Critical Review of

EU Nuclear Stress Tests in

Bulgaria, Hungary, Romania and Ukraine

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1 Introduction

In March 2011, the core melt accidents at the Fukushima Daiichi 1 nuclear power plant (NPP) showed the world that the nuclear industry cannot prevent severe accidents from happening. The accidents in Japan proved that highly unlikely accidents cannot be excluded. The Fukushima accident confirmed the mistrust towards nuclear power among the Japanese but also European citizens.

In reaction to the devastating nuclear disaster in Japan 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 the task to provide a "targeted reassessment of the safety margins of nuclear power plants", thus examining whether the safety margins which were used in the licensing of NPPs are sufficient to cover unexpected events. It is important to understand that the stress tests could not take into account all key safety issues such as the capability to prevent accidents - the scope of the stress tests defined by ENSREG didn´t promise to deliver a comprehensive risk and safety assessment. According to some observers the stress tests were mainly set up to improve the confidence in the safety of European NPPs. Nevertheless, the stress tests provided some interesting findings concerning safety:

This study assesses the safety of the nuclear power plants in Bulgaria, Hungary, Romania and the Ukraine. The introduction contains an overview of the content and procedure of the stress tests. This "Critical Review of the Stress Tests" is based on the national stress tests reports written by the national nuclear safety authorities and on the Peer review country reports attached to the Peer review report - Stress tests performed on European nuclear power plants written by the Peer review Teams, the Peer Review Board respectively, and endorsed by ENSREG [ENSREG 2012a, ENSREG 2012c]. It continues by listing the main weaknesses as identified by operators, national regulator and Peer review team and a selected range of the suggested remedial measures. Important shortcomings not mentioned in the stress tests reports are also discussed. These evaluations do not claim to be exhaustive, but the findings contribute to a more comprehensive understanding of safety and risk of nuclear power plants in Europe.[1]

[1] The evaluations are based on the study "Critical Review of the EU Stress Test performed on Nuclear Power Plants" published in May 2012 [WENISCH 2012a].

2 The EU Stress Tests

2.1 Accident Risk

The operation of nuclear power plants is inevitably connected with the residual risk of a major nuclear accident (BDBA, Beyond Design Basis Accident). Absolute nuclear safety does not exist. The expression "a nuclear plant is safe" only means that the level of residual risk is presumed to be "acceptable". Combinations of failure – technical and human – cannot be assessed and excluded in advance. In spite of this, common understanding tends to believe that tests can make nuclear power plants safe. A sound safety assessment can only help to reduce the nuclear risks [RENNEBERG 2011].

2.2 Aims

The EU stress tests were defined as a targeted reassessment of the safety margins of nuclear power plants and developed by ENSREG, including the European Commission, in the light of the events which occurred at the Fukushima Daiichi NPP.

Their aim was to assess whether the safety margins which were used in the licensing of nuclear power plants are sufficient to cover unexpected events. The stress tests were to draw the important lessons from the accident at Fukushima NPP that e.g. two natural disasters can hit at the same time and leave the NPP without any electrical power supply.

An overview of the stress tests is available under:

- http://www.ensreg.eu/EU-Stress-Tests (here all reports are/will be available)
- http://ec.europa.eu/energy/nuclear/safety/stress_tests_en.htm

2.3 Procedure

Definition of scope and modalities

In March 2011, the European Council (following an extraordinary meeting of Ministers, regulators and industry held on March 15) concluded that in the light of the Fukushima accident in Japan, the safety of all EU nuclear plants should be reviewed based on a comprehensive and transparent risk assessment (stress test). ENSREG and the European Commission were invited to develop the scope and modalities of these tests in a coordinated framework with involvement of member states, making use of available expertise, like e.g. WENRA (network of nuclear Regulators). WENRA started working on the scope and methodology – the final WENRA proposal on scope/modalities for the stress tests was submitted to ENSREG May 7, 2011. On May 25, 2011 ENSREG published the scope and modalities for the risk and safety assessments of EU nuclear power plants (NPPs). The document determined the concept, methodology and time schedule.

All EU Member States operating nuclear power plants – plus Lithuania – and some neighbouring countries that have accepted to be part of the process (Ukraine, Switzerland) performed the stress tests on a voluntary basis.

The ***first phase*** of the EU stress tests started in June 2011 – the ***operators*** of the NPPs prepared a ***self-evaluation*** of their plants. According to Annex I of the "Declaration of ENSREG" national regulators initiated this process by sending requirements to the licensees (operators) on June 1, 2011, at the latest. Licensees had to provide a progress report to the regulators by August 15, 2011 and a final report by October 31, 2011.

In the ***second phase*** the ***national authorities reviewed*** the progress and final reports submitted by the operators. The progress report had to be handed over by the regulators to the EU Commission until Sept. 15, 2011 – all final national reports were handed over to the EU Commission by December 31, 2011.

The European Commission presented a progress report to the European Council for the meeting scheduled on December 9, 2011. This Interim report was published on November 24, 2011.

Then the ***third phase*** started: the ***peer review***, which was conducted by experts nominated by the national states to review the national reports. Under the leadership of ENSREG, requirements on content and structure of the reports and the peer reviews were developed. The requirements were agreed at a meeting on October 11, 2011. During the peer review, teams reviewed the national reports in a desktop research. Each country was visited by one expert team.

The technical scope of the peer reviews comprises:

- Compliance of the national reports to the stress test specifications
- Safety improvements should be highlighted
- Suitable standard/best practices of margins to hazard and fault conditions

The peer review process comprised:

- Horizontal = topical reviews as well as
- Vertical = country specific peer reviews
    1. Earthquake, flooding and other external events
    2. Loss of power, loss of UHS and combination of loss of power + loss of Ultimate Heat Sink (UHS)
    3. Severe accident management issues
- As the final step, an ENSREG Summary Report prepared under supervision of peer review Board will be issued.

The results of topical reviews fed the country reviews with inputs, the country reviews provide an opportunity for follow-up discussions on the relevant issues.

The Peer review was completed with a main report that includes final conclusions and recommendations at European level regarding the three topical parts and 17 country reports including country-specific conclusions and recommendations. The report was endorsed and published by ENSREG on April 26, 2012.

The European Commission presented the ENSREG report in June 2012 to the European Council.

The EU Commission did not see the Council mandate for stress tests fulfilled and demanded further testing; six additional plant visits were undertaken, those follow-up reports were published in late October 2012.[2] To implement the stress tests findings, an ***ENSREG action plan*** (published 1 August 2012) has been developed to track implementation of the recommendations. in line with this action plan each national regulator will generate a country-specific action plan and publish it by the end of 2012. In October 2012 ENSREG published a compilation of Peer review recommendations and suggestions to assist the review of national action plans by national regulators [ENSREG 2012b]. Also in October 2012, the European Commission published a "Technical summary on the implementation of comprehensive risk and safety assessments of nuclear power plants in the European Union (Commission Staff Working Document)" [EC 2012]. All reports, including the licensee reports have been made available on the ENSREG website.

2.4 Content

The reassessment of the safety margins of NPPs within the EU stress tests consisted of:

- an evaluation of the response of a nuclear power plant when facing different extreme situations (earthquakes, floods and extreme weather events, and the combination of events). In these extreme situations sequential loss of the lines of defence was assumed in a deterministic approach, the probability of this loss is not taken into account).
- as well as the plant's capabilities to cope with consequences of loss of power including Station Black-out (SBO) and loss of heat removal via Ultimate Heat Sink (UHS). Safety reserves (margins) should also be assessed as well as Severe Accident Management (SAM).

The design basis of many European NPPs was determined many decades ago. Not all operators have reassessed the seismic hazards in compliance with state-of-the-art-methodologies. Any major effects to be expected from an earthquake would be related to the vibrations induced in the Systems, Structure and Components (SSCs). This can cause the lost of safety relevant SSC directly or indirectly (internal flooding due to pipe-breaks or fires due to release of flammable substances). Station Black-out (SBO) cannot be excluded even if the electricity supply has a high redundancy but the switchyard (cables, connections or the switches) are not seismically qualified.

At many NPP sites the **flood threat** has increased in recent decades for several reasons (e.g. climate change and reduction of natural flood plains). But still appropriate safety margins rarely exist. Fukushima highlighted the need for better flood protection. Large, destructive floods are now expected to happen more frequently. The presence of water in many areas of the plant may be a common cause of failure for safety related systems. The dynamic effect of the water can be damaging to the structure and the foundations of the plant. Flooding of a NPP could result in the total loss of electric power and/or loss of heat removal supply and so trigger a severe accident. Flooding may also affect the communication and transport networks around the plant site and can contribute to the dispersion of radioactive material to the environment.

[2] http://www.ensreg.eu/node/520, accessed on November 12 2012

The frequency and the intensity of **extreme weather events** are expected to increase. Changes (e.g. of heavy rainfall) have been observed already. Many design standards of NPPs were based on an understanding of a climate system that is now decades out of date. Thus, the protections of the NPPs are probably not sufficient to prevent disaster. Sometimes, what is being thought to be a "worst case" scenario is not really the worst case. Extreme weather events can aggravate or even initiate an accident.

Total loss of electrical power – **Station Black-out** (SBO) – and loss of **Ultimate Heat Sink** (UHS) scenarios could result in severe accidents. All NPPs need electric power supply, particularly for the instrumentation and safety systems, even when they are shut down. Typically an NPP has three or more transmission line to the electric grid. Natural hazards (e.g. heavy storms, earthquake, flooding) can lead to multiple damage of the transmission lines, and hence to loss of off-site power. Every NPP has Emergency Power Supplies, which are often diesel-driven. These generators provide power to emergency pumps, valves, fans, and other components that are required to prevent core melt. If the Emergency Diesel Generators (EDG) fail, the situation at the plant becomes critical[3].

NPPs also need an **Ultimate Heat Sink** (UHS) to remove heat from the primary cooling circuit and other vital systems necessary to avoid a severe accident. Usually, the Ultimate Heat Sink is a river or the sea. The Ultimate Heat Sink (UHS) removes heat from the (primary) cooling circuit and other vital systems necessary to avoid a severe accident. If the UHS gets lost, fuel damage can occur in the reactor core and/ or Spent Fuel Pool quite rapidly. One important new feature of the stress tests is the evaluation of the so called "cliff edge effects".[4] Of high importance in this context is the time until critical situations, particularly core melt arise.

Severe Accident Management (SAM) to mitigate the consequences of a severe accident, especially regarding Spent Fuel Pools and multi-unit accidents is an issue in all countries. However, the development and implementation of SAM guides, measures, equipment as well as organization and training of personnel is in very different state in the countries. The means for maintaining containment integrity should in particular include prevention of damaging hydrogen explosions (as it happened in Fukushima), and means of addressing long-term containment over-pressurization[5], such as filtered venting.

[3] There are also batteries that supply direct current in case of an emergency; however, the batteries cannot provide electricity for large components such as pumps and have only very limited capacity (few hours).

[4] A cliff edge effect describes a qualitative degradation of the plant's safety conditions (comparable to walking on a cliff and the next step fall down).

[5] When the reactor core has melted through the reactor pressure vessel and residual heat removal has failed, pressure in the containment rises.

2.5 Shortcomings

Limited scope[6]

- Besides natural hazards, other external or internal events can initiate a severe accident, for example an airplane crash, an internal fire, a human failure or combinations of those events.
- Particularly an airplane crash has to be considered as a relevant safety issue, because several plants have reactor buildings that are insufficiently robust to protect the containment and the reactor system against the impact of an airplane. An airplane crash (deliberate or accidental) could cause an accident with a containment failure or bypass and lead to a large and early radioactive emission into the atmosphere. The EC technical document on the stress tests stated that the stress tests have to a considerable extent covered the indirect effects of airplane crashes through the work undertaken on Station Black-out and loss of plant cooling [EC 2012]. But this is not true, because the effects of mechanical impacts and fires are not considered. Furthermore, the EC document conceals that the stress tests reveal that SBO situations mostly rely on perfect functioning of Severe Accident Management. However, they are not often is not implemented or not sufficient.
- The operating European NPPs differ in age and therefore in design. At none of those NPPs, the defence-in-depth concept[7] applied is complying with state-of-the-art requirements. Naturally it is better to try and prevent accidents from happening rather than dealing with the consequences of an accident. In spite of this, the capability of accident prevention was only partly under review in the stress tests. One important issue the stress tests do not review is the quality of systems and components (e.g. material of reactor vessel, pipes and valves).
- Weaknesses of the safety management or the safety culture could also cause faults that trigger or aggravate accident situations.
- Ageing induced degradation effects of safety-related systems and components can significantly aggravate the development of an accident caused by an external event. Ageing related incidents have also the potential to trigger a severe accident. Incidents could also be caused by ageing indirectly: If old components are replaced, new faults because of defective mounting are possible.

