Critical Review of the Swedish Stress Tests Report

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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 incidents cannot be excluded. Contrary to accepted practice Probabilistic Safety Assessments (PSA) do not constitute a sufficient basis to declare a plant operation safe. Safety of NPPs needs to be backed by deterministic assessments, which excludes initiating events and accident scenarios only if they are proven to be physically impossible.

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 this task.

In particular, they should examine the consequences of natural hazards (earthquakes, floods and extreme weather events, and the combination of events). The EU stress tests should analyse the plant’s capabilities to cope with consequences of loss of power including station black-out and loss of ultimate heat sink[1]. Safety reserves (margins) should also be assessed as well as severe accident management.

However, the tests were limited in scope: important safety issues such as ageing or safety culture/management have not been taken into account. The tests were introduced to improve confidence in the safety of European NPPs.

Best possible outcome of the stress tests could be recommendations of improvements for water and power supply in emergency situations. ENSREG has no regulatory mandate. However, the implementation of safety improvements can be ordered by the national regulatory authorities, who are members of ENSREG.

The first phase of the EU stress tests started in June 2011, when the operators of the NPPs prepared the self-evaluation of their plants. This was followed by the second phase, when the national authorities reviewed the reports submitted by the operators. The Swedish stress tests report was published by the Swedish Radiation Safety Authority (SSM) [SSM 2011]. All national reports were handed over to the EU Commission by December 31, 2011 and the next part started: The peer review, which conducts the review of the three topical parts (Initiating Events, Loss of Safety Functions and Severe Accident Management) in parallel. The results of this peer review were published in a country stress tests report for each country.

The following chapter presents a review of the Swedish NPPs based on national stress tests report as well as on the country stress tests report [ENSREG 2012]. The review details the main weaknesses identified by operators, national regulator and peer review team. Some of the suggested remedial measures are also listed. Important shortcomings not mentioned in the stress tests reports are also discussed. Those evaluations[2] do not claim to be exhaustive, but it is hoped that the findings will contribute to a more complete understanding of nuclear power plant safety in Sweden.

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1 A NPP needs 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 water from the "Ultimate Heat Sink" is passed through large heat exchangers where it cools other mediums. If this function fails a core melt could occur.

2 The evaluations are based on a study published in May 2012 [WENISCH 2012].

2 Weaknesses the Swedish Stress Test Described

2.1 Earthquake

Despite the fact that Sweden is a zone with low seismic activity, earthquakes can occur. But only the newest reactors, Oskarshamn 3 and Forsmark 3, were originally designed to withstand earthquakes. The other Swedish reactors became subject to general requirements imposed on resilience against earthquakes when the Swedish Nuclear Power regulations, entered into force in 2005. However, the required improvements (e.g. anchoring of mechanical components) have not been implemented immediately. In order to allow licensees sufficient time to fulfil the requirements, the deadline for taking measures is the year 2013. That means: There are known weaknesses that could cause a severe accident during an earthquake. Identified weaknesses are for example:

- Roof elements of the **Ringhals-1** reactor building may fall down into the spent fuel pool; this can cause damages to the fuel and endanger the possibilities for cooling. Identified deficiencies at **Ringhals-2,-3,-4** are e.g. anchors for cabinets.
- At **Forsmark-1,-2**, there are lot of known shortcomings, e.g. unintentional operation of relays (relay chatter[3]) as well as insufficient anchorage of mechanical components of a large number of component types. The most important deviations are found in the emergency power supply. These deviations will be corrected during the outage in 2012. The remaining deviations will be taken care of “as soon as possible”. Until these deviations have been corrected, the level of earthquake that the plant is verified to withstand is not at all sufficient.
- At **Oskarshamn-1**, the inner ceiling in the main control room is not verified against design basis earthquake (DBE), thus the operators’ safety could be jeopardized and necessary manually actions to prevent an accident could be impossible.

Furthermore, especially for **Ringhals and Forsmark**, there is a need to carry out more detailed analyses for earthquake-induced flooding, because, e.g. leakage from broken water storage tanks and cracks in the cooling water channels can aggravate an accident.

But also after finishing the back-fitting measures in 2013, the protection will not be adequate, because the methodology used for seismic hazard assessment is not fully compliant with current international standards and research results. Further investigations are necessary. Reassessments of seismic hazards for NPPs almost always show that the protection is not sufficient.

