of the completion of Mochovce 3&4. The Austrian Expert Team identified several points that require further clarification (BMLFUW SK 2014):

- Hazard assessment: Open issues concern the earthquake catalogue (in particular, the estimation of the magnitude of historic earthquakes), seismic zoning, and the determination of maximum and minimum (lower-bound) magnitudes.
- Investigation of faults: Open issues concern the study of faults in the near-region, and the results of geological investigations there. The re-evaluation of the capability of near-regional faults is particularly suggested by the new seismologic data obtained from the seismic monitoring system. These data were acquired after the completion of seismic hazard assessment and are therefore not included in the assessment.
- Peak ground acceleration (PGA): This open issue concerns the discrepancy between the results of seismic analyses for the Mochovce site and the SESAME and GSHAP hazard maps.

The protection against the Design Basis Flood (DBF) is adequate mainly due to relatively high differences in the altitude between the site and nearby rivers. Strong rainfalls were identified as the only potential sources of flooding.

Evaluations of the effects of extreme meteorological conditions in the stress test report are mostly qualitative. Due to the lack of information in the plant documentation on resistance of SSCs to the beyond design weather conditions, engineering judgment was applied to estimate the plant response and assess the safety margins. The peer review recommended to the Slovak regulator to consider monitoring the implementation of the measures for strengthening the level of protection of the plants against extreme weather conditions. Thus an evaluation of the resistance of selected SSCs against extreme weather events (floods caused by heavy rain, high and low external temperatures, direct wind and other relevant events) on the basis of updated new studies on meteorological conditions was required. Protection against extreme weather events has to be implemented (ID 4, ID 14).
According to the 2019 NAcP, necessary measures are being incorporated into the ongoing seismic reinforcement project.[2]
Since the program has not been completed, adequate protection against extreme weather events is not in place. In view of the climate-related increase in the frequency and intensity of extreme weather events, this is not appropriate in terms of safety.

Also, other necessary safety upgrades are not completed because of the difficulties with the seismic reinforcement program: Remote control of selected equipment should be installed within the SAM project in the ongoing project of the Emergency Centre modification. (ID 26)
According to the 2019 NAcP, the implementation of the seismic reinforcement with a qualification to extreme external conditions is still in progress.
The incomplete seismic reinforcement program also means that the Emergency Center will not be available after an earthquake.

An independent diversified alternate ultimate heat sink (UHS) to prevent the loss of the primary UHS does not exist nor is it planned. Only the following limited back-fitting measures were done regarding

[2] Evaluation of the outcomes of the study on the impact of extreme external temperatures in selected rooms after loss of cooling has been completed without identifying any need for additional measures.

alternative cooling and heat sink by 31/12/2013 (ID 18): The emergency feedwater source for the steam generators (SG) was to be diversified by mobile high-pressure sources.
However, in case of an accident those mobile sources first have to be moved and installed by the staff.

The severe accident management (SAM) implementation project, initiated in 2009, was accelerated after the Fukushima accident, with the new deadline was set with 2015.[3] It consisted of the following measures:

One of the most important modifications concerning the prevention of major radioactive releases during accidents is the external cooling of the reactor pressure vessel (RPV). This in-vessel retention (IVR) concept aims to ensure the integrity of the RPV during a severe accident. The implementation was already planned before the Fukushima accident, and was completed in 2011/2012. The measure required a number of technical modifications. Since the cooling of the RPV from the outside is a complex procedure, extensive analyses and experiments have been performed at the CERES test facility to demonstrate the feasibility. But proof that this concept fulfils all the intended functions was delivered only with limited experimental analyses.

The need for filtered containment venting and other potential technical measures for long-term heat removal from the containment were to be analysed by 31/12/2015 (ID 2).
According to the NAcP, the best solution based on the outcomes is a SAM dedicated, independent long-term heat removal system. Concept of a filtered containment venting system for severe accident raises problems with permanent loss of coolant from the containment required *for external cooling of reactor pressure vessel. Successful in-vessel retention leads to rather limited pressure increase in the containment, and to limited release of radionuclides into the containment atmosphere. Comparatively low releases into the environment are the result.*
However, if a late containment failure due to over-pressure occurs, the radioactive releases will be significant. Furthermore, no explanation was given why the Slovak regulator UJD SR did not follow the Peer Review Team's recommendation to take a reactor pressure vessel (RPV) failure into consideration.

The update of the severe accident management guidelines (SAMGs) with regard to potential damage of infrastructure, including long-term accidents and accidents with an impact on several units and neighbouring industrial facilities is necessary; however only an analysis and plan of implementation of additional measures were scheduled to be conducted by 31/12/2015 (ID 40).
According to the 2017 NAcP, the post Fukushima SAMG update is in progress with support of the company Westinghouse.According to the 2019 NAcP, the activity is completed. It also explained that the previously identified delays related to verification and validation of SAMGs were resolved during 2018 and the verification and validation of SAMG is completed. However, it is also noted that based on the Pre OSART mission the SAMG will be reviewed.
To date the nuclear power plant staff is not able to cope with a severe accident. The Pre OSART mission (December 2020) at Mochovce 3 identified weaknesses, some of which are related to the stress test action plan; among others the accessibility of some locations for the Severe accident management during emergencies was put into question.

A study to find a **solution for the treatment of large volumes of contaminated water** was to be performed (ID 47).
According to the 2019 NAcP, the study was completed. The aim of the study was the preparation of a conceptual study for addressing issues, dealing with high activity liquid wastes after severe accident.
However, the NAcP does not provide any information on measures being prepared. No

[3]Reactor Cavity Flooding 2011/2012; Primary circuit depressurization 2013/2014; Containment hydrogen management 2012/2013; alternative coolant system 2014/2015; alternative power supply system 2013/2014; I&C post-accident monitoring system 2014/2015; containment long term heat removal 2015.

information is available whether additional actions will be taken, such as purchasing equipment, changing structures or retrofitting systems.

In addition to the actions recommended by ENSREG, a concept of large area fire control, (including fire control documentation, analysing the equipment and training of the staff) is to be prepared by 31/12/2015 (ID 55).

According to the 2014 NAcP, analyses of fire distribution after the impact of cargo Airplane were prepared by the Technical University in Ostrava. Based on the analysis, the fire brigade on the site prepared an operative fire control plan. According to the 2019 NAcP, the purchase of special streamlines large-scale fire extinguishing flammable liquids, hose wagon with automatic laying were bought.

However, the implementation of fire control measures will not prevent a destruction of the reactor building in case of a crash of an airliner, which will probably cause the loss of reactor cooling and thus a core melt accident with a major release of radioactive substances.

3.3 Examples of further safety and security issues of Mochovce

The Topical Peer Review (TPR) as set out in Article 8e of the nuclear safety Directive 2014/87/EURATOM has been carried out in 2017. It revealed the gap between the ageing management program in Slovakia and the safety level expected in Europe by ENSREG: During long construction periods or extended shutdown of NPPs, relevant ageing mechanisms are not identified and no appropriate measures are implemented to control any incipient ageing or other effects. This shortcoming is also of utmost importance for Mochovce 3&4. (ENSREG 2018)

From the WENRA Reference Levels (RL) 2014, Slovakia has not transposed 20 out of the 342 RL into the regulatory framework as of 2020. (WENRA RHWG 2020a)

The most recent OSART mission at Mochovce 1&2 took place in 2006. The operator has not invited an international mission to the plant for an international review of those units for15 years. (IAEA 2021a) The PRE-operational OSART mission for Mochovce 3 identified several deficiencies. An OSART Follow-up Mission to Mochovce 3 is planned for April 2021.The IAEA Team pointed to the same issues which were already known from the "leaked" WANO report 2017 among others (IAEA 2019b):

- High standards and expectations are not always set or applied to ensure safe operation.
- Unsafe behaviour and conditions in the plant are not always challenged and corrected by managers and supervisors in a timely manner to ensure safety of personnel and equipment.

It is rather unlikely that the operation of Mochovce 1& 2 would be free of the same deficiencies in the safety culture.

The reactor buildings do not provide sufficient protection to the plant against external impacts caused by **airplane crashes or explosions**. The spent fuel pool (SFP) is located outside the containment barrier in the reactor hall. Taking into account the existing risk of **terrorism**, it is irresponsible to operate a nuclear power plant with such a high vulnerability to external attacks.

The Nuclear Security Index 2020 shows Slovakia with a total score of only 73 points, ranked as the 24th out of 47 countries. The score for the section "security and control measures" (56) is low. Of particular concern are the low scores for the "security culture" (0), "cyber-security" (38) and "insider threat protection" (55). (NTI 2020) These low scores indicate weaknesses in the protection.

3.4 Conclusions

For decades it has been known that earthquakes are a major hazard for the Mochovce NPP making comprehensive upgrades necessary. But in 2021, 10 years after the accident in Fukushima, the preparations and measures have not been completed. This effort of increasing the seismic robustness turned out being a very difficult task because sufficient documentation of the existing components is missing.It cannot be excluded that sufficient earthquake protection will not be in place even once the ongoing upgrade measures will have been completed.Furthermore, the reliability of the current seismic hazard assessment that is highly important has not been assured yet.

The necessary upgrade of the protection against extreme weather events is included in the ongoing seismic upgrade. Since this program has not yet been completed, adequate protection against extreme weather events is not yet in place. In view of the climate-related increase in the frequency and intensity of extreme weather events, this is not appropriate in terms of safety.

Also, other necessary safety upgrades have not been completed because of the difficulties with the seismic reinforcement program, e.g. the remote control of the Emergency Centre. The unfinished seismic reinforcement program also means that the Emergency Center will not be available after an earthquake.

Only limited measures - the use of mobile equipment – are planned to prevent the total loss of power and/or heat removal. Compared to the installation of new bunkered safety systems (e. g. An independent alternate ultimate heat sink (UHS) mobile equipment is less reliable. The issue of severe accidents will remain open because no guarantees are in place to prove that the most important modification (the in-vessel retention (IVR) concept) can reliably prevent major radioactive releases. A measure commonly installed to prevent major radioactive releases in case of a severe accident – a filtered containment venting system - will not be implemented.

The Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM has been carried out in 2017. It revealed the ageing management program in Slovakia shows a gap compared to the expected level of safety in Europe by ENSREG: During long construction periods or extended shutdown of NPPs, relevant ageing mechanisms are <u>not</u> identified and appropriate measures not implemented to control any incipient ageing or other effects. This shortcoming is also of utmost importance for Mochovce 3&4.

From the WENRA Reference Levels (RL) 2014, Slovakia has not transposed 20 out of the 342 RL into the regulatory framework in 2020.

The most recent OSART mission at Mochovce 1&2 took place in 2006. The operator has not invited an international mission to the plant for an international review of those units for 15 years. The PRE-operational OSART mission for Mochovce 3 identified several deficiencies. An OSART Follow-up Mission to Mochovce 3 is planned for April 2021. The IAEA Team pointed to the same issues which were already known from the “leaked” WANO report 2017. It is likely that the operation of Mochovce 1&2 shows the same deficiencies in the safety culture. Under these circumstances it is hard to recognise nuclear safety as being the guiding principle of the Slovak Authority ÚJD SR.

The VVER 440/V213 reactors have safety deficits which cannot be remedied: The reactor buildings do not provide sufficient protection against external impacts like airplane crashes. The spent fuel pool (SFP) is located outside the containment barrier in the reactor hall. Taking into account the existing risk of **terrorism**, it is irresponsible to operate a nuclear power plant with such a high vulnerability to external attacks.

More threats in terms of sabotage and attacks need to be mentioned: The Nuclear Security Index 2020 shows Slovakia with an overall score of only 73 out of 100 points, ranking only 24th out of 47 countries. The score for the section "Safety and control measures" (56) is very low. Of particular concern are the low scores for "Security culture" (0), "Cyber-security" (38) and "Protection against insider threats" (55). These low scores indicate immense vulnerabilities in protection.

Mochovce 1&2 is a nuclear power plant with severe design deficiencies. At the same time, the Nuclear Regulator and the operator have not developed a reliable approach to safety culture.

4 TEMELIN, CZECH REPUBLIC

NPP Temelin consists of two units with pressurized water reactors (PWR) of the type VVER 1000/V320, which has a primary cooling circuit with four loops. The VVER-1000 unit has a nominal electric output of 1000 MW. During construction several technical modifications were implemented to achieve “western” safety standards.[4]

Temelin NPP is located in South Bohemia, about 25 km north of České Budějovice. The first grid connection took place in 2000 for unit 1 and in 2002 for unit 2. For the units the Nuclear Regulator SUJB has granted operating licenses to 2020 and 2022. In March 2020, the operator CEZ submitted an application to extend the license of unit 1.

4.1 Czech National Action Plan (NAcP)

The NAcP of the Czech Republic, which resulted from the stress tests, conducted by ENSREG after the Fukushima accident, defined 76 actions/activities for Dukovany and Temelín NPPs (SUJB 2012). All NAcP measures were to be completed by the end of 2015. However, this was not the final implementation date for the necessary back-fittings, because measures which consist of performing a study or an analysis may result in the need to identify and implement additional measures.

After its visit to the Temelín NPP, the ENSREG fact-finding team pointed out that the regulatory authority (SUJB) had a good and open communication with the licensee (CEZ). They agreed on a safety enhancement program (that includes the stress tests recommendations) as a condition for the next 10-year licence. (ENSREG CZ 2012).

According to the ENSREG Rapporteurs’ Report, a challenge remains in implementing measures for which the timeframe has been shortened after Fukushima compared with the original one. **It was emphasised that some measures scheduled for long term were identified during the workshop as crucial ones, like analyses for maintaining the integrity of the containment and cooling of the molten core.**(ENSREG RR-CZ 2014)

The 2014 NAcP stated that eight additional measures (77-84), which emerged from a detailed analysis of the ENSREG document have been added to the NAcP. (SUJB 2014)

Updated NAcPs were published in January 2018 and again in December 2019.*Note: the 2019 NAcP, listed only the envisaged implementation date regardless of when the action was implemented.*According to the 2019 NAcP, one action was still not completed. (No 50) (SUJB 2019a)

4.2 Weaknesses identified by the Czech Stress Tests the NAcP should remedy

Secondary effects of earthquakes were to be assessed by 2014. Furthermore, a seismic PSA including earthquakes, induced floods or fires with a proposal for remedial measures were to be performed by 2015. (No. 4; No. 70)[5]
According to the 2014 NAcP, these activities have been finished.
However, the outcomes of these assessments are not provided. No information is available about remedial measures proposed by the operator or additional measures required by SUJB.

The reinforcement of the fire brigade building to withstand earthquakes was to be completed by 2014 (No. 2).
According to the 2014 NAcP, this action has been finished.
However, the value defining the seismic hazard which the fire brigade building should be able to

[4]Those measures included a new I&C system, replacing the original cables with non-inflammable ones and other significant modifications in the electrical part; qualification of pressurizer safety and relief valves for working with water and SG safety valve with water and steam-mix, implementation of a reactor pressure vessel (RPV) evaluation program and measures for the protection of the high energy pipeline at the elevation +28.8 m.

[5] Number according to the NAcP

withstand is not provided. Note: The fire brigade at the Temelín NPP is very important to cope with a severe accident.

To increase the resistance against rainfall, the flood protection of the diesel generator (DG) was improved (No. 9) New procedures for coping with extreme conditions at NPP sites (wind, temperature, snow, and earthquake) were issued in 2013 (No. 52).
However, it remains unclear whether the recommendation by the ENSREG Peer Review Team has been taken into account*:* The ENSREG Peer Review Team emphasised that consequences of extremely low temperatures may not have been properly assessed by underestimating related effects, e.g. station blackout. Thus, some more refined analyses and the verification of current analyses were necessary.

Because the ultimate heat sink (UHS) is dependent on power supply, loss of UHS is an inevitable consequence of station black-out (SBO. The time available to recover the loss of the heat sink before fuel damage in the worst case is only 2.5 hours (coping time). The time until the water in the spent fuel pools starts boiling (SFP) is 2 hours, while the time available until the fuel is uncovered is 20-30 hours.

The Peer Review Team recommended to SUJB to require an effective solution to the diverse ultimate heat. But this recommendation was not taken up adequately.

To ensure an alternative heat sink (for core cooling and heat removal) the plan foresees pumping water from fire trucks into the steam generators (SG) via the emergency feed-water system. This water will evaporate in the secondary side of the SG and the steam will be released into the atmosphere. For this measure were procured fire brigade trucks equipped with the necessary devices to cope with selected severe accidents (No. 84).[6]
However, the fire trucks constitute the Czech response to the following ENSREG recommendation calling for "provisions for the bunkered of ´hardened´ systems to provide an additional level of protection ... designed to cope with a wide variety of extreme events including those beyond the design basis." But here the prevention of a severe accident depends strongly on sufficient actions of the staff.

The coping time could be prolonged by feeding the steam generators (SG) from feed-water tanks relying on gravity.[7] But only an analysis about gravity feeding use for SG in emergency operation procedures (EOPs) was required. (No. 73)
However, neither the outcome of the analysis nor the implementation of measures is mentioned.

The 2014 NAcP listed several measures (provisions) to prevent Station Black-out (SBO) and to cope with a SBO situation and the consequent loss of UHS to prevent core melt accidents.
However, limited improvement measures depending mainly on actions of the staff to remedy design deficiencies have been performed.

Furthermore, several activities to remedy design issues are also listed but consist of paperwork only, e. g. summarisation of existing documents that prove long term tightness of the main cooling pump seals in SBO situation, and additional analyses (if considered necessary). (No. 80) Feasibility analysis of heat transfer from the spent fuel pool (SFP) without additional water supply (No. 81)
However, the outcome of the studies is not mentioned. Probably the studies concluded that no further actions are necessary. Safety is demonstrated on paper only.

In case of a severe accident with core melt, the retention of the molten core inside the vessel is not possible. The design of the VVER-1000/V320 containment and the reactor cavity are such that water supplied to the containment through the spray system or other means would not reach the reactor

[6]The following was done: implementation of back-up water supply into the SG from external mobile equipment using external connection points (No. 14); implementation of provisions of back-up coolant supply into depressurised reactor and storage pools with additional and sufficient sources of coolant (No. 16) and

[7]This measure is implemented at the other Czech NPP (Dukovany) and could prolong the coping time to about 10 hours.

cavity. The Peer Review Team stated: In general, the core melt coolability, stabilisation and termination of severe accidents is still an open issue for the Temelín NPP. Taking into account the reactor's thermal power and the design-basis solution of the concrete reactor cavity, there is no possibility for VVER 1000 units with V320 reactors to ensure any RPV cooling from outside. When the RPV fails, the core debris would move to the concrete reactor cavity or other parts of containment. Molten core-concrete interactions could result in containment failure.

The current severe accident management (SAM) includes instructions to avoid containment overpressure in case of a severe accident for using ventilation systems: this unfiltered release would lead to the emission of large amounts of radioactive products into the environment. **Note: Urgent implementation of the recognised measures to protect containment integrity is a finding of the peer review that national regulators should consider. However, these measures are not implemented yet – and no plan suggesting they will be implemented.**

An analysis and a proposal for a strategy to stabilize the core melt and prevent overpressure were completed in 2014. (No. 49) The deadline for the implementation of measures for maintaining long-term containment integrity according to selected severe accident management strategies was 2022. (No. 50)
According to the 2014 NAcP, results of analyses have shown that an effective strategy for stabilizing the corium and maintaining long-term containment integrity is spilling corium leaked from the reactor pressure vessel and its flooding by coolant, thus ex-vessel cooling of the corium (ExVC). Furthermore, since the in-vessel retention (IVR) strategy is preferable in terms of severe accident management, the study of effectiveness and applicability of the IVR strategy will continue in parallel.

However, the 2019 NAcP explained that these measures have been cancelled.

ČEZ, a. s. completed its extensive technical analyses of potential technical provisions for the Ex-Vessel-Cooling (ExVC) and the In-Vessel-Retention (IVR). It yielded the following results:

- Ex-Vessel-Cooling: The Feasibility study concluded that full scope of the technical provisions proposed for ExVC **is not reasonably implementable** in conditions of operated VVER-1000 units.[8]**The reasons are adverse radiological conditions in the reactor cavity and negative interactions of the pertinent technical modifications with normal / outage plant operation (affected systems and constructions)**.
- In-Vessel-Retetention: The extensive work[9] undertaken showed that the IVR concept is **not reasonably implementable** at VVER-1000 for the following reasons: problematic proof of physical effectiveness (significant uncertainties, lack of sufficient margin), the design of additional technical systems / features is very complicated – large extent of new active systems with required actuation in very short time, adverse interactions with normal / outage operation.

Instead, a new independent system for RPV makeup will provide additional option of cooling and stabilization of the partially degraded core inside the RPV and an additional option of containment flooding. The primary purpose of an additional independent system is to terminate the severe accident progression in its early phase and prevent RPV failure. The other function of this system is to provide alternative long-term containment heat removal (spray and closure of the circulation through the existing heat exchanger with external cooling water supply by means of other mobile pumping station

[8]Basic design of technical provisions facilitating acceleration of corium spreading from reactor cavity (GA301) to GA302 room and corium retention in the GA301 / GA302 intercepting area was elaborated. The corresponding provisions consist of substantial modification of floor composition and implementation of heat-resistant liner in the intercepting area and of the modification of the double door between GA301 and GA302. The goal is to prevent the containment melt-through failure in the hypothetical severe accident scenarios progressing to the ex-vessel phase.

[9]Basic design of technical provisions facilitating controlled coolant supply into the reactor cavity (GA301), steam outlet from the cavity, intensification of heat transfer through RPV wall and other supporting systems was elaborated. Implementation feasibility study was completed. The physical effectiveness of the IVR at VVER-1000 was investigated by means of thermo-hydraulic analyses and through experiments on the THS-15 experimental facility in ÚJV Řež.

driven by diesel engine Furthermore a containment filtered venting system (FCVS) with the ultimate goal of practical elimination of the containment overpressure failure will be implemented. (Project no. G839).[10]According to SUJB, the implementation of these projects (G839 and G840) suffices to call the NAcP action No.50 completed. Whereas the measures initially envisaged are not reasonably implementable and further solutions have to be sought, the proposed final date for completion is now postponed to 2024.

Ten years of investigation resulted in the decision to refrain from implementing the only measure that could have brought a certain safety. The information made available suggests that economic constraints rather than technical reasoning led to the decision to cancel the implementation of this measure. From a safety point of view, this is completely incomprehensible.

The existing hydrogen removal system was designed for design basis accidents (DBAs) only. Additional passive auto-catalytic re-combiners designed (PARs) for severe accident conditions were installed. (No. 47) **However, it remains unclear whether re-combiners (PARs) will be installed in the area of the spent fuel pool to prevent hydrogen explosions during severe accidents. This was recommended by ENSREG.**

An upgraded probabilistic safety analysis (PSA) Level 2 for the identification of plant vulnerabilities, quantification of potential releases related to extreme external conditions was *finished in 2018* (No. 69)

This was organized in the wrong order, since the results of the PSA should have been the basis for developing the severe accident management (SAM). Furthermore, the core damage frequency (CDF) for external hazards is 1.19E-5 per year and for the large early release frequency (LERF) is 2.58E-6 per year. More than 20 % of core melt accidents will result in an early large release. Extreme snow load, extreme temperatures and tornadoes are the largest contributors to the risk of external events. The contribution of seismic events, aircraft crashes and extreme wind to the risk is less significant. (SUJB 2019b)

4.3 Examples of further safety and security issues of Temelin

In case of a severe accident with core melt, the retention of the molten core inside the vessel is not possible because the baseplate of the containment is on elevation +13 m. In case of a core melt accident, the baseplate could fail after 24 hours. A very large release of radionuclides would follow. (WENISCH 2012)

In the course of the comprehensive discussion procedure (Melk-process follow-upon the safety of Temelín 1&2, a number of issues were discussed extensively between Czech and Austrian experts in a series of expert workshops. (BMLFUW CZ 2014) Most of these issues have been resolved. However, regarding the high energy pipelines of the secondary circuit (main steam and feed-water pipelines), some questions remained open. It is important to have adequate protection against the break of the **high energy pipelines** of the secondary circuit.