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[6] 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 the task to provide a “targeted reassessment of the safety margins of nuclear power plants. One of the reasons of this limitation in the defined scope of the stress tests was the lack of time provided to the ENSREG. This is a reason for the shortcomings the stress tests have compared to the original idea of a “comprehensive and transparent risk and safety assessment”.

[7] The first level of defence provides a safe operation within the defined operational data specifications. The second level of defence serves for those cases when the operational specification data are exceeded. In those cases systems are needed to lead the reactor back into the allowed range of operational limits. If this second level fails and the reactor might get out of control, the most important the third level of defence is needed. This third level of defence consists of safety systems that must be able to shut down the reactor and to cool the fuel. If this third level fails, only the fourth level of defence, which consists mainly of accident management, should prevent a core melt accident with major radioactive releases.

- The stress tests take for granted that all the Structures, Systems and Components (SSC) assessed are in place and in perfect condition and functioning flawlessly, but the operational experience shows that this is not the case in reality.

Lack of criteria

- The stress tests specifications lack the definition of the safety level to be reached to continue plant operation, to make back-fitting necessary or to require shut down. The German Reactor Safety Commission, for example, has defined four levels of robustness in the frame of the German stress test. The basic level is chosen as a level that must be fulfilled by all operating plants. Each of the three levels of robustness defines a specific larger kind of safety-margin.

Involved experts

- Almost none of the experts involved in the stress tests are really "independent". The operators´ reports are the most important basis for the final national report and the assessment of the safety of the plant. For obvious reasons the operators cannot be considered independent: it is in their interest to demonstrate that a plant does not require costly back-fitting measures.
- The nuclear authority published the national stress tests reports. In the past the members of a nuclear authority and their technical support organisations legitimated the operation of the power plants under their supervision and they informed the public that the plants were operating safely. Conducting the stress tests makes them review their own practice and their own statements about safety and about acceptable risks.
- The EU Commission does not have the technical experts necessary to assess the safety of NPPs. The EU 27 nuclear regulators formed ENSREG, who provide technical guidance on nuclear safety. With the exception of the members nominated by countries without commercial nuclear power programmes, the ENSREG peer review teams[8] consisted mostly of employees of the nuclear authorities. It is not common practice or to be expected that colleagues would criticize each other within an official process which is additionally public in some parts.

Peer review process

- The complexity of data, of calculation methods, of assumptions about the safety parameters and their interdependence within the complex system of a NPP is extremely high. Despite the fact that a considerable effort was made, in terms of human and financial resources to analyse the safety of all NPPs of the EU-17 in the short time of about three month, taking into account the immense workload and the limited number of experienced experts able to review the assessments, it was not possible to perform a very well-founded peer review process.

[8] The Peer Review teams were composed of nuclear safety experts from EU Member States, Switzerland, Ukraine and the EU Commission, with observers from third countries (Croatia, Japan USA,) and the IAEA.

2.6 Conclusions

Considering the limited scope of the stress tests, the lack of defined assessment criteria, and the interests of the experts involved, the stress tests cannot confirm or guarantee safety of the plants in the EU or the other two states who fully participated, Switzerland and Ukraine. They will hardly fulfil the political intention, which was to demonstrate to the public that the plants are operating safely.

The outcomes of the stress tests consist only of recommendations for “further improvements”. ENSREG stress tests did not assess the current safety level of the European nuclear power plants, but the potential increase of the safety level in the next decade.

Nevertheless the stress tests revealed a number of shortcomings regarding the plants´ capability to withstand several external hazards and the possible consequences of these events.

Until now ENSREG has not defined or even recommended any time schedule for implementation of the required measures or prioritization of these measures. ENSREG does not have a regulatory mandate. To define, require and monitor the implementation of safety improvements stays in the competence of the national regulatory authorities, who are members of ENSREG.

The most important phase of the stress test will start at the beginning of the year 2013. The national regulators agreed to develop national action plans to remedy the identified shortcomings by the end of 2012. No clarity was achieved yet on the question of how comprehensively the following peer review process will be conducted.

This might be seen as an opportunity to force the nuclear authorities to formulate mandatory requirements, which need to be fulfilled in a rather short time schedule; in contrast to the years or even decades usually applied. This could make operators decide to stop operation for economic reasons and shut down the NPP. In cases when NPPs with out-dated reactor design cannot reach an acceptable safety level and/or the probability of a natural hazard is relatively high, the operation time should be limited and safety upgrading measures implemented in a very strict time schedule. The regulators should not approve lifetime extensions.

Until now, ENSREG does not assess, but only describe the shortcomings of the NPPs. The country stress tests reports do not formulate any overall conclusions – not even if a specific NPP has shortcomings similar to those at Fukushima NPP [ENSREG 2012a]. However, this is insufficient to use as basis for deciding on the future of an NPP. A comprehensive assessment taking into account all facts is necessary for the politicians and the public to decide about the risk for people and environment.

Currently it seems that even the oldest plants with severe deficiencies in the defence-in depth concept will apply for life time extension. The stress tests do not provide sufficient information about the reliability of plant safety measures to prevent postulated failures of the safety systems; a second part is necessary to assess accident prevention capability. The WENRA safety objectives for new reactors can be applied as a minimal safety level for this assessment.

3 Cernavoda NPP (Romania)

In Romania, there is one nuclear power plant (Cernavoda NPP), which is located in Constanta county, about 2 km southeast of the Cernavoda town boundary, at 4 km southeast of Danube River and at about 1.5 km northeast from the first lock on the Danube-Black Sea Channel. Cernavoda NPP is owned and operated by the National Company Nuclearelectrica (Societatea Nationala Nuclearelectrica, SNN) [RNR 2011].

Cernavoda NPP has two pressurised heavy water reactors (PHWR) of CANDU 6 design. These are the only units in Europe based on the CANDU (CANadian Deuterium Uranium) technology. The plant project was initiated in the 1970s and was initially proposed to house five units. Construction began in 1980 on all the reactors, but this was scaled back in the early 1990s to focus on unit 1, which was completed in 1996. The second unit was connected to the grid in August 2007.[9] Unit 1 and 2 (650 MWe net capacity each) generated 10.8 TWh or 19 percent of Romania's electricity in 2011 [SCHNEIDER 2012].

The Romanian Government plans the completion of Cernavoda units 3 and 4. The project was started in 2007 and the works were estimated to start in 2010. But 2010/2011 four of six involved companies[10] withdrew from the project. The project was halted, as the government could not find other partners for the project [SCHNEIDER 2012]. In October 2012, Romania announced that the state is willing to bring the four companies back in the project under any form by the end of the year [RBN 2012].

The Romanian Regulator, the National Commission for Nuclear Activities Control (CNCAN), agreed that any potential design improvements resulting from the stress tests for the operating units will have to be implemented also in units 3 and 4. Their detailed design is not yet finalized [RNR 2011].

3.1 Weaknesses the Romanian Stress Tests Described

The following chapter is based on the information provided by the national stress tests report and the peer review country report of Romania [RNR 2011; RCR 2012].

Romania is one of the most active **earthquake** regions in Europe. Nevertheless, currently there are major shortcomings regarding earthquake:

- The calculation of the original Design Basis Earthquake (DBE) was based only on a deterministic assessment; in 2004 a Probabilistic Seismic Hazard Analysis (PSHA) was performed. However the value for the exceedance probability (return period) associated to the DBE is considerably lower than the current European practices. The value is 1/1,000 per year instead of 1/10,000 per year.

[9] Unit 2 was completed with foreign financial assistance (Canadian loan of US$146 million and a Euratom loan of US$324 million).

[10] CEZ (Czech Republic), RWE (Germany), Iberdrola (Spain) and GDF Suez (French-Belgium group) left, only Enel (Italy) and ArcelorMittal Romania did not withdraw. The Romanian ministry of economy, through Nuclearelectrica got to own 80% of the project company.

- The absence of a seismic level comparable to the SL-1 defined by IAEA[11] leading to plant shutdown and inspection is regarded as being a critical issue taking into account the fact that the probability of large earthquakes is extremely high (recurrence intervals for the Vrancea seismic zone: 50 years for MW > 7.4). The peer review team suggested to the regulator to adopt adequate regulations.
- The peer review team criticized that only little information about margins to cliff edge effects, weak points and plant behavior under beyond design earthquake was provided. The fact, that further improvements in the seismic upgrading have been not been considered was also a point of critic. The peer review team asked for further efforts in this area and recommended that the CNCAN obtains good quality programmes from the licensees and ensures proper follow-up.

The Cernavoda site grate is about two meters higher than the calculated Design Basis Flood DBF). According to the national report, the existing margins are considered as being adequate and no additional measures are required to protect the plant against **external flooding**. However, the peer review team criticized that the margins for flooding have been assessed with limited identification of cliff edge effects and weak points. The peer review team pointed out that for a number of safety significant equipment located underground the protection against flooding needs to be improved. Furthermore, the peer review team criticized the lack of routine inspections of the flood protection design features.

The national report provides limited information about **extreme weather conditions**. The peer review team pointed out, that there is no information about the plant capability beyond the design basis and also no identification of cliff edge effects and weak points. Thus, the plant resistance against extreme weather is still unknown.

Because **Station Black-out (SBO)** was not considered in the design basis of the units, there is no adequate protection against this kind of situations.

- In case of SBO, the dousing tank contains sufficient water for at least 23 hours to prevent core damage. During this time span, the operators have to restore the Emergency Power Supply (EPS) in order to start the Emergency Water Supply (EWS) pumps and ensure a long term heat sink. If the EPS cannot be recovered, the operator would use mobile DGs (autonomy for only 6 hours). If the EWS system is unavailable the fire water trucks would be used to provide water directly to the steam generators (SG) through the EWS pipes, but the location of the fire trucks is not qualified against extreme external events.
- However, in case SBO will be induced by an earthquake, fuel damage could occur after only 4 hours as a consequence of not being able to depressurize the SGs. To avoid this scenario operator action in less than 2 hours are necessary (manual opening of the Main Steam Safety Valves and in addition, in 2.5 to 3 hours, the mobile DGs have to be available to provide electrical power). The licensee is currently undertaking

[11] According to IAEA, for the design basis earthquake (DBE) two levels of ground motion hazard should be evaluated for each plant sited, seismic level 1 (SL-1) and seismic level 2 (SL-2). SL-2 is associated with the most stringent safety requirements, while SL-1 corresponds to a less severe, more probable earthquake level [IAEA 2003].

preparatory work to increase the seismic robustness of the batteries to prolong the coping time.

- In case SBO were to occur at certain points during the refuelling process, two spent fuel bundles would not be adequately cooled. Fuel damage would occur in about 1.4 hours and the fuel starts melting after approx. 1.9 hours. (Fission products are supposedly be retained either within the pressure boundaries of the refuelling machine or in the worst case in the spent fuel discharge room which is part of the containment extension.)

Currently no regulatory requirements are in force on **Severe Accident Management** (SAM), the peer review team pointed out that CNCAN should finalize the incorporation such requirements in the regulation and also incorporate some qualitative or quantitative safety objectives related to the protection of the population.

The stress tests reveal the lack of a filtered venting system, the lack of passive autocatalytic recombiners (PAR) to prevent hydrogen explosions as well as the lack of instrumentation for severe accident (SA) condition (e.g. hydrogen concentration monitoring in different areas of the reactor building). Further necessary actions are planned, among others they include:

- A design modification for water make-up to the calandria vessel (completed for unit 2) and the calandria vault to ensure cooling of the fuel,
- Use of a new, seismically qualified, fire water pipe to allow water makeup without entering in the Spent Fuel Pool (SFP) area,
- A new seismically qualified building to host the on-site Emergency Control Centre fire fighter's facility and main intervention equipment,
- Assessment of the habitability of the main control room (MCR) in the case of a total core melt accident associated to a containment failure (or voluntary venting).