One intention of the stress tests was the evaluation of safety margins in case of an earthquake. The stress test reveals that the Swedish NPPs cannot even withstand a calculated earthquake which could occur with a low probability. Investigations are to be performed to evaluate the margins of structures, systems and components against ground motions exceeding the design basis earthquake (DBE).[4]

The assessment of SSM regarding the licensees (operators) conclusions is that data is somewhat lacking for demonstrating functions needed to bring the reactors Oskarshamn 2, Forsmark-1,-2 and Ringhals-2,-3-4 to a safe state (i.e. to prevent an accident) after a DBE.

Jan Hanberg, head of the Swedish Radiation Safety Authority (SSM) pointed out that: "What we can already see is that some plants do not fully meet requirements in the case of earthquakes.” Hanberg added that nuclear plant operators will continue to work towards the 2013 deadline, but may introduce additional safety measures in light of what has been learned through the stress tests. That may require a revision of the 2013 deadline [WNN 2011]

The ENSREG peer review team criticized the situation only indirectly. They recommend the

[3] The consequence of relay chatter may be that objects are given incorrect signals.
[4] The DBE is an earthquake with the occurrence frequency of 100.000 per year.

evaluation of the earthquake risk according state of art methodology and the implementation of identified back fitting measures in timely manner.

2.2 Flooding

The flood threat at many NPP sites has increased in recent decades for several reasons (e.g. climate change and reduction of natural flood plains). Large, destructive floods are now expected to happen more frequently. Appropriate safety margins rarely exist despite the fact that Fukushima highlighted the need for better flood protection**.** The presence of water in many areas of the plant may be a common cause failure for safety related systems. The dynamic effect of the water can be damaging to the structure and the foundations of the plant. 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.

All Swedish nuclear power plants are situated near the sea, making the threat posed by flooding a key consideration. The stress tests report shows that all Swedish NPPs are able to withstand a seawater level of 3.0 meters above the average water level without resulting in core damage. This sound good, but it is not really sufficient. Important for the assessment of the flood protection is the calculated design basis floods (DBF). This is a possible the sea-water level with a low occurrence probability. The calculated values of the DBF are (above normal sea water level):

- Forsmark: + 3.00 m (safety margin: 0 m)
- Oskarshamn: +2.02 m (safety margin: 0.98 m)
- Ringhals: + 2.65 m (safety margin: 0.35 m)

The safety margins at Ringhals are too small, at Forsmark there is not any safety margin at all. Additionally, the detailed methodology for the definition of high sea level is identified as an open issue by SSM, which means higher water levels are possible. Furthermore, in Ringhals and Forsmark, the effect of waves has not been considered despite the fact that historical extreme sea levels are associated with storm, and thus phenomena as wave setup and wave run-up and associated dynamic effect should be investigated combined with extreme sea levels.

Forsmark: The ground elevation is a few decimeters above the calculated DBF. In case of an external flooding above ground level, the water level in the respective buildings rises to the same level. The safety systems are not protected against water, thus damage to core is likely (if no manual action is taken). For Forsmark-1 and -2, even at a seawater level 0.5 m below the calculated DBF, the emergency diesel generators (EDG) can be jeopardized. Furthermore high sea water level will cause traffic disruptions on the roadways and blockades of transportation roads.

Ringhals: The ground elevation is only 0.35 m above the value of the not appropriate calculated DBF If the seawater level (including waves) is more than 0.65 m above this value, large amounts of water will enter the units through various openings and fuel damage is possible.

The ENSREG peer review team criticizes the protection against flooding only indirectly. It is stated in the country report: The Reviewers' appreciate that the licensees compiled a list of improvements and recommend SSM to consider approving and implementing the possible measures in a timely manner. They further recommend carrying out more detailed flooding risk analysis including cliff edge analysis and studying of the combination of high sea water level and other external phenomena such as swell, strong wind and organic material (for the Forsmark and the Ringhals)

2.3 Extreme Weather Events

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 40 years 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 trigger or aggravate an accident.

The current Swedish regulation addresses extreme weather without quantification of the loads. The effect of tornadoes, heavy rainfall, extreme temperatures and the cumulative effects of extreme weather events have not been adequately analyzed. Therefore the stress tests do not reveal whether or not the units could continue operating safely during extreme weather events.