In July 2000, an anonymous witness informed the Czech office of Greenpeace that while working on the Temelín construction site, he participated in a repair of one of the **welding seams** directly between the primary cooling circuit and the reactor of unit 1. He claims that the main pipe was connected 180° wrong. On order was issued to cut directly on the seam of the reactor vessel, turn the pipe and re-weld it. The indicated welding seam was later identified by SUJB as the seam number 1-4-5.Greenpeace organised several meetings between the witness and international experts. The conclusion was that the witness was credible, and the story needed intensive follow-up. In September 2000, Greenpeace informed the Czech regulator SUJB of the case, a team of SUJB inspectors decided to start an

[10]To gain further knowledge in the area of corium stabilization, the R&D project ROSAU (Reduction of severe accident uncertainties) has been launched. This is an international project governed by OECD/NEA with the support of NRC and EPRI. ČEZ, a. s. actively participates in this project. This project will bring more insight into the corium behaviour in ex-vessel phase.

investigation into the matter. In the next years, there were some investigations concerning the welds, but not the specific welding seam 1-4-5. (GREENPEACE 2006) Although a lot of experts and Czech courts have been involved, the case is not closed yet.

The **Nuclear security index** 2020 shows Czech Republic with a total score of 82 points ranked 9 out of 47 countries. (NTI 2020) However, the score for the section “security and control measures” are low. Of particular concern are the low scores for “Cyber-security” (63), Insider threat protection (73) and security culture (50). Furthermore, the score for the section “Risk Environment” (67) is low, in particular because of shortcomings in “Pervasiveness of Corruption” (50) and “Effective Governance” (50). Furthermore, the reactor buildings are designed only against accidents of small aircraft.

Ageing is also an issue for NPP Temelin. The topical peer review in the frame-work of the nuclear safety directive showed that even the ageing management of the reactor pressure vessel (RPV) showed deficiencies compared to the safety level ESNREG expects for Europe. Regarding the Non-destructive examination (NDE) of the RPV, the Peer Review Team criticized that the NDE is not performed in the base material of the beltline region to detect defects. The Peer Review Team criticized also the ageing management of concealed pipe-work: The inspection of safety-related pipe-work penetrations through concrete structures is not a general part of ageing management programs in the Czech Republic. (ENSREG 2018)

According to the Czech nuclear regulator SUJB, all 342 WENRA Reference Levels were implemented in the National Regulation as of January 1, 2018. However, based on the below mentioned report, this statement should be questioned. (WENRA RHWG 2018b) The WENRA RHWG (Reactor Harmonisation Working Group) conducted a review on the implementation status of some of the 2014 WENRA RLs for existing plants into their respective National Codes. This review focused on the 101 RLs that were revised or newly added after Fukushima. According to the self-assessment a total of 45 RLs of these 101 RLs had been implemented in the Czech Republic as of October 31, 2015, while this was not the case for 56 RLs. The peer review came to a completely different conclusion: of the 101 RLs, only 16 RLs had been implemented, while 85 RLs had not yet been implemented. (WENRA RHWG 2018a) In all countries, the results of the self-assessment and the peer review assessment differed. However, in no other country was the difference between self-assessment and peer review as significant as for the Czech Republic.

The most recent Operational Safety Review Team (OSART) mission took place in 2012. (IAEA 2021a)

4.4 Conclusions

Although the urgent implementation of measures to protect containment integrity was a key outcome of the stress tests, the deadline for implementing measures to maintain long-term containment integrity (ex-vessel cooling) during a severe accident was as late as 2022.But more importantly: the planned action has been canceled. The licensee (ČEZ, a. s.) has carried out extensive analytical work. Result: the technical arrangements for Ex-Vessel-Cooling, a solution similar to the core catcher for the French EPR-reactors, were dismissed as not reasonably practicable. The information made available suggests that economic consideration rather than technical reasoning led to the decision to cancel the implementation of this measure. This is irresponsible in view of the possible consequences of such an accident. The rather ineffective replacement measures are scheduled for 2024. **In case of Temelin, 10 years of investigation resulted in the misguided decision to refrain from implementing the only measure that could have brought a certain safety increase for economic reasons.**

In the last 10 years, only limited improvement measures – depending mainly on actions of the staff – have been performed to remedy design deficiencies.

According to the 2020 Nuclear Safety Index the Czech Republic ranked 9th out of 47 countries with an overall score of 82. However, the score for the section “security and control measures” are low. Of particular concern are the low scores for the “cyber-security” (63) and security culture (50).

Ageing is an increasing risk for the 20 years old Temelin. The topical peer review conducted in the framework of the nuclear safety directive found that the ageing management of the reactor pressure vessel (RPV) showed deficiencies compared to the safety level expected by ENSREG for Europe. Regarding the Non-destructive examination (NDE) of the RPV the Peer Review Team criticized that the NDE to detect defects is not performed in the base material of the beltline region. It also criticized the ageing management of concealed pipe-work: Inspection of safety-related pipe-work penetrations through concrete structures are not a general part of ageing management program in the Czech Republic.

Temelín NPP has no means to cope with a severe accident at this point because it lacks both the measures to cool the molten core and the filtered containment venting system. Thus, a severe accident with a major radioactive release would be the result. The prevention of a severe accident depends on the quick response of the staff. Thus, the prevention of a severe accident could fail. The idea of having fire trucks supplying water to cool the core under accident situations during e.g. an earthquake is unacceptable and reveals a dangerous approach to safety culture.

In case of a severe accident with core melt the retention of the molten core inside the vessel is not possible. The base-plate of the containment is on elevation +13 m and could fail after 24 hours in this case. The release of radionuclides would be very large.

An upgraded probabilistic safety analysis (PSA) Level 2 for the identification of plant vulnerabilities, quantification of potential releases related to extreme external conditions was finished in 2018. **This was organized in the wrong order, since the results of the PSA should have been the basis for developing the severe accident management (SAM)**. Furthermore, both the core damage frequency (CDF) and the large early release frequency (LERF) for external hazards are still relatively high. More than 20 % of the core melt accident will result in an early large release. Extreme snow load, extreme temperatures and tornadoes are the biggest contributors to the risk of external events.

5 Krško, Slovenia

The Krško NPP, located in a seismically active region, is a 2-loop Westinghouse PWR with a net capacity of 688 MWe, operating since 1983. Within the 25 km radius around the NPP, 55,000 people live in Slovenia and 147,700 people in Croatia.

The Slovenian and Croatian state-owned energy companies GEN energija and HEP, which manage Slovenia's NPP at Krško, have decided in 2016 to extend its lifespan by 20 years until 2043. (WNN 2016a) In May 2016, a spokeswoman for the operator NEK (Nuklearna Elektrarna Krško) said: "*The lifespan of Krško has been extended providing that the plant passes a safety check every 10 years with the next checks due in 2023 and 2033*." (WNISR 2020)

The regulator, the Slovenian Nuclear Safety Administration (SNSA) took over the Krško operator´s stress test report, added its own executive summary and conclusions and submitted it as the National Slovenian Report to the European Commission.

5.1 Slovenian National Action Plan (NAcP)

The main part of the NAcP consisted of the planned Safety Upgrade Program (SUP), which was ordered, reviewed and approved by SNSA. In response to the Fukushima accident, the SNSA decided to speed up the implementation of the SUP and demanded that all measures of the SUP should be completed by 2016. (SNSA 2012)

However, in September 2013, the Krško NPP applied for the extension of the final SUP deadline. As the main reasons for the delay were mentioned the size of the project, complexity of design documentation and delivery times for some of the main components. The SNSA approved the extension of the deadline until the end of 2018. (SNSA 2014)

In 2014, the Krško NPP notified the SNSA that the implementation of the SUP until the end of 2018 is going to be challenged due to financial constraints. Namely, the two owners of the Krško NPP became unwilling to finance the SUP due to doubts that the plant could, after the implementation of the project, still continue to generate electricity at a competitive price. The owners ordered a financial viability study, after which they will decide about the continuation of the project. However, the supervisory board of the Krško NPP has endorsed a study that found it would be feasible to extend its lifespan until 2043. (PMR 2015)

The NAcP was updated in December 2017 and again in December 2019. According to the last update in 2019, the implementation of the Slovenian NAcP is still ongoing. In December 2019 about 92% of the NAcP actions have been implemented. The deadline for a large part of the Slovenian NAcP, the SUP, was further delayed due to the need to redesign improvements and large component delivery running late. The SUP is on schedule to be implemented by the end of 2021. (SNSA 2019)

5.2 Weaknesses identified by the Slovenian Stress Tests the NAcP should remedy

The Krško NPP is the only NPP in Europe situated in a seismically active region. In line with US NRC nuclear regulation and standards, the peak ground acceleration (PGA) of 0.3 g was used for the safe shutdown earthquake (SSE). New seismic hazard assessments led to raising the PGA values for the SSE: In 1994 to PGA= 0.42g and in 2004 to a PGA= 0.56g, which is nearly double the original PGA.

Seismic events with PGA over 0.8 g were assessed as very rare at the site, with the return period in the order of 50,000 years or more. However, earthquakes of a PGA ranging above 0.8g or higher are a hazard for the reactor core, mechanical damage could disturb the core geometry and thus the insertion of the control rods. Partial core melt is not excluded in such a situation. In this PGA range also containment spray and low-pressure emergency cooling would be unavailable. Late radioactive releases cannot be excluded.
However, there are uncertainties in the calculated recurrence period of 50,000 years for the seismic events with a PGA of 0.8 g.

Seismic events resulting in early radioactivity releases to the environment would be likely to occur when the PGA significantly exceeds 1g. For earthquakes exceeding the PGA of 0.9g, structural failures of SFP and pipes cannot be excluded, and uncovering of the fuel is considered likely.

A very strong earthquake (PGA > 0.9g) causes fuel damage in the reactor core and in the spent fuel pool more or less simultaneously. The report assesses those two events separately.

Seismic reassessment of the Krško site became necessary in the context of the planned new reactor Krško-2. The regulator SNSA raised questions about the potential impact of a fault known as Libna for the seismic hazard at Krško as well as the need to update the seismic hazard assessment of Krško 1. In an open letter to the operator and the SNSA, the French national expert organisation, the Radioprotection and Nuclear Safety Institute (IRSN) urged to seek further clarification. The IRSN suggested to the operator to assure sufficient local data input for study concerning Libna fault in order to minimise the identified uncertainties. (GREENPEACE 2014a).

A study by Slovenian experts pointed out that the results of the stress test report, e.g. the consequences of *PGA* > 0.8 g, should be weighed in the context of both the presently known relatively high accelerations due to moderate-magnitude earthquakes, and of the seismo-tectonic setting of the area. The study concluded that the statement of the SNSA "a return period for seismic events with PGA above 0.8 g is considered to be larger than 50,000 years" cannot be based on the revised PSHA and SPSA. (SIROVICH 2014)

Nevertheless, today the Krško NPP complies only with the current requirements for the original design basis of 0.3g. Only the additional systems, structures and components (SSCs) which will be

implemented within the SUP, will be designed and structured in accordance with the design extension conditions (DEC) requirements specific for the NPP design and site location. DEC systems, structures and components will be located in two new bunkered buildings.
However, the PGA value of the Design Extension Condition (DEC) for earthquakes is 0.6 g. This value provides almost no seismic safety margin (0.04 g) regarding the current value of the SSE. Performing a new seismic hazard assessment is not mentioned. The last seismic hazard assessment was conducted in 2004. Very serious is the fact that the seismic hazard at the Krško site is significantly higher than the original design base of the plant. (BMLFUW SL 2014).

The Slovenian regulator SNSA claims that in case of an earthquake with a PGA over 0.6 g, core cooling can be assured by alternative means, but pointed out that implementation of alternative means requires that manual actions are performed in relatively short time.
Taking into account the destruction of the NPP and the infrastructure after an extreme earthquake with a PGA over 0.6g, it seems quite impossible to prevent a core melt accident with alternative means.

After all the measures taken the necessary earthquake resistance remains an issue. Firstly, the possible maximal strength of an earthquake has not been sufficiently clarified. Secondly, even the **raised hazard levels did not lead to a change of the design base. Instead, only the** additional systems which will be implemented within the SUP, will be designed against an updated PGA 0.6 g. And thirdly, the seismic margins are very limited even though the consequences of an extreme earthquake are known. And despite those facts the NPP's life-time has been extended by the Slovenian nuclear regulator.

The Krško NPP site is located in an area prone to flooding. The Krško NPP is located in the Krško-Brežice Basin, on the left bank of the Sava River. The flood protection of the nuclear island and the bunkered building was improved in 2015. he newly installed equipment will be protected against the failure of flood protection dikes or extreme water level exceeding flood protection dikes by 0.4 m
Taking into the account that climate change will exacerbate extreme weather and flooding events, this safety margin is certainly too small.

Since the Krško NPP has only one water intake construction an ultimate alternative seismically qualified ultimate heat sink (UHS) independent from the Sava River was planned. (SUP, No. 1.3)
According to the 2019 NAcP, however, the installation of the alternative UHS was canceled.

Now only an alternate long-term heat sink through alternate SG injection system should be realized:

To assure core cooling in case of SBO and/or UHS, the installation of an additional high-pressure pump for feeding steam generators (SGs) installed in the separated bunkered building with dedicated source of water was scheduled for2015 (SUP, No. 1.2)
According to the 2019 NAcP, the progress of the measure is 60 %, completion is now scheduled for 2021. **The design value of the bunkered building is the protection against the DEC, which is not sufficient.**

Additional pumps (low and high pressure, as well as a special pump for seal injection[11]) were to be implemented by 2015. (SUP, No. 1.4)
According to the 2019 NAcP, the **installation of an additional heat removal pump (ARHR) with a dedicated heat exchanger capable of removing heat from the primary system and the containment** is now re-scheduled to 2021 **because the delivery of the main component (the ARHR pump) was delayed.**

To assure containment integrity during a severe accident, the implementation of containment filtered venting systems and passive auto-catalytic re-combiners (PARs) to avoid hydrogen explosion were implemented. (SUP, No. 1.5)

[11]The Krško NPP has considered installing temperature resistant reactor pump seals but decided against. Instead, one more of above-mentioned charging pumps will be installed as part of the SUP.

However, the seismic margins of the containment filtered venting systems and the PARs are – as explained above – very limited.

A fixed spray system around the spent fuel pool with provisions for quick connection from different sources of water (SUP, No. 1.7) and a mobile heat exchanger with provisions to quickly connect to spent fuel pool (SFP), containment sump or reactor coolant system (SUP, No. 1.8) should be available by 2015.
According to the 2019 NAcP, the implementation of the SUP actions 1.7 and 1.8 were delayed until April 2020 due to needed redesign and implementation of other tasks with higher priority.

The new emergency **control room** in the separate bunkered building **was implemented in 2019** (SUP, No. 1.6) The establishment of new technical support centre (TSC) and upgrade of existing operational support centre (OSC) (emergency operating facilities) were to be finished by 2015 (SUP, No. 1.10)
According to the 2019 NAcP, both OSC and TSC are around 90% complete, the implementation was delayed due to other tasks with higher priority.

SNSA considers preparing a national strategy (also amending legislation if needed) in regard to the handling of large volumes of contaminated water after and during a severe accident by 2016. (No. 3)
According to the 2019 NAcP, the measure is still in progress and should be finalized in 2020.

The 2019 NAcP explained: Within the reassessment of its severe accident management strategy, existing design measures and procedures, the operator has also reassessed the possibilities for an alternative spent fuel strategy. The results showed that the best strategy would be storing the spent fuel in dry cask storage.

Currently the spent fuel from the operation of NPP Krško is stored in a pool which is located in the fuel building. The fuel assemblies will be transferred from the storage pool into the dry storage in four campaigns: In the years 2020 and 2028 respectively 592 fuel assemblies and in 2038 the next 444 fuel assemblies will be re-located; the remaining fuel assemblies in 2048. The re-location of the spent fuel from the wet storage into a dry storage reduces the risk posed by the Krško NPP site. However, the time plan for the re-location is not set up accordingly. After the launch of the dry storage, it would be possible to move about 1,000 fuel assemblies. Due to economic considerations only 592 fuel assemblies will be re-located. However, safety aspects should be prioritized above economic aspects, thus a faster re-location should be done. (UMWELTBUNDESAMT 2020a)

5.3 Examples of further safety and security issues of Krško

The Krško NPP also prepared an analysis of the impacts of aircraft crashes on the plant. While this report is confidential and was not part of the peer review process, the national regulator states that the plant is well prepared even for such events. However, there is no proof to underpin this statement. It cannot be assumed that this reactor type would withstand a crash of an airliner. The Nuclear security index 2020 showed Slovenia with a total score of 81 points ranked 14thout of 47 countries. The score for the section "security and control measures" (69) is low. Of particular concern are the low scores for the "cyber-security" (38), insider threat protection (64) and security culture (50). (NTI 2020) These low scores indicate weaknesses in the protection.

At the request of the government of Slovenia, an **IAEA Operational Safety Review Team** (OSART) of international experts visited Krško Nuclear Power Plant from 15 May to 1 June2017. (IAEA 2017a)The team identified 20 issues, resulting in 4 recommendations, and 16 suggestions. 3 good practices were also identified. The most significant recommendations included:

- The plant should enhance training program for all personnel performing tasks important to safety, including emergency duties;
- The plant should improve the prioritization, implementation and monitoring of safety related activities to ensure their timely completion.

These two recommendations of international experts pointed to shortcomings that are related to the stress tests results.On the one hand, the operating team is obviously not sufficiently trained for accident situations. However, the actions of the operating team are of key importance in the accident management for the NPP Krško. In addition, safety-relevant upgrades are not carried out in a timely manner.

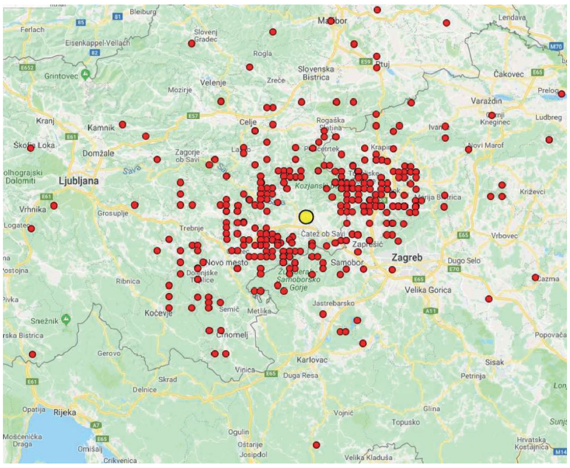
A PRE-SALTO mission on the preparation of the Long-Term Operation (LTO) is planned for 2021. (IAEA 2021a) It is a good decision that such an international mission is planned. However, it may be too late to identify and remedy deficits regarding the extension of operations. An open question is also how the mission's results will be incorporated into the Environmental Impact Assessment (EIA) documentation, the EIA is supposed to start already in spring 2021.

In 2020, all 342 **WENRA safety reference levels** of 2014 have been implemented in the Slovenian regulatory process. (WENRA RHWG 2020a)

Ageing is an issue for the NPP Krško after almost 40 year in operation. In the framework of the Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM that has been carried out in 2017, the Peer Review Team criticized the scope of the structures, systems and components subject to ageing management program (AMP): The scope of the AMP is not reviewed and, if necessary, updated, in line with the new IAEA Safety Standard after its publication. Also, the ageing management of the RPV show deficiencies compared to the safety level expected by ENSREG for Europe. Regarding the non-destructive examination (NDE) of the reactor pressure vessel the Peer Review Team criticized that comprehensive NDE is not performed in the base material of the beltline region to detect defects. Furthermore, the Peer Review Team criticized also the ageing management of concealed pipe-work: Inspection of safety-related pipe-work penetrations through concrete structures are not routinely applied in ageing management programs. (ENSREG 2018)

A recent study evaluates the possible impact of a severe accident at the Krško NPP to Italian territory. The results, presented in terms of Cs-137 total ground deposition probability distribution maps, show that in some northeastern and central Italian areas there is a 50% likelihood of exceeding the ‘‘equivalent“ Cs-137 threshold limit for leaf vegetables (220 Bq/m²). *(*GUGLIELMELLI 2017)

While Croatia does not have a NPP on its territory, it co-owns the NPP Krško in Slovenia which is 10 km away from the Croatian border. Croatia needs to include the NPP Krško in comprehensive hazard assessment. A recent article presents hazard assessment based on calculations using RODOS.[12] Results from hundreds of calculations have been statistically analyzed and compared to the current protection zones in Croatia around the NPP Krško.(JOE 2019)



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[12]Real-time weather prepared by Croatian National Weather Service and collected by the State Office for Radiological and Nuclear Safety over the years are used.

Figure 1: Maximum distances for necessary evacuation after a severe accident at the Krško NPP(JOE 2019)

On the Croatian side an Urgent Protective Action Zone (UPZ) is set up to the distance of 20 km from the NPP Krško. This is the zone where evacuation plans should be set up. The analysis shows that the current UPZ covers only about 30% of cases where evacuation is needed. Evacuations of the population should be undertaken before the arrival of the cloud to protect from cloud-shine, from inhalation during the passage of radioactive cloud and from ground-shine. (JOE 2019

5.4 Conclusions

The Krško site is not suitable as a location for a NPP; the main hazard for the plant is an extreme earthquake, but there is also a flood hazard. Cliff-edge effects caused by a beyond-design-basis earthquake, flood, or a combination of both events are ruled out primarily on the basis of their low probability of occurrence (similar to the Fukushima NPP).

The implementation of the Slovenian NAcP is still ongoing. Combined with the ongoing preparation of the lifetime extension (for additional 20 years), the comprehensive safety upgrading program (SUP) was to be finished by 2016, but finalisation was postponed to 2021.

The earthquake resistance remains an open issue. In 2004, a new assessment has shown that the seismic hazard (PGA= 0.56g) is significantly higher than was used for original design base of the plant (PGA=0.3g). The increased hazard levels, however, did not lead to an upgrade of the resistance of all safety relevant systems, structures and components (SSCs) of the plant. Only the earthquake resistance of the additional SSCs which will be implemented within the SUP has to be improved. However, the new value of the earthquake protection (0.6 g) provides almost no seismic safety margin (0.04 g).Implementation of seismic resistance has not even been finished for the newly introduced SSCs. Furthermore, some experts questioned the reliability of the most recently conducted seismic hazard assessment. All in all, the key issue will remain: Despite the Nuclear safety authority, SNSA, and the operator being fully aware that Krško NPP is situated in a seismic active region, obviously insufficient measures are taken.

The Krško NPP site is located in the Krško-Brežice Basin, on the left bank of the Sava River which is an area prone to flooding.The flood protection of the nuclear island and the bunkered building was improved in 2015. The newly installed equipment is protected against the failure of flood protection dikes or against extreme water level exceeding the flood protection dikes by 0.4 m. Taking into the account that climate change will exacerbate extreme weather and flooding events, this safety margin is certainly too small.

Since the Krško NPP has only one water intake structure, an ultimate alternative seismically qualified ultimate heat sink (UHS) was planned independently of the Sava River. However, the installation of an alternative UHS was cancelled for economic reasons.

Several provisions are now in place to support SAM with the use of mobile equipment. **Taking into account the destruction of the NPP and the infrastructure after an extreme earthquake with a PGA over 0.6g, it seems quite impossible to prevent a core melt accident with alternative means.**

But even more worrisome, a study pointed out that an extreme seismic event causing an unavoidable core melt accident could not be excluded. However, the last update of the NAcP does not mention a new seismic hazard assessment. In case of a core melt accident, the containment filtered venting systems should prevent a major release of radioactive substance, but the earthquake protection of this system is also insufficient.

The Nuclear security index 2020 shows Slovenia with a total score of 81 points ranked 14thout of 47 countries. Of particular concern are the low scores for the “cyber-security” (38), "insider threat protection" (64) and "security culture" (50). These low scores indicate weaknesses in the protection.

An IAEA Operational Safety Review Team (OSART) visited Krško NPP in 2017. The international experts observed shortcomings that are related to the stress tests results. The operating team is obviously not sufficiently trained for accident situations. However, the actions of the operating team are important in the accident management of Krško. In addition, safety-relevant upgrades are not carried out in a timely manner.

Ageing is an issue for the NPP Krško after almost 40 year in operation. In the framework of the Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM that has been carried out in 2017, the Peer Review Team criticized the scope of the structures, systems and components subject to ageing management program. The ageing management of the RPV is of fundamental importance for a plant given the envisaged lifetime extension to 60 years. But also the ageing management of the RPV show deficiencies compared to the safety level expected by ENSREG for Europe.

Summing up, it is irresponsible to operate a nuclear power plant in a seismically active area with all the plant's **known shortcomings**.