The peer review team noted the good progress in the implementation of SAMGs, associated with a significant number of hardware modifications during a short time period. However, the peer review team highlighted that the licensee has not examined, particularly for plant shutdown states, any possible weaknesses of the Cernavoda units in agreement with the stress test specifications. Furthermore, SAMGs for shutdown states have to be developed (they are under consideration) and the completeness of Emergency Operating Procedures (EOPs) for all accidental situations needs verification. This shows that not all weaknesses the stress tests should reveal are known yet.

3.2 Weaknesses the Romanian Stress Tests Ignored

The design of the units 1 and 2 of Cernavoda NPP shows many shortcomings, among others [HIRSCH 2005; UBA 2007]:

- The core consists of many pressure tubes instead of being confined in a pressure vessel, this design precludes the possibility of massive pressure vessel failure, but the accompanying greater length, surface area and complexity of the primary system piping results in a greater risk of loss-of-coolant accidents. Additionally the possibility for on-load refueling introduces means by which loss-of-coolant can be initiated. The refueling machine is also the major pathway for releases of radioactive “hot particles” – particles that have broken off the fuel or other activated metal particles.

- Material degradation of the pressure tubes is a persisting problem of existing CANDU plants. The pressure tubes are exposed to the neutron flux, with consequent weakening effects. There have been problems with delayed hydride cracking as a result of deuterium-zirconium alloy reactions. Also, pressure tube fretting corrosion appears to be a generic flaw of the CANDU design. This degradation mechanism has been traced back to vibrations of the pressure tubes and could lead to a loss-of-coolant accident. Hydride cracking and fretting were observed at the Cernavoda-1.
- The fuel used is natural uranium (i.e. not enriched), and heavy water serves as coolant and moderator. This combination has seriously negative safety implications. The void coefficient of reactivity is positive, so that any loss-of-coolant accident could lead to a power excursion (sudden rise of power). A loss-of-coolant with shut down failure (scram) will result in rapid melting of the fuel and possibly common mode breach of the containment.
- The large zirconium inventory of the CANDU could react exothermically with steam during a severe accident. This reaction produces hydrogen, which is a threat for the containment stability, because it reacts explosively with air in the containment.
- The reactor building has a pre-stressed concrete structure (diameter 41.46 m with a cylindrical perimeter wall of only 1.07 m thickness). It is seismically qualified, but external threats as natural disasters, airplane crash and other human impacts as terrorism and sabotage are not considered in the design.
- The CANDU 6 reactor has a containment consisting of a concrete dome, which is not designed to withstand worst case accidents, for example hydrogen detonations. Furthermore, the CANDU containment is not a passive system, as most PWRs are equipped with (e.g. ventilation dampers and dousing system need power).
- Spent Fuel Pool (“bay”) is located outside the containment, which could result in a major release of radioactive substances in case of an accident.

Several design weaknesses of the reactor, which the stress tests did cover, cannot be remedied. Not surprisingly the owner of the Canadian CANDU 6 reactor Gentilly-2 (Hydro-Quebec’s) recently decided to close its reactor after the planned operation time of 30 years and explained that the decision was made for financial reasons, because major problems were encountered in comparable refurbishment projects at CANDU 6 reactors[12] and also the Fukushima accident in March 2011 contributed to concerns about lifetime extension [NW 2012a].

3.3 Conclusions

The main findings of the stress tests show that seismic risk, flooding and Severe Accident Management are not sufficiently addressed and the Romanian Regulator seems not to insist on adequate responses.

[12] Point Lepreau PP (Canada) and Wolsong NPP (South Korea)

The protection of the Cernavoda NPP against seismic impacts is inadequate, although earthquakes have to be expected at the site. This is a serious deficit, particularly regarding the fact that for a seismically induced Station Black-out (SBO) a situation occurs, when four hours only need to suffice to prevent a core melt accident. Four hours is not enough time to guarantee that the necessary manual actions can be conducted under the conditions after a severe earthquake. This situation is even aggravated by the fact that appropriate measures to assure containment integrity during a severe accident are lacking; this amounts to a relatively high risk of a core melt accident with major radioactive releases.

On the issue of external flooding the operator missed the opportunity to investigate and if necessary improve the protection as did the regulator. The stress tests revealed that plant resistance against earthquakes is too weak and that flood protection is insufficient.

Regarding Severe Accident Management (SAM), the operator has not examined all possible weaknesses of the Cernavoda units in line with the stress tests specifications, i.e. not all weaknesses the stress tests should examine were assessed. This approach shows that both operator and regulator are not trying to understand the full range of risks and threats to the NPP. This is mirrored by the lack of qualitative or quantitative safety objectives related to the protection for the population in the regulatory requirements.

Units 1 and 2 of the Cernavoda NPP have been operating for only relatively short periods (since 1996 and 2007 respectively), but the reactors were designed in the 1970ies and are outdated. Several design weaknesses of the reactor – original design not being covered by the stress tests in general, cannot be remedied (e.g. wall thickness of reactor building and location of Spent Fuel Pools).

Overall conclusion shows the risk of a severe accident with major release to the environment being unjustifiably high: Cernavoda units 1 and 2 need to stop operation immediately – at least until comprehensive backfitting measures will have been completed.

4 Kozloduy NPP (Bulgaria)

In Bulgaria, there is one nuclear power plant (KOZLODUY NPP), which is located in the north-west of Bulgaria on the right bank of the River Danube, 5 km to the east of the town of Kozloduy and 200 km to the north of Sofia [BNR 2011]. The NPP is operated by Kozloduy NPP-Plc. In 2011, this NPP provided 15.3 TWh or 32.6 percent of the Bulgarian's electricity [SCHNEIDER 2012].

Today, Kozloduy 5 and 6, two WWER-1000/V-320 reactors with a net capacity of 953 MW each are in operation. The first grid connection of these reactors was 1987 (unit 5) and 1991 (unit 6) respectively. Kozloduy NPP previously operated also four older reactors of the WWER-440/V230 design, but under an agreement between the European Commission and the Bulgarian government, units 1 and 2 were taken off-line at the beginning of 2004; units 3 and 4 at the end of 2006 [BNR 2011].

Currently, a feasibility study on a potential seventh unit at Kozloduy NPP is performed by Westinghouse in partnership with the Kozloduy NPP – New Build PLC. This study will encompass a review of two potential designs: a WWER design utilizing equipment already purchased by the customer (for the abandoned Belene project)[13] or a construction of a 1000 – 1200 MW PWR design [NEI 2012a].

The Bulgarian Nuclear Regulatory Authority (BNRA) has published the National stress tests report.

4.1 Weaknesses the Bulgarian Stress Tests Described

The following chapter is based on the information provided on the national report stress tests report and the peer review country report of Bulgaria [BCR 2012; BNR 2011].

The evaluation of the seismic characteristics of the Design Basis Earthquake (DBE)[14], confirmed by IAEA during the period 1992 – 2008, is widely acceptable in comparison with international standards; however adequate paleo-seismological studies are missing. The peer review team recommended performing such studies to evaluate the need of re-assessment of the seismic hazard on site.

A considerable amount of work has been done to protect the units against DBE, but the qualification or replacement of equipment is not completely finished. Important modifications to the plant have been implemented, especially concerning the heat sink and the implementation of an alternative feedwater pump, powered by the mobile Emergency Diesel Generator (EDG). But the peer review revealed that the sheltering structure of the EDG will be probably destroyed in case of earthquake, which could also damage the EDG.

[13] Construction of a reactor at the Belene site began in 1985 but was suspended following the political changes in 1989 and formally stopped in 1992, partly due to concerns about the geological stability of the site. However, in 2004, a call for tender for completion was made and seven companies initially expressed an interest. After Fukushima, the Bulgarian Economy Minister stated that Bulgaria would request additional information and guarantees from the manufacturer. In March 2012, the Prime Minister officially cancelled the project [SCHNEIDER 2012].

[14] recurrence period of 10,000 years, peak ground acceleration (PGA) of 0.2g

The assessment of the impact of potential failures of not seismically qualified Structures, Systems and Components (SSC) showed deficiencies. A complementary action plan including studies and modifications was developed. The action plan suggests delivering two additional mobile generators. The peer review team pointed out that if these mobile generators are supposed to cope with beyond design basis events, they should be adequately protected for such events.

The site is located in the northern part of the first non-flooded terrace of the river Danube and has average height of the site elevation about 2 m above the calculated water level of the **Design Basis Flood** (DBF). There is no risk of flooding the rooms where the safety equipment is installed. Nonetheless the scenarios for beyond Design Basis Flood showed that some locations could be flooded. The peer review team recommended that regulator should monitor the back-fitting measures for beyond design basis conditions identified in the action plan (such as improvement of the leak tightness of certain rooms below ground level and modification of the drain and sewage system).

Extreme weather effects were not sufficiently evaluated, because the operator did not take all possible combinations of extreme weather conditions into consideration. Thus, the regulator BNRA required a review of extreme weather hazards in line with IAEA guidance. The peer review team criticized furthermore the lack of an extreme weather monitoring and alert system with adequate operating procedures.

According to the peer review team, the so-called coping times for most cases of **SBO and UHS situations** are sufficient to implement measures to prevent a severe accident, and if not successful or possible, to implement measures to mitigate the consequences of a severe accident with major radioactive release. However, the peer review team pointed out that several vulnerabilities were identified which require further attention. These are linked to SBO situations and concern the heat removal from the reactor, shortly after shut down (coping time only 7.5 hours) as well as from the Spent Fuel Pool (coping time 17 hours). Envisaged backfitting measures are, among others, the delivery of two new mobile DGs.

The implementation process of the WENRA Reference Levels regarding **Severe Accident Management** (SAM) is under way, but not yet fully completed. Furthermore, the stress tests revealed the need for a lot of additional improvements. The "*Program for Implementation of Recommendations Following the Stress Tests Carried Out on Nuclear Facilities at Kozloduy NPP plc*" covers these measures. Among them:

- Development of technical means for direct water supply to the steam generators (SG), Spent Fuel Pools (SFPs) and the containment using mobile fire equipment;
- Installation of additional hydrogen recombiners in the containment[15];
- Closing the ionizing chamber channels located in the walls of the reactor cavity (see below);
- Study of the options for localizing the molten core in case of a severe accident;

[15] The installed PARs were designed for DBA, but there is no prove they can mitigate hydrogen explosion risks in severe accidents.

- Updating on-site and off-site emergency plans, taking into account that the Emergency Control Rooms (ECR) might be inaccessible; and providing alternative routes for evacuation, transport of fuels and materials and access of staff;
- Implementation of Emergency Operation Procedures (EOPs) for the shutdown states;
- Implementation of Severe Accident Management guidelines (SAMGs);
- Development and implementation of the SAMGs for Spent Fuel Pools (SFPs);
- Installation of instrumentation for monitoring severe accident conditions.

The peer review team pointed out, that it is an open issue under which conditions implementation of the different SAM measures is feasible, e.g. due to possible lack of some hardware provisions. Additionally, the peer review team recommended that the above mentioned program should be monitored and regularly updated to guarantee co-ordination of all activities and their timely completion.

The peer review team assessed the envisaged program the Bulgarian regulator required the operator to implement as being insufficient. The peer review team pointed out that more measures are necessary within the framework of this program, for example:

- Considerations and analyses for mitigation of hydrogen risk; and prevention of basemat melt through (see below) should be pursued with high priority;
- Accidents in Spent Fuel Pools (SFP) should be analysed in detail;
- Simultaneous core melt accidents in both units should be further investigated;
- SAMGs fully covering shutdown states, including those with open reactor, should be developed;
- The issue of the management of large volume of liquid releases in the event of a severe accident should be investigated further.

4.2 Weaknesses the Bulgarian Stress Tests Ignored

Design weaknesses

Important design weaknesses of Kozloduy 5 and 6 are:

- The WWER-1000/V320 is fitted with a full-pressure single containment; however, it has a basic shortcoming not encountered in western PWRs. The lower containment boundary (containment basemat) is not in contact with the ground, but is located at a higher level inside the reactor building. In case of a severe accident, melt-through can occur within approx. 48 hours. The containment atmosphere will then blow down into parts of the reactor building that are not leak-tight resulting in high radioactive releases. The reactor building – including the Main and Emergency Control Rooms – will have to be abandoned [HIRSCH 2005].
- The plant layout has weaknesses that make the redundant safety systems vulnerable to hazardous systems interactions and common-cause failures due to fires or internal floods [HIRSCH 2005].