Some cliff edge effects and improvements are identified yet (e.g. against tornado induced missiles), for example:

- The licensees have not dealt with how severe weather will affect the access to the plants for staff, heavy equipment and supplies.
- Extreme snowfall could jeopardize **Ringhals-1**. If no snow removal will take place, a collapse of the buildings could cause damage to the fuel.

It is expected that the further analysis will identify additional measures against extreme weather. Ice storms are of particular interest. They are not covered by the nuclear power plants’ safety analysis reports and have not been analyzed in detail in the stress tests. An ice storm could be a danger for a NPP, because it could knock out the offsite power and also block the ventilation systems.

Again the ENSREG peer review team criticizes the protection against extreme weather events only indirectly. It is stated in the country report: The Reviewers’ appreciate that the licensees compiled a list of improvements and recommend SSM to consider approving and implementing the possible improvements in a timely manner. They further recommend carrying out more detailed external hazard analysis on the basis of the state of the art requirements.

2.4 Loss of Electric Power and Loss of ultimate heat sink

Loss of electrical power (SBO) and loss of ultimate heat sink (UHS) scenarios could result in severe accidents. If loss of off-site power occurs, power will be supplied by emergency diesel generators (EDG)[5]. To cope with the situation in which all Emergency Diesel Generators (EDGs) fail, gas turbines (GTs) are installed as alternate AC power sources, however the GTs are in most cases not fully qualified against external hazards (e.g. earthquake). If the power supply with a GT fails, various mobile units can be used. However, the analysis indicates that the capacity and number of mobile units are insufficient especially when several reactors are affected simultaneously.

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 is lost, fuel damage can occur in the reactor core and/ or spent fuel pool quite rapidly. To secure cooling of the spent fuel pool, manual actions are required for all Swedish NPPs. Aggravating conditions for manual actions including connection of mobile generators are destruction of buildings etc., high radiation outdoors, extreme cold temperature, large amount of snow or flooding.

<u>Forsmark:</u>

- Each unit has four physically and electrically separated EDGs; only two out of these are required to operate during accident conditions. However all EDGs are dependent of the sea-water cooling and at loss of UHS (e.g. by blocking of the water intake channel) all EDGs are expected to quickly fail.

[5] With the exception of Oskarshamn 2, where the gas turbines at present serve as primary electricity back up.

- The UHS for all Forsmark units is sea water from the Baltic Sea. There is no alternate UHS available for the Forsmark units.[6]
- The gas turbine (GT) could not withstand an earthquake.
- There are only three small external mobile generators available on site.
- Without power supply, for unit 1 and 2 damage to the fuel is calculated to be unavoidable after 35 minutes, for unit 3 after 60 minutes.
- If blockage in the sea-water intakes occurs, the spent fuel pool (SFP) cooling systems will be lost. To prevent damage to spent fuel, make-up water from the fire-water system has to be manually provided. If the fire-water system is not available, hoses could be connected to fire trucks. However, there is only one fire truck available at the site. If make-up water for the SFPs is not available, fuel in the SFPs is anticipated to be uncovered within 23 hours.

Oskarshamn

- For Oskarshamn 2, two GTs and two EDGs serve as power supply in case of loss of off-is site power.[7] None of them is seismically qualified.
- For Oskarshamn 3, if the off-site power and the EDGs fail, to prevent fuel damage in the reactor core the connection to the GTs has to be manually accomplished within 1 hour.
- For Oskarshamn 1, two EDGs are cooled by sea water and two cooled by a roof-mounted air-cooling system at Oskarshamn 1. However, during large amounts of snow, it is possible that the cooling system could be covered in snow and the capacity of the system might be reduced.
- There is only one mobile diesel power generator located at the site.
- If all electrical power supplies are assumed to fail, fuel damage in the reactor core is calculated to occur for Oskarshamn 2 after around 2 hours and for Oskarshamn-3after around 1 hour. For Oskarshman-1, if the emergency condenser is assumed to be available, damage to the fuel is calculated to begin within 3 hours. However, in case of an earthquake the emergency condenser is assumed to be unavailable, damage to the fuel is calculated to begin within 1 hour.
- Loss of ultimate heat sink (UHS) or loss of all power supply (SBO) will causes all cooling systems for the spent fuel pools to fail. In this situation hoses must be manually carried to the spent fuel pools. Without taking any action, the available time before the onset of boiling in the SFPs is 18 hours for Oskarshamn 1, 40 hours for Oskarshamn 2 and 21 hours for Oskarshamn 3.