6 Ringhals, Sweden

The Ringhals NPP is situated on the west coast of Sweden about 60 km south of Gothenburg. The plant comprises four reactors: Ringhals 1 and 2 started operation 1975/76. Ringhals 3 and 4 are pressurized water reactors (PWR), operating since 1981 and 1983 respectively. The Ringhals NPP is owned by Vattenfall (70 %) and EON (30%) and operated by Ringhals AB.

In April 2015, government-owned Vattenfall announced that due to declining profitability and increased costs exacerbated by the nuclear tax, it proposed to close Ringhals 1&2 by 2020 instead of 2025 as previously planned. Ongoing investment projects that would have been implemented from 2017 onwards would cease. Ringhals 2 was shut down in December 2019, followed by Ringhals 1 in December 2020. Ringhals units 3 and 4 will remain in operation, with a planned lifespan of 60 years, i.e., to 2041 and 2043 respectively.

6.1 Swedish National Action Plan (NAcP)

The Swedish NAcP which resulted from the ENSREG stress tests listed the measures in three different categories – 2013, 2014 and 2015 – according to the year when the measures have to be completed. However, according to the Swedish Radiation Safety Authority (SSM), the measures are considered completed when the investigation into necessary changes is submitted, assuming that actions resulting from the investigations will be fully implemented before the end of 2020. (SSM 2012)

After their visit tothe Ringhals NPP in September 2012, the ENSREG fact-finding team concluded: The plant is advised to update the action plan taking into account the full set of ENSREG recommendations. (ENSREG SE 2012). However, these references were not included in the updated NAcP. Furthermore, plant specific actions are not mentioned at all.

The 2014 NAcP is a long report including mainly the same general information provided by the original NAcP. The Swedish National Action Plan clarified that no measures have been removed or modified. It is also pointed out that the independent core cooling (ICCS) is the issue that has strongly dominated the work with implementation of the NAcP. The ICCS was not an explicit part of the first version of the NAcP but was foreseen as a consequence of the results of the analyses, studies and investigations.(SSM 2014)

Two further updates of the NAcP were published in December 2017 and March 2020 respectively.

According to the 2020 NAcP, all measures have been completed according to the time schedule. The only remaining measure is the Independent Core Cooling System (ICCS), which should be implemented by the end of 2020. The installation of the ICCSs is the most important measure. (SSM 2020)

6.2 Weaknesses identified by the Swedish Stress Tests the NAcP should remedy

The original design of the Ringhals units did not take into consideration the protection against earthquakes. Ringhals became subject to general requirements imposed on resilience against earthquakes when the new Swedish regulations entered into force in 2005. The deadline for taking measures was determined to be 2013. The reason for the long time was to allow licensees sufficient time to fulfill the requirements. The NAcP mentioned that work is on-going at all units in order to fulfill the regulation regarding design basis earthquake (DBE).[13]

The 2014 NAcP does not mentioned whether all back-fitting measures designed to meet the Swedish regulation of 2005 have been completed. However, the approach of the SSM is not appropriate: the implementation time has to be chosen to protect people and the operator.

The ENSREG peer review revealed that the methodology used for seismic hazard assessment (SHA) is not fully compliant with current international standards and research results. Thus, SSM will start a research project concerning the influence of paleo-seismological data on the existing model regarding frequency and strength of the ground response spectra in 2013 (T1.RA.1).

According to the 2020 NAcP, this measure is completed: A literature search has been initiated and results presented in a SSM technical report.

However, the results were not provided, making it impossible to assess whether the seismic hazard protection is sufficient.

The Ringhals units are located near the sea. The stress tests revealed that the Ringhals units could be significantly affected by a flood: Full compliance for protection against external flooding in accordance with the Swedish requirements of 2005 was expected to be reached in 2013.

The site ground elevation (+2.65 m) is only 35 cm above the seawater level of the calculated design basis flood (DBF =+3 m), but this water level does not include possible waves. The licensee plans to eliminate the possibilities of water entering the building (installing new doors, improve sealings etc.), but only in case of a sea water level up to + 3.3 m.Once the seawater level (including waves) rises higher than 65 cm, large amounts of water will enter the units through various openings; fuel damage is possible. When the sea water level is 1.35 cm above the DBF (+4 m), all doors of the units will break and water will instantly flood all units causing fuel damage.

The Peer Review Team recommended examining the combination of high sea water level and other external phenomena such as swell, strong wind and organic materials for the Ringhals site. SSM underlined the fact that historically extreme sea water levels in Scandinavia have always been accompanied by very high wind speeds. An analysis of the combined effects of waves and high water including potential dynamic effects was scheduled for completion by 2015 (T1.LA.5)The NAcP requires a flooding margin assessment in line with the initial ENSREG specification for the stress tests of 2014 (T1.LA.6).

According to the 2020 NAcP, analyses of incrementally increased flooding levels beyond the design basis and identification of potential improvements have been performed. Weaknesses have been addressed and physical measures have been taken at some plants.

However, the new values for the extreme sea water levels were not presented. The risks of flooding and extreme weather events are increasing significantly due to climate change. Thus, the new values could be outdated soon and the plant will remain at risk from the sea.

[13]Identified deficiencies during the stress tests were for example the spent fuel cooling systems, the roof of the reactor building at Ringhals-1; control room ceiling at Ringhals-3 and -4.

ENSREG recommended to conduct a new evaluation of the flooding protection (volumetric approach)[14] which was scheduled for completion by 2014 (T1.LA.7).
However, the result of this evaluation was not presented, only an announcement saying that "[b]ased on performed stress tests, measures will be performed at some plants." Neither measures nor time schedule of the implementation are provided.

The Peer Review Team recommended carrying out a more detailed external hazard analysis on the basis of the state-of-the-art requirements.A formal assessment of margins for all external hazards plus identification of potential improvements was performed (T1.LA.9).
According to the 2020 NAcP, the analyses and in some cases the corresponding administrative and physical improvements show that the NPPs can handle external hazard with the exceedance frequency of 10-5 per year.
However, no explanation was provided on how the plants can handle external hazards.

The stress tests revealed that the Swedish regulation addresses <u>extreme weather</u> without quantification of the loads. An investigation of plant characteristics in extreme weather conditions is required to be performed by 2015. SSM has requested to perform further analysis in this area.(T1.LA.4)
According to the 2020 NAcP, the analyses, and in some cases corresponding administrative and physical improvements, shows that the NPPs can handle extreme weather with the exceedance frequency of 10-5 per year. It is also explained, that SSM will initiate a study to better estimate extreme weather conditions. The study will be performed as a research project in cooperation with the licensees. The project has not yet been initiated.
Some shortcomings were already identified[15] but it is likely that further analyses will identify additional deficiencies. The protection against extreme weather conditions seems not to be sufficient. It remains unclear how long this problematic situation will last.To evaluate extreme weather events and to ensure appropriate protection a research project will be started, which is the correct approach, however, it is incomprehensible why this project starts only 10 years after the Fukushima accident. The need for better protection against extreme weather events was one of the key lessons learned from the accident.

The primary **ultimate heat sink** for all units at Ringhals is sea water.Ringhals 3 and 4 have another option to release residual heat to the atmosphere via the steam generators. However, this procedure is dependent on the water sources available for the auxiliary feed water system and is thus limited.If the ultimate heat sink (UHS) is lost, fuel damage can occur in the reactor core and/ or spent fuel pool quite rapidly depending on the level in the water supply tanks systems. **No reason was given why the licensees or SSM did not consider implementing an alternate ultimate heat sink earlier.**

If loss of off-site power occurs, power is to be supplied by emergency diesel generators (EDG). Most of the emergency diesel generators (EDG) depend on seawater cooling and will fail if the ultimate heat sink fails. To cope with the situation in which all EDGs fail, gas turbines (GTs) are installed as alternate AC power sources. But the GTs are in most cases not fully protected against external hazards (e.g. earthquake) and thus could fail in case of an external event.

All in all, there are several weaknesses that could result in the total loss of power supply (station black-out SBO) and loss of heat removal, but the time to prevent fuel damage in such situation is very short: In case of loss of UHS, fuel damage becomes unavoidable at Ringhals3 and 4 after 8 hours.If manual actions are delayed, damage to fuel will be unavoidable within 2 hours.

The Swedish nuclear regulator SSM requires the implementation of an **Independent Core Cooling <u>System</u>**by 2020**. The Independent Core Cooling System is the most important safety measure in the Swedish Action Plan. An independent core cooling system reduces the risk of a meltdown in**

[14] This study serves to identify critical areas and spaces regarding flooding of the sites and considers the need of further protection of the buildings containing safety related equipment located in rooms at or below ground level.

[15]If no snow removal will take place, the maximum consequences of a collapse of the Ringhals-1 reactor building or the Ringhals-2 fuel building is the damage to the fuel in the fuel pools.

an accident and of a major radioactive release.The need to increase the reliability of core cooling by introducing an independent function was brought up already in the early 2000s.The need for Independent Core Cooling received further attention after the Forsmark 1 event on 25 July 2006, and after the serious accident at the Fukushima Daiichi nuclear power plant.

World nuclear news informed its readers that the public announcement followed many years of “dialogue” between SSM and the operators concerning diversification and improvement to core cooling in emergencies. (WNN 2014a)

The licensees must also submit an implementation plan by the end of June 2015 for the temporary measures. SSM requires an **independent core cooling function** to be in place by 2017**.** These transitional/temporary measures do not have to fully meet the design basis for the independent Core Cooling system. The measures consist mainly of enforcing the emergency power by upgrading the existing gas turbines (GT) and purchasing new mobile equipment, with new connection points and new power feed trains.

Ringhals 1 and 2 stopped operation in 2019 and 2020 respectively. Thus, part of the risk is completely eliminated, but this does not justify the decision to allow the oldest and most vulnerable plants to operate almost 10 years after the Fukushima accident without major safety improvements.

In December 2014 SSM issued an injunction requiring the installation of the ICCS, as a pre-condition for an operational permit beyond 2020.[16] The ICCS is designed to provide alternative core cooling if the ordinary safety systems are unavailable in a situation with design extension conditions (DEC). The main basic design requirements for ICCS are extended Loss of AC Power and Loss of Ultimate Heat Sink (for 72 hours). These events are assumed to coincide with, or be the consequence of, severe external events. These events should have an exceedance frequency of 10-6 per year, without the need for manual action the first 8 hours. The system is in operation since December 2020.

At the Ringhals NPP, all features of the ICCS, including supportive functions, are housed in a separate building, one for each unit. The ICCS building has a separate electrical power supply system, galvanically, functionally and physically separated from the regular electrical power system. Inside the building are two large water tanks that provide the different functions with water for independent core cooling.

In December 2020, SSM announced that the ICCSs have been implemented. However, SSM also explained that they identified a number of shortcomings in the licensees' reports, including the current methodology for analysis of earthquake resistance, reporting of resistance to extreme temperatures and reporting probabilistic safety analyses. SSM has instructed the power companies to remedy the identified deficiencies.(WNN 2020a)

As long as these deficiencies are not remedied, the ICCSs cannot be considered being completely functional. They would possibly fail in extreme situations in which they are supposed to ensure the cooling of the core or the stored spent fuel.To ensure that the ICCS functions for eight hours without intervention by the staff is not an ambitious goal anyway.

The stress test revealed that in case of a total loss of power (SBO) or loss of Ultimate Heat Sink (UHS), no system is available for cooling the **spent fuel pools (SFP).** The only usable source for the preparation of make-up water necessary for the pools is firefighting water. Manual actions must be performed before the onset of harsh conditions (humidity, temperature, radiation) in the spent fuel area.

Improving the capability of SFP cooling (e. g. installation of permanent pipes for make-up water from a protected location) and their instrumentation was to be considered by 2014 (T3.LA.1; T3.LA.3).

According to the 2020 NAcP, the licensees have in a common project developed a ”Position Paper” that defines requirements that shall be adopted. Improvements should be in place in parallel to the

[16]This applies to six reactors.

installation of Independent Core Cooling System.
However, when the implementation will be finished was not announced. In addition to the independent core cooling system main function, the system also improves the capability to cool the spent fuel pool by establishing a feed and boil-off cooling function. This function will be fulfilled by permanently installed piping for make-up water from the ICCS building. All the improvements will be completed by the end of 2020.

Important measures for the Severe Accident Management (SAM) were introduced in Swedish NPP in the eighties; however, there are no measures in place to cope with a multi-unit event. Furthermore, the containment filtered venting system is not designed to cope with accident scenarios with the duration and aggravated conditions which have occurred during the Fukushima accident. Therefore, a review of the usability of the containment filtered venting system was ordered (T3.LA.16).
According to the 2020 NAcP, this measure is completed. Investigations and assessments of the ability to manage a severe accident have been performed by the licensees. Different solutions have been suggested.
However, SSM's assessment of the diverse solutions suggested for the filtered venting system have not been presented. No mention was made about the deadline for the implementation of the necessary back-fitting measures.

Means to manage large volumes of contaminated water are to be evaluated by 2015. (T3.LA.12)
According to the 2020 NAcP, plans on how to manage large volumes are in place.
However, it is not explained whether any action needs to be taken such as purchasing equipment, changing structures, or retrofitting systems.

6.3 Examples of further safety and security issues of Ringhals

Ringhals 3 willreachits 40th year of operation in 2021, thus entering long-term operation (LTO).In March 2018 an IAEA SALTO review mission was performed for Ringhals 3. The IAEA team stated thatthe plant had improved ageing management of civil structures and buildings. However, the team noted that further work is necessary to ensure that ageing management and LTO related data are consistent and complete, and to establish a long term staffing plan for LTO.Seventeen issues were raised, among others (IAEA 2018a):

- Ageing management of mechanical components is not fully implemented;
- Ageing management of civil structures is not comprehensive for LTO;
- The plant ageing management programme for cables and connections is not sufficiently comprehensive for the purposes of LTO;
- The plant equipment qualification programme is insufficient to demonstrate the qualification of all components important to safety;
- The plant has not demonstrated that the containment pre-stressing tendons can maintain their design function during LTO.

For a nuclear power plant that has been in operation for 40 years this is a high number of deficiencies in ageing management. Based on these deficiencies, it can be assumed that there are a number of previously undetected aging defects in the plant.

The Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM has been carried out in 2017. The first TPR focused on the Ageing Management Programmes. In the course of the TPR, national results have been evaluated through the peer review process. Also the Peer Review Team criticized the scope of the structures, systems and components subject to ageing management in Sweden: The scope of the AMP is not reviewed and, if necessary, updated, in line with the new IAEA Safety Standard after its publication. Also, the ageing management of the reactor pressure vessel (RPV)shows deficiencies compared to the safety level expected by ENSREG in Europe: Regarding the

Non-destructive examination (NDE) the Peer Review Team criticized that comprehensive NDE is not performed in the base material of the beltline region to detect defects. (ENSREG 2018)

Sweden has still not implemented all WENRA Reference Level of 2014 in 2020, 50 are still lacking. (WENRA RHWG 2020a)

In 2015, a power uprate has been approved for Ringhals 4. The operator, Ringhals AB applied to the regulator in 2007 for permission to increase thermal output of Ringhals 4 by 18% from 2783 MWth to 3300 MWth. (GOS 2019) A prerequisite for the uprate was the replacement of the unit's three steam generators. These were replaced during the summer of 2011 as part of an uprating and life extension project. Power uprates – the increase of the NPP electricity output – can cause unexpected failures in safety systems that could aggravate accident situations. Power uprates also accelerate the development of accidents thereby shortening the intervention time needed to take action to minimize the accident. Furthermore, in case of a severe accident, the potential radioactive release is considerably higher. And very important for the old plant: power uprates accelerate negative ageing processes.

In May 2011, the management decided to start a containment pressure test three days earlier than scheduled but forgot to inform the staff. A short circuit in a vacuum cleaner forgotten in the containment caused a fire. The fire generated a substantial amount of ash that is difficult to remove from the containment. During cleaning measures, old scrap from welding work was found in important safety systems (containment sprinkler systems) at Ringhals-2 and later in Ringhals-4. Considerable modernisation was conducted at those units in the 1980s and 1990s and it is possible the scrap had been there since then. That the scrap was not detected earlier is alarming and shows that the safety systems were not tested properly over many years. Checking and maintenance of safety systems is a key to nuclear safety. (WENISCH 2012) But not only the safety culture but also the security culture is a dangerous issue.

The Nuclear security index 2020 shows Sweden with a total score of 82 points ranked 9th out of 47 countries. However, the score for the section "security and control measures" (63) is low. Of particular concern are the low scores for the "Cyber-security" (50), Insider threat protection (45) and security culture (25). (NTI 2020)

6.4 Conclusions

The evaluation of the Ringhals site in the light of the Fukushima accident and in accordance with the ENSREG stress tests specification has revealed a number of shortcomings. Ringhals 1 and 2 stopped operation in 2019 and 2020 respectively. **Thus, part of the risk has been eliminated completely, but this does not justify the decision to allow the oldest and most vulnerable plants to operate almost 10 years after the Fukushima accident without major safety improvements.**

The original design of the Ringhals units did not take into consideration the protection against earthquakes. Ringhals became subject to general requirements imposed on resilience against earthquakes when the new Swedish regulations entered into force in 2005. The deadline for taking measures was scheduled to 2013. The reason for the long time was to allow licensees sufficient time to fulfill the requirements. However, the approach of the SSM is not appropriate: the implementation time has to be chosen in regard of the protection of the people.

The Ringhals units are located near the sea. Obviously neither the operator nor the regulator took the flooding hazard seriously enough to take action. The design basic flood (DBF) has been not calculated according to the State-of-the-Art. The stress tests revealed that the Ringhals units could be significantly affected by the flood. The licensee plans to eliminate the possibilities for water entering the building, but only to a limited height. A new evaluation was performed, but the new values for the extreme sea water levels are not presented. The risks of flooding and extreme weather events are rising significantly due to climate change. Thus, the danger for the Ringhals units remains.

The protection against extreme weather conditions seems not to be sufficient. It remains unclear how long this problematic situation will last. To evaluate extreme weather events and to ensure appropriate protection a research project will be started, which is the correct approach, however, it is incomprehensible why this project starts only 10 years after the Fukushima accident. The need for better protection against extreme weather events was one of the key lessons learned from the accident.The primary ultimate heat sink for all units at Ringhals is sea water.A very serious safety issue is the lack of an alternate ultimate heat sink. It is not explained why the licensees or SSM did not consider implementing an alternate ultimate heat sink.

The Independent Core Cooling System (ICCS) is the most important safety measure in the Swedish Action Plan to reduce the risk of core melt accident and of a major radioactive release. The need to reduce the probability of this accident has been discussed for about 20 years.Apparently very long periods of time for the remedy of recognized risks of the NPPs are the standard approach in Sweden, though highly irresponsible.The ICCS is ready for operation since December 2020. However, SSM identified a number of shortcomings including the current methodology for analysis of earthquake and extreme temperature resistance. The regulator SSM required the operator to remedy the identified deficiencies. As long as these deficiencies are not remedied, the ICCSs cannot be considered being completely functional. They would possibly fail in extreme situations in which they are supposed to ensure the cooling of the core and the stored spent fuel.

Ringhals 3 will reach its 40thyear of operation in 2021, thus entering long-term operation (LTO). In March 2018 an IAEA SALTO review mission was performed for Ringhals 3. The IAEA raised 17 issues (e.g. ageing management of mechanical components, civil structures and cables are not sufficiently for LTO). Based on these deficiencies, it can be assumed that there are several undetected aging defects in the plant. Also, the Topical Peer Review (TPR) as set out in 2014/87/EURATOM has been revealed weaknesses in the ageing management in Sweden.

In 2015, a huge power uprate has been approved for Ringhals 4. Power uprates also accelerate the development of accidents thereby decreasing intervention time needed to take action to minimize the accident. Furthermore, in case of a severe accident, the potential radioactive release is considerably higher. And very important for old plants: power uprates accelerates negative ageing processes.

Safety culture at NPP Ringhals has been a serious problem for many years. This could result in a partly or total failure of safety systems in the course of an accident. But not only the safety culture also the security culture is a dangerous issue. The Nuclear Security Index 2020 shows deficiencies in the "security and control measures". Of particular concern are "security culture" as well as "cyber-security" and the low protection against the "insider threat".

7 Gundremmingen, Germany

The Gundremmingen NPP consists of two boiling water reactors (BWR) of the German construction line ´72 with high power output: net capacity per unit 1284 MWe, 1288 MWe respectively. Commercial operation started in 1984/1985. The site is located at the Danube River about 90 km northwest of Munich; distance to Austria is around 100 km.

Right after the Fukushima accident, German NPPs were subjected to a two-month safety review by the Reactor Safety Commission (RSK).[17] Furthermore an Ethics Commission "Secure Energy Supply" re-assessed the risks associated with the use of nuclear energy. These projects resulted in the decision to phase-outby amending the Atomic Energy Act (August 6, 2011): The operational licenses for the seven oldest NPP (commissioning before 1980) and the incident-prone Krümmel NPP were declared expired. The licenses for the operating NPPs should expire on a step-by-step basis between 2015 and

[17] During the safety review, the operators had to shut down the operating NPPs commissioned prior to 1980.

2022. Gundremmingen B had to stop power operation in 2017; Gundremmingen C will stop operation in 2021.

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) prepared the German stress tests report.

7.1 German National Action Plan (NAcP)

The NAcP which resulted from the stress tests comprised 23 actions, which are explained in some detail and refer to the ENSREG recommendations made for Germany. The German NAcP also included a plant-specific list of measures. The specific action plan for the Gundremmingen NPP only announced 13 very general measures without descriptions of any details.[18](BMU 2012) Depending on the competent nuclear authorities the scope of the provided information differs, the measures listed for the NPP of Baden-Württemberg are prepared in more details than for Gundremmingen (Bavarian NPP).

The 2014 NAcP contained one additional action to cover resilience against extreme weather conditions. Many of the NAcP activities were completed in 2012 and 2013. However, some activities were studies which are likely to deliver results calling for further improvements. These will be implemented within the normal regulatory oversight processes. (BMU 2014) The nuclear authority and the operator will have to take decisions about necessary improvements "taking in account the remaining operation time" behind closed doors in a highly in-transparent process. According to the ENSREG Rapporteur's Report there may be a need for further clarity on how the plans will be fully developed and reported when the relevant studies and consultations are complete. (ENSREG RR-GE 2014) However, the NAcP does not mention this issue.

After having visited the Gundremmingen NPP, the ENSREG fact-finding team voiced concerns about the scope of back-fitting measures: *A challenge may exist in implementing improvement measures for plants with (legally) limited operational time. ...Regardless of this circumstance, nuclear safety is an overriding priority and has to be maintained at a high level until the end of the operation time* (ENSREG GE 2012). It is not known how the nuclear authority responded to this however it does not seem that the scope of back-fitting measures has been extended. Possible differences between the requirements for Gundremmingen B or C taking the different operation time into account are not mentioned. All in all, the information provided by the 2014 NAcP is very limited, as was the scope of back-fitting measures at the Gundremmingen B/C.

However, 2014 was the last time the National Action Plan was updated.

7.2 Weaknesses identified by the German Stress Tests the NAcPshould remedy

The units are designed to withstand a design basis earthquake (DBE) corresponding to a PGA value of 0.1 g. The last re-evaluation of the seismic hazard at the Gundremmingen NPP site took place twenty years ago (in 1993) and is completely outdated.

According to the evaluation conducted during the stress tests, the water level of the calculated design basis flood (DBF) is 0.33 m higher than the Gundremmingen NPP site. Thus, some parts of the plant would already be flooded in this case. The NAcP requires that the flood protection of German NPPs needs to fulfill at least Level 1 of the criteria specified in the German Reactor Safety Commission's(RSK) safety review[19]. However, according to RSK, this is not the case for

[18]The nuclear regulatory body in Germany is composed of authorities of the Federal Government and authorities of the Länder governments. Licensing and supervision, inspection and enforcement as well as plant-specific safety assessments and reviews of nuclear power plants are executed by the Länder. The national regulator sets up the NAcP, but the Länder define the plant-specific actions.

[19] The safety can be demonstrated only by applying probabilistic considerations: "Alternatively, it may be demonstrated on the basis of site-specific conditions that a postulated discharge quantity, which is determined by extrapolation of existing probabilistic curves to an occurrence frequency of 10^{-5}/a, will not result in the loss of vital safety function. In this respect, the uplift resistance of canals and buildings is to be considered."