An analysis performed as part of a European Union pre-accession instrument (PHARE project) Kozloduy 5 and 6 discovered a vulnerability of the design consisting of very early (one-hour) containment melt-through via ionization chamber channels situated around the reactor pit. According to a recently published article [NEI 2012b] a technical solution was developed. However, implementation of the improvements usually takes several years.

INES 2 incident at unit 5 [NIRS 2006]

On March 1, 2006, the function a considerable amount of control rods failed at unit 5. The operator had tried to activate one cluster of regulation rods to reduce the reactor's capacity by 30% after one of its four main cooling pumps became disconnected. Of the six rods in the cluster, three remained in place. In order to shut down the reactor, workers pumped boric acid in. After the reactor was stabilized, the remaining nine clusters were tested by carrying out an emergency shutdown resulting in a total 22 of the 60 regulation rods remaining stuck in the highest position. This means, that in the case of an emergency shutdown with loss of cooling water, it would not have been possible to stop the reactor quickly, which could have led to core meltdown.

This situation occurred after the Russian maintenance company Gidropress made changes to the fuel lay-out during one of the safety upgrades at Kozloduy 5 in the summer of 2005; the upgrade programme was partially funded by Euratom.

Not only the incident itself and the cause of it, but also the handling of the incident raised relevant safety concerns. Following the incident Kozloduy 5 remained off-line for ten days, the incident was rated as INES[16] 0 (“no safety significance”) by the operator. Almost two months later whistleblowers from the NPP leaked the details of the incident to their former chief. He informed the German press, and Bulgaria became aware of the real circumstances behind the incident. The director of the Kozloduy NPP accused the Bulgarian press of being un-patriotic for quoting information on the incident from the German press and showed no understanding of the safety culture, which should be applied an NPP.[17]

The Bulgarian Nuclear Regulation Agency (BNRA) immediately reacted to the revelations by upgrading the incident rating to INES 1 (“abnormally”). However, later the incident was upgraded to INES 2 (“incident”).

Power uprate and lifetime extension

In January 2012, the operator of Kozloduy NPP has notified the Bulgarian Nuclear Regulatory Agency (NRA) about the intended **power uprate** of units 5 and 6 by a combined 120 MWe (gross). According to NRA, the new license could be given to the plant by the end of 2013, provided that all the necessary documents would be supplied in time [WNN 2012a].

Power uprating, which is often combined with life time extension, is an option to increase the profitability of a NPP. Increasing the thermal power of the reactor, usually by increasing coolant temperature, results in the production of more steam. Thus the reactor can produce more electricity via the turbines. An increase of thermal power implies more nuclear fissions and more fission products as a result. Also, higher loads to the reactor systems are

[16] International Nuclear Event Scale
[17] e.g.“Things like this happen every day in the power station”

unavoidable. Safety margins are reduced and at the same time ageing processes are accelerated.

An IAEA report highlighted the negative safety effects of power uprates: Because changing the thermal power affects very high number of systems and analyses, there are numerous “opportunities” to overlook potential problems. Experiences have shown that an increased flow will have an impact on flow-induced vibration in the steam/feedwater lines; non-linear effects might occur. Higher excitation/vibration of steam lines leads to accelerated wear of supporting structures and studs. Higher steam flows can also result in valves not performing as they did before the power uprate. Effects on electrical components may sometimes be neglected or overlooked because of lack of knowledge or incorrect assumptions. The US nuclear power industry, for example, has experienced over 60 events related to power uprates between 1997 and 2010 [IAEA 2011].

All in all, power uprates caused unexpected failures in safety systems that could aggravate accident situations. Power uprates would also accelerate an accident sequence, which could lead to a further decrease of the intervention time (coping times). Furthermore, in case of a severe accident, the potential radioactive release will be higher.

Kozloduy 5 and 6 have been operating for over 20 years; therefore ageing of materials becomes a safety issue. It has to be expected that ageing induced effects will increase in the next years, particularly if lifetime extension for additional 20 years will be approved.

The units are currently licensed to operate until 2017 and 2019, but there are plans to extend their operating **lifetimes** beyond the current 30 years to 50 years. This was initiated in April 2012 when the operator signed a contract with a consortium of Rosenergoatom and EDF to investigate this issue [WNA 2012].

4.3 Conclusions

At units Kozloduy 5 and 6 earthquake protection is insufficient, further assessment and back-fitting is needed. The stress tests also revealed dangerous sloppiness in this field: Emergency Diesel Generators (EDGs) necessary to prevent a core melt accident after a Design Basis Earthquake (DBE) are stored in a not earthquake resistance shelter. Appropriate seismic margins do not exist. The first step of the envisaged back-fitting measure is the delivery of two new mobile diesel generators (DG) which obviously will be stored inadequately as well.

Operator and regulator are not fully responding to the threat of an earthquake or to the (increasing) threat of flooding or the possible negative effects of extreme weather events. To summarize: currently natural hazards, particularly earthquakes can cause a severe accident at both units.

Appropriate Severe Accident Management (SAM) provisions do not exist. Even as a result of the stress tests, a lot of necessary measures are envisaged. According to the peer review team it remains open whether the different measures are feasible. The peer review team also criticizes that the envisaged programme is insufficient. Moreover, the containment of the reactor type (WWER-1000/V320) shows design weaknesses that can be remedied only with great difficulty or not at all.

The incident in 2006 caused by the control rods of unit 5 proves that backfitting measures can result in new safety problems. This is an important issue regarding the need of comprehensive backfitting measures. The incident also proved that in the past the safety culture at Kozloduy NPP was not strong enough; obviously this has not been changed sufficiently as the example of storing the EDGs proves.

Moreover, the operator is planning to uprate the power and to extend the life time of the units. These measures will lead to a further increase of the risk those units pose.

Operation of Kozloduy 5 and 6 should be halted – at least until the necessary protection against earthquakes and Severe Accident Management provisions were implemented. Neither power uprate nor lifetime extension can be performed without causing an unacceptably high nuclear risk. On the contrary: we recommend reducing power output and shutting down the reactors soon.

5 Paks NPP (Hungary)

In Hungary one NPP (Paks NPP) is in operation. It is located 5 km south of the city centre of Paks, 114 km south of Budapest and 1 km west of the River Danube. Paks NPP comprises four units of WWER-440/V-213 reactors. The four units are placed in two building structures in a twin arrangement. The first grid connection of unit 1 and 2 was in 1982, unit 3 and 4 followed in 1984 and 1986 (473 MWe). After modifications being implemented on the secondary circuit in the nineties, and on the primary circuit and on the fuel on the first decade of the century, the net capacity of the four units is 500 MWe each. In 2011, the Paks NPP provided 14.7 TWh or 43.2 percent of Hungary's electricity [HAEA 2011; SCHNEIDER 2012].

Paks NPP is owned and operated by Paks Nuclear Power Plant Ltd, which is a subsidiary company of state-owned Hungarian Power Companies Ltd (*Magyar Villamos Művek*, MVM). The Hungarian Atomic Energy Authority (HAEA) published the national stress tests report [HAEA 2011; SCHNEIDER 2012].

5.1 Weaknesses the Hungarian Stress Tests Described

The following chapter is based on the information the national stress tests report and the peer review country report of Hungary provided [HNR 2011; HCR 2012].

The plant has not been originally designed to withstand **earthquake** loads, but a large number of important reinforcement and qualification measures were implemented, thus the plant complies with the current seismic safety requirements. However during the stress tests, some weaknesses were identified. Additional protection against seismic induced fire and internal flooding as well as upgrading or fixing of Structures, Systems and Components (SSCs) are necessary.

The filter structures of the Essential Service Water System (ESWS) are not seismically resilient, so it is possible that heat removal fail in case of DBE. The regulator required investigations of this issue and a review of the database of the seismic safety classification of components after having come discovered mistakes. A quantitative assessment revealed only narrow seismic safety margins. Therefore measures are necessary to prevent failures of underground line structures and connections due to buildings settlement caused by liquefaction. The peer review team highlighted the importance of the planned measures and recommended the regulator to monitor the implementation.

The level of the Design Basis Flood (DBF) of the Danube River is above the level of the machine room, which houses the Essential Service Water Pumps[18]. Thus, it is necessary to seal the penetrations of the machine room wall. If the ESWS get lost, the function of the EDGs, the Emergency Core Cooling and the Spent Fuel Cooling is jeopardized.

The vulnerability of structures with respect to beyond design basis loads has been assessed and evaluated, however, the National stress tests report does not contain specific information

[18] In emergency situations, the Essential Service Water System (ESWS) supplies Emergency Diesel Generators (EDG), Emergency Core Cooling System (ECCS) and cooling of the Spent Fuel Pool (SFP) with cooling water; however the fire water system can also provide cooling water.

about the numerical values of the safety margins of the **extreme weather conditions** parameters. In this context, the peer review team stated special attention should be paid to the rain drainage system in case of extreme precipitation and snowmelt. Backfitting measures are already identified. The peer review team suggested to the regulator to monitor the implementation of specific measures for strengthening the protection (e.g. against lightning).

The total loss of Electric Power Supply, Station Black-out (SBO) is always connected with the loss of Ultimate Heat Sink (UHS). If the Ultimate Heat Sink (UHS) is unavailable, the secondary feed & bleed via steam generator (SG) may be initiated. In case of SBO occurring during operation at normal power, without any countermeasures the steam generators dry-up within 4.5 hours, the heat removal gets lost and core damage may occur in about 10 hours after the loss of power.

Without electrical power supply the circulation of the cooling water stops in the Spent Fuel Pool (SPF). Boiling could start after 4 hours already; damage to the cladding of the fuel assemblies may start after about 19 hours.

In the case of SBO, mobile severe accident diesel generators are available, but their capability is limited thus it is decided to supply additional, diverse diesel generators to manage accident situations. A lot of further measures have been envisaged, among others:

- The equipment necessary for the cooling water supply to at least one Emergency Diesel Generator (EDG) of each unit from the fire water system have to be available; so as the EDG can be started and operated in case of loss of the essential service water.
- The water make-up to the SFP from an external source has to be made possible by the construction of a supply pipeline having adequate design against external hazards.

According to the peer review team, the deficiencies identified are covered by proposed improvement measures. The peer review team also stated that the proposed possibility of using discharge water canal for water intake of fire water pumps, which could in turn supply Essential Service Water System, might lead to loss of separation. Before the implementation, separation issues should be investigated carefully.

At the time of construction of the Paks NPP no regulatory requirements existed for Beyond Design Basis Accidents (DBDA). The program on development and implementation of hardware measures for **Severe Accident Management** and of SAMGs started before the Fukushima accident. In 2011 it was completed on unit 1, units 2 – 4 will be completed by 2014. HAEA requires that the modifications necessary for the management of severe accidents shall be completed prior to the expiry of the original design lifetime (30 years) for each unit.

The peer review team stated that in general, the stress tests review did not identify major weak points for SAM. This statement is only true compared to the shortcomings discovered at reactors in other countries, particularly Ukraine. The Paks units are not equipped with a filtered containment venting system. HAEA required that suitable measures to prevent over-pressurization of the containment have to be developed and implemented to avoid the release of radioactive material to the environment; this should be realized with filtered venting or additional measures for internal containment cooling. HAEA stated that the envisaged specific long term internal containment cooling that is envisaged by the operator is only considered to be adequate in the case of a successful in vessel retention of the molten core.

Regarding SAM, HAEA requires the operator to conduct following studies and measures in reaction to the stress tests:

- Water supply with (boron concentration) to the SFP from an external source has to be made possible by pipeline having adequate design against external hazards, with additional connection from outside.
- The on-site organization and management of events, especially of multi-unit accidents, including severe damage to the infrastructure has to be improved.
- The SAMGs have to be developed to manage simultaneous accidents in the reactor and Spent Fuel Pool (SFP).
- Analyses have to be carried out in order to avoid hydrogen explosion in the reactor hall during severe accidents that simultaneously affect both units in the common reactor building.
- Liquid radioactive waste management procedures have to be developed for severe accident situations.