Ringhals

- If loss of off-site power occurs, power will be supplied by EDG or by the two GTs common for the site. In case of loss of off-site power, manually action for Ringhals 1 is necessary to connect to the GTs.
- There are only two mobile units at the site. This is not sufficient, in particularly in case of simultaneously events at more than one unit. If the mobile unit is unavailable, fuel damaged becomes unavoidable after approximately 16 hours for Ringhals-1 and after approximately 9 hours for Ringhals-2,-3,-4.[8]

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[6] If only blockage in the sea-water intakes occurs for Forsmark 3 the redundant auxiliary cooling water intake from the outlet tunnel will provide water to the cooling water pumps. Forsmark 1 and 2 do not have the option to take water from the outlet.

[7] Four new diverse EDGs with robust I&C are planned to be installed in 2013 for Oskarshamn 2For

[8] All units are equipped with steam driven systems to provide core cooling capabilities, either directly to the reactor pressure vessel (BWR) or via the steam generators (PWR) as long as the batteries

- The primary ultimate heat sink (UHS) for all units at Ringhals is sea water. At loss of primary ultimate heat sink, fuel damage becomes unavoidable at Ringhals 1 after 35 hours, at Ringhals 2 after 11 hours, and Ringhals 3 and Ringhals 4 after 8 hours. If manual actions are delayed damage to fuel will be unavoidable within 2 hour for Ringhals-2,-3,-4.
- The spent fuel pools (SFP) have no prepared connection for the mobile units. When only battery power remains the fire-water system could manually provide water to the spent fuel pools. The time needed to get the fire-water system operating is estimated to be a few hours. The time from loss of cooling of the SFPs to the onset of boiling is, without taking any action, for Ringhals 1 around 14 hours, and to a loss of shielding, around 91 hours. For Ringhals 2, 3 and 4, the time from a loss of SFP cooling to the start of boiling is around 9 hours and to a loss of shielding, is around 50 hours.

There are a number of measures, both simple and more complex, that are envisaged to remove the weaknesses. Simple measures that could implement immediately are for example increasing the number of mobile diesel generators or construction of a line from a shielded position outside the reactor building giving the possibility to fill water in the spent fuel pool from a fire-truck. More expensive, but more effective measures are the implementation of a new independent core cooling system, a diversified residual heat removal (without using the sea) and the introduction of improved capabilities to provide make-up water (and emergency cooling) to the spent fuel pools without using hoses. In order to prevent a core melt accident, such measures should be implemented as soon as possible.

2.5 Severe Accident Management

Measures for severe accident management (SAM) were already introduced in Swedish NPP in the eighties; however, the SAM shows the need of comprehensive improvements as well as the need of further analyses. Currently, they have nearly the same weaknesses as has been seen in Fukushima. The main weaknesses are:

- In the event of a total loss of power (SBO), there is **no way to supply water to the reactor pressure vessel** of the BWRs[9].
- When the reactor core has melted through the reactor pressure vessel and residual heat removal has failed, pressure in the containment rises. In this situation, the **filtered venting system,** which shall capture the majority of the radioactive substances, enables the release of pressure from the containment to the environment. However, the stress tests have revealed that the filtered venting system is not designed for accident scenarios with the duration and aggravated conditions corresponding to the situation during the Fukushima accident.[10]
- The risk of hydrogen gas leakage to reactor buildings in the BWRs has not been dealt sufficiently, thus **hydrogen explosion** are possible. Furthermore the handling of hydrogen gas in a long-term perspective in the containment has to be improved. Hydrogen explosions can cause damage of concrete buildings, as it happened in Fukushima.
- There are no SAM measures in place for **loss of the containment** function. A containment failure leads to radioactive emissions that can affect regions some hundreds of kilometres away.

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allow or for as long as the water from available water sources lasts. Therefore the time spam before damage to the fuel is unavoidable is short, but prolonged in comparison to Forsmark and Oskarshamn units.