Gundremmingen B/C. The site-specific NAcP for Gundremmingen asked for the review and improvement of flood protection by 2012 (No 9; N-15).
According to the 2014 NAcP, this action was completed. Recent studies have shown that the site will not be flooded in case of design basis flood (DBF). The safety margins until the design flooding levels are reached are greater than originally assumed.
However, the differences between the assumption for the new and the previous evaluation of the water level of the design basis flood are not provided. Protection of safety relevant safety systems is only assured by protection of the buildings (e.g. cable penetrations are sealed). Experiences with flooding events in other NPPs showed that these protection measures can fail. Furthermore, the area surrounding the site will be flooded in case of a flooding event. This leads to the assumption that the Gundremmingen NPP flood protection was a paper exercise conducted to demonstrate the low probability of flood events.

Regarding flooding margins, the NAcP requires a systematic analysis to prove that the safety is ensured in case of beyond design flooding. However, the site-specific NAcP for the Gundremmingen NPP requires only the purchase ofboats to improve accessibility of the plant grounds during a flood. (No 8; N-13, N-15).
According to the 2014 NAcP, three boats for conveyance of passengers have been acquired.
However, this is far from sufficient being an effective response against extreme flooding events.

In case of a total station black out (SBO), when the NPP loses the external power supply, each unit has an additional residual heat removal system (AHRS) – but the functionality of the AHRS relies on one emergency diesel generator (DG). The DG is protected against site-specific earthquakes (DBE), which is, as mentioned above, probably lower than necessary.

The operator claims that loss of primary ultimate heat sink and the AHRS to be extremely unlikely; and for this case accident management measures are available (depressurization of the reactor cooling system, water injection from different sources e. g. injection by mobile pumps, heat removal by filtered containment venting). But in this case the core cooling is only ensured for 15 minutes.

In case of a total station black-out (SBO) and loss of ultimate heat sink (UHS), accident management (AM) measures have to ensure decay heat removal from the spent fuel pool. The evaporation losses of water can be made up by mobile pump(s) only. Because the spent fuel pools are located outside the containment in the upper part of the reactor building, comparable with the pools at the reactor of Fukushima NPP, the injection of water is quite difficult. Therefore, a permanently installed injection path into the spent fuel pool from outside the reactor building was to be installed in 2013. (No 6; *N-8, N-22)*
According to the 2014 NAcP, the new deadline for the measure is April 2015. The report mentioned that an injection path is permanently installed so that there is no need to enter any rooms that are at risk.

Because no severe accident management (SAM) measures for the mitigation of radioactive releases or preventing hydrogen explosions after severe damage of spent fuel in the pools were available, the NAcP calls for installing hydrogen re-combiners (deadline 2014) (No. 4, N-7).
According to the 2014 NAcP, this measure has been completed: Passive autocatalytic re-combiners (PARs) are installed in the area of the spent fuel pool in both units.

Obtaining and providing a mobile emergency power generator and connection points protected against external hazards for the supply of the accident overview measuring systems and for the reactor pressure vessel (RPV) feeding was to be accomplished by 2013 (No. 1; N-1, N-2, N-19).
According to the 2014 NAcP, the activity is completed. Mobile diesel generators have been deployed.

In 2011, the plant-specific safety review of German NPPs undertake nin the light of the events in Fukushima revealed that the successful use of accident management/emergency measures under long-term SBO conditions and severe accidents condition is not assured. Also, the ENSREG Peer Review Team pointed out that in most cases detailed qualitative descriptions of the measures designed as reactions to various severe accident scenarios are presented without comments regarding their adequacy also under extreme conditions.

In general, the feasibility and operability of accident management measures (e. g. injection possibilities for the cooling of fuel assemblies) under adverse conditions even after a design basis earthquake or another design base natural hazard is not proven. This is very important, because it has to be expected that after a natural hazard, accident management measures are necessary to prevent the release of radioactive substances. Thus, the introduction of new/improved emergency measures was required by 2013 (No 5; N-8, N-18, N-19).
According to 2014 NAcP, this action is completed.
However, no further information is provided. It seems that only or mostly paperwork was performed and the prevention of radioactive releases or the mitigation of the consequences is not guaranteed in case of a severe accident.

A systematic review of the robustness of emergency measures with consideration of external hazards was scheduled for completion by the end of 2013 (No. 2; N-5, N-6, N-9, N-16).
According to the 2014 NAcP, the activity has been finalized and a report has been prepared.
However, measures resulting from the review are not mentioned. The implementation of further improvements is expected to be necessary; i.e. the current measures are not sufficient to prevent core melt accidents with large radioactive releases after an earthquake or flooding event.

The German NAcP also required reviewing the performance of the filtered venting system under severe accident conditions (e.g. long lasting SBO).
Without explaining this decision, the2014 NAcP stated that this review is not required for Gundremmingen B/C.

7.3 Examples of further safety and security issues of Gundremmingen

The safety of the NPP relies on completely outdated rules and regulations (1977 – 1996).The new "Safety Requirements for Nuclear Power Plants" have been pending for years in Germany. Therefore, accident prevention does not meet state of the art requirements.

A study on risks of the NPP Gundremmingen B and C pointed to several **design deficits**, amongst other issues to that fact that (RENNEBERG 2013):

- the construction of the reactor vessel does not represent the technical state of the art
- only two of the required three redundancies of the emergency core cooling system are sufficiently qualified as safety systems;
- some safety-relevant components and subsystems are not qualified to withstand the design basis earthquake (DBE);
- the basic design of the spent fuel pool and its cooling system is outdated.

With an operating time of more than 35 years, negative **aging** effects play an increasingly important role for the Gundremmingen reactors. The Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM has been carried out in 2017. The first TPR focused on the Ageing Management Programmes. In the course of the TPR, national results have been evaluated through the peer review process. The Peer Review Team criticized the scope of the structures, systems and components subject to ageing management in Germany: The scope of the AMP has not been reviewed and, if necessary, updated, in line with the new IAEA Safety Standard after its publication. During long construction periods or extended shutdown of NPPs, relevant ageing mechanisms are <u>not</u> identified and appropriate measures are implemented to control any incipient ageing or other effects. Also, the ageing management of the RPV show deficiencies compared to the safety level in Europe expected by ENSREG.Regarding the Non-destructive examination (NDE), the Peer Review Team also criticized that comprehensive NDE is not performed in the base material of the beltline region to detect defects. (ENSREG 2018)

Another gap with regard to the expected safety level in Europe can be seen in the implementation of the WENRA Reference Level (RL). Germany has not implemented 31 of the 342 WENRA RL of 2014 in 2020. (WENRA RHWG 2020a)

The Gundremmingen NPP never hosted an IAEA OSART mission. Therefore, it is impossible to say how the operation in Gundremmingen would be evaluated by international experts. (IAEA 2021)

A major weakness of the Gundremmingen NPP is the location of the spent fuel pools: They are located inside the reactor building, but above and outside the containment (like in the Fukushima Daiichi NPP). In case of a severe accident, there is no barrier to the environment. Also the vulnerability against a terror attack is high. In total about 3200 spent fuel assemblies could be stored in the spent fuel pool of each unit. These are four times more than in the reactor cores (784). Currently, the fuel pools are nearly full.A rough estimate for the spent fuel pool results in a caesium 137 inventory of approx. 3,100 peta becquerel (PBq). Investigations assume that a share of 10% to 100% of the caesium inventory would be released into the atmosphere. This would correspond to a Cs-137 source term of 310-3,100 PBq.i.e. considerably more than was released during the Fukushima accident (about 10 PBq Cs-137 or the Chernobyl accident (about 85 PBq Cs-137.) (UMWELTBUNDESAMT 2017a)

A crash of a Boeing 737 against the reactor building can cause a severe accident. In case of (1) a major destruction of the reactor building or (2) a damage of the control room by fire and debris combined with leakages in the cooling system, a severe accident could occur. This is the result of a study commissioned by the BMU. According to the Federal criminal police office, the probability of a terror attack against a nuclear power plant is low; however, a terror attack has to be taken into account (BMU2002).

The Nuclear Security Index assessment points to further weaknesses regarding protection against sabotage or terrorist attacks. The Nuclear security index 2020 shows Germany with a total score of 84 points ranked 5thout of 47 countries. However, the score for the section “security and control measures” (77) is low. Of particular concern are the low scores for “security culture” (50), “cyber-security” (63) and “insider threat protection” (73). These low scores indicate weaknesses in the protection. (NTI 2020)

7.4 Conclusions

Right after the Fukushima accident, German NPPs were subjected to a two-month safety review by the Reactor Safety Commission (RSK) and furthermore an Ethics Commission “Secure Energy Supply” re-assessed the risks associated with the use of nuclear energy. These projects resulted in the decision to phase-out nuclear power in Germany: The operational licenses for the seven oldest NPP and the incident-prone Krümmel NPP were declared expired. The licenses for the operating NPPs should expire on a step-by-step basis between 2015 and 2022. Gundremmingen B had to stop power operation in 2017, Gundremmingen C will stop operation in 2021.

After having visited the Gundremmingen NPP, the ENSREG fact-finding team voiced concerns about the scope of back-fitting measured ant stated r*egardless of this circumstance nuclear safety is an overriding priority and has to be maintained at a high level until the end of the operation time*. The German nuclear authority’s response to this concern is not known, however the scope of back-fitting measures has not been extended.

The stress tests revealed that the site will be flooded in case of a design basis flood (DBF). Despite the recommendation to improve the flood protection, a new study “shows” the site will probably not be flooded. The improved “flood protection” consists only of paperwork. No information concerning the review of extreme weather situation was provided. Heavy rains could even aggravate flooding events for the Gundremmingen NPP site. Regarding flooding margins, the NAcP requires a systematic analysis to prove that the safety is ensured in case of beyond design flooding. However, Gundremmingen NPP only acquired boats to improve accessibility of the plant grounds during a flood. However, this is an utterly insufficient response to extreme flooding events.

The stress tests found that the severe accident prevention at Gundremmingen NPP relies on outdated (severe) accident management measures which are insufficient to respond to external hazard conditions or the need of long-term heat removal. The operability of accident management measures has been reviewed. However, for Gundremmingen the scope and the time schedule for necessary improvements are not known. Most likely the improvements consist of paperwork mostly.

In sum, the information provided by the updated NAcP is very limited. It is fair to conclude that the scope of back-fitting measures implemented at the Gundremmingen B/C is very limited as well. The Nuclear authority and the operator take decisions about necessary improvements - while “taking into account the remaining operation time” - behind closed doors without any transparency.

After an operating time of more than 35 years, negative aging effects play an increasingly important role at Gundremmingen. The Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM has been carried out in 2017. The first TPR focused on the Ageing Management Programmes. In the course of the TPR, national results have been evaluated through the peer review process. The Peer Review Team criticized the scope of the structures, systems and components subject to ageing management in Germany. Also, the ageing management of the reactor pressure vessel RPV shows deficiencies compared to the safety level expected by ENSREG for Europe. Another gap with regard to the safety level in Europe can be seen in the implementation of the WENRA Reference Level (RL). Germany has not implemented 31 of the 342 WENRA RL of 2014 in 2020.

Gundremmingen C has several design deficits: the construction of the reactor vessel does not represent the technical state of the art; some safety-relevant components and subsystems are not qualified to resist the design basis earthquake (DBE) among other.

A major weakness of the Gundremmingen NPP is the location of the spent fuel pools: They are located inside the reactor building, but above and outside the containment (like in the Fukushima Daiichi NPP). In case of a severe accident, there is no barrier to the environment. A crash of a Boeing 737 against the reactor building can cause a severe accident. In case of (1) a major destruction of the reactor building or (2) a damage of the control room by fire and debris combined with leakages in the cooling system, a severe accident could occur. This is the result of a study commissioned by the BMU. According to the Federal criminal police office, the probability of a terror attack against a nuclear power plant is low; however, a terror attack has to be taken into account.

The Nuclear Security Index assessment points to further weaknesses regarding protection against sabotage or terrorist attacks. Of particular concern are the low scores for the “security culture” (50) and “cyber-security” (63). These low scores indicate weaknesses in the protection.

8 Doel and Tihange, Belgium

Belgium has two nuclear power plants, which are operated by Engie Electrabel.

The Doel NPP comprises four pressurised water reactors (PWR): The twin units Doel 1&2 commissioned in 1975, and Doel 3 (1982) and Doel 4 (1985). The units Doel 1&2 are Westinghouse 2-loop reactors with a net capacity of 433 MWe each. Doel 3 and 4 are Westinghouse 3-loop reactors with a net capacity of 1006 MWe and 1039 MWe, respectively. The site is located on the left bank of the Scheldt River 15 km northwest of Antwerp with 490,000 inhabitants and 3 km from the border between Belgium and the Netherlands.

The other Belgium NPP, Tihange, comprises three PWR: Tihange 1, commissioned in 1975, Tihange 2 (1983) and Tihange 3 (1985). Tihange 1 is a Framatome 3-loop reactor with a net capacity of 962 MWe; Tihange 2 (1008 MWe) and Tihange 3 (1054 MWe) are Westinghouse 3-loop reactors. The site is located on the Meuse River, 25 km southwest of Liege with 200,000 inhabitants and about 80 km southeast of Brussels; with one million inhabitants the Brussels Region is densely populated.

In January 2003, the Belgian government announced the schedule for the shut-down of all NPPs. All Belgian reactors were scheduled for shut-down between 2015 and 2025, roughly in line with their 40th anniversaries. In spite of this decision, in June 2015 the Belgium parliament passed legislation to enable a 10-year life extension for Doel 1&2 to 2025. Also Tihange 1 was permitted to extend operation to 50 years. Currently all reactors are allowed to operate until 2025, except Tihange 2 – scheduled for shut-down in 2023 and Doel 3, shutdown in 2022.

On 22 December 2015, the Belgium nuclear regulator FANC authorized the lifetime extension (LTE) and restart of Doel-1 and -2. On 6 January, 2016, two Belgian NGOs filed a complaint against the law passed on 28 June, 2015 with the Belgian Constitutional Court, arguing in particular that the lifetime extension had been authorized without a legally binding public enquiry. On 29 November, 2018, the Advocate General of the European Court of Justice (ECJ) presented its advice on the request of the Belgian Constitutional Court concerning the applicability of the EU-Aarhus/Espoo with regards to the LTE of Doel 1&2 and Tihange-1.[20] In its decision of July 29 2019, the European Court of Justice (ECJ) took the view that an environmental impact assessment (EIA) must be carried out before the approval of a lifetime extension. In its ruling of March 5 2020, the Belgian Constitutional Court followed the ECJ. The judges set December 31 2022 as the deadline for completing the EIA after all.

The following chapter describes the weaknesses of the very old units, Doel 1&/2 and Tihange 1.

8.1 Belgian National Action Plan (NAcP)

The NAcP, as the result of the ENSREG stress tests contained about 600 site and reactor-specific actions. When it was set up the majority of planned actions was to be implemented by the end of 2013. A number of these actions are actually analyses to be performed first and will probably result in necessary back-fittings. The intended target date for implementing all actions was not mentioned. According to the updated NAcP 2014, out of 366 actions 113 have not been completed. The number of actions differed but also the structure of report of the 2014 NAcP had changed completely when compared to the original NAcP. The report did not list the status of all actions and rather highlighted only the major actions. This made it almost impossible to compare the original NAcP with the updated NAcP and to keep track of the progress made in implementing the actions. Transparency is not guaranteed at all. (FANC 2014)

The Belgian regulatory published updates of the NAcP in March 2016, in 2017, in 2018 and in 2019.

The 2016 NAcP explained: Over time some actions specific to a particular reactor have been amended or put (temporarily) on hold in the context of decisions on the future operation of the reactors. This was the case for the actions planned for Doel 1&2, and partly for the actions planned for Doel 3 and Tihange 2.

In 2012/2013, the Belgian government decided to cease the operation of Doel 1&2 in 2015. The NAcP was amended for these two reactors accordingly, since certain actions had become unnecessary in the light of the shut-down and decommissioning plans. But in 2014, the Belgian government decided to allow for a 10-year life extension for these two reactors after all. A specific Long Term Operation (LTO) was issued for Doel 1&2. This LTO action plan incorporated all remaining stress test actions for Doel 1&2. Similarly, some actions for Doel 3 and Tihange 2 which were temporarily put on hold as a result of the prolonged shutdown in 2014-2015 were resumed after in 2015the regulator had decided to allow operation again. (FANC 2016)

The nuclear regulator FANC stated in the 2019 NAcP that the review and the assessment progressed slightly slower than expected. The reasons indicated were workload related, for both licensee and regulator, triggered by the safety events that occurred in 2018 and by Long Term Operation of Tihange1 or Doel1&2 that are resource-intensive for both organizations. (FANC 2019)

In September 2020, the Final Report has been published, stating that ENGIE Electrabel had finalized the NAcP by mid-2020. The Belgian regulatory body (FANC and Bel V) declared the NAcP closed. (FANC 2020)

[20]The Advocate General states that the definition of ‘project’ under Article 1(2)(a) of Directive 2011/92 includes the extension by 10 years of commercial production of electricity by a NPP and that public participation must take place in accordance with Article 6(4) of Directive 2011/92 as early as possible, when all options are open, that is to say, before the decision on the extension is taken.

8.2 Weaknesses identified by the Belgian Stress Tests the NAcP should remedy

In April 2011, following the Fukushima accident, Electrabel commissioned a probabilistic seismic hazard analysis (PSHA) using a state-of-the-art methodology. This PSHA resulted in a considerable increase of intensity of the design basis earthquake (DBE): For the Tihange site the value of the peak ground acceleration (PGA) increased from 0.17 g to 0.23 g (increase of 35%), for the Doel site from 0.056 g to 0.081 g (45%). A more elaborate PSHA study, e.g. with due consideration of results arising from the EC-project SHARE (seismic hazard harmonization in Europe) was required. Detailed studies for both sites were conducted by the Royal Observation of Belgium (ROB). (No. 1 and No. 429)[21]
According to the 2020 NAcP, this detailed analysis confirms the rough results obtained in 2011 so that the licensee concludes that the two sites are adequately protected against seismic hazards and that additional measures are not necessary.

The **safety margin assessment** for the Doel and Tihange units was performed on the basis of a review level earthquake ("RLE") as high as 1.7 times the peak ground acceleration (PGA) of the current design basis earthquake. The stress tests have highlighted that 28 Structures, Systems and Components (SSC) of Doel and Tihange had a low probability of resisting an earthquake exceeding the RLE.[22] Following the stress tests, the licensee has committed to either confirming that the current margins are sufficient by means of more precise calculations, or raising these SSCs to a high probability of resisting an RLE by means of corrective actions.
According to the 2020 NAcP, all actions related to the protection against earthquakes were carried out by the licensee by the end of 2015. During 2018, the regulatory body finalized its review and assessment of most remaining actions concerning the protection against earthquakes in Belgian NPPs.

Apparently, FANC does not consider the back-fitting measures to be sufficient, thus an adequate protection against earthquakes is not provided yet.

To mitigate the risk of internal flooding induced by an earthquake, only the seismic management procedures were modified: After an earthquake, a person is to be sent out as quickly as possible to check if the cooling tower is overflowing. In this case the pumps have to be shut down rapidly. This action is required for Doel 3 and 4, as well as for Tihange 2 and 3.
This is one example of many where design deficiencies of the plants were solved by the introducing procedures.

Flooding hazard for the Tihange NPP site:

The original design basis flood (DBF) was fixed with reference to the practice used in civil engineering, which is the flow rate derived as the highest historically recorded flood level of the river increased by 20% (2220 m³/s). The heavy floods in 1993 and 1995 in the Meuse valley reached nearly this flow rate, thus a reassessment of the flood risk has been conducted – but using the same outdated methodology.

Using the probabilistic approach according to international standards for calculating a flood rate of a return period of 10,000 years (3488 m³/s) led to new DBF parameters derived as a result of the re-assessment conducted during the most recent Periodic Safety Review (PSR).Corresponding water levels would significantly exceed the site platform elevation (up to 1.70 m), causing flooding of the three units and loss of safety related equipment, including all on site power sources and both primary and alternate ultimate heat sink.

The stress tests revealed the following situation: Tihange 1, which is located most upstream, will be the first unit to be hit. Already at a flow rate with a calculated return period of about 400 years (2,800 m³/s), the unit is completely surrounded by water and all buildings except the reactor building will be flooded (first cliff edge effect). The second cliff edge effect is a flow rate that occurs statistically nearly every 600 years (2,900 m³/s), corresponding to the flooding of equipment in Tihange 1. The

[21] Number according to the updated NAcP
[22]22 SSCs were identified at Tihange 1, 3 at Tihange 2, 1 at Doel 1&2, 1 at Doel 3 and 1 at Doel 4.

third cliff edge effect occurs at 3,000m m^3/s: The auxiliary feed-water system of Tihange 2 would fail. The fourth cliff edge effect occurs for higher flow rates: Loss of cooling for Tihange 3.

Because of the dangerous situation, a peripheral protection of the site was required. This consists of a wall, together with isolation devices of water intakes and solutions for discharging cooling and sewer water into the Meuse River. *According to the 2020 NAcP, the construction of this peripheral protection began in October 2013 and was completed in 2015. According to the 2014 NAcP, Electrabel planned to construct a wall not higher than the water level of the DBF. The peer review team recommended including a safety margin to adequately cover uncertainties associated with a calculated DBF. As requested by FANC, a safety margin for the wall height to adequately cover uncertainties associated with the new design basis flood was considered.*
However, the NAcP does not explain how large the added safety margin is. Thus, it cannot be excluded that the protection is insufficient and even more so when taking into account the increasing flooding hazards caused by climate change effects.

The original NAcP required another level of flood protection (local volumetric protections).
According to the 2014 NAcP, the other level of protection was cancelled, because further analyses had shown that the implementation would not provide an infallible protection.
Given the existing flooding threat, it is not justified to cancel this level of flood protection.

An additional provision should protect the site either in case of a beyond design basis flood, or when the external protection would fail in protecting the site. When conventional equipment is rendered unavailable through flooding, the **non-conventional means (NCM)** equipment preinstalled during the alert phase should be used.These non-conventional means consist of: Additional diesel generators located in new specific buildings, fixed pipes (with a few exceptions of flexible elements; pumps for make-up of water from water tables to the primary circuit, the steam generators and the spent fuel pools. *According to the 2014 NAcP, all the corresponding actions to these non-conventional means were finalized by Electrabel in 2013. At the end of 2014, the FANC carried out the assessment of the modifications and officially closed the actions linked to this level of protection.*
However, it will be very difficult and dangerous for the staff to prevent a core melt accident during a flooding of the site and parts of the nuclear power plant using mobile equipment. This is an irresponsible approach to achieving safety margins for extreme flooding events, in particular regarding the increasing risk of flooding events caused by climate change effects.

The emergency intervention strategy and the crisis management, including corresponding procedures should have been improved by 2012.
According to the 2020 NAcP, at Tihange the means for on-site transport of personnel and equipment during floods (amphibious vehicles) have been available since June 2012. In 2013, the licensee finalized the implementation of the associated procedures and the organization of the training of its staff.
The already difficult and dangerous actions of the staff during flooding of the site and the plant will be even more difficult and dangerous when boats are used for transport.

Flooding hazard for the Doel site:

The stress tests showed: The flood level of the design basic flood (DBF: high tide + storm surge, 95th percentile for a return period of 10,000 year) remains below the minimum height of the embankment. But flooding of the site can occur when a very high River Scheldt level and an embankment breach occur simultaneously. The embankment would fail during a subsequent storm event if no repairs were performed in the time after initiation.

To evaluate the safety margin, in case of an embankment breach near the site, the most severe storm is cumulated with a high level of the Scheldt. For this scenario, the water would reach the first buildings very quickly (after about one hour) and significant water depths could be found around several buildings (between 20 and 50 cm). This would turn the site which is situated on a raised platform surrounded by lower-lying polders into an island. Electrabel claimed that the probability of a significant cliff edge effect is very low. A number of buildings for which tightness cannot be guaranteed in case of tens of cm of water flooding the site constitute another serious weakness.

To prevent any possible weakening, Electrabel reinforced the embankment with concrete tiles in 2013. Electrabel also modified the internal procedures to perform embankment inspections more regularly. In 2014, the FANC finalized the assessment and officially closed these actions.

<u>Extreme weather</u>

The stress tests revealed that the design parameters for **extreme weather conditions** for the Belgian NPPs are mainly based on historic data and therefore on a return period in the order of 100 years. The Peer Review Team recommended the derivation of design basis parameters with 10,000 years return periods.