5.2 Weaknesses the Hungarian Stress Tests Ignored

Design weaknesses and vulnerability against external hazards

The WWER-440/V213 is a second-generation WWER of Russian design with six primary cooling loops. This reactor type is not equipped with a full-pressure containment. The so-called confinement consists of compartments, which enclose the essential primary circuit components: steam generator, pipelines, pumps, shut off valves and Reactor Pressure Vessel. But the confinement itself does not guarantee to hold back the radioactive steam from large leaks, but needs to condense the steam in the special pressure relief system (Bubbler Condenser). A failure of the relief system can cause the confinement to burst and result in a major emission of radioactive material. In recent years studies on the behaviour during severe accidents were commenced. Safety analyses showed that the confinement and in particular the Bubbler Condenser have very low or even no safety margins under certain conditions [WENISCH 2012a].

The vulnerability of the Paks NPP against external hazards is relative high: The reactor building does not provide sufficient protection against external impacts like airplane crashes or explosions, but houses two reactors. WWER-440 plants are twin units, located in a common reactor building. Furthermore, the Spent Fuel Pool (SFP) is located outside the containment in the reactor building. An airplane crash could cause a severe accident with a large radioactive emission: the worst case could even lead to releases from two cores and molten fuel from two Spent Fuel Pools.

Lifetime extension and power uprate

The original design lifetime of the reactor type (WWER-440/V213) is 30 years, thus the four units of Paks NPP reach the end of their operating lifetimes between 2012 and 2017.

However, a feasibility study on extending the operational lifetimes of the units by 20 years was carried out in 2000 (and updated in 2005). The Hungarian Atomic Energy Authority (HAEA) has approved the lifetime extension program (submitted in November 2008). Additionally, between 2002 and 2009, the thermal capacity of the units were uprated to 108% (1485 MWth), compared to the original value (1375 MWth), resulting in upgrading the electric capacity to 500 MWe. A contract signed in May 2007 with Atomstroyexport relates to this work, in particular: new design fuel assemblies, modernization of the in-core monitoring system, the reconstruction of the primary pressure control system, and the modification of the turbine and the turbine control system [WNA 2012b]. Ageing is an issue at all units of Paks NPP, which are now near the end of their design operation time. In addition, the power uprates accelerate the ageing process. Degradation effects of safety-related systems and components could significantly aggravate the development of an accident or even trigger a severe accident.

Serious incident at Paks 2 (2003)

In April 2003, at Paks 2 a severe damage to a batch of 30 fuel assemblies occurred inside a cleaning tank designed, manufactured and operated by Framatome. The event was rated on the International Nuclear Event Scale (INES) as a “serious incident” (INES Level 3). It resulted in evacuation of the main reactor hall and the venting of radioactivity to the outside environment. The accident was caused by inadequate cooling of the fuel rods during maintenance and cleaning, leading to their overheating and to their damage. The reactor was out of operation for 18 months. According to the Hungarian Atomic Energy Authority (HAEA) problems associated with organization and safety culture contributed to the fuel leakage event. An International Atomic Energy Agency (IAEA) mission requested by the Hungarian government to provide an independent assessment concluded that operator, vendor (Framatome ANP) and regulator shared responsibility for the fuel cleaning incident. On regulatory oversight, the IAEA team said the HAEA underestimated the safety significance of the proposed designs for the fuel cleaning system, which resulted in a less than rigorous assessment than was necessary. On the fuel cleaning operation in the course of the incident, the team found that the contractor worked without proper supervision of Paks personnel, who did not receive adequate safety training for this operation [NEI 2003a, b; SCHNEIDER 2012].

At the beginning of 2007 the Russian company TVEL removed the damaged fuel and the cleaning tank. Fuel debris was put into purpose-built containers. The containers are allowed to be stored in the cooling pond of the reactor; the long term handling of those containers is far from being solved.

5.3 Conclusions

The stress tests for the only NPP in Hungary, with four units at Paks, revealed on the key issues of seismic hazard, flooding and extreme weather conditions and the existing safety margins certain deficits.

While it remains a fact, that Paks NPP underwent comprehensive reinforcement and qualification programs, still upgrading or fixing of Structures, Systems and Components (SSCs) will be necessary in response to the insufficient protection against seismic hazards: the quantitative assessment proved that current safety margins are too small to guarantee sufficient resilience against earthquakes. Further investigations are necessary to assess the situation.

The stress tests found, that extreme precipitation and snowmelt could also jeopardize the units because they could flood parts of the units. The peer review team recommended to commission additional investigations to be able to assess additional back-fitting needs.

Loss of electrical power supply and heat removal triggered by an external hazard during operation of normal power – if countermeasures cannot be taken in time –result in core damage after approx. 10 hours; damage of the fuel in the Spent Fuel Pools starts after about 19 hours.

The EU stress tests devoted gave attention to the question of accidents and how the individual plants are prepared to deal with severe accidents in particular. At Paks the implementation of hardware measures for Severe Accident Management (SAM) and Severe Accident Management Guidelines SAMG had started before the Fukushima accident happened. This program was completed for unit 1 in 2011, and will be completed for units 2 – 4 by 2014. HAEA requires that these modifications will be implemented prior to the expiry of the original design lifetime of 30 years. However as a reaction of the stress tests, regarding SAM, the regulator HAEA requires further studies and measures, especially regarding multi-unit events and Spent Fuel Pools, to remedy deficiencies that the stress tests revealed. The topics to be resolved concern e.g. water supply with boron concentration to the SFP, multi-unit accidents, prevention of hydrogen explosion etc.

A serious deficit of Paks NPP is the fact that the Paks units are not equipped with a filtered containment venting system to mitigate the amount of radioactive emissions caused by long term containment over-pressurization; implementation of these systems is not planned. Instead Paks management intends to introduce internal containment cooling. This measure is only adequate if reliable in-vessel retention can be guaranteed, but this is not completely proven yet.

To remedy all design weaknesses of the outdated second generation reactors (WWER 440/V213) is not possible, in particular wall thickness of the reactor building and location of the Spent Fuel Pool. 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.

At this point it is important to understand that the stress tests did not assess design, siting and the highly safety relevant issue of ageing of all plant components. This will become an increasingly serious issue for all units. All four units are supposed to be in operation for additional 20 years. The combination of design weaknesses, ageing impacts and the recently recognized additional safety hazards revealed by the stress tests show that the Paks NPP life-time extension would pose an irresponsibly high nuclear risk. The four units at Paks should not be licensed for prolonged operation and be shut-down soon instead.

6 Khmelnitsky, Rovno, South Ukrainian and Zaporizka NPP (Ukraine)

In the Ukraine all 15 operating reactors are WWERs (Water-Water Energetic/Pressurized Water Reactors). These reactors provided 84.9 TWh or 47.2 percent of the electricity consumed in the Ukraine in 2011. All units are operated by NNEGC (National Nuclear Energy Generating Company) known as “Energoatom” at four sites (see table 1) [SCHNEIDER 2012; UNR 2011].

The **Khmelnitsky NPP** (KhNPP) with two operating reactors (WWER-1000) is located in Slavuta area of Khmelnitsky region, near a tributary to the Pripyat River. The first unit started operation in late 1987. Construction of units 2 – 4 was halted as part of a moratorium on new plant construction in 1990. However, in August 2004 the construction of unit 2 was completed after the moratorium had been lifted. On 10 February 2011, Energoatom and Atomstroyexport signed a contract for the completion of units 3 and 4, which were 75% and 28% complete, respectively [SCHNEIDER 2012; UNR 2011]. On 26 July, 2012 Ukraine’s cabinet of ministers published its approval of a feasibility study for the completion of construction of the units. The units are expected to be commissioned in 2017 and 2019, respectively [NW 2012b].

The **Rovno NPP** (RNPP) is located in Rovno region on the bank of the river Styr. Four units (two WWERs-440/V213 and two WWERs-1000) are operating at the site. In December 2010, the operating license of Rovno-1 and -2, Ukraine’s oldest operating reactors (30 years), were extended for another 20 years.

The **South Ukrainian NPP** (SUNPP) is located in the south of Ukraine on the river Yuzhny Bug in Nikolayev region, about 350 kilometers south of Kiev. The NPP comprises three WWER-1000 units.

The **Zaporizka NPP** (ZNPP) is situated in the south-eastern part of Ukraine on the bank of Kakhovka reservoir on the Dnieper River. With six operating WWER-1000 units it is the largest NPP in Europe. The first five units were successively brought online between 1985 and 1989, and the sixth was added in 1995 [SCHNEIDER 2012; UNR 2011].

Table 1: Operating reactors in Ukraine (October 2012)

Reactor unit	Reactor Type	Net capacity	First grid connection	Design lifetime (expiry date)
Khmelnitsky 1	WWER-1000/V-320	950	1987	2017
Khmelnitsky 2	WWER-1000/V-320	950	2004	2034
Rivne 1	WWER-440/V-213	381	1980	2010* ext. 2030
Rivne 2	WWER-440/V-213	376	1981	2011* ext 2030
Rivne 3	WWER-1000/V-320	950	1986	2016
Rivne 4	WWER-1000/V-320	950	2004	2034
South Ukrainian	WWER-1000/V-302	950	1982	2012
South Ukrainian	WWER-1000/V-338	950	1985	2015
South Ukrainian	WWER-1000/V-320	950	1989	2019
Zaporizka 1	WWER-1000/V-320	950	1984	2014
Zaporizka 2	WWER-1000/V-320	950	1985	2015
Zaporizka 3	WWER-1000/V-320	950	1986	2016
Zaporizka 4	WWER-1000/V-320	950	1987	2017
Zaporizka 5	WWER-1000/V-320	950	1989	2019
Zaporizka 6	WWER-1000/V-320	950	1995	2025

The stress tests report also included the fifth NPP in Ukraine, the **Chernobyl NPP**. The site is situated in the north of the Kyiv region in the 30 km exclusion zone that was established after the accident at unit 4 in 1986. Units 1 – 3 are under decommissioning, the stress tests did not cover the destroyed unit 4.

It is out of the scope of this study to assess all 15 operating units individually.

The State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) prepared the national stress tests report.

6.1 Weaknesses the Ukrainian Stress Tests Described

The following chapter is summarizing the key information the peer review country report and the national report of Ukraine provided on the nuclear safety in the Ukraine [UNR 2011; UCR 2012].

The peer review team stated that the 'design safety assessment' of Ukrainian NPPs shows that these NPPs are to be compliant with only 172 of 194 requirements of IAEA NS-R-1 'Safety of Nuclear Power Plants: Design'. Issues that were found to be not fully compliant included: equipment qualification, consideration of severe accidents, NPP seismic resistance, completeness of probabilistic and deterministic safety analysis, and post-accident monitoring.

Implementation of necessary improvements is on-going under the recently adopted Upgrade Package (e.g. Comprehensive (Integrated) Safety Improvement Program for Ukrainian NPPs (C(I)SIP)). Scheduled completion of the main improvements is 2012 – 2017. According to the peer review team these non-full compliances represent a significant weakness of Ukrainian NPPs in the context of the stress tests. The peer review team recommended that the national regulator gives priority to achieving or enhancing this schedule. The peer review pointed out that this should include due consideration of the parallel needs arising from envisaged long term operation. Addressing most of these issues forms a part of the licensing basis for lifetime extension.[19]

Measures identified from the lessons of the Fukushima accident and the ENSREG stress tests review have been incorporated into the "*Comprehensive (Integrated) Safety Improvement Program for Ukrainian NPPs" (*C(I)SIP)[20] updated in 2011/2012 by the operator and approved by the regulator.

Re-assessment of the **seismic hazard** has been carried out between 1999 and 2010. The recently accepted design basis of 0.1g (0.12g SUNPP) is in compliance with the IAEA recommendation for the minimum PGA. However, the seismic evaluations for some parts of the equipment, piping, buildings and structures important to safety are not yet completed. Some additional seismic safety upgrading measures are envisaged, but not implemented yet. Furthermore, additional seismic investigations of NPP sites are necessary. A seismic PSA for all NPPs still needs to be developed. Currently, no NPP has a seismic monitoring systems installed.

The peer review team criticized that the regulator confirmed that the robustness of the main equipment and piping essential for safety functions has been proven against design basis seismic impacts while many assessments and investigations still need to be performed. Furthermore, the peer review team pointed out that the National Report the National Report did not provide a satisfactory justification on the sufficiency of overall safety margins.

The peer review team recommended that the regulator should monitor in a systematic way the implementation of the upgrading measures in order to assure timely completion as a part of the (C(I)SIP).