[9] Forsmark 1,2,3 Ringhals 1, Oskarshamn 1,2,3

[10] For Oskarshamn 1 and 2 the system is shared, which is a further weakness.

- The **batteries** for instrumentation are not dimensioned appropriate; they are only capable of managing the initial accident sequences (1-4 hours).
- In case of a total loss of power (SBO) or loss of ultimate heat sink (UHS), there is currently no system that can be used for cooling the **spent fuel pools (SFP)**. Make-up of the pools is only possible with the use of fire fighting water. To secure spent fuel pool cooling manual actions are required for all Swedish NPP. This action must be performed before the onset of harsh conditions (humidity, temperature, radiation) in the spent fuel area. As seen in Fukushima, it is a desperate measure to have the fire brigade to fight against a severe nuclear accident.
- When **two or more units simultaneously** are subjected to severe accident it can be difficult to have sufficient number of competent personnel available, which can lead to that all required accident management cannot be executed as intended. The on-site emergency control centers are not organized to handle events on several units simultaneously.

3 Weaknesses the Swedish Stress Tests Ignored

3.1 Power Uprate

Power uprating, which is often combined with life time extension, is an option to increase the profitability of a NPP. To uprate the electrical power output, there are two different possibilities:

- Increasing the thermal efficiency of the plant, mostly achieved by optimising the turbines).
- Increasing the thermal power of the reactor, usually by raising coolant temperature. Thus, more steam is produce and the reactor can produce more electricity via the turbines. An increase of thermal power implies more nuclear fissions and so more fission products. Also, higher loads to the reactor systems are unavoidable. Safety margins are reduced and at the same time ageing processes are accelerated.

A recent published IAEA report highlighted the negative safety effects of power uprates: Because changing the thermal power affects so many 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. Especially large power uprates have sometimes resulted in equipment degradation and damage in secondary piping systems. The US nuclear power industry 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 leads to a decrease of intervention time. Furthermore, in case of a severe accident, the potential radioactive release is considerable higher.

<u>Oskarshamn</u>

In 2005, a project for power uprate under licensed safety (PULS) was initiated. The goal was to achieve around a 30% increase in thermal power such that the electric power could be increased to 1450 MWe, as well as an operational life extension until to 2045. Project PULS was completed in December 2009, but during a test period a number of deficiencies were detected. The reactor was first taken offline in February 2010 to attend to a problem with the valves that control the steam flow from the reactor to the turbine condenser. Analyses showed that the valves had a faulty construction and needed to be rebuilt. At the end of August 2010, problems with the one of the turbines occurred. The problem was later discovered to be with turbine bearings. On 28 March 2011, Oskarshamn 3 was forced offline to deal with a control failure in one of the control valves in the turbine steam line system [NEI 2011]. Up to now, deficiencies related to the power uprate occur: In August 2012, a defected valve in a system controlling the water influx to the reactor vessel has caused a standstill. The deficiency was detected in connection with one of the tests being performed to verify the unit's new capacity [OKG 2012].

The experience in Oskarshamn-3 has shown so far, that a lot of unexpected deficiency occur during normal operation and tests, thus it has to be expected that also unexpected deficiencies will occur during an accident, which can aggravate the situation.

There is also a project to modernize and uprate Oskarshamn-2, which began in 2007. Work was originally planned to be completed in 2013, but now the project completion is expected in 2015. The uprate, and a new turbine, shall increase the unit's generating capacity by almost 38%.Transforming a nuclear power station designed and built in the early 70s to comply with modern standards requires several measures to be taken. Thus, even more unexpected problems during normal operation and accident situations have to be expected compared to Oskarshamn-3.

<u>Forsmark</u>

Power uprates planned for Forsmark-1 and -3 have been postponed; the units had been scheduled for power uprates in 2011 and 2014, respectively. The work is to be postponed to allow time to develop a solution for issues with high-pressure turbine control valves that caused problems during similar work at Forsmark-2 in 2010 [WNN 2010].