A reassessment of the capacity of the sewer system for return periods up to 100 years using a detailed hydrodynamic model in order to cover both **short-duration heavy rains and long-lasting rains** was required.
According to the 2020 NAcP, Electrabel finalized its revaluation of the impact of heavy rains in 2014 at Doel. At Tihange, the licensee performed in 2016 major improvements in order to avoid a flooding internal to the site by sewer overflow. These improvements mainly consist of deviating the underground municipal sewers that were crossing beneath the site, construction of a new sewer and the modifications of the discharge points of the Tihange site in the Meuse River. A complementary assessment of the capacity of the drainage systems of Tihange, considering the impact of rainfall of 1.0E-3 return frequency, is still ongoing.
However, the ENSREG recommendation (derivation of design basis parameters with 10,000 years return periods) has not been followed. Even the plant's robustness against the impacts of rain with 1000 years return period is not guaranteed, because the assessment is still ongoing. In the light of the increasing probability and intensity of extreme weather events this is highly irresponsible.

Complete Station Black-Out (CSBO) consists in a loss of off-site power supply and of the first-level and second-level internal power supplies. The stress tests revealed very short intervention times, e.g. for Doel 1&2: In case of a total SBO, only the turbo-pump of the auxiliary feedwater (AFW) system remains available in the short term to feed water into the steam generators (SG). After 90 minutes the first cliff edge effect sets in: the auxiliary feedwater reservoirs are empty, the SG can continue cooling the primary circuit for several hours only. There are limited possibilities to refill the AFW tank. If the cooling via SG fails, the primary circuit begins to boil and steadily loses its water volume. This results in uncovering and later to melting of the fuel, the relocation of the corium towards the bottom of the reactor pressure vessel (RPV) and the piercing of the bottom of the RPV. Without the operator's intervention this process takes between 2 and 3 hours.

To prevent this scenario, Electrabel committed to using non-conventional means:

- to refill the steam generators and the spent-fuel pools,
- to ensure make-up for the primary circuit in open configuration,
- to avoid the overpressure in the reactor building,
- to restore the electrical power supply to instrumentation and control panels, and
- to make operable the emergency compressed air circuit.

Also "Loss of primary and alternate ultimate heat sink" is a beyond design basis accident (BDBA). To avoid cliff edge effects, several measures have been proposed by the licensee. Some of them are similar to the CSBO measures like the use of non-conventional means to refill the steam generators and the spent fuel pools, to ensure make-up for the primary circuit in open configuration or to avoid the overpressure in the reactor building.

Electrabel had to delay several actions related to the CSBO project in order to primarily focus on the flooding project at Tihange in 2012-2013. By the end of 2014, most actions related to the CSBO topic in Tihange have been re-scheduled for 2016. **To respond to the delay of all projects at Tihange, it would have been FANC's task to order prolonged plant outages.**

At Doel 3&4, in the framework of the CSBO, the installation of nozzles on the intake and discharge of the spray pumps, and of connections to the emergency cooling and to the emergency feed water systems, was planned by the end of 2014.
According to the 2014 NAcP, a new fire truck, which is multifunctional and can also play the role of a mobile pump and a fuel tanker transport of diesel fuel, was also purchased.

At Doel, alternative water supply for the spent fuel pools (SFP) using supplementary nozzles, connections and mobile pumps has been made operational by the licensee in 2014-2015. A similar improvement has been realized in Tihange 1 in 2017. On both sites, improvements of level measurements in the spent fuel pools are implemented in 2016.

A study was to be conducted to assess the residual risk of hydrogen accumulation in the spent fuel pools buildings. *According to the 2014 NAcP, the study performed by Electrabel shows that there is no explosion risk due to the accumulation of hydrogen in the SPF buildings.*
The regulator FANC's opinion on this issue was not mentioned and whether FANC demanded the installation of PARs as the Peer Review Team had recommended. In 2012 the Peer Review Team had recommended to consider the installation of passive autocatalytic hydrogen re-combiners (PARs) irrespective of the outcome of the licensee's study. The existing high risk clearly justifies FANC ordering the installation of PARs.

During a severe accident when the core has melted through the reactor pressure vessel and residual heat removal has failed, pressure in the containment rises. Only venting could prevent containment collapse. Filtered containment venting is considered state-of-the-art for some years, but none of the Belgian NPPs was equipped with a **filtered venting system** in 2011. Filtered containment venting systems have been installed at each unit and made operational by the end of 2017 (except for Doel 1 and 2, where the FCVS project is integrated in the LTO action plan and must be made operational by 2018-2019).

As a result of the Fukushima accident, a study on modifying and strengthening the emergency management organization has been launched to include "**multi-unit**" events at Doel and Tihange. In this respect, several procedures have been modified in order to enhance the operator response.
As mentioned above, many improvements consisted only in introducing new procedures.

Treatment of potentially **large volumes of contaminated water** after an accident was to be developed by 2013. **However, this measure was not mentioned again.**

8.3 Examples of further safety and security issues of Doel and Tihange

The design of the old reactors is outdated. The reactors' overall concept of defence in-depth and therefore the prevention of accidents is insufficient. This is in particular true for Doel 1&2 and Tihange 1. With respect to the limited number of initiating events considered at the design phase, the units of Doel 1&2 have significant **design deficits**, among others (FANC 2011):

- Not all of the first level safety systems are physically separated and/or design basis earthquake resistant. Unavailability of first safety systems should be covered by the second level systems, but these systems are not housed in a bunkered building and are mainly manually operated from emergency control room.
- Doel 1&2 share the control room and several first level systems. This increases the probability that both units are affected in case of an incident.

- The low-level safety injection pumps have duties in the normal operation (no independence between the levels of the-defence-in-depth concept),
- The physical separation of the electrical power supply and instrumentation cabling is limited.
- The number of redundant safety systems is low compared with current state-of-the- art.
- The spent nuclear fuel is stored in pools in the nuclear service building instead in a bunkered nuclear fuel building.

Tihange 1 has significant design deficits:

- Only partially physically separated redundant safety systems; a fire has the potential to simultaneously damage all these systems.
- The safety injection system pumps have duties in the normal operation, i.e. there is no independence between different levels of the-defence-in-depth.
- The second level emergency systems had not been considered in the initial design, which includes only two emergency power supplies, one water cooling circuit and pump.
- The thickness of the basement is only 2.15 m. Thus, the time until a potential containment basement melt-through occurs is relatively short.
- The spent nuclear fuel is stored in pools located outside the containment.

Tihange 1 and Doel 1&2 have been in operation for 45 years. This means that **negative ageing effects** are major safety issues for those plants. The frequency of ageing related incidents is likely to increase. These incidents have the potential to trigger, but particularly to aggravate accidents. Incidents could also indirectly be caused by ageing: If degraded components are replaced, defective mounting or other errors will be possible, as has shown the experience at nuclear power plants around the world.

The Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM has been carried out in 2017. It has revealed gaps compared to the safety level expected by ENSREG in Europe. The ageing management program in Belgium for the considered areas Overall Ageing Management Program consists of four thematic areas: electrical cables, concealed pipe-work, reactor pressure vessels and concrete containment structures. (ENSREG 2018) However, in the same year, Electrabel identified serious flaws in the concrete of a building adjacent to the reactor buildings of Doel-3. These bunkered buildings contain backup systems for the safety of the facilities and are supposed to withstand impact from outside like an airplane crash. Similar problems, to varying degrees, have been identified at Tihange-2 and -3, as well as Doel-4. (FANC 2020b

As of 2020, Belgium has not implemented 52 of the 342 WENRA Reference Levels of 2014. (WENRA RHWG 2020a)

In addition to the design deficits and ageing the operational practices also show significant weaknesses: In March 2010, an **IAEA Operational Safety Review Team** (OSART) visited Doel 1&2 to review operating practices. 15 safety issues were identified by the team. They pointed to a dangerous lack of safety culture (IAEA 2010b):

- Analyses for some events are not being performed to the required depth and they are not being completed in a timely fashion.
- In certain plant areas inadequate conditions exist due to lack of attention and insufficient maintenance workmanship. Deficient material conditions could lead to the deterioration of the equipment and systems, resulting in their unreliability.
- In some areas of the electrical building, cable separation schemes and compartmentalization are inadequate, resulting in an increased risk of an electrical fire.

According to the OSART-follow up mission (March 2012), there are still some important safety issues unsolved (IAEA 2010b).

The last OSART mission in Tihange took place in May 2007, but another OSART Mission is envisaged for Tihange 3 in the last quarter of 2022.

Invited by the Belgian Nuclear Regulatory Body (FANC), a **SALTO** (Safety Aspects of LongTerm Operation) mission was conducted at Doel 1&2 in February 2017. The team identified some fundamental areas for further improvement. The majority of the issues is connected to the halt of the LTO works between July 2012 and December 2015 due to the changing national nuclear strategy. 13 issues were raised, among others:

- Continuous improvement of ageing management process is not well established;
- Maintenance practices for electrical and I&C equipment is not fully comprehensive;
- Some practice of storing equipment in close proximity of electrical and I&C safety equipment may jeopardize operability during and after a seismic event;
- A lack of sufficient trained and competent staff can negatively impact LTO.

The SALTO Follow-up mission was conducted from 25 to 28 June 2019, the mission found only 4 out of13 issues solved.(IAEA 2019a)

In January 2015, an IAEA SALTO was performed for Tihange 1. Ten issues were raised by the IAEA team, among others:

- The process for evaluating preventive and predictive maintenance programmes for active mechanical components is not comprehensive;
- There are no planned periodic and documented condition visual inspections and tests during the LTO period aiming at preserving cable system qualification and functionality (cables, cable trays and connections);
- The design intent of cable tray support anchoring is not performed as required by the design;
- The current approach to the testing of containment structural integrity is not fully consistent with IAEA Safety Standards;
- Loss of concrete durability due to leaching Calcium Hydroxide has not been appropriately addressed in the plant;

A follow-up mission was organized from 6 to 9 December 2016. The team concluded that the plant has made significant progress to resolve most of the issues: 8 issues were assessed as issue resolved. (IAEA 2016a)

Doel-3 and Tihange-2 stopped operating in June and September 2012, respectively, after the discovery of **thousands of flaws in their reactor pressure vessels** (RPV). A new ultrasound measuring technique – specifically designed to detect underclad cracks – was used for the first time in June 2012 over the whole surface of the Doel 3 RPV, rather than just around the weld zones. These flaws (Doel 3: about 8000, Tihange 2: about 2000) increased later to over 13,000 and over 3,000 respectively and are thought to having originated from the casting and forging process when the RPV were manufactured. Both RPVs were produced by the same manufacturer (Rotterdam Drydock Company) in the late 1970s.

After having analyzed this issue, a nuclear material expert questioned the assumption that the flaws originated from the manufacturing processes since no defects were found during the final tests after manufacturing while the flaws found 30 years later have extensions up to 24 mm wide and up to 100 mm deep and exist in remarkable density. The origin of the flaws is still unknown and can hardly be determined since sampling cannot be performed without destruction of the RPV. The assumed hydrogen flaking process has a considerable incubation time and is continuing during operation. The influence of radiation effects and low-cycle fatigue on possibly manufacture-induced defects has not been considered by Electrabel although it is known the radiation embrittlement of the base metal is underestimated by the predictive curves. (TWEER 2013).

FANC allowed the reactors to restart with 16 conditions, 11 to be undertaken before restart and five to be conducted after the restart. With all the pre-restart checks validated, Electrabel resumed operation at both reactors in June 2013. However, in March 2014, Electrabel announced that the testing done to assess the mechanical properties revealed unexpected results. The reactors were then shut down on March 25, 2014 in order to conduct further testing. On 17 November 2015, FANC authorized the restart of Doel-3 and Tihange-2 again.

The technical assessment of the safety implications of the flaw indications remains the subject of intense controversy. Several independent safety analysis reports are highly critical of the restart authorizations. In April 2018, the International Nuclear Risk Assessment Group (INRAG) stated that for Tihange-2 the risk of reactor pressure vessel failure is not practically excluded. It is still unclear if the defects formed over time or if they originated in the manufacturing process, although the latter theory is favoured by FANC. A possible failure of the RPV due to sudden crack growth in case of local thermal stresses cannot be excluded. The potential for RPV failure could lead to major releases of radioactive substances. (WNISR 2019)

The most recent inspection of the Tihange 2 reactor vessel, which was completed in late 2020, showed that there are slight variations in the measurement results, but these are inherent to the measurement method. This result is within expectations. No evolution was observed in the size of hydrogen flakes already detected in the Tihange 2 RPV; no new hydrogen flakes were added either. (FANC2021)

In addition to the high number of safety issues, Belgium also has **security issues:**

- In case of an aircraft crashing on the plants Doel 1&2 of Tihange 1 significant damage can occur to the external concrete structure, with the possibility of projectiles penetrating into the containment. The extremely likely failure of the cooling system would result in a severe accident of the most hazardous category: core melt with an open containment. The radioactive releases would be very high and occur particularly early. (FANC 2012b)
- A Greenpeace report pointed to the vulnerability of the spent fuel pool buildings. The report is "secret" but a summary has been published.
- The Nuclear security index 2020 shows Belgium with a total score of 80 points ranked 16thout of 47 countries. Of particular concern are the low scores for the "security culture" (50), "Cybersecurity" (50) and "Insider threat protection" (55). These low scores indicate weaknesses in the protection. (NTI 2020)
- On 5 August 2014, information about an act of sabotage was revealed, it had caused significant damage at Doel 4. Lubricant had been discharged from the high-pressure turbine through a valve which had probably been opened deliberately by a worker. (WISE 2015a) It is still not clear who was responsible for the sabotage.
- At the end of 2015, information emerged that the home of a high-ranking official in the Belgian nuclear sector had been spied on by individuals linked to the perpetrators of the Paris attacks in November 2015. In late 2015 the Belgian government decided to create a specialized surveillance and protection corps within the Belgian State Police, with particular responsibility for the security of nuclear facilities in Belgium. Until this specialized police corps is effectively established, soldiers will be stationed at Belgian nuclear sites. (FANC 2020a)

8.4 Conclusions

In April 2011, following the Fukushima accident, Electrabel commissioned a probabilistic seismic hazard analysis (PSHA) using a state-of-the-art methodology. This PSHA resulted in a considerable increase of intensity of the design basis earthquake (DBE). The safety margin assessment highlighted that 28 Structures, Systems and Components (SSC) of Doel and Tihange had a low probability of resisting an earthquake. The licensee finalized its improvements in 2015. But FANC does not consider the back-fitting measures to be sufficient, thus an adequate protection against earthquakes is not provided yet.

To mitigate the risk of internal flooding induced by an earthquake, only the seismic management procedures were modified: After an earthquake, a person is to be sent out as quickly as possible to check if the cooling tower is overflowing and if so to shut down the pumps. This is one example of many where design deficiencies of the plants were solved by the introduction of procedures.

The flood protection and the possible consequences call the disastrous accidents at Fukushima NPP 2011 to mind. The Tihange NPP did not comply with the requirements regarding flood protection. In case of a design basis flood with the statistical return period up to 10,000 years the water level on the Tihange site is nearly two meters high and all safety systems of the three units are flooded and not operational. Because of the dangerous situation, a wall was built to protect the Tihange NPP. Although the flood hazard will obviously increase in the next decade sufficient safety margins most likely have not been not used for the protection wall.

An additional provision should protect the site either in case of a flood beyond-design, or when the wall would fail in protecting the site: The non-conventional means (NCM) equipment preinstalled during the alert phase should be used. These consist of with a few exceptions of flexible elements; pumps for make-up of water from water tables to the primary circuit, the steam generators and the spent fuel pools. The prevention of accidents depends strongly on actions performed by the staff while a severe accident is developing.

However, it will be very difficult and dangerous for the staff to prevent a core melt accident during a flooding of the site and parts of the nuclear power plant with mobile equipment. This is an irresponsible approach to achieving safety margins for extreme flooding events, in particular regarding the increasing risk of flooding events caused by climate change effects. The already difficult and dangerous actions of the staff during flooding of the site and the plant will be even more difficult and dangerous when boats are used for transport. All in all, flooding will remain a dangerous hazard for the Tihange NPP.

A reassessment and an upgrade of the capacity of the sewer system for return periods up to 100 years in order to cover both short-duration heavy rains and long-lasting rains was required by FANC. However, the ENSREG recommendation (derivation of design basis parameters with 10,000 years return periods) has not been followed. Not even the plant's robustness against the impacts of rain with 1000 years return period is not guaranteed, because the assessment is still ongoing. In the light of the increasing probability and intensity of extreme weather events this is highly irresponsible.

The stress tests revealed that a complete Station Black-Out could result very fast in a core melt accident. To prevent core melt scenarios, Electrabel commits to use the NCMs to refill the steam generators and the spent-fuel pools, and to avoid the overpressure in the reactor building,

None of the Belgian NPPs was 2011 equipped with a filtered venting system. It took until 2019 to implement these systems in all reactors. These back-fittings improve the mitigation of the consequences of serious accidents, but this does not apply to accident prevention.

The design of the old reactors is outdated. The overall concept of defence in-depth and therefore the prevention of accidents are insufficient at the old reactors. This is in particular true for Doel 1&2 and Tihange 1. With respect to the limited number of initiating events considered at the design phase, the units of Doel 1&2 have significant design deficits. Belgium has not implemented 52 of the 342 WENRA RL of 2014 in 2020. The applied safety level for required safety analyses and back-fitting measures is not sufficient at all.

Furthermore, Tihange 1 and Doel 1&2 have been operating for 45 years. This means that negative ageing effects are a major safety issue in the plant. It has to be expected, that the frequency of ageing related incidents will increase. These incidents have the potential to trigger, but particularly to aggravate accidents. In 2017, Electrabel identified serious flaws in the concrete of a building adjacent to the reactor buildings of Doel-3. These bunkered buildings contain backup systems for the safety of the facilities and are supposed to be able to withstand impacts from outside like an airplane crash. Similar problems, to varying degrees, have been identified at Tihange-2 and -3, as well as Doel-4.

At the invitation of the Belgian Nuclear Regulatory Body (FANC), a SALTO (Safety Aspects of Long Term Operation) mission was conducted at Doel 1&2 in February 2017. The team identified some several weaknesses.

Doel-3 and Tihange-2 stopped operating in June and September 2012, respectively, after the discovery of thousands of flaws in their reactor pressure vessels (RPV). These flaws (Doel 3: about 8000, Tihange 2: about 2000, which later increased to over 13,000 and over 3,000 respectively) are thought to having originated from the casting and forging process when the RPV were manufactured. The technical assessment of the safety implications of the flaw indications remains the subject of intense controversy. Several independent safety analysis reports are highly critical of the restart authorizations. In April 2018, the International Nuclear Risk Assessment Group (INRAG) stated on Tihange-2 that the risk of failure of the reactor pressure vessel is not practically excluded. A possible failure of the RPV due to sudden crack growth in case of local thermal stresses could lead to major releases of radioactive substances.

In addition to all the safety issues there are also several security issues in Belgium:

The Nuclear security index 2020 shows Belgium with a total score of 80 points ranked 16th out of 47 countries. Of particular concern are weaknesses in "security culture" as well as deficit in the protection against "cyber-security" and "insider threat". Already on 5 August 2014 it was revealed that sabotage (i.e. an action by an insider) had caused a significant damage at Doel 4. It is still not clear who was responsible for the sabotage. In addition, at the end of 2015, it emerged that the home of a high-ranking official in the Belgian nuclear sector had been spied on by individuals linked to the perpetrators of the Paris attacks in November 2015.

A major weakness of Tihange 1 and Doel 1&2 are the vulnerability against aircraft crashes that can seriously damage the external concrete structure, with the possibility of projectiles penetrating into the containment. The highly probable failure of the cooling system would result in a severe accident of the most hazardous category: core melt with an open containment. The radioactive releases would be very high and occur particularly early. When Germany was taking its decision on the closure of eight NPPs after the Fukushima accident, one of the important arguments was that their protection against terrorist attack was very low.

9 Beznau, Switzerland

The Beznau nuclear power plant (KKB) comprises two units with Westinghouse 2-loop pressurized water reactors. They each provide a net electrical output of 365 MWe. The Beznau NPP is located in the canton of Aargau in Switzerland. The NPP is enclosed by the course of the Aare River and the channel of the Beznau Hydropower Plant. It is owned and operated by Axpo AG. The reactors have been in commercial operation since 1969 and 1971, for 52 and 50 years, respectively. Axpo is planning an operating time of 60 years for Beznau.

9.1 Swiss National Action Plan (NAcP)

In the Swiss NAcP, which was prepared by the Swiss Federal Nuclear Safety Inspectorate (ENSI), a clearly arranged table of all required and planned actions is missing. ENSI has set the goal of investigating the identified issues and implement the derived measures by 2017. (ENSI 2012)

ENSI carried out an analysis of the events at Fukushima and published the results in four reports. 37 specific checkpoints (PP) were identified from the lessons learned for further investigation. Eight open points (OP) were added to the list on completion of the analyses for the European Stress Tests. Two additional issues (PRT) were identified by the Peer Review Team of the European Stress Tests.

A complete listing of the PPs, OPs and PRTs are provided in the updated NAcP of 2014, but these tables do not include the implementation status or the envisaged deadline for the implementation. It is explained that the issues related to the PPs, OPs and PRTs are being processed in a Swiss action plan, called "Action Plan Fukushima", which is updated and published on a yearly basis. ENSI has set the goal of investigating the identified issues and implementing the derived measures by 2015. Some additional major back-fitting, in some cases linked to LTO requirements, may take two additional years to complete. It is explained that further details on the planned actions will be presented in the ENSI Fukushima Action Plan 2015 to be published in German in February 2015. (ENSI 2014, ENSI 2015)

With the publication of the final report containing all measures identified and implemented post-Fukushima by the end of 2016, Switzerland concluded its post-Fukushima Action Plan. (ENSI 2016)

9.2 Weaknesses identified by the Swiss Stress Tests the NAcP should remedy

The seismic hazard assessment of the PEGASOS project (2004) indicates that the current design maximum horizontal PGA (peak ground acceleration) of 0.15g for safety significant buildings and systems could be exceeded. In order to reduce the uncertainty of the PEGASOS results, the PEGASOS Refinement Project (PRP) was initiated. The re-assessment should define the updated site-specific seismic hazard levels. The PRP project was expected to be completed in 2013 (PP1).
According to the 2015 NAcP, the PRP results were submitted in 2013 to ENSI by the operators for final review.

It took ENSI considerably longer than originally anticipated to examine the report and formulate definitive seismic hazard assumptions. Two sub-projects were acknowledged by ENSI as being technically correct. In contrast, «seismic source characterisation» (sub-project 1) was not investigated in sufficient detail. ENSI has therefore decided to replace the rejected PRP models with data and models from the Swiss Seismological Service.

In May 2016, ENSI decided that the results of the SED-PRP model should be used, referred to as ENSI-2015 seismic hazard assumptions. At the same time, ENSI asked the licensees to assess the consequences on NPP safety and, in particular, on risk. According to ENSI-2015, a PGA value of more than 0.30 g is to be used.

ENSI has set out new requirements for assessing seismic hazards in the light of the latest scientific findings. The seismic safety case that the plants now need to provide is considerably more extensive than the document that the nuclear power plants had to provide after Fukushima. Taking into account the complexity of the new safety case procedure, ENSI allows operators to go through the process in three stages until the end of 2020. (ENSI 2016b)

At the beginning of 2021, ENSI stated that the review of the documents submitted by the operators to update the verifications with the new earthquake hazard assumptions ENSI-2015 showed the following: Both the core cooling and the cooling of the fuel pools are guaranteed in the event of a severe earthquake, which occurs only once every 10,000 years. The maximum permissible dose level of 100 millisieverts (mSv) would not be exceeded in the event of such an accident. The present demonstration represents the first stage of the process. The other above-mentioned stages are still under review by ENSI. (ENSI 2021)

Extensive studies on the earthquake risk have been carried out over the last 20 years. Already in 2011 it was known that the seismic hazard evaluation was inadequate. As only the first stage of the required analyses has been assessed by ENSI, sufficient protection is still not guaranteed. Despite the existing earthquake hazard, ENSI has apparently not taken any steps to have the operator speed up completion of its earthquake studies. If further upgrades are required, the operators will probably be granted an extension of the deadline.