Regarding **external flooding** hazards, the stress tests evaluations did not identify any cliff edge effects yet. But the safety margins evaluation reveals weaknesses for the Zaporizka NPP, which is most likely to be affected by impacts of the combination of upstream dam (Kakhovka Hydroelectric Plant) breaking caused by an earthquake and followed by a flood. Measures against possible flooding of the reactor building have been implemented; however, additional detailed analyses of possible loss of Ultimate Heat Sink (UHS) still need to be performed.

Regarding **extreme weather events**, special attention should be paid for defining vulnerability in case of beyond design basis tornado. Tornado strikes can potentially result in a failure of spray ponds of the Essential Service Water System (ESWS) due to its impact on the open water surface. Loss of ESWS can cause failure of Emergency Power Supply (EPS) from Emergency Diesel Generators (EDGs). The peer review team agreed on the recommendation that the regulator should monitor additional analysis of this threat. The peer review team also pointed out that the issue of power plant staff being able to reach all NPP sites under severe weather conditions needs to be answered. Furthermore safety margins with

[19] Robustness of safety equipment at 0.1g/0.12g, performance of main safety functions in 'harsh' environments, containment venting for WWER-1000, measures to ensure Steam Generator (SG) and Spent Fuel Pool (SFP) make-up under Station Blackout (SBO) and loss of UHS.

[20] Upon results of deterministic and probabilistic safety assessments (within the Safety Analysis Report, SAR) the (C(I)SIP) was developed. On 30 November 2010, the SNRIU and the Ministry of Energy and Coal Industry of Ukraine approved this Program.

respect to extreme wind and extreme snow are not evaluated yet, thus the possible threat of these extreme events is not known.

In case of loss of off-site power, power is supplied from Emergency Diesel Generators (EDG) and batteries. In case of also all EDGs fail, decay heat removal function is not performed. Currently, reliable measures to prevent core damage do not exist.[21] Without operator actions, loss of the primary coolant and uncovering and damage of fuel would result. The minimum time available to prevent core damage after Station Black-out (SBO) and loss of heat removal to the **UHS** occurred without operator actions are (assuming power operation before the initiating event started): only 3.5 – 4 hours for type WWER-1000 and 10 hours for type WWER-440/V-213. The time available until the fuel stored at the Spent Fuel Pool (SFP) heats up and reaches temperatures above the design limits are 6.5 hours for type WWER-1000/V302, V338, 7.5 hours for type WWER-1000/V320 and 16 hours[22] for type WWER-440/V-213.

The operator plans the modernisation of I&C and DC[23] power supply within the C(I)SP, which increases the discharge time of batteries (1 hour to 8 hours) and thus prolong the coping times. The peer review team pointed out that the national regulator should ensure that these measures are implemented on schedule. The operator is investigating to improve makeup possibilities to primary circuit, to the steam generators (SGs) and to the spent fuel ponds (SFP) via so-called Mobile Diesel Generator and Pumping Units (MDGPUs). However, the deployment of the (MDGPUs) requires more detailed analyses. The peer review team highlighted that the regulator should monitor the resolution of this proposal.

Currently, neither Severe Accident Management Guidelines (SAMGs)[24] nor hardware provisions for SAM have been implemented (e.g. for prevention of hydrogen explosions). Work on SAM has been started in 2005 – 2008 and it is now part of the C(I)SIP. These safety upgrades should be implemented to avoid large releases to the environment after core melt and consequent reactor vessel rupture, since existing safety system will not be helpful on the latest phase of the severe accident propagation without support of the dedicated SAM system.

It is the intention of the regulator to accelerate the development and implementation of the Severe Accident Management Guidelines (SAMGs)[25], the implementation of measures to prevent hydrogen (H_2) explosions in the containment and the implementation of a filtered containment venting system (only WWER-1000).

The impact of a severe accident on accessibility of Main and Emergency Control Rooms (MCR and ECR) has not yet been analyzed and may be a relevant cause of a cliff edge effect in the case of evacuation. Also measures for diagnostics in the case of a severe accident have to be developed and implemented.

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[21] It is planned that fire trucks provide make-up water to the steam generators (SG). According to the Peer Review team the time needed to install this mobile equipment could be several hours, especially taking into account degraded conditions.

[22] An independent steam generator additional emergency feedwater system (AEFS) has been introduced at Rivne NPP units 1 and 2 (WWER-440).

[23] I&C = Instrumentation and Control, DC= Direct Current

[24] Furthermore, emergency operation procedures (EOPs) for shutdown states have to be completed.

[25] SAMG are to be put into implementation at Rivne-1 and South Ukrainian-1 by the end of 2012.

The peer review team highlighted the dangerous lack of any SAM provision (i.e. SAMGs equipment qualification in severe accident conditions and hardware provisions). Because of the possibility of cliff-edge effects in the case of a severe accident, the team insisted that the implementation of the envisaged SAM provisions is given high priority. But the SAM provisions planned by Ukraine are far from being sufficient. Thus, the peer review team sees the need for much higher efforts to be undertaken; the schedule for hardware and procedures implementations should stay under strict control of the regulator:

- A strategy and program for the qualification of equipment needed in severe accident conditions should be implemented.
- Further analysis of accidents regarding Spent Fuel Pools (SFPs) is necessary.
- The robustness of the means to cool the SFP after core melt should be improved.
- The risk induced simultaneously by reactor and SFP in case of a severe accident should be assessed.
- The habitability of the Main and Emergency Control Rooms (MCRs and ECRs) in case of a severe accident should be further investigated.
- Protection of population with regard to the SAM provisions should be considered.
- The feasibility of immediate actions required to avoid core melt, to prevent large release, and to avoid site evacuation for a disaster affecting more than one unit at site should be verified in detail.
- Enhanced seismic capabilities for the building hosting the crisis center should be assessed.

This long list of additional measures and investigations proves that the operator and not even the regulator take the danger of a severe accident seriously into account.

6.2 Weaknesses the Ukrainian Stress Tests Ignored

Design weaknesses and safety upgrade programmes

According to the date of design, the operating units in Ukraine belong to second (1970ties) and third (1980ties) generation of Russian reactors[26]: Second generation units are SUNPP 1,2 (WWER-1000/V-302, V-338) and RNPP 1,2 (WWER-440/V-213); third generation units are ZNPP 1-6; SUNPP 3; RNPP-3,4; KhNPP-1,2 (WWER-1000/V-320). The safety design of nuclear power plants is crucial for preventing as well as dealing with incidents or accidents, but is not part of the stress tests. The safety design of all Ukrainian reactors is outdated and show deficiencies (see chapter 4.2 and 5.2)

Under the framework of joint **EC-IAEA-Ukraine projects** a design evaluation was carried out to conduct an overall evaluation of the compliance of the design of each of the Ukrainian NPPs with the IAEA Safety Standards. The Design Safety evaluation was based on the IAEA document "*Safety of Nuclear Power Plants: Design*" (NS-R-1) published in 2000 [IAEA 2000]. Ukrainian NPPs non-compliant with 22 of these requirements (194).

[26] The first generation (WWER-440/230) reactors have been declared as "non upgradeable" or high risk reactors by the European Union and the G7. They must be closed in all new EU member states.

Meanwhile, this IAEA document is outdated; IAEA published new safety requirements in January 2012 [IAEA 2012].

During the last decade, the European Commission, the EBRD, Euratom and the IAEA supported the safety analysis of WWER reactors and provided significant funds to enhance the safety of these plants.

In 2002, the first safety upgrade program started. It was based on IAEA Issues Books[27] containing safety issues ranked into categories. While implementation of 389 measures was planned for completions between 2002 and 2005, only 35% of these measures were implemented during this period. The content of the second program (2006 – 2010) was supposed to complete the safety measures from the former program and to adopt the new requirements formulated by international organizations (IAEA and WENRA) - the Ukrainian nuclear authority SNRIU. The implementation required a substantial time and money; however backfitting measures were not completed when the second project finished in 2010. Only 80% of 253 the pilot[28] measures and 37 % of 472 adopted measures were implemented [BOZHKOA2009; WENISCH 2009b].

Taking into account the results of implementation of safety upgrade and modernization programs, outcomes from joint IAEA-EU-Ukraine project and strengthening national regulatory requirements, United Safety Upgrade Program (2010 – 2017) has been developed [BOZKOA 2009].

Currently the EBRD is preparing a loan for safety upgrades only, at all 15 operating reactors "to bring them in line with internationally accepted safety standards and the Ukrainian requirements." The project includes measures to replace equipment in safety relevant systems, such as the modernisation of monitoring and control equipment. The EC has provided assistance to the Ukrainian nuclear regulatory authority in the review of the proposed upgrade programme. According to EBRD, the project will also allow, as part of the loan requirements, to engage with the authorities to ensure that the results of the stress tests are implemented at all units. EBRD pointed out that the project is a key milestone to the further integration of Ukraine into the EU and is a requirement for the energy cooperation between EU and Ukraine. The long-term sovereign loan up to EUR 300 million to Energoatom is expected to be granted in parallel with a similar loan, also to part-finance the Project via the Euratom loan facility. Total project costs are 1.45 billion EUR. The project passed the final review; the EBRD board approval is pending. The decision is expected to be taken on 18th December 2012 [EBRD 2012].

A recently published report discussed this "Ukraine NPP Safety Upgrade Program" (SUP), within the framework of the loan applications to the EBRD and EURATOM [WENISCH 2012b]. Proponent of the SUP, the Ukrainian state nuclear operator, Energoatom, claims that SUP measures will address only safety measures and are not a precondition for the lifetime extension of reactors. According to the above mentioned report this claim is misleading: SUP measures will be used to provide a sufficient safety level to extend operations. The other

[27] IAEA-EBP-WWER_03, IAEA-EBP-WWER_05 and IAEA-EBP-WWER_14

[28] Khmelnitsky 2, (WWER-1000/320), Rivne 1 (WWER-440/213), South Ukrainian 1 (WWER-1000 small series) were selected for the first reviews on the basis of being representative of the three types of reactors operating in Ukraine.

major point of critique is that European institutions intend to finance this major, high-risk project without the public in EU member states being informed. One year after the Fukushima accident, the European public would welcome information about the lifetime extension of NPPs that are already in operation for three decades [WENISCH 2012b].

An important issue for SUP for RNPP 1/2 (WWER 440/V 213), is e.g. the modernization of the fire alarm system and the improvement of the fire extinguishing system, which are ongoing. Fire was the most important internal hazard for RNPP 1/2 according to [IAEA 1999]. However, not all deficiencies in this field were eliminated by 2011 [WENISCH 2012b].

For WWER 1000 reactors, measures to prevent cold overpressure in primary circuit and the "Leak before Break" concept are currently being implemented. Also ongoing is the assessment of the Reactor Pressure Vessel (RPV) as well as the improvement of RPV joints and connections. The RPV is exposed to heavy loads (tension, neutron flux, temperature, pressure); in particular changes of these loads contribute to material fatigue. After 30 years these effects are likely to be substantial. Also the modernization of several monitoring systems is ongoing. They concern neutron flux, emergency protection, core control and protection system including control rod drives and position indicators. Strengthening the electrical power supply is an important issue for all WWER 1000 reactors. For example, the replacement or modernization of accumulators, switches and relays are required. This area is in need of enormous efforts to achieve an acceptable standard concerning separation, redundancy and diversity [WENISCH 2012b].

Lifetime extension

Original design lifetime of the Russian reactor types that were operator in Ukraine is 30 years. The first units in Ukraine that have reached their original 30 year lifetime of operation were Rivne NPP-1 and -2 both WWER 440/V213 units. Relevant safety relevant issues from 1999 are not completely solved for RNPP-1, 2. In spite of this, a 20-year extension of the operating licenses for RNPP-1, 2 the State Nuclear Regulatory Committee (SNRC) of Ukraine granted a life time extension in December 2010.

Energoatom stated that these units are pilot facilities and that lifetime of all reactors is planned to be extended in a similar way. In mid 2011 (after the Fukushima accident), the Ukraine Energy Strategy to 2030 was updated. The strategy emphasizes the role of nuclear power in the electricity sector while improving safety. In mid 2012, Energoatom announced that the eleven oldest WWER-1000 reactors are to receive 20-year life extensions by 2030. Additional 5 to 7 GWe of new nuclear capacity is to be realized by 2030 [WNA 2012a].