3.2 Safety Culture

<u>Ringhals</u>

In July 2009, the Ringhals NPP has been placed under special investigative measures by the Swedish Radiation Safety Authority (SSM) to address shortcoming deficiencies in safety culture. The authority highlighted a series of failures that could jeopardise reactor safety have been highlighted since 2005 [NW 2010; NW 2011]. But obviously these measures have not change the situation: One example: In May 2011, a fire broke out when performing a pressure test of the containment caused by a short circuit in a forgotten vacuum cleaner. The management decided to start this test three days earlier than scheduled, but forgot to inform the personnel. The fire generated a substantial amount of ash that is difficult to remove from the containment. The functionality of electric and control systems could be affected [NW 2012]. If the cleaning was not really sufficient, possible faults of these systems could aggravate an accident situation.

During cleaning measures, after the fire, scrap from welding work was found in important safety systems (containment sprinkler systems) at Ringhals-2 and – later in Ringhals-4. The scrap would have caused the systems to function at efficiency of only about 85%, but failure to detect the scrap is worrisome. Considerable work was done on the units in the 1980s and 1990s and it is possible the scrap has been there since then. SSM also demanded a report explaining why testing of safety systems has not been done properly [NW 2011].

Checking and maintenance of safety systems is a key to nuclear safety. According to SSM, Ringhals management will have to explain in its report why safety culture problems have persisted at the site [NW 2011]. On November 8, 2011, SSM decided to continue its special oversight [NW 2011a] But SSM failed to take appropriate measures.

<u>Oskarshamn</u>

A routine annual control of Oskarshamn 3, in early October 2008 turned up a control rod that had broken off. On closer inspection other rods were found to be cracked.[11] Investigation ordered by the safety authority found cracks at Forsmark 3, as well. SSM has asked both operators to explain why the cracks have occurred and especially why the problems went undetected. Both the Oskarshamn and Forsmark plants have repeatedly been faulted for poor safety routines [WISE 2008].

An IAEA Operational Safety Review Team (OSART) visited Oskarshamn-2 to review operating practices in 2009 and 2010. The results are among others [IAEA 2010]:

- The unit has not developed an effective key control system in the main control room to prevent unauthorized access to systems and equipment important to safety.
- Low level events are not reported, analysed and effectively trended to identify event precursors in a systematic and consistent manner. Without a comprehensive reporting programme, the plant's capability of identifying event precursors and emergent issues by trending different event factors may be impaired.

Forsmark

In January 2007, an internal document revealed safety concerns at Forsmark. Three members of Forsmark's maintenance compiled a report, which indicates a poor safety culture among staff. For example: Internal forms for reporting safety-related events had been redesigned without the industry-standard 'Lessons learned' section due to lack of use. The spotlight has been on the Forsmark since the sudden shutdown of unit 1 following a short-circuit in the plant switchyard on 25 July, 2006. A complex sequence of over- and under-voltages caused the unit to shut down, but with only two of four safety trains in operation. The other two were manually started 22 minutes later, but the discovery of the design fault was a shock to the Swedish nuclear industry. The very old reactors with similar systems, Forsmark 2 and Oskarshamn 1 and 2 were shut down as a precaution. Changes have now been made to all the units to protect against similar conditions [WNN 2007].

3.3 Ageing Effects (direct and indirect)

The age of the ten Swedish reactors is between 27 years (Forsmark 3, Oskarshamn-3) and nearly 41 years (Oskarshamn 1)[12], the average age is 33 years. This means that ageing of materials is a major safety issue in all units, especially for Ringhals-1,-2 and Oskarshamn-1,-2. The quality of the plants' safety-related systems and components, such as the material of pipes, reactor vessel, valves and pumps, control and instrumentation equipment is not investigated in the ENSREG stress test. The tests take no account of degradation effects, even though these could significantly aggravate the development of an accident caused by an external event. It has to be expected, that the frequency of ageing related incidents will increase. These incidents have the potential to trigger, but particularly to aggravate accidents sequence. Incidents could also be caused by ageing indirectly: If old components are replaced, (new) faults because of defective mounting or of forgotten scrap etc. are possible. The ENSREG stress test takes for granted that all the structures, systems and components (SSC) assessed are in place and without fault, but the operational experience shows this is not the reality.

3.4 Airplane Crash

An airplane crash is not obligatory to be evaluated in the EU stress tests, and indeed several plants have reactor buildings that are insufficiently robust to protect the reactor system from the crash of an airplane. The reactor buildings' roof of Ringhals 1 would not even withstand a

[11] A reactor typically has 160-170 control rods. Used to regulate temperature in the reactor core, they are the first line of defence should it be necessary to interrupt criticity. The second line of defence is to pump in boron.