In 2013, ENSI has set up a working group to investigate the necessity to implement automatic scrams triggered by seismic instrumentation. Based on these results, a back-fitting demand could be sent to the licensees, if considered necessary. (OP 2-1).
The 2015 NAcP explained: In order to be able to classify this safety gain, the possible reduction of the core damage frequency (CDF) was estimated on the basis of available probabilistic safety analyses. Depending on the plant, this reduction is between 0.1 and 2 % of the total CDF. Based on the investigations, from a deterministic and probabilistic point of view, and also according to the general status of retrofits carried out in Europe, such a retrofitting is not necessary.
The automatic scram after an earthquake recommended by experts as part of the EU stress test

is not to be retrofitted. The calculated reduction of the core damage probability (CDF) was assessed as too low by the operator and ENSI. But even if the probability of an accident scenario is very low, every additional reasonably practicable measure should be taken to reduce the risk. This applies in particular to the earthquake hazard, which is the most significant risk at the Beznau NPP.

It has to be assumed that the Beznau NPP site would be flooded during the **design basis flood** (DBF) and that the tightness of the buildings required for the emergency functions would therefore be of essential importance. Thus, it must be verified that the required tightness of buildings with safety-related equipment is guaranteed in the event of flooding of the site. (PP3)
According to the 2015 NAcP, the deterministic demonstrations for 10,000-year flooding (DBF) were accepted by ENSI in 2011. Further follow-up requirements were included and pursued within the framework of the ERSIM project and ongoing regulatory supervision.

In 2016, ENSI stated that it was currently assessing whether further measures would be useful to further improve the protection of safety systems against external flooding. With regard to a possible flood hazard, it is noteworthy that at the beginning of February 2016 the Federal Office for the Environment (Bundesamt für Umwelt - BAFU) launched a study on possible extreme floods along the Aare. Among other things, this study will serve to reassess the risks of such events for the Beznau NPP. The study is the main part of the "Fundamentals of Extreme Floods along the Aare-Rhine (EXAR)" project, which has been ongoing since 2013.[23] Based on the results, operators will have to reassess the risks for their respective plants. (ENSI 2016a)
Before the review will be completed, the sufficient protection of the Beznau NPP against extreme flooding events is not proven.

The stress tests revealed that margins **for extreme weather events** (besides winds and tornadoes) and combinations thereof were not considered adequately. The ENSREG Peer Review Team recommended considering the assessment of margins with respect to extreme weather conditions exceeding the design bases. In 2012, ENSI defined specifications for analyses on the protection against extreme weather conditions, including combinations thereof, to be performed by the licensees. The probabilistic hazard analyses, as well as the proof of sufficient protection of the NPPs against these hazards, have to be submitted by the end of 2013, including submission of the existing margins. (PP1, OP 4-1).
According to the final NAcP, the updated hazards for extreme weather conditions and safety cases were submitted until2014. After reviewing the submitted documents, ENSI came to the conclusion that proof had been provided that the core cooling system is guaranteed to be fail-safe in the event of extreme weather conditions with a frequency up to 10-4 per year. After reviewing the submitted safety margin analyses, ENSI came to the conclusion that the robustness against extreme weather conditions is increased by the project AUTANOVE. ENSI has identified further measures to increase the safety margins, particularly with regard to the hazards of heavy rain and extreme temperatures. The implementation of the requirements is still pending and will be followed up by ENSI in the supervisory procedure.
The retrofits regarding improved protection for the particularly relevant extreme weather events have not been completed. This is not justified in terms of risk minimization, as climate change is causing extreme events to occur more frequently and more intensively.

The AUTANOVE project involves a significant redesign of the Beznau NPP's emergency power supply. A new earthquake- and flood-proof building was constructed for each unit, each housing two diesel generator groups designed to withstand earthquakes. (ENSI 2015a) This back-fitting reduces the risk of external hazards during normal operation. When steam generators are unavailable during plant shutdown, only accident measures conducted by the staff with mobile equipment for the core cooling are available at the Beznau NPP.

In 2012, the ENSREG peer review team criticized the **hydrogen management**, i.e. the prevention of hydrogen explosions in case of severe accident. It was recommended to require a passive system for hydrogen management for severe accident conditions. In addition, also further studies on hydrogen

[23] The study "Extreme Floods on the Aare" and all related documents should be available on the website of the WSL Research Institute from February 22, 2021. https://www.wsl.ch/de/projekte/exar-1.html

management for the venting systems were recommended. Within its action plan for 2013, ENSI requested the NPPs to investigate systematically the issue of hydrogen migration (PP7, OP6-1; PRT-2).

The final NAcP explains: The Beznau nuclear power plant plans to increase the existing hydrogen removal capacity by installing additional, passive recombiners inside the containment. At present, the Beznau nuclear power plant is carrying out investigations to determine which plant-specific measures could be taken to reduce the hydrogen concentration outside the reactor building.

Note: The need of an improvement of the prevention of hydrogen explosions was one of the important lessons learned from the Fukushima accident, which is still ongoing for Beznau NPP.

Large containment openings are present for a specified period during shutdowns in connection with the annual refuelling and maintenance outages. The restoration of the containment integrity in case of a total Station Black-Out (SBO) during shutdown, ENSI also identified as an open issue during the stress tests. (OP6-2)

According to the final NAcP, ENSI specified the scope of the investigation in this regard by requiring operators to analyze the tools needed to restore containment closure, the personnel required, existing instructions and work steps in the regulations, and the duration of the closure process. The operators submitted the relevant studies in October 2014. Based on these analyses, the operators identified several improvements. These relate in particular to measures for faster closing of the containment material gate.

For Severe Accident Management, the **mobile equipment** stored on-site plays an important role. In addition to the on-site stored mobile equipment, a flood-proof and earthquake-resistant external storage facility is in place (at Reitnau) since June 2011. It contains various operational resources, in particular mobile motor-driven pumps, mobile emergency power generators, hoses and cables, radiation protection suits, tools, diesel fuel and boration agents. The storage facility is accessible by road or by helicopter.

Mobile equipment is essential for accident management at the Beznau NPP in various scenarios. Even though storing the equipment much safer is an improvement the lack of fixed systems available for SBO situations during a plant shutdown remains a serious safety deficit.

ENSI required an investigation of the management of **contaminated water** in case of a severe accident. (PP35)

The final NAcP stated: The studies submitted at the end of 2015 to assess the release of liquid radioactive substances in the event of beyond-design-basis accidents (severe accidents) were based on five damage states ranging from core damage in the reactor pressure vessel to a core meltdown penetrating the reactor building structure. After reviewing these studies, ENSI concluded that no major contamination of groundwater and watercourses is to be expected because the floor slabs and concrete structures of the reactor buildings have been designed to be very robust and emergency measures are in place to cool the core meltdown. The situation in Fukushima, where groundwater permanently penetrates the reactor building and leads to a large accumulation of radioactively contaminated water, is also not transferable to Swiss nuclear power plants due to the groundwater situation at the sites and the robustness of the reactor buildings. ENSI therefore does not consider further precautionary measures with regard to retention and treatment of contaminated water to be appropriate.

Within the scope of this study, it is not possible to evaluate whether ENSI's assessment is accurate or just another example of the narrative "Fukushima cannot happen here".

9.3 Examples of further safety and security issues of Beznau

The age of the plant and the original design of the reactor mean that there are several safety deficits compared to new plants. Martin Richner (Axpo Power AG, Beznau NPP) stated that Beznau is the most upgraded NPP in the world. That is certainly true, but it does not mean that it is the safest nuclear power plant in the world! (RICHNER 2015) Many weaknesses cannot be remedied by retrofits, or only to a limited extent. Despite extensive retrofits, current safety standards have not been achieved.

ENSI stated that despite the upgrading and replacement measures that have been implemented, a nuclear power plant that is over 40 years old does not have all the design features of a nuclear power plant of the latest generation. The differences typically concern the degree of redundancy, functional independence and spatial separation of safety trains; the degree of automation of safety systems; earthquake and aircraft crash safety; and precautions against beyond-design-basis accidents.

Examples of safety deficits of the Beznau nuclear power plant include (see for example ÖKO-INSTITUT 2012):

- spatial separation of the redundancies of the emergency trains is not consistently implemented.
- the plant has only one boron water storage tank (BOTA) per unit with a relatively small water volume, which is a particularly relevant weakness in terms of safety.In the event of a loss of coolant, the tank has to compensate for this. It is also highly vulnerable to external impacts. Failing of the water supply leads to the risk of a core meltdown.
- a limited inspectability of all welds on the reactor pressure vessel and other safety-critical piping or components
- the type of steel used for the reactor pressure vessel has too low a toughness, which increases the risk of brittle fracture
- the wall thicknesses of the pipes have no or only small reserves for loads from beyond-design-basis events
- the spent fuel pools are not located in the containment
- due to the low thickness of the primary containment and reactor building, there is inadequate protection against the targeted and accidental aircraft crash of large civilian aircraft.

Another safety issue are the defects in the Reactor Pressure Vessel (RPV): After ultrasonic inspections in the Doel 3 and Tihange 2 nuclear power plants in Belgium in 2012 had revealed a series of indications in the reactor pressure vessel base material, an ultrasonic inspection (UT) of the base material of the RPVs in the Beznau NPP was performed in 2015. A large number of indications were found in Beznau 1. The individual UT indications were considerably smaller than the ones detected in Doel 3 and Tihange 2, but nevertheless required justification and a detailed assessment.

The safety case (SC) for the Beznau1 RPV was submitted by Beznau NPP in November 2016. According to ENSI the safety case contained insufficient supporting data on the effect on material properties as well as incomplete validation of the UT testing method. Thus, ENSI requested an extended materials characterisation program. For the detailed investigations, a replica of the forged ring was produced. The additional assessments and review of the UT validation and the updated safety case were completed early in 2018. ENSI concluded that the UT indications are caused by agglomerates of alumina inclusions formed during manufacturing, which do not significantly affect the materials properties relevant for structural integrity or irradiation sensitivity. Beznau1 went back into operation in March 2018. ENSI has issued a requirement to repeat the UT inspection on the base material of RPV shell C where the indications with the highest UT amplitudes are located.

In November 2019, experts released an assessment of the safety case of the Beznau 1 RPV prior to its restart after a three-year outage. Their study argued that the methodology and the existing uncertainties used to discover the material defects would not have proven any effect on the embrittlement of the vessel. ENSI claimed this study would be containing mistakes and false statements and postulated that RPV of Beznau1 is safe. The experts replied and stated again the RPV shows a high level of embrittlement and, in addition, material defects. Furthermore, a methodology and approaches were chosen for the safety case, which have been implemented for the first time worldwide. (WNISR 2020)

The operator of the Beznau NPP submitted the revised PSA level 1 and 2 at the end of 2013 as part of the periodic safety review to ENSI. The analysis already takes into account the retrofit with the project AUTANOVE. The PSA study for power operation calculates an average core melt frequency (CDF) of about $1*10^{-5}$ per year ($9.35 *10^{-6}$ per year).[24] The calculated accident probabilities are relatively high

[24]The submitted PSA has to be reviewed by ENSI, the outcome is not known.

compared to other nuclear power plants.This confirms the lower safety level of Beznau due to design deficits that cannot be retrofitted. The following graph illustrates the contributions of initiating events in the frequency of core damage and severe accidents with large and early releases.

It is noteworthy that an earthquake contributes 83% to the CDF and 96% to the frequency of a large and early release. Should an earthquake trigger a core melt accident, it will result in high and early releases in almost all cases. This means that the releases are so large that the population would have to be evacuated, but there is not enough time to do so.

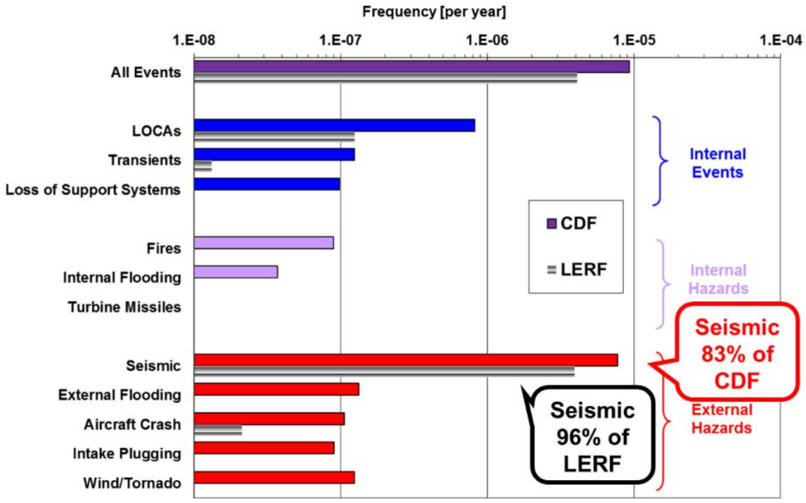

Figure 1 Core damage frequency (CDF) und Large early releases frequency (LERF) at Beznau NPP (Status 2015)(RICHNER 2015)

The Beznau NPP has been in operation for 40 years, thus **ageing of components and equipment** is an important issue. Small failures could develop into breaks (pipes and tanks), pumps, valves and other equipment could fail. To limit ageing related failure at least to a certain degree, a comprehensive **ageing management program** (AMP) is necessary. The Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM has been carried out in 2017. It revealed that the ageing management program in Switzerland shows gaps compared to safety level ENSREG expected in Europe: The peer review team criticized the scope of the structures, systems and components (SSCs) subject to the AMP: The scope of the AMP has not been reviewed and, if necessary, updated in line with the newly published IAEA Safety Standard. Furthermore, the scope of concealed pipework included in ageing management is insufficient because non-safety-related pipework was not included, however its failure may impact SSCs performing safety functions. In addition, opportunistic inspection of concealed pipework is not undertaken when the pipework becomes accessible for other purposes. (ENSREG 2018)

The most recent IAEA Operational Safety Review Team (OSART) of international experts visited Beznau in 1995 with follow-up in 1998. (IAEA 2020)

As of 2020, Switzerland has not implemented 10 of the 342 WENRA Reference Levels of 2014, which represent their expected safety level for operating plants in Europe. (WENRA RHWG 2020a)

The Nuclear Security Index 2020 shows that Switzerland with a total score of 82 points ranked 9thout of 47 countries. The low scores for "security culture" (25) and "cyber-security" (50) indicate weaknesses in the protection. (NTI 2020)

9.4 Conclusions

The Beznau NPP combines a high number of serious safety issues: seismic and flooding hazards, defects in the reactor pressure vessel and several design shortcomings of the old reactor.

Extensive studies on the earthquake risk have been carried out over the last 20 years. Already in 2011 it was known that the seismic hazard evaluation was inadequate. Because ENSI has assessed only the first stage of the required new analyses, sufficient protection is still not guaranteed. ENSREG's recommendation to retrofit the automatic scram after an earthquake will not be taken up. The calculated reduction of the core damage probability (CDF) was assessed by the operator and ENSI as being too little. But even if the probability of an accident scenario was very low, every additional reasonably practicable measure should be taken to reduce the risk. This applies in particular to the earthquake hazard, which is the most significant risk at the Beznau NPP.

When the Beznau NPP site would be flooded during a design basis flood (DBF), the tightness of the buildings required for the emergency functions would therefore be of essential importance.
A study which has is being conducted since 2013 will serve to reassess the risks of flooding events for the Beznau NPP. Based on the results, operators have to reassess the risks for their respective plants. Until the review is finished, sufficient protection of Beznau against extreme flooding events has not been proven.

The retrofits regarding improved protection for the particularly relevant extreme weather events have not been completed. This is not justified in terms of risk minimization, as climate change is causing extreme events to occur more frequently and more intensively.

One of the important lessons learned from the Fukushima accident was the need to improve the prevention of hydrogen explosions. The necessary measures are still ongoing at the Beznau NPP.

Mobile equipment is essential for accident management at the Beznau NPP in various scenarios. Even though it is an improvement to store the equipment safer, the deficit of not having fixed systems available for SBO situations during a plant shutdown persists.

An important safety issue are the material defects of the Reactor Pressure Vessel (RPV): After ultrasonic inspections of the base material of the RPVs in the Beznau NPP in 2015, a large number of defects were found in Beznau 1. ENSI claimed that the defects caused during manufacturing do not significantly affect the material properties relevant for structural integrity. Beznau 1 went back into operation in March 2018. In November 2019, German nuclear experts released an assessment of the safety case of the Beznau 1 RPV. According to their study the used methodology and the existing uncertainties cannot provide evidence that the discovered material defects would not have any effect on the embrittlement of the vessel.

Beznau NPP has been in operation for 40 years, thus ageing of components and equipment is an important issue. Small failures could develop into breaks (pipes and tanks), pumps, valves and other equipment could fail. To limit ageing related failure at least to a certain degree, a comprehensive **ageing management program** (AMP) is necessary. The Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM has been carried out in 2017. It revealed that the ageing management program in Switzerland shows gaps compared to the safety level ENSREG expected for Europe.

Beznau NPP, the oldest operating NPP in Europe, has design weaknesses that cannot be remedied by retrofits, or only to a limited extent. Despite extensive upgrading and replacement measures current safety standards are not achieved. The probabilistic safety analysis (PSA) for Beznau NPP calculated an average core melt frequency (CDF) of about 1*10-5 per year, which is relatively high compared to other nuclear power plants. The analysis already takes into account the retrofit with the project AUTANOVE. This confirms that Beznau's lower safety level which results from design deficits cannot be remedied with retrofits. It is noteworthy that an earthquake contributes 83% to the CDF and 96% to the frequency of a large and early release (LERF). Should an earthquake trigger a core melt accident, it will result in high and early releases in almost all cases. Large early releases means that the releases are so high that the population would have to be evacuated to avoid health risks, but this type of accident scenario develops too quickly to make evacuation possible.

10 Gravelines and Cattenom, France

All 56 French nuclear power plants (NPPs) are owned and operated by Electricité de France (EDF) and equipped with two, four or even six pressurised water reactors (PWR). The oldest reactors (32) belong to the 900 MW class; the 1300 MW reactors (20). The 1450 MW reactors, or N4 series, comprise four reactors.

Gravelines NPP is the biggest nuclear power plant in France and comprises six reactors. All units belong to the 900 MW class. Units 1 – 4 started commercial operation in 1980/81, units 5 and 6 followed in 1985. The NPP is situated on the French coast of the British channel between Calais and Dunkirk (both about 20 km). The distance to Belgium is around 35 km, to Bruges about 90 km.

Cattenom NPP comprises four reactors that belong to the 1300 MW class. Commercial operation of the four units started successively in 1987, 1988, 1991 and 1992. The NPP is situated at the river Mosel about 9 km south of the boarder and about 50 km south of the city of Luxembourg.

10.1 French National Action Plans (NAcP)

In France, the stress test process was fitted into a dual framework: firstly a European framework with the organisation of the stress tests, and secondly in a national framework with the performance of a safety audit of the French civilian nuclear facilities in the light of the Fukushima Daiichi accident, as demanded by the Prime Minister on 23rd March 2011. Representatives of the French High Committee for Transparency and Information on Nuclear Security (HCTISN), the local information committees (CLI) and several safety regulatory bodies from abroad were invited to attend the technical meetings as observers and to take part in the targeted inspections carried out by ASN. Some observers provided input to the analysis of the reports submitted by EDF. (ASN 2012)

According to the 2014 NAcP, ASN has supplemented the prescription it issued in 2012 by a set of resolutions dated 21 January 2014 aiming to clarify certain design provisions of the "hardened safety core". These clarifications lead to the organisation of several meetings of ASN's Advisory Committees of Experts in 2015 to examine in detail the various studies carried out by EDF. (ASN 2014)

The NAcP of 2012 was updated in 2014 and 2017, the "Closure Report" of the NAcP was published in December 2020. (ASN 2020)

10.2 Weaknesses identified by the French Stress Tests the NAcP should remedy

The stress tests revealed that France has not evaluated the design basis earthquake (DBE) using state-of-the art methods but relied on a deterministic approach only. ENSREG recommended to perform a probabilistic seismic hazard assessment (PSHA).
The 2020 NAcP explained: Within the framework of the ongoing periodic reviews, probabilistic studies to complement the seismic hazard analysis will be carried out.[25]
However, probabilistic seismic hazard analyses are not available for all NPP sites yet. This kind of analyses is state-of-the-art for the seismic hazard evaluation. In general, they result in significant higher earthquake values and thus the need for improvements in this area.

The seismic margins of safety relevant equipment (e.g. electrical equipment, seals between buildings and tanks) are small. The Peer Review Team stated 2012 that the safety margins for seismic events above the Design Basis Earthquake have been roughly estimated by EDF. ASN requested EDF to conduct a more in-depth seismic margin assessment (SMA). The review of the equipment likely to suffer cliff-edge effects, and the initiating of the necessary corrective measures was to be done until mid-2014.
According to the 2020 NAcP, EDF has written guides for verifying the seismic behavior of equipment beyond their design basis requirements. EDF also develops seismic probabilistic safety assessments for the periodic safety reviews.
However, the seismic margin assessment and in particular the necessary back-fittings are not finished. They will be performed in connection to the Periodic Safety Review, and it remains unclear when the necessary backfitting measures will be performed once the analyses will be ready.

The stress tests revealed that fire detection and extinguishing systems are not electrically backed-up by

[25]Through a set of resolutions dated 21 January 2014, ASN set the extreme seismic hazard defined by a response spectrum: encompassing the safe shutdown earthquake (SSE) for the site, plus 50%, encompassing the probabilistic site spectra with a return period of 20,000 years, taking into account the particular site effects, in particular the nature of the soil, in its definition.

seismically qualified equipment. Thus, it can be assumed that these components are not available in the event of an earthquake. A study evaluating the seismic resistance to an earthquake of the fire-fighting systems and a program of necessary modification was to be done by 2012 (ECS-12).
According to the 2014 NAcP, this measure is completed.The necessary modifications will be carried out during the periodic safety reviews of the reactors concerned.
However, until the back-fitting has not been completed, the firefighting system would fail in case of an earthquake. Only the study is completed but not the necessary measures.

The dangerous **flooding** event of the French NPP Blayais in 1999 illustrated the urgent need for reinforcement of the French NPPs against flooding. However, not all modifications and tasks defined by the experience feedback approach were implemented in 2011. Following the flooding of the Blayais site in 1999, EDF has to put in place a protected volume perimeter[26] on all the sites. The conformity of this protected volume was specifically inspected by ASN during the targeted inspections conducted in 2011. Following the stress tests, ASN has set the following prescriptions:

- works to integrate experience feedback from the Blayais flood in 1999 for the Blayais, Bugey, Cruas, Dampierre, Gravelines, Penly, Saint-Laurent-des-Eaux and Tricastin sites (ECS-04).
- restoring conformity of the protected volume (ECS-05).

According to the 2020 NAcP, work to restore conformity was completed on 30th June 2012 and all the planned work to enhance the safety of the installations following the Blayais NPP flooding was completed in 2014.
However, these modifications were completed only 15 years after the dangerous flooding event in France. In particular for the Gravelines NPP with six units located at the sea, this an irresponsible approach.

The analysis performed by IRSN during the stress test review revealed cliff-edge effects close to review flood levels (DBF). ASN has issued a specific requirement to EDF relating to the protection of the facilities against flooding beyond the baseline requirement to prevent the cliff-edge effects associated with heavy rainfall or the failure of on-site equipment due to an earthquake beyond design-basis earthquake (ESC-06).
According to the 2020 NAcP, the modifications were carried out on all the sites concerned.
However, the risk of flooding is increasing due to the climate change: From late May until mid-June 2016, a persistent large-scale weather pattern with thunderstorms produced intense precipitation which caused both local flash floods and widespread flooding in central Europe. The floods struck many places without a warning. Almost simultaneously, storms in France and the Benelux countries caused floods: at first only smaller rivers were affected, but the Loire and Seine later burst their banks too.[27] We are now observing persistent weather patterns more and more frequently during the summer half-year in the northern hemisphere. Their long duration can result in extreme outcomes. The summer of 2016 demonstrated that a single weather pattern can trigger both localised intense precipitation with flash floods and large-scale precipitation with river floods. Following the events of 2016 in Europe, it should be clear that extreme amounts of precipitation within a very short time are possible almost anywhere. (MUNICH RE 2017)

In the stress tests report ASN asked the licensee to conduct the analyses for those climatic phenomena which are related to flooding. The Peer Review Team recommended including also tornadoes, heavy rainfall, extreme temperatures and the relevant combinations of **extreme weather conditions** in these complementary studies.
According to the 2020 NAcP, ASN has defined the natural hazards to be considered for the definition of the hardened safety core, in particular extreme meteorological conditions.