Unit 1 of the South Ukrainian NPP is the next candidate for lifetime extension. The original operational lifetime of SUNPP 1 ends on the 31 December 2012. For this reactor type, the V302 and V338 models (SUNPP 1/2), which are earlier models of the WWER-1000/320 [WENISCH 2012b], the relevant safety document [IAEA 1999] emphasizes the relevance of physical separation for safety systems.

6.3 Conclusions

In general the stress tests for Ukraine showed that after decades of safety programs, Ukrainian reactors remain to be exceptionally high risk nuclear power plants. The strategy of continuous upgrading programs did not prove successful and did not deliver the promised results.

The implementation of the stress tests results should not follow this example from the past: For assessing the safety risk of the current safety level is decisive, not the safety level the plants could have reached in 2017. This is true for all NPPs in the world, but particularly for the Ukrainian NPPs, because the experience shows that back fitting measures are severely delayed. During the last improvement programmes only about 40% of the planned measures were implemented. It seems that despite of permanent safety upgrade programs the gap between the required safety level and the envisaged safety level keep growing. It cannot be expected that the Ukrainian NPP reach the safety level of comparable NPP in the EU in the foreseeable future.

The stress tests showed that today at Ukrainian NPP neither Severe Accident Management Guidelines (SAMGs)[29] nor hardware provisions for SAM have been implemented. SAM are designed to avoid large releases to the environment after core melt. Furthermore, the impact of a severe accident could result in the inaccessibility of the control rooms and measures for diagnostics under severe accident condition are lacking. This is a serious issue and cannot be solved quickly.

The peer review team highlighted that the implementation of the envisaged SAM provisions must have a high level of priority; before that however a wide range of further measures and investigations needs to be started and completed; a long list of additional measures and investigations was identified by the peer review team. This very serious situation highlights one more time that both operator and regulator do not adequately respond to the danger of a severe accident.

Seismicity at the NPP sites is another issue the Ukrainian side does not devote the necessary attention to. The stress tests peer review found that the protection against seismic hazards has of several weaknesses. Again, additional seismic measures are envisaged, but not implemented yet. Seismic monitoring systems are not installed. But also after implementing the envisaged back-fitting measures the protection against earthquake probably is not sufficient, because additional seismic investigations are necessary. A seismic PSA for all NPPs still needs to be developed. At other NPP the re-assessment of the seismic hazards in almost all cases showed the protection level needed to be improved.

Regarding external flooding, the safety margins evaluation reveals weaknesses for the Zaporizka NPP. Measures against possible flooding of the reactor building have been implemented; however, additional detailed analyses of possible loss of Ultimate Heat Sink (UHS) still need to be performed.

Beyond design basis tornadoes can potentially cause failure of Emergency Power Supply additional analysis are necessary. Furthermore safety margins with respect to extreme wind and extreme snow are not evaluated yet, thus the possible threat of these extreme events is not

[29] Furthermore, emergency operation procedures (EOPs) for shutdown states have to be completed.

known. According to the peer review team currently it is not possible to prove that staff can reach all NPP sites under severe weather conditions.

The bigger picture shows that this might lead to very dangerous situations: In case of loss of all power supply (SBO) reliable measures to prevent core damage do not exist.[30] The time span to prevent core damage after Station Black-out (SBO) and loss of heat removal to the UHS without operator actions are only 3.5 – 4 hours for type WWER-1000 units and 10 hours for type WWER-440/V-213 units. The time span until the fuel stored at the Spent Fuel Pool (SFP) heats up and reaches temperatures above the design limits are 6.5 - 7.5 hours (WWER-1000) and 16 hours (WWER-440) respectively.

Ageing is an increasingly serious issue at the Ukrainian NPPs (with the exception of KNPP-2 and RNPP-4), table 1 offers an overview over the operational lifetimes of the reactor fleet. This is only one issue contributing to the irresponsibly high operational risk. A look at the operator´s safety culture and the situation of the regulator does not give much hope that safety could improve in the foreseeable future.

The peer review team also pointed to one of the problems, which are characteristic of nuclear safety in the Ukraine when it recommended that the regulator should monitor in a systematic way the implementation of the upgrading measures in order to assure timely completion as a part of the (C(I)SIP). One key result of this study is that the Ukrainian side constantly has been engaging in safety upgrade programs without completing them. ENSREG (European Nuclear Safety Regulators Group) draw the very same conclusion and formulated a warning by stating that "So far no comprehensive modernization program in Ukraine (except for Khmelnitsky2/Rovno4 was completely solved, but in most cases replaced by new ones before all measures were implemented;" [31]

Currently this is happening again. The Nuclear Regulatory office requested safety upgrades for the South Ukrainian unit 1 to be implemented until the end of 2012 as a precondition of granting an operational license: the required measures were again not fully implemented cannot be completed during December any more.

However, in spite of lack of safety culture and reliable management of safety programs, the operator Energoatom with the support of the government of Ukraine is preparing life time extensions for all its reactors. The stress tests result confirms one more time, that the status of nuclear safety of the Ukrainian nuclear power plants is significantly lower than in EU countries. The very unreliable implementation of safety measures even when they were agreed upon by all sides and are part of an international program is not a viable basis for life time extensions.

Instead of an unlimited and undirected continuation of the NPP the Ukraine needs to receive support for implementing nuclear safety programs with strict deadlines on selected NPP which will continue operating for a clearly limited time after a sensible shut-down program was established and the most dangerous NPP are shut-down one by one.

[30] Furthermore, Emergency Operation Procedures (EOPs) for shutdown states have to be completed.

[31] Technical Opinion of ENSREG, Final report of the EC-IAEA-Ukraine Joint Project: "Safety Evaluation of Ukrainian Nuclear Power Plants", 20 Feb 2012

7 Potential Impacts of Severe Nuclear Accidents

The first chapters explained the EU stress tests results for the nuclear power plants in Bulgaria, Hungary, Romania and the Ukraine. Chapter 7 assesses the potential impacts of severe accidents of these NPPs. The accident results were taken from flexRISK project (Flexible tools for assessment of nuclear risk in Europe).

The flexRISK project modelled the geographical distribution of severe accident risk arising from nuclear facilities, in particular nuclear power plants in Europe. Using source terms and accident frequencies as input, for about 1,000 meteorological situations the large-scale dispersion of radionuclides in the atmosphere was simulated.

For each reactor an accident scenario with a large release of nuclear material – usually rather unlikely – was selected. To determine the possible radioactive release for the chosen accident scenarios the specific known characteristics of each nuclear installation were taken in consideration.

The figures provided by the operators come from Probabilistic Safety Analyses (PSA), which however are not always based on comparable assumptions: some consider only accidents caused by failure of nuclear power plant components, the ageing of materials is difficult to include, others take accidents caused by external triggers into consideration (flooding, earthquakes, plane crash,...). Human failure is especially hard to quantify. The estimated frequencies of severe accidents are therefore afflicted with high uncertainties (factor of 10 and more).

The accident scenarios for the dispersion calculation are core melt accidents and containment bypass or containment failure; the release rates are in the range of 20 to 65% of the core inventory of caesium.

The dispersion of radioactive clouds as a consequence of serious accidents in nuclear facilities in Europe and neighbouring countries is calculated for selected accidents with varying weather conditions.

Using the Lagrangian particle model FLEXPART both radionuclide concentrations in the air and their deposition on the ground were calculated and visualised in graphs. The total cesium-137 deposition per square-meter is used as the contamination indicator.

The following pages show the results which were calculated for one unit of each of NPP site. More results also for other NPP can be found on the FlexRISK website [FLEX 2012].

Explanation of the legend used here: After the Chernobyl accident in the Soviet Union the following contamination limits were used:

- 37 – 185 kBq/m² (3.7E+04 – 1.85E+05 Bq/m²) was defined as a contaminated area; radiation monitoring was carried out in this area (estimated dose < 1 Sv/a)
- 185 – 555 kBq/m² (1.85E+05 – 5.55E+05 Bq/m²) people were allowed to leave the region (estimated dose 1 – 5 mSv/a)
- 555 – 1480 kBq/m² (5.55E+05 – 1.48E+06 Bq/m²) relocation at a later time (estimated dose > 5 mSv/a)
- > 1480 kBq/m² (1.48E+06 Bq/m²) immediate evacuation (estimated dose > 5 mSv/a)

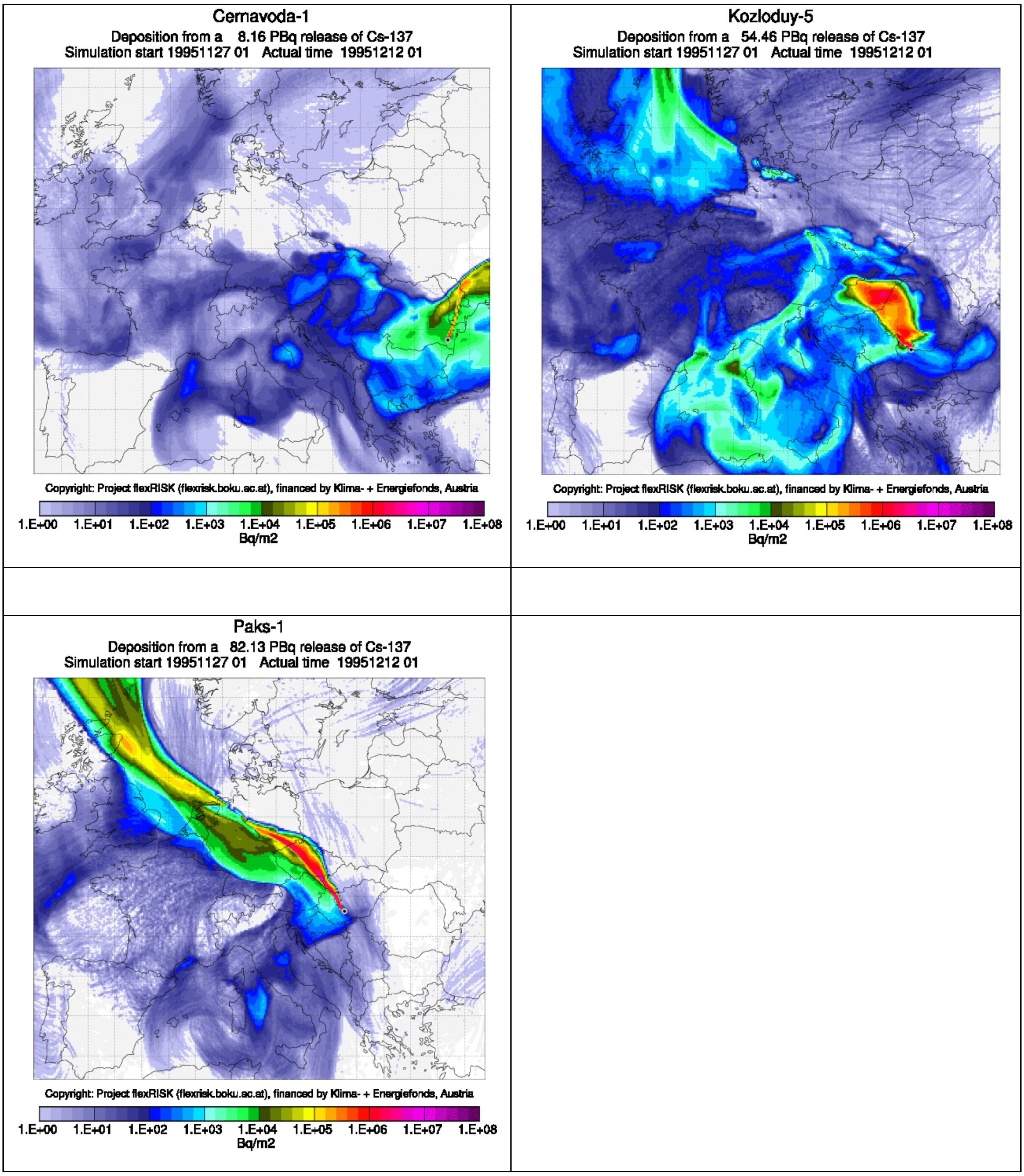

Figure 1: Caesium-137 deposition after a severe accident at Cernavoda NPP unit 1; Kozloduy NPP unit 5; or Paks NPP unit 1 [FLEX 2012]