ASN asked EDF to propose **a Hardened Safety Core** (HSC) of robust material and organisational measures designed in response to the extreme situations studied in the stress tests, to prevent an accident with fuel melt, or limit its progression, limit large-scale radioactive releases, enable the licensee to perform its emergency management duties. (ECS-1)

[26] The protected volume consists of walls, ceilings, floors and structures to that close openings in these surfaces (doors, covers, etc.) that can constitute potential water ingress points in the event of flooding.
[27] In Paris, the Louvre and the Musee d'Orsay had to be closed and works of art moved to higher floors.

According to the 2020 NAcP, the measure is completed. EDF presented the elements of the hardened safety core.
ASN stated: To take account of the engineering constraints involved in these major works but also the need to introduce the necessary post-Fukushima improvements as soon as possible, their implementation is planned in three phases (ASN 2014):

- Phase 1 (2012-2015):implementation of temporary or mobile measures to enhance protection against the main situations of total loss of the heat sink or electrical power supplies.
- Phase 2 (2015-2020):implementation of definitive design and organisational means that are robust to extreme hazards, such as the fundamental elements of the hardened safety core designed to respond to the main situations of total loss of the heat sink or electrical power supplies beyond the baseline safety requirements in force.
- Phase 3 (as from 2019): this phase supplements phase 2, in particular to improve the level of coverage of the potential accident scenarios considered. EDF indicates that these means have also been defined with a view to continuing operation of the reactors beyond forty years.

However, 10 years after the Fukushima accident, the Hardened Safety Core (HSC) that shall have an important role for the prevention core melt accidents but also for the mitigation of the consequences of core melt accidents has not been implemented. The implementation is likely to take at least another decade.

Furthermore, it is not assured that after implementation the HSC in interface with the existing structures, systems and components (SSCs) will meet adequate requirements in terms of resistance to extreme hazards and their induced effects. The SSCs of the HSC will not be independent from the existing SSCs. Thus it will not be ensured that the HSC constitutes the expected ultimate line of defence and is not affected by the potential failures that may occur in the existing SSCs. (Umweltbundesamt 2021)

None of the French reactors is equipped with an alternative **ultimate heat sink** (UHS). But the vulnerability of the UHS was highlighted by the events of clogging and partial loss of the heat sink at Cruas and at Fessenheim in December 2009, which shows that reinforcement of all heat sinks is necessary. A situation with loss of UHS can currently be induced by a DBE or by flooding slightly beyond the DBF and will affect all units at a site. In those cases, the core could become uncovered in just a few hours. EDF started to reinforce the robustness of the UHS. ASN requires completing the heat sink design review, in particular with regard to prevention of the risk of clogging. (**ECS–15)**
According to the 2020 NAcP, EDF has carried out studies and has proposed several changes which bring about an improvement in the monitoring of heat sinks and their protection against external hazards.
However, it is not mentioned when this necessary improvement will be implemented.

During the stress tests, the licensee analysed situations entailing loss of heat sink and loss of electrical power supplies to the reactors, going **beyond the situations studied in the current baseline requirements**, more specifically considering scenarios which, on the one hand, have a lasting effect on all the reactors on a site and which can, on the other, be induced by an earthquake or external flooding, including of a level greater than that considered in the current baseline requirements. These additional studies have led ASN to issue the prescriptions ECS–16 and ECS–17.

Reinforcement of the facilities to manage long-duration situations of total loss of heat sink or total loss of electrical power supplies (ECS-17): The licensee shall examine the requirements assigned to the equipment needed to manage total loss of heat sink or total loss of electrical power situations, with regard to temperature resistance, resistance to earthquakes, flooding and the effects induced on the facility by these hazards. The licensee shall submit proposals for changes.
According to the 2020, EDF has defined the requirements. The need for changes in the reference systems is examined as part of the periodic safety review process.

Emergency water supply resources and emergency water make-up in the reactor coolant system (ECS-16): EDF shall present modifications for installing technical backup devices for long-term heat removal from the reactor and the spent fuel pool in the event of loss of UHS (emergency water supply

resources). These devices must meet the requirements for the hardened safety core.
According to the 2020 NAcP, EDF presented the modifications (new shafts, basins or tanks depending on the site), as well as their requirements, to provide new means to ensure cooling of the reactor and the fuel pool.
The new emergency water supplies (alternate heat sink) have the potential to reduce the risk of core melt accident. However, 10 years after the Fukushima accident, it is not implemented.

Additional electrical power supply means: As early as possible, given the constraints of fleet-wide deployment, and in any case before 31 December 2018, the licensee shall - for each reactor on the site - install an additional electrical power supply capable of supplying the systems and components of the hardened safety core as per prescription ECS–1 if the other off-site and on-site electrical power supplies are lost. (ECS–18.II).
According to the 2020 NAcP, for each of the 56 reactors in operation, EDF has built a "bunkerized" building, which must resist extreme hazards. This large building houses the ultimate backup diesel generator set (DUS) and the means to ensure its cooling and power supply, as well as its fuel tanks.[28]
The delays in the commissioning of the DUS on all the reactors are the result of difficulties encountered in construction operations, hazards encountered during commissioning tests, and specific measures implemented to limit the spread of the Covid-19 pandemic.[29]
Although ASN has already granted EDF long deadlines for the implementation of the required upgrades, despite the significant vulnerabilities and the risks they pose, there are further delays. This is one example of several delays.

The stress tests revealed a lot of shortcomings concerning the **spent fuel pools**, which have led ASN to issue several prescriptions. Some limited measures are performed:

- Installation of reinforced instrumentation in the pool for measuring the state of the spent fuel pool (temperature and water level) and the radiological atmosphere in the fuel building hall (ECS-20).
- Reinforcement of the measures to prevent accidental rapid draining of the fuel storage pools (ECS-22).

The **fuel building** is not designed to contain steam generated by the boiling of the water of the spent fuel pools (SFP) during events with a pressure increase. It consists of a metal cladding roof and a thin concrete wall (about 30 cm). The thermohydraulic development of a pool accident, i.e. a study of behaviour of the fuel and the water in the SFP under loss of cooling and loss of water situations including measures to be taken was to be performed by 2012. (ECS-24).
According to the 2020 NAcP, the studies submitted describe the kinetics and consequences of boiling in the spent fuel pool. The measures consist in maintaining a sufficient water inventory in the pool through water make-up, and then providing cooling by mobile means.

As part of the Hardened Safety Core an additional cooling system for the spent fuel pond (SFP), make-up water system and an emergency water source should be implemented as a result of the 4th PSR. Those significant upgrades could reduce the risk of uncovering the spent fuel assemblies in many accident situations.

ASN however criticized the limited target which was set for the intended safety level for the life-time extension. EDF’s range of investigations on possible accident situations in the SFP is insufficient so far. For accident situations due to explosions and leakage further studies and possible upgrades are expected. Also concerning fires, the safety level which was reached with upgrades does not fulfill currently required safety levels. ASN demanded further studies, however already limited the necessary upgrades by calling them “proportionate”. Whether those yet to be determined further upgrades will reach the safety goal defined by ASN is questionable at this point**. However, the main weakness – the SFP’s vulnerability against extreme impact – would persist for another 20 years, because no measures are foreseen to remedy this weakness.** (UMWELTBUNDESAMT 2021)

[28]In the interim, EDF has equipped each reactor with a generator set that can supply electrical power for the necessary instrumentation and control and lighting of the control room in the event of loss of the on-site and external power sources. This modification has been in place since the end of June 2013.
[29]At the end of 2019, EDF had commissioned only 35 DUS.

The stress tests revealed that the protection of the severe accident equipment against external hazards (earthquake, especially) was not considered before the Fukushima Daichi accident. For this reason, many **severe accident management** (SAM) related provisions were not seismically qualified. These include the venting filters, but also mobile equipment. ASN required general improvement of such equipment.

The installed filtered venting systems are not resistant against earthquakes; also, the filters are not designed to retain iodine which is mainly responsible for exposure of people living in the NPP vicinity. A detailed study of the possible improvements to the venting-filtration system, taking into account the existing deficiencies was to be performed by 31 December 2013. (ECS-29)
According to the 2020 NAcP, EDF has submitted to ASN a detailed study of the possible improvements to the U5 venting-filtration system, considering in particular its resistance to hazards.
Though the significant safety deficits have been known since 2011, the retrofit of the U5 filter system, which is necessary due to the deficits in the design against earthquakes and iodine filters has not yet been performed. The ENSREG Peer Review Team stated after the stress tests that the consideration and implementation of these issues is important to be realized as soon as possible, apart from the PSRs.

The U5 filter system is intended to provide filtered venting to the atmosphere during a severe accident when the containment pressure is too high. Due to the envisaged installation of the ultimate containment residual heat removal device (EASu system), EDF has not submitted a study to improve the effectiveness of the U5 filter system. However, the ASN believes that the U5 filter system must be in place to be used in the event of an EASu system failure. Recent research by IRSN has demonstrated good filtering capacities for organic iodine compounds. EDF has committed to continue its research and development on this issue and, if necessary, submit a program for retrofit in December 2024. (UMWELTBUNESAMT 2021)

A feasibility study for the installation or renovation of a geotechnical containment or equivalent technical measures to prevent the transfer of radioactive contamination to groundwater in the event of a severe accident leading to corium melt-through of the vessel was to be performed by 2012. (ECS-27-1)
According to the 2020 NAcP, EDF concluded that a geotechnical containment at an economically acceptable cost is not feasible. ASN requested that EDF continue its studies on this subject.
The development of sufficiently effective measures to limit the spread of contaminated water into the environment at reasonable costs is still ongoing.

EDF has reinforced the current emergency organisation, particularly by setting up a Nuclear Rapid Intervention Force ("FARN") with material and human resources. The FARN's mission is to intervene after 24 hours, in continuity and in relief of the operating shift teams which will have started responding to the emergency actions of the site concerned, where access infrastructures may be partially destroyed. The FARN is made up of a headquarters and four regional centres located at the nuclear power plants of Bugey, Civaux, Dampierre and Paluel.

The FARN will be able to support the plant staff in a severe accident situation only after 24 hours, thus it is important that the plant staff is able to cope with a severe accident in the first 24 hours. **The envisaged severe accident management relies to a large extent on manual actions of the staff. The success of the Severe Accident Management (SAM) is dependent on the fast targeted actions of the staff. EDF so far has not proven that this is possible**. (ASN 2020b)

Improvement of SAM in context of life-time extension

In France, a total of 56 nuclear power plants (NPP) is in operation, 32 of them are 900 MW reactors, which will soon reach or have already reached a life-time of 40 years. The 4th Periodic Safety Review (PSR) which is currently being performed is of specific importance, because originally the reactors were designed for a life-time of only 40 years. This PSR involves a generic part to be applied for the entire 900-MW fleet with plant-specific additions.[30]ASN defined the objectives for the 4th PSR: improvement of facility safety to attain a safety level similar to that specified for the third-generation

[30]The generic phase of the PSR is now being completed with this public consultation which started at the end of 2020. In the next step until 2031, the PSR for individual reactors will be undertaken, involving regional consultative procedures.

nuclear reactor under construction at Flamanville (EPR). This requires changes to limit the radiological impacts of accidents without core melt, to prevent or mitigate the impacts of accidents with core melt (severe accidents) and to reinforce the safety of stored spent fuel.

To cope with core melt accidents the following systems are envisaged by EDF:

- Installation of a new hardened safety core containment-cooling system for cooling the corium (ultimate containment residual heat removal device - EASu system) and for removing residual heat without having to use the containment filtered venting system;
- Stabilisation of corium once it has spread across the reactor-building basement and has been flooded with water, thereby guarding against the potential loss of containment due to basement melt-through.

The ASN review in the field of core melt accidents revealed several deficits in the concepts presented by EDF so far. ASN now demands the implementation of significant improvements of the concepts.The ASN review showed that the key safety system (EASu) can fail under different accident situations. According to ASN, numerous additional components and measures are needed to use the residual heat removal system in the containment.Also, it remains questionable whether all those requirements can be implemented.

The concept which EDF proposed as means to prevent a melt-through of the basement cannot be called effective. A melt-through of the foundations has to be expected for half of all NPP. The decision to undertake the necessary enforcement of the affected foundations has not yet been taken.

The assessment of the concepts for the 900 MW reactors in the area of accidents with melt-down clearly pointed to the technical (and economic) limits of achieving a safety level comparable with an EPR. The overall goal of achieving a limit to the radiological effects during a severe accident will not reached with the proposed measures by EDF.

10.3 Examples of further safety and security issues of Cattenom and Gravelines

Alike all 900 MW and 1300 MW reactors, the NPP Gravelines and the NPP Cattenom have **several design weaknesses** which make them vulnerable against internal and external events. The deficiencies with regard to diversity, redundancy and independence in the safety system increase the probability of a severe accident.

Without sufficient reliability of the safety systems, there is a significantly increased probability that an accident scenario will not be controlled according to design, but that accident scenario beyond design basis with multiple failure of safety equipment will occur. If, for example, a failure occurs in these areas due to internal events such as a fire or a piping failure, or also due to external impacts, the required safety functions will fail completely. At the same time, the possibility of limiting the release in the event of a severe accident is low.

In connection with the existing design deficits, ASN refers to the planned retrofits in connection with the Hardened Safety Core (HSC). However, these systems of safety level 4 cannot be used to compensate for existing deficits on safety level 3. (PISTNER 2018)

Ageing is a major safety issue of the old French NPPs. Faults caused by ageing of material have the potential to aggravate or even trigger an accident. An example for a safety relevant ageing fault is the occurrence of micro cracks in a bottom-mounted instrumentation penetration nozzle at the bottom of the reactor pressure vessel of Gravelines-1. The cracks were detected with non-destructive examinations conducted during the reactor’s 30th-year outage in summer 2011. In France's 900-MWe class pressurized water reactors, some 50 small tubes around 38 mm in diameter penetrate the bottoms of the reactor pressure vessels. They allow for instruments to be inserted through the vessel and into the reactor core, but their construction is important to nuclear safety because it represents part of the boundary of the pressurized cooling system. (WNN 2011)

According to ASN (2016), the number of events relating to confinement has increased slightly. The leak test carried out on the containment of reactor 5 at Bugey NPP in 2011, during the third ten-yearly reactor safety review, revealed a higher leakage rate than previous tests. Although the leakage rate observed during the test meets regulatory criteria, the increase indicates that the containment is changing over time. ASN therefore laid down a requirement that the containment should be leak tested again within five years, rather than waiting until the next ten-yearly leak test. The following pressure tests in October 2015, revealed that the containment's impermeability had deteriorated compared with the 2011 test. IRSN pointed out, it cannot be ruled out that this defect occurs on the other 900 MWe reactors. EDF has planned to examine the interest of deploying similar actions on the other 900 MWe reactor enclosures. (IRSN 2018) Containment should be carried out for all 900 MWe reactors in 2020.

The Topical Peer Review (TPR) as set out in Article 8e of Directive 2014/87/EURATOM has been carried out in 2017. It revealed that the ageing management program in France shows gaps compared to safety level ENSREG expected for Europe: During long construction periods or extended shutdown of NPPs, relevant ageing mechanisms are not identified and appropriate measures are implemented to control any incipient ageing or other effects. Opportunistic inspection of concealed pipework is not undertaken when the pipework becomes accessible for other purposes. (ENSREG 2018)

During an inspection carried out on 21 December 2011 as part of the measures taken following the post-Fukushima complementary safety assessments (CSA), the operator found out that siphon-breakers were missing in the spent fuel pools on the reactors 1 and 4. Owing to its potential consequences, this event was rated level 2 on the INES scale. The absence of siphon breaker is not at all the first non-conformance the inspections in the frame of the CSA have been revealed. In August 2011, the ASN found 35 defects in safety-relevant components during random tests at Cattenom. The high number and their safety relevance indicates an insufficient **safety culture** of the operator (MAJER 2012) In this respect, we can assume that a lot of unidentified defects exist at every NPP that would lead to the functional failure of components or systems in case of an incident/accident.

In 2016, the French regulator ordered EDF to close up to a third of its 58 reactors for safety checks and repairs following problems with Areva-made components. Irregularities have been found in around 50 Areva-made components installed in French nuclear reactors. ASN said that after the discovery of weak spots in the reactor vessel of the EPR reactor under construction in Flamanville, Areva began a review of manufacturing procedures at its Creusot steel forging plant. Areva had found evidence of irregularities in about 400 components produced since 1965, of which some 50 are believed to be in use in French nuclear plants. Areva said some reports on manufacturing and quality control at Creusot may have been falsified. ASN stated: *This situation shows that neither the robustness of the monitoring and inspection chain, at the top of which are the manufacturers and the licensees, nor the high level of quality demanded in the nuclear industry, were able to completely rule out the risk of counterfeit, suspect and fraudulent items (CSFI.)*(ASN 2018a)

However, this means that it must be assumed that other components that do not meet the requirements are in the plant and can fail in an accident situation. One known example is the following:

In 2017, EDF notified two events significant for safety which occurred on the emergency diesel generator sets of its nuclear power reactors. ASN rated these two events level 2 on the INES scale. Each of the 900 MWe and 1300 MWe reactors of the French NPP fleet is backed up by two emergency diesel generator sets. A first significant event for safety concerns the failure to demonstrate the earthquake resistance of the anchors in the civil engineering of the emergency diesel generator set auxiliary systems. It covers both design problems which are generic to all the reactors concerned and local problems relating to the poor condition or poor installation of the anchors. This event was rated level 2 on the INES scale. It concerned 26 of the 900 and 1300 MWe reactors.

Another safety-significant event which concerns the failure to demonstrate the earthquake resistance of the surge tanks of the emergency diesel generator sets due to deficiencies associated with corrosion. These deficiencies result in particular from insufficient maintenance of these items of equipment. Identified by EDF at the Penly NPP in July 2017, they formed the subject of a generic significant event notification to ASN on 9th November 2017 for. It concerned 7 reactors in the 1300 MWe series (including Cattenom 2). (ASN 2019a)

In 2020, France has not implemented 123 of the 342 WENRA Reference Levels (RL) of 2014. No other European country has implemented less RL. (WENRA RHWG 2020a)

The last OSART to the Cattenom NPP took place in 2011, and the last OSART mission to the

Gravelines NPP in 2012. (IAEA 2021)

Security issues

The **reactor buildings** at the *Gravelines NPP* are particularly vulnerable to external hazards. Their reactor cores are surrounded by a relatively thin-walled containment vessel (thickness: 90 cm). This design no longer reflects current standards in science and technology. Planners regard a thickness of about 2 meters as the standard for new construction projects.

The reactor buildings at *Cattenom* are better protected but still not protected sufficiently against external hazards. They are enclosed by a double-walled containment vessel, but these walls are not very thick (90 cm). In this respect, basic protection of the Cattenom plant results only from the design against an accidental aircraft crash at the level of a small business aircraft. Thus, the Cattenom plant has only a low robustness of safety-relevant buildings and facilities. This applies in particular to the single storage tanks for the coolant water and the steam generator feed. Like other safety-relevant equipment, these are located outside the reactor building and are therefore not particularly protected against mechanical or thermal impacts from an aircraft crash.Furthermore, the safety-relevant buildings, both the reactor building and in particular the fuel pool building, are only comparatively weakly designed against mechanical impacts from an aircraft crash. The protection against external impacts currently implemented at the Cattenom plant does not correspond to the state-of-the art already implemented both in new plants in France and in existing plants abroad. In view of the low level of basic protection, there is thus a significantly increased risk at the Cattenom plant that, in the event of a deliberate aircraft crash, accident scenarios up to and including an accident with large and early release. (PISTNER 2018)

These **spent fuel pools** are in a separate building that is not adequately protected against external hazards. These buildings at all sites have a thin metal roof and their concrete walls are not thick (30 cm). Available data about the spent fuel building show that the thickness of the wall in the area of the water basin is about 0.8 to 1 m. Because of the walls' thinness the probability of a severe damage of the spent fuel building by external hazards is relatively high.

The threat of a large breach of the spent fuel pool (after an earthquake) was also highlighted during the Fukushima accident in 2011. An external event resulting in major damage to the building would cause cooling water loss. If the water drains off and refilling of water is not foreseen or possible, very severe radioactive releases begin within hours. This leads to a dangerous challenge: As soon as the water has drained out of the pool, not only the cooling, but also the shielding effect of the water is lost.Fuel that has been extracted only a short time earlier from the reactor would generate a relatively high amount of heat and can reach a temperature of 900 °C within a few hours. At that temperature, the fuel cladding made of zircaloy would burn in the air. The fire is very hot and cannot be extinguished with water. Within the cooling pool it could spread to older fuel assemblies that would otherwise not heat up so rapidly. Thus, the entire inventory of the cooling pool could melt. About 75 percent (10-90 percent) percent of the caesium-137 inventory could be mobilized in the plume from the burning spent fuel pool. (IPPEL 2016) In this situation, the population would have to be evacuated during an extremely short time.

Spent fuel pools are also vulnerable when the reactor is not in operation, even more so. The most dangerous situation occurs during refuelling when all the fuel has to be unloaded from the reactor core to the spent fuel pool.

The spent fuel buildings at the French NPPs are highly visible and therefore relatively easy targets for an attack from the air. No studies about the consequences of a deliberate aircraft crash against a French NPP (reactor building or the building of the spent fuel pool) are available. It is, however, possible to draw conclusions from the results of studies carried out in other countries e.g. Germany and general considerations regarding the possible effects of such an aircraft crash. A generic study commissioned by the German Federal Environment Ministry (BMU) revealed that even a small commercial aircraft (e.g. an Airbus A320) would cause major damage to the reactor building with a wall thickness of 0.6 to 1 metres. (BMU 2002)

EDF also investigated the consequences of the crash of a commercial airplane on the spent fuel building. According to EDF it would not lead to an uncovering of the spent fuel assemblies in the SFP.

This statement cannot be justified with the existing studies on airplane crashes and cannot be assessed with an explanation of the assumptions (e.g. on the airplane type) the study used.

The French power company and NPP operator, Electricité de France (EdF), announced late in October 2014 that **drones** had been observed over several nuclear power plants since 5 October. On 19 October, for example they had flown over four NPPs located far from each other, indicating that this was a well-coordinated action. According to the media, the drones were sometimes two meters wide and therefore could potentially carry smaller quantities of explosives.A report of Greenpeace concerning this issue did not go into the many speculative ideas regarding the background of current events (GREENPEACE 2014b). The subject of the report was the question of what dangers are associated with such drone overflights – were they to be carried out by a terrorist group. The danger from terrorist attacks on nuclear power plants is mostly played down, claiming that nuclear power plants are sufficiently secured but for confidentiality reasons no details can be released. These arguments are dramatically contradicted by the drone overflights: For one thing it appears that operators and officials are powerless to halt the overflights and for another, it must now be assumed – after potentially successful reconnaissance flights – that existing security measures are known. The goal of the report, however, was to examine whether terrorist attack scenarios using drones is conceivable and whether as a consequence a core meltdown would be practically inevitable; in other words, an attack that would cause damages for which intervention measures to hinder the release of a radioactivity would be impossible.

The Nuclear security index 2020 shows that France with a total score of 77 points ranked 18thout of 47 countries. The score for the section "security and control measures" (59) is low. Of particular concern are the low scores for the "Security culture" (25), "Cybersecurity" (63) and "Insider threat protection" (45). These low scores indicate weaknesses in the protection.(NTI 2020)

10.4 Conclusions

The French nuclear power plants we assessed show considerable deficiencies. Safety important systems, for example the fire-fighting systems and the filtered venting systems of the containment, are not seismically qualified, i.e. these systems would fail during an earthquake. These weaknesses are known since the stress tests, however the necessary reinforcement will be carried out only in the next decade(s).

Flood protection shows a lot of shortcomings. Urgent modifications were completed only 15 years after the dangerous flooding event in 1999 at the Blayais NPP. In particular for the Gravelines NPP with six units located at the sea, this an irresponsible approach.However, due to climate change, the risk of flooding is increasing. Thus, it is not assured that the protection is sufficient now.

None of the French reactors is equipped with an alternative ultimate heat sink, but recent events highlighted the vulnerability of the existing ultimate heat sinks (UHS). In case of the loss of the UHS, respectively its unavailability, the core could be uncovered in just a few hours. However, the danger will persist until an alternate heat sink will be built as part of the implementation of a hardened safety core.

The new emergency water supplies (alternate heat sink) have the potential to reduce the risk of core melt accident. However, it is not implemented. Although ASN has already granted EDF long deadlines for the implementation of the additional electrical power supply means, despite the significant vulnerabilities and the risks they pose, there are further delays. It is only one example of several delays.

EDF and the responsible authorities ASN tried to outline protection measures in the future, after the Hardened Safety Core (HSC) will have been implemented. However, 10 years after the Fukushima accident, the HSC that shall have an important role for the prevention core melt accidents but also for the mitigation of the consequences of core melt accidents is not implemented and will probably take at least another decade. The implementation of the necessary back-fitting measures is planned in three phases. Until now only the implementation of temporary or mobile measures is completed (phase 1). The full implementation will most likely not be completed before 2030.

The stress tests revealed a number of shortcomings concerning the **spent fuel pools**, which have led the regulator ASN to issue several prescriptions. Some limited measures are performed. As part of the Hardened Safety Core an additional cooling system for the spent fuel pond (SFP), make-up water system and an emergency water source will be implemented. Those significant upgrades could reduce the risk of uncovering the spent fuel assemblies in many accident situations. However, the main weakness – the SFP's vulnerability against extreme impacts – would persist in case of Lifetime extensions (LTE) for another 20 years, because no measures are foreseen against this weakness.

Though the significant safety deficits of the filtered venting systems have been known since 2011, the retrofit of the U5 filter system, which is necessary due to the deficits in the design against earthquakes and iodine filters has not yet been performed.

To cope with core melt accidents the new systems for cooling the molten core and heat removal are envisaged. The ASN review in the field of core melt accidents revealed several deficits in the concepts presented by EDF so far. The assessment of the concepts for the 900 MW reactors in the area of accidents with melt-down clearly pointed to the technical (and economic) limits of achieving a safety level comparable with an EPR. The overall goal of achieving a limit to the radiological effects during a severe accident will not be reached with the proposed measures by EDF.

It is common understanding, that a second-generation reactor cannot be back-fitted to the same safety level as a reactor that was designed to withstand severe accidents. However, some of the back-fitting measures which were required as a result of the stress tests, EDF was already preparing in the framework of the utility's plan to receive the permit for 60-year reactor operation. Life-time extension (LTE) for the old dangerous plants is an irresponsible approach. For the 900 MW reactors, a core melt accident with a major release is possible today and will be possible after the implementation of the currently envisaged LTE program.

An operation time of 60 years for the old dangerous plants means ageing becomes an increasing safety issue for the very old plants, faults caused by ageing could trigger accidents which are not incorporated in the scope of the hardened safety core. Furthermore there are design weaknesses that cannot be remedied.

Alike all 900 MW and 1300 MW reactors, the NPP Gravelines and the NPP Cattenom have **several design weaknesses** which make them vulnerable against internal and external events. The deficiencies with regard to diversity, redundancy and independence in the safety system increase the probability of a severe accident. In connection with the existing design deficits, ASN refers to the planned retrofits in connection with the Hardened Safety Core (HSC). However, these systems of safety level 4 cannot be used to compensate for existing deficits on safety level 3.

In France, a fundamental problem of nuclear safety is particularly evident; while on paper attempts are made to increase the level of safety, the reality in the plants is different.

In addition to aging issues and design deficiencies, there are problems with quality control and safety culture, as evidenced by, among other things, the 2017 mounting and maintenance failures on emergency diesel generators and the 2016 irregularities on a variety of components. This means that it must be assumed that other components that do not meet the requirements are in the plant and can fail in an accident situation.

On top of all safety issues, there are security issues: All reactor buildings and spent fuel pools are vulnerable against a deliberate crash of an airliner. In autumn 2014, drones had been observed over several nuclear power plants. Not only the over-flights of about 30 drones as such but also the inability of security officials to explain and prevent such activity caused concern. The Nuclear Security Index points to deficits of the "security culture" as well as deficits of cyber-security and the protections against the insider threat.

11 References

ASN 2012: Complementary Safety Assessments Follow-up of the French Nuclear Power Plants Stress tests, National Action Plan of the French Nuclear Safety Authority, December 2012

ASN 2014: Follow-up to the French Nuclear Power Plants Stress tests, Updated National Action Plan of the French Nuclear Safety Authority, December 2014

ASN 2016: Seventh National Report for the 2017 Review Meeting of the Convention on Nuclear Safety. French Nuclear Safety Authority (ASN); 2016

ASN 2018: ASN reviews the steps taken to deal with counterfeit, suspect and fraudulent items (CSFI) French Nuclear Safety Authority (ASN);08.06.2018; http://www.french-nuclear-safety.fr/Information/News-releases/ASN-reviews-the-steps-taken-to-deal-with-counterfeit-suspect-and-fraudulent-items-CSFI

ASN 2019a: ASN rates a significant event affecting the emergency diesel generator sets on the Civaux, Gravelines and Paluel NPPs level 2 on the INES scale; 14.05.2019; French Nuclear Safety Authority (ASN); http://www.french-nuclear-safety.fr/Information/News-releases/Civaux-Gravelines-and-Paluel-NPPs-significant-event-level-2-on-the-INES-scale

ASN 2020: Follow-up to the French Nuclear Power Plants Stress tests, Closure Report of the Action Plan of the French Nuclear Safety Authority (ASN), December 2020

ASN 2020b: Phase générique du quatrième réexamen périodique des réacteurs de 900 MWe. Projet de rapport d'instruction. CODEP-DCN-2020-058834. Décembre 2020. https://www.asn.fr/content/download/173204/1783817/version/1/file/4e%20R%C3%A9examen%20p%C3%A9riodique%20des%20900MWe%20-%20projet%20de%20Rapport%20d%27instruction.pdf.

BECKER 2013: Critical Review of the National Action Plans (NAcP) of the EU Stress Tests on Nuclear Power Plants; Study commissioned by Greenpeace,Oda Becker, Patricia Lorenz; Vienna, Hannover, April 2013;

BECKER 2015: Critical Review of the Updated National Action Plans (NAcP) of the EU Stress Tests on Nuclear Power Plants; Study commissioned by Greenpeace,Oda Becker, Patricia Lorenz; Vienna, Hannover, Juni 2015;

BMLFUW CZ 2014: Stress tests Follow-Up Actions; Issue Paper for Czech Republik; Authors: Kurt Decker, Helmut Hirsch, Bojan Tomic; Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management;Prepared by the Order of the BMLUFW; Report Final Version Vienna; 20-01-2014; http://www.bmlfuw.gv.at/umwelt/strahlen-atom/antiakwpolitik/stresstest.html

BMLFUW SK 2014: Stress tests Follow-Up Actions; Issue Paper for Slovakai; Authors: Kurt Decker, Helmut Hirsch, Bojan Tomic; Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management; Prepared by the Order of the BMLUFW; Report Final Version Vienna; 20-01-2014; http://www.bmlfuw.gv.at/umwelt/strahlen-atom/antiakwpolitik/stresstest.html

BMLFUW SL 2014: Stress tests Follow-Up Actions; Issue Paper for Slovenia; Authors: Kurt Decker, Helmut Hirsch, Bojan Tomic; Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management;Prepared by the Order of the BMLUFW; Report Final Version Vienna; 20-01-2014; http://www.bmlfuw.gv.at/umwelt/strahlen-atom/antiakwpolitik/stresstest.html

BMU 2002: Schutz der deutschen Kernkraftwerke vor dem Hintergrund der terroristischen Anschläge in den USA vom 11. September 2001. Zusammenfassung de GRS-Studie durch das Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Bonn, den 27.11.2002.

BMU 2012: German Action Plan for the implementation of measures after the Fukushima Dai-ichi reactor accident; Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU); 31 December 2012

BMU 2014: Updated German Action Plan for the implementation of measures after the Fukushima reactor accident; Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU); December 2014

CRS 2005: Nuclear Power Plants: Vulnerability to Terroristic Attack; Congressional Research Service (CRS) Report for Congress; August 9, 2005

CSN 2012: Post-Fukushima European action plan – Spain National action plan, Consejo de Seguridad Nuclear (CSN); December 2012

CSN 2014: European Post-Fukushima action plan – Spain National action plan, Revision 1, Consejo de Seguridad Nuclear (CSN); 17th December 2014

CSN 2017: European Post-Fukushima action plan – Spain National action plan, Revision 2, Consejo de Seguridad Nuclear (CSN); 21st December 2017

ENSI 2012: EU Stress Test: Swiss National Action Plan Follow up of the Peer Review, 2012 Year-End Status Report; Swiss Federal Nuclear Safety Inspectorate (ENSI), December 2012

ENSI 2014: EU Stress Test: Swiss National Action Plan Follow up of the Peer Review, Swiss Federal Nuclear Safety Inspectorate (ENSI), December 2014

ENSI 2015: Aktionsplan Fukushima 2015; Swiss Federal Nuclear Safety Inspectorate (ENSI), 28.02.2015

ENSI 2015a Zusammenfassung des ENSI zur Erhöhung der Sicherheitsmargen; 25. Juni 2015; Swiss Federal Nuclear Safety Inspectorate (ENSI) http://www.ensi.ch/de/dokumente/zusammenfassung-des-ensi-zur-erhoehung-der-sicherheitsmargen/

ENSI 2016: Schlussbericht Aktionsplan Fukushima; Swiss Federal Nuclear Safety Inspectorate (ENSI), December 2016

ENSI 2016a Kernkraftwerk Beznau: Berichte der AXPO zu Hochwasser und Verklausung; Swiss Federal Nuclear Safety Inspectorate (ENSI) https://www.ensi.ch/de/2016/02/15/kernkraftwerk-beznau-berichte-der-axpo-zu-hochwasser-und-verklausung/

ENSI 2016b: Aktualisierte Gefährdungsannahmen für Erdbeben erfordern neuen Sicherheitsnachweis der Schweizer Kernkraftwerke; Swiss Federal Nuclear Safety Inspectorate (ENSI); 30. Mai 2016https://www.ensi.ch/de/2016/05/30/aktualisierte-gefaehrdungsannahmen-fuer-erdbeben-erfordern-neuen-sicherheitsnachweis-der-schweizer-kernkraftwerke/

ENSI 2021: Alle Schweizer Kernkraftwerke erfüllen die aktualisierten Erdbebensicherheits-Standards;Swiss Federal Nuclear Safety Inspectorate (ENSI); 5. Februar 2021; https://www.ensi.ch/de/2021/02/05/alle-schweizer-kernkraftwerke-erfuellen-die-aktualisierten-erdbebensicherheitsstandards/

ENSREG (2018) European Nuclear Safety Regulator's Group: 1st Topical Peer Review "Ageing Management" Country specific findings, October 2018.

ENSREG CZ 2012: Report of the stress test peer review Follow-up fact finding site visit to Temelin, Czech Republic, 11-12 September 2012

ENSREG GE 2012: Report of the stress test peer review Follow-up fact finding site visit to Gundremmingen, Germany, 12-14 September 2012

ENSREG RR-CZ 2014: Rapporteur's report – Czech Republic, ENSREG National Action Plans Workshop, 2014

ENSREG RR-GE 2014: Rapporteur's report – Germany, ENSREG National Action Plans Workshop, 2014

ENSREG SE 2012: Report of the stress test peer review Follow-up fact finding site visit to Ringhals, Sweden, 12-14 September 2012

ENSREG SE 2012: Report of the stress test peer review Follow-up fact finding site visit to Ringhals, Sweden, 2012

FANC 2011: Belgian stress tests – National report for nuclear power plants; Federal Agency for Nuclear Control, December 2011

FANC 2012: Belgian Stress Tests, National action plan for nuclear power plants; Federal Agency for Nuclear Control, 20 December 2011

FANC 2012b: Belgian stress tests National report on nuclear power plants - Man-made events, Federal Agency for Nuclear Control, January, 18, 2012

FANC 2014: Belgian Stress Tests, National progress report on the stress tests of nuclear power plants; Federal Agency for Nuclear Control, December 2014

FANC 2016: Belgian Stress Tests, National progress report on the stress tests of nuclear power plants; Federal Agency for Nuclear Control, March 2016

FANC 2019: Belgian Stress Tests, National progress report on the stress tests of nuclear power plants; Federal Agency for Nuclear Control, March 2019

FANC 2020: Belgian Stress Tests, National Final report on the stress tests of nuclear power plants; Federal Agency for Nuclear Control, September 2020

FANC 2020a: Terroristische Bedrohung; Federal Agency for Nuclear Control 11.06.2020; https://fank.fgov.be/de/dossiers/kernkraftwerke-belgien/aktuelles/terroristische-bedrohung

FANC 2020b: Beschädigung des Betons in Doel und Tihange;Federal Agency for Nuclear Control 12.06.2020; https://fank.fgov.be/de/dossiers/kernkraftwerke-belgien/aktuelles/beschaedigung-des-betons-doel-und-tihange

FANC 2021: Anzeichen für Defekte in den Reaktorbehältern von Doel 3 und Tihange 2; Federal Agency for Nuclear Control; 19.01.2021; https://fank.fgov.be/de/dossiers/kernkraftwerke-belgien/aktuelles/anzeichen-fuer-defekte-den-reaktorbehaeltern-von-doel-3

GOS 2019: Swedens´s Eight National Report under the Convention on Nuclear Safety;Government Office of Sweden, Ministry of the Environment; 2019

GREENPEACE 2006: The risk of Skoda – Unsettling facts on the Temelin Nuclear PowerPlant concerning faulty weltding work and documentation in Temelin block 1, Fact sheet, version 5.0, Jiri Tutter, Jan Haverkamp; 29 May 2006. http://gruene-fichtelgebirge.de/uploads/media/The_Risks_of_Skoda_Greenpeace.pdf

GREENPEACE 2014a Greenpeace: Lifetime extension of ageing nuclear power plants: Entering a new era of risk; Report commissioned by Greenpeace; Editor Jan Haverkamp; March 2014

GREENPEACE 2014b: At Risk from above – drone overflights threaten French nuclear facilities, A risk analysis using the examples of nuclear power plants Fessenheim, Cattenom and Gravelines, Oda Becker; Report on behalf ofGreenpeace Germany; November 2014

GUGLIELMELLI 2017:Statistical methodology for the evaluation of the radiological impact over the Italian territory of a severe accident at Krško NPP; Antonia Guglielmelli; Frederica Rocchi; Eurosafe 2017

HIPPEL2016: Reducing the Danger from Fires in Spent Fuel Pools; Frank N. von Hippel and Michael Schoeppner; SCIENCE & GLOBAL SECURITY 2016, Vol 24, No.3, 141-173;

IAEA 2010b: International Atomic Energy Agency, Report of the OSART Mission to the Doel NPP, 8-25 March 2010

IAEA 2016a International Atomic Energy Agency, SALTO Follow-up Mission to Tihange 1; 6 Dec 2016; Executive Summary https://www.iaea.org/sites/default/files/documents/review-missions/21_tihange_1_salto_fu_executive_summary.pdf

IAEA 2017a International Atomic Energy Agency, OSART Mission to Krsko, 15 May -1 Jun 2017; https://www.iaea.org/sites/default/files/documents/review-missions/194_krsko_summary_report.pdf

IAEA 2018a International Atomic Energy Agency, SALTO Mission to Ringhals 3 and 4; 27 Feb 2018; Executive Summary https://www.iaea.org/sites/default/files/documents/review-missions/33_ringhals_salto_executive_summary.pdf

IAEA 2018b International Atomic Energy Agency OSART Mission to Almaraz;5 – 22 Feb 2018https://www.iaea.org/sites/default/files/documents/review-missions/200_almaraz_summary_report.pdf

IAEA 2019a International Atomic Energy Agency, SALTO Follow-up Mission to Doel 1 and 2; 25 Jun 2019; Executive Summary https://www.iaea.org/sites/default/files/documents/review-missions/30_doel_salto_fu_executive_summary.pdf

IAEA 2019b International Atomic Energy Agency: Pre-operational OSART Mission to Mochovce 3; 18 Nov – 5 Dec 2019;https://www.iaea.org/sites/default/files/documents/review-missions/209_executive_summary_of_mochovce_report.pdf

IAEA 2021a: International Atomic Energy Agency: Peer Review and Advisory Services Calendar, Status: 22/02/2021; https://www.iaea.org/services/review-missions/calendar

JOE 2019: Journal of Energy Hazard Assessment of NPP Krško for Republic of Croatia; Saša Medaković, Davor Rašeta, Davor Grgić; State Office for Radiological and Nuclear Safety,; Volume 68 (2-3); 2019

MUNICH RE 2017: Naturkatastrophen 2016, Analysen, Bewertungen, Positionen, Ausgabe 2017

NTI (2020) NTI Nuclear Security Index; https://www.ntiindex.org/

ÖKO-INSTITUT 2012: Analyse der Ergebnisse des EU Stresstest der Kernkraftwerke Fessenheim und Beznau, Teil 2: Beznau; Mathias Brettner (Physikerbüro Bremen), Christoph Pistner, Stephan Kurth (Ökoninstitut) im Auftrag des Ministeriums für Umwelt, Klima und Energiewirtschaft Baden-Württemberg, Darmstadt, 11.10.2012

PISTNER 2018: Sicherheitsdefizite des AKW Cattenom. Pistner, C., Sailer, M., Mohr, S., Küppers, C. Im Auftrag der Bundesländer Rheinland-Pfalz und Saarland, Öko-Institut Darmstadt.

PMR 2015 Power market Review: Study finds feasible extending lifespan of Slovenia's Krsko NPP until 2043, January 9, 2015; http://powermarket.seenews.com/news/study-finds-feasible-extending-lifespan-of-slovenias-krsko-npp-until-2043-457583

RENNEBERG 2013: Risiken des Betriebs des Kernkraftwerks Gundremmingen unter besonderer Berücksichtigung der beantragten Leistungserhöhung. Institut für Sicherheits- und Risikowissenschaften. Universität für Bodenkultur, Vienna. Commissioned by FORUM Gemeinsam gegen das Zwischenlager und für eine verantwortbare Energiepolitik e.V., Renneberg, W.; Majer, D. 2013, November 2013.

RICHNER 2015: Backfitting Measures at Swiss Nuclear Power Plants; Martin Richner, Senior Expert Nuclear Safety, Beznau NPP of Axpo Power AG; 46th Annual Meeting on Nuclear Technology May 5 – 7, 2015, Berlin

SIROVICH 2014: A review of the seismotectonics and some considerationson the seismic hazard of the Krško NPP area (SE Slovenia);L. Sirovich (1), P. Suhadolc (2), G. Costa (2) and F. Pettenati (1)1:Istituto Nazionale di Oceanografia e di Geofisica Sperimentale21a) (OGS), Trieste, Italy, 2: Dipartimento di Matematica e Geoscienze, Università degli Studi di Trieste, Italy; Bollettino di Geofisica Teorica ed Applicata Vol. 55, n. 1, pp. 175-195; March 2014

SNSA 2012: Slovenian Post-Fukushima National Action Plan; Slovenian Nuclear Safety Administration; December 2012

SNSA 2014: Update of the Slovenian Post-Fukushima Action Plan; Slovenian Nuclear Safety Administration; December 2014

SNSA 2019: Update of the Slovenian Post-Fukushima Action Plan; Slovenian Nuclear Safety Administration; December 2019

SSM 2012: Swedish action plan for nuclear power plants; Response to ENSREG´s request; Dec 2012

SSM 2014: Swedish action plan for nuclear power plants; Response to ENSREG´s request Rev.1; Dec 2014

SSM 2014: Swedish action plan for nuclear power plants; Response to ENSREG´s request Rev.1; Dec 2014

SSM 2020: 2020 Status Report;Response to ENSREG´s request within the European Stress Tests; Swedish Radiation Safety Authority; March 2020

SUJB 2012: Post Fukushima, National Action Plan (NAcP) on Strengthening Nuclear Safety of Nuclear Facilities in the Czech Republic; State Office for Nuclear Safety (SUJB); December 2012

SUJB 2014: Post Fukushima, National Action Plan (NAcP) on Strengthening Nuclear Safety of Nuclear Facilities in the Czech Republic, Rev. 2; State Office for Nuclear Safety (SUJB); 6 January 2015

SUJB 2019a: Post Fukushima, National Action Plan (NAcP) on Strengthening Nuclear Safety of Nuclear Facilities in the Czech Republic, State Office for Nuclear Safety (SUJB); 31.12. 2019

SUJB 2019b: the Czech Republic National Report under the Convention on Nuclear Safety State Office for Nuclear Safety (SUJB); 2019

TWEER 2013: Flawed Reactor Pressure Vessels in Belgian Nuclear Plants Doel-3 and Tihange-2; Ilse Tweer Materials Scientist, Consultant; Commissioned by the Greens/EFA Group in the European Parliament. January 2013

UJD 2012: National action plan of the Slovak Republic, regarding actions to comply with the conclusions from the stress test performed on nuclear power plants; Marta ŽIAKOVÁ; Chairperson of the Nuclear Regulatory Authority of the Slovak Republic (UJD SR); December 2012

UJD 2014: National action plan of the Slovak Republic, Update; Nuclear Regulatory Authority of the Slovak Republic (UJD SR); December 2014

UJD 2019: National action plan of the Slovak Republic, Update; Nuclear Regulatory Authority of the Slovak Republic (UJD SR); December 2019

UMWELTBUNDESAMT 2017: UVP-Verfahren Abbau des Kernkraftwerks Gundremmingen (KRB II Block B), Fachstellungnahme, Oda Becker, Erstellt im Auftrag desBundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft; Report Rep-0603; Wien 2017

UMWELTBUNDESAMT 2021: Frankreich: Konsultation zu den Bedingungen für den Weiterbetrieb der 900 MW-Reaktoren über 40 Jahre hinaus, Fachstellungnahme, Oda Becker, Manfred Mertins, Gabriele Mraz, Erstellt im Auftrag des Bundesministeriums für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie; Report Rep-0752; Wien 2021

UMWELTBUNESAMT 2020: Umweltverträglichkeitsprüfung Zwischenlager für abgebrannte Brennelemente KKW Krško /Slowenien, Fachstellungnahme, Oda Becker, Kurt Decker, Gabriele Mraz, Erstellt im Auftrag des Bundesministeriums für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie; Report Rep-0742; Wien 2020

WENISCH 2012 Wenisch, A.; Becker, O. Lorenz, P.: Critical Review of the EU Stress Test performed on Nuclear Power Plants; commissioned by Greenpeace, Wien, Hannover, May 2012

WENRA RHWG 2014a: WENRA Safety Reference Levels for Existing Reactors, Update in relation to lessons learned from TEPCO Fukushima Dai-ichi Accident; 24th September 2014. www.wenra.org/media/filer_public/2014/09/19/wenra_safety_reference_level_for_existing_reactors_september_2014.pdf.

WENRA RHWG 2018a Peer Review of the Implementation of the 2014 Safety Reference Levels in National Regulatory Frameworks (A Reactor Harmonization Working Group RHWG report to WENRA); 23 March 2018

WENRA RHWG 2018b: Status of the Implementation of the 2014 Safety Reference Levels in National Regulatory Frameworks as of 1 January 2018; Annual Quantitative Reporting by Reactor Harmonization Working Group RHWG; 09 March 2018

WENRA RHWG 2020a: Status of the Implementation of the 2014 Safety Reference Levels in National Regulatory Frameworks as of 1 January 2020; Report; WENRA Reactor Harmonization Working Group Annual Quantitative Reporting by RHWG; 1st January 2020

WISE 2015a World Information Service on Energy (WISE) and the Nuclear Information & Ressource Service (NIRS): Belgium and the END of nuclear power; Nuclear Monitor No. 800, March 19, 2015

WNN 2011: World Nuclear News: Gravelines 1 shut down for crack repair; 22 December 2011; www.world-nuclear-news.org/C_Gravelines_1_shut_down_for_crack_repair_2212112.html

WNN 2014a: World nuclear news: Upgrade ultimate for Swedish plants; 10 October 2014; http://www.world-nuclear-news.org/RS-Upgrade-ultimatum-for-Swedish-plants-1010141.html

WNN 2016a: World nuclear news**:** Life extension for Slovenia's Krško NPP;6 May 2016; https://www.neimagazine.com/news/newslife-extension-for-slovenias-krslo-npp-4885976/

WNN 2020a: World nuclear news: **Swedish reactors meet new emergency cooling requirements;** 18 December 2020; https://www.world-nuclear-news.org/Articles/Swedish-reactors-meet-new-emergency-cooling-requir

WNSIR 2019: The World Nuclear Industry Status Report 2019; Mycle Schneider, Anthony Frogatt, et al., September 2019

WNSIR 2020: The World Nuclear Industry Status Report 2020; Mycle Schneider, Anthony Frogatt, et al., September 2020