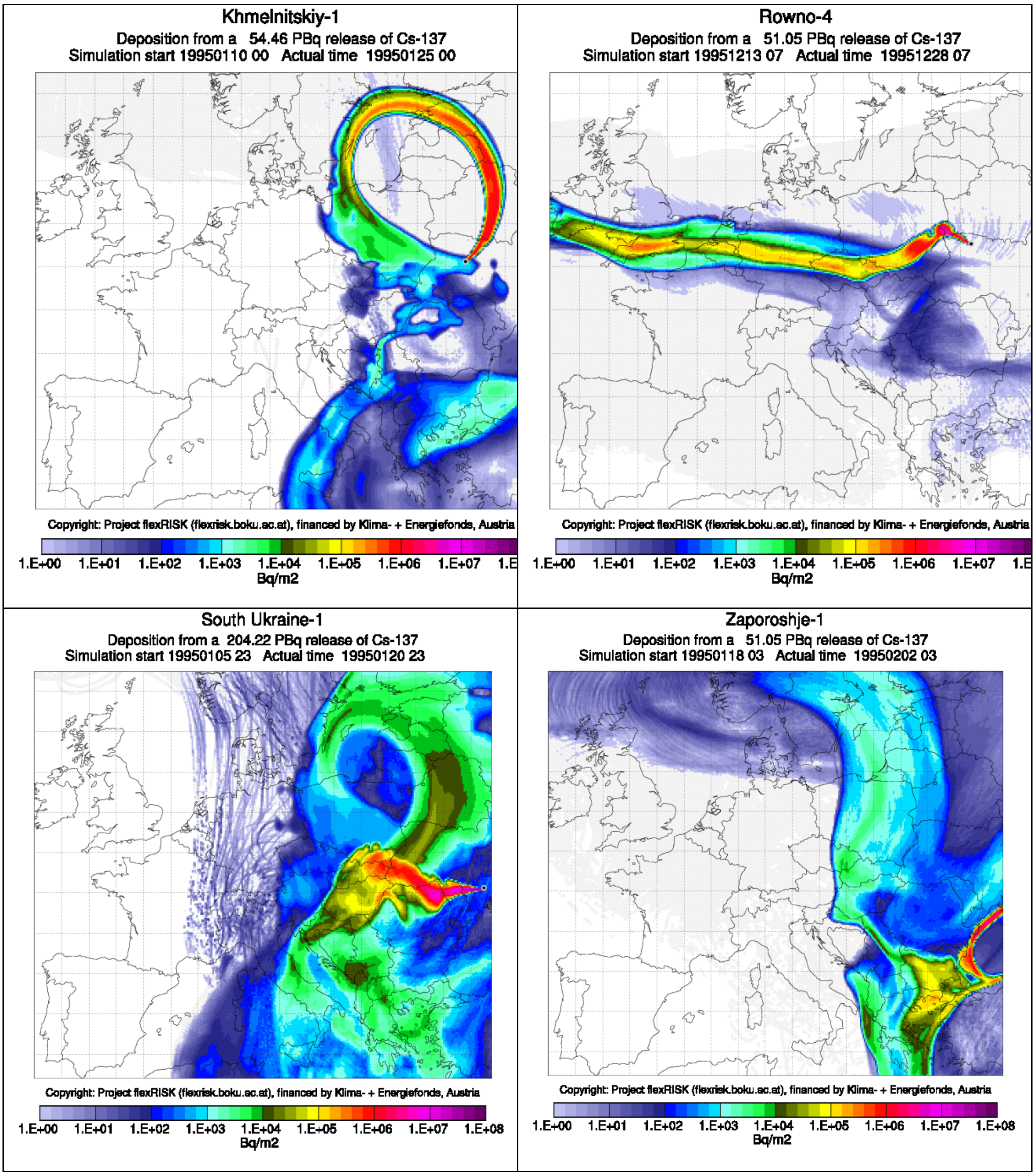

Figure 2: Caesium-137 deposition after a severe accident at Ukrainian NPPs [FLEX 2012]

8 Conclusions and Recommendations

8.1 General Conclusions and Recommendations

The stress tests cannot be understood as a „safety label“ awarded to NPP in Europe. Too many factors were not taken into account - most importantly design, siting and ageing. The study at hand points out those design weaknesses, e.g. wall thicknesses, location of Spent Fuel Pool outside the containment, which cannot be remedied.

The next step in the EU stress tests is the presentation of the National Action Plans. They also will be subjected to the EU peer review. Clearly, those plans need to contain measures which are defined on a technical level; information should be provided also on the intended safety level and the costs of the measures. The ENSREG peer review hopefully will insist on including more measures than the National Regulators suggested; e.g. the Ukrainian regulator suggested significantly less safety measures than the peer review did.

A very strict timetable needs to be agreed upon and monitored by the National Regulator. We strongly recommend conducting the whole process starting with setting up the plan, actual implementation of the measures as well as follow-up in a fully transparent manner and open to public control, including independent experts who have no links to nuclear industry as well as members of civil society and NGOs. Transparency is one important tool to control nuclear risk; while ENSREG certainly recognizes this fact, not all national nuclear regulators and operators act accordingly to fulfil this need of higher transparency.

This study but also the EU Communication (EC COM 2012) on the stress tests concluded that a general lack of safety culture exists in most countries. In combination with ageing as a high risk factor and the higher awareness of risk, this study arrives at the conclusion that power uprate and particularly lifetime extension cannot be conducted without increasing nuclear risk to an irresponsible level.The IAEA safety system as such cannot guarantee safety, which has been clear. What came as a surprise, that in-spite of high numbers of IAEA missions, many National Regulators were confronted with stress test results showing that IAEA recommendations were not fully implemented, while the operators and regulators constantly informed the public about successful missions proving the best safety practices. The EU Communication on the stress tests made a remark showing severe deficiencies: “Following the accidents at Three Mile Island and Chernobyl, urgent measures to protect nuclear plants were agreed. The stress tests demonstrated that even today, decades later, their implementation is still pending in some Member States.” [EC COM 2012]

8.2 Conclusions and Recommendations by Country

Bulgaria

At units Kozloduy 5 and 6 earthquake protection is insufficient, further assessment and back-fitting is needed. The stress tests also revealed dangerous sloppiness in this field: Emergency Diesel Generators (EDGs) necessary to prevent a core melt accident after a Design Basis Earthquake (DBE) are stored in a not earthquake resistance shelter. Appropriate seismic margins do not exist. The first step of the envisaged back-fitting measure is the delivery of two new mobile diesel generators (DG) which obviously will be stored inadequately as well.

Operator and regulator are not fully responding to the threat of an earthquake or to the (increasing) threat of flooding or the possible negative effects of extreme weather events. To summarize: currently natural hazards, particularly earthquakes can cause a severe accident at both units.

Appropriate Severe Accident Management (SAM) provisions do not exist. Even as a result of the stress tests, a lot of necessary measures are envisaged. According to the peer review team it remains open whether the different measures are feasible. The peer review team also criticizes that the envisaged programme is insufficient. Moreover, the containment of the reactor type (WWER-1000/V320) shows design weaknesses that can be remedied only with great difficulty or not at all.

Operation of Kozloduy 5 and 6 should be halted – at least until the necessary protection against earthquakes and Severe Accident Management provisions were implemented. Neither power uprate nor lifetime extension can be performed without causing an unacceptably high nuclear risk. On the contrary: we recommend reducing power output and shutting down the reactors soon.

Hungary

The WWER-440/V213 like Paks, a second-generation WWER of Russian design, is not equipped with a full-pressure containment; they have a so-called confinement and Bubbler Condenser. Safety analyses showed that the confinement and in particular the Bubbler Condenser have very low or no safety margins under certain conditions.

The vulnerability of the Paks NPP against external hazards is relative high: The reactor building does not provide sufficient protection against external impacts like airplane crashes or explosions, but houses two reactors. (WWER-440 plants are twin units, located in a common reactor building.) Furthermore, the Spent Fuel Pool (SFP) is located outside the containment in the reactor building. An airplane crash could cause a severe accident with large radioactive emissions. An airplane crash can cause a severe accident with a large radioactive emission: the worst case could even lead to releases from two cores and two Spent Fuel Pools.

The plant should not undergo life-time extension and be shut-down soon: 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. In addition ageing will become an increasingly serious issue for all units especially in case of lifetime extension.

Romania

The main findings of the stress tests show that the safety level concerning seismic risk, flooding and Severe Accident Management are in-sufficient and the Romanian Regulator seems not to insist on adequate responses.

The protection of the Cernavoda NPP against seismic impacts is inadequate, although earthquakes have to be expected at the site. This is a serious deficit, particularly regarding the fact that for a seismically induced Station Black-out (SBO) a situation occurs, when four hours only need to suffice to prevent a core melt accident. Four hours is not enough time to guarantee that the necessary manual actions can be conducted under the conditions after a severe earthquake. This situation is even aggravated by the fact that appropriate measures to assure containment integrity during a severe accident are lacking; this amounts to a relatively high risk of a core melt accident with major radioactive releases.

Overall conclusion shows the risk of a severe accident with major release to the environment being unjustifiably high: Cernavoda units 1 and 2 need to stop operation immediately – at least until comprehensive back-fitting measures will have been completed.

While in Bulgaria, Hungary and Ukraine the dependence on nuclear energy is high, Romania should profit from its advantage of a much lower nuclear power share and take the direction of phasing-out. Because in an economic perspective and the long-term energy supply investing in other capacities of energy generation like wind, solar and small water power as energy of the future will have higher benefits than back-fitting the units 1 and 2 and the considered completion of unit 3 and 4.

Ukraine

In general the stress tests for Ukraine showed that after decades of safety programs, Ukrainian reactors remain to be exceptionally high risk nuclear power plants. The strategy of continuous upgrading programs did not prove successful and did not deliver the promised results.

The implementation of the stress tests results should not follow this example from the past: For assessing the safety risk of the current safety level is decisive, not the safety level the plants could have reached in 2017. This is true for all NPPs in the world, but particularly for the Ukrainian NPPs, because the experience shows that back fitting measures are severely delayed. During the last improvement programs only about 40% of the planned measures were implemented. It seems that despite of permanent safety upgrade programs the gap between the required safety level and the envisaged safety level keep growing. It cannot be expected that the Ukrainian NPP reach the safety level of comparable NPP in the EU in the foreseeable future. The stress tests showed that today at Ukrainian NPP neither Severe Accident Management Guidelines (SAMGs) nor hardware provisions for SAM have been implemented.

The bigger picture shows that this might lead to very dangerous situations: In case of loss of all power supply (SBO) reliable measures to prevent core damage do not exist. The time span to prevent core damage after Station Black-out (SBO) and loss of heat removal to the UHS without operator actions are only 3.5 – 4 hours for type WWER-1000 units and 10 hours for type WWER-440/V-213 units. The time span until the fuel stored at the Spent Fuel Pool (SFP) heats up and reaches temperatures above the design limits are 6.5 - 7.5 hours (WWER-1000) and 16 hours (WWER-440) respectively.

Ageing is an increasingly serious issue at the Ukrainian NPPs (with the exception of KNPP-2 and RNPP-4). Table 1 offers an overview over the operational lifetimes of the reactor fleet. This is only one issue contributing to the irresponsibly high operational risk. A look at the operator´s safety culture and the situation of the regulator does not give much hope that safety could improve in the foreseeable future.

The peer review team also pointed to one of the problems, which are characteristic of nuclear safety in the Ukraine when it recommended that the regulator should monitor in a systematic way the implementation of the upgrading measures in order to assure timely completion as a part of the (C(I)SIP). One key result of this study is that the Ukrainian side constantly has been engaging in safety upgrade programs without completing them. ENSREG (European Nuclear Safety Regulators Group) draw the very same conclusion and formulated a warning by stating that "So far no comprehensive modernization program in Ukraine (except for Khmelnitsky2/Rovno4 was completely solved, but in most cases replaced by new ones before all measures were implemented;" [32]

Instead of an unlimited and undirected continuation of operation of the NPP the Ukraine needs to receive support for implementing nuclear safety programs with strict deadlines on selected NPP which will continue operating for a clearly limited time after a sensible shut-down program was established and the most dangerous NPP are shut-down one by one.

[32] Technical Opinion of ENSREG, Final report of the EC-IAEA-Ukraine Joint Project: "Safety Evaluation of Ukrainian Nuclear Power Plants", 20 Feb 2012

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