[12] Ringhals-4: 29 years, Ringhals-3, Forsmark-2: 31 years; Forsmark-1: 32 years; Ringhals-1,2: 37 years; Oskarshamn-2: 38 years (Status September 2012);

high snow load. The operators do not consider the risk of an airplane crash because of the low likelihood of such an event. However, an airplane crash must be considered as a relevant safety issue, because an accident with a containment failure (or a bypass) leads to a large and early radioactive emissions in the atmosphere – such emissions can affect not only the immediate vicinity of the reactor, but also regions some hundreds of kilometres away.

4 Addendum

On 15 September 2012, the Swedish regulator SSM published the **action plans of the operator** for the remedy of the deficits found in stress tests. SSM shall now assess theses action plans, and then formulate a national action plan for the continuation of the work of the ENSREG stress tests. The national action plan shall be handed to ENSREG by SSM at the end of December 2012 [SSM 2012]. A very short glance to actions plans of the operators shows:

Ringhals: Main strategy of the operator is to introduce flexible mobile systems to prevent a severe accident in case of loss of power supply like it is proposed for the US NPPs. The use of mobile pumps or diesel generators is presented as the solution to compensate deficiencies of the safety systems of reactors and spent fuel pools. The operator plans to finalize a timetable for planned investigations and measures during the first half of 2013. Decisions' about back-fitting measures are not made yet. Planned actions include the extension of batteries' capacity, investigations about the reinforcement of buildings and the implementation of measures which make it possible to refill the spent fuel pools from the outside with mobile equipment. The ongoing work of prepare and implement simple measures is expected to be finished in 2013. Besides two measures to prevent water from entering into the buildings at high sea level, these measures are only review of instructions for severe accidents situation (e.g. regarding refueling of diesel in the exiting mobile units).

Forsmark: The operator will finish a prestudy about backfitting measures in November 2012 and then prepare a progress report, which will be delivered to the regulator in March 2013. The operator plans four steps to remedy the weaknesses revealed in the stress tests. The first step, already underway, includes improvement of instructions and implementation of simple improvements. The second step comprises implementation of mobile equipment (e.g. for power supply). The third step intends to implement simple fixed installations. The last step, the implementation of larger systems, requires extensive feasibility studies and developing of requirements, and therefore takes a number of years to complete. The activities listed on the action plan are mainly analyses (e.g. regarding possible high sea level including waves, plant robustness in case of ice storms, possibilities to enhanced the availability of power supply, possibilities for diversified emergency core cooling, multi-unit accidents, hydrogen accumulation and refilling of water in the spent fuel pools). Decisions about backfitting measures are not made yet.

Oskarshamn: The operator has listed 24 activities for measures to strengthen resistance to earthquakes, floods and extreme weather conditions and prolonged loss of electricity supply and heat sink as well as measures to deal with severe accidents in a short very general manner. Only three activities consist of (small) back-fitting measures (protection against water, new mobile diesel generator, new software). All other activities begin with a feasibility study, and for only four of these activities backfitting measures are expected yet (installation of the equipment that enables water supply for spent fuel pools, installation of a diesel driven fire water pump, implementation of an automatic connection between Oskarshamn-3 and the gas turbines, improvements of the gas turbines).

Conclusion: At this moment an assessment of the action plans is not really possible, because it is not decided yet, which measures are being implemented. However, there is the tendency to choose cheap solutions (mobile equipment) instead of comprehensive measures. But under accident conditions, it is difficult to implement the proposed mobile equipment as quickly as necessary. An US expert criticized the idea to use portable equipment to cope with a severe accident at US NPPs as "*a highly unpredictable mixture of desperate measures*" [NW 2012a]. In France, for example, the integration of an electricity generating set and an emergency cool down water supply in the so called "hardened safety core", which will be subject to more stringent requirements, particularly with respect to the earthquake and flooding risks, is required by the French regulator ASN. The hardened safety core will be based mainly on new equipment diversified form the existing one to prevent common cause failure.

Up to now only few backfitting measures regarding shortcomings revealed in the stress tests have been performed at the Swedish NPPs. For example, at Forsmark-1 and -2 the earthquakes resistance of the emergency diesel generators (EDGs) and switchgear have been enhanced during the annual outages in 2012 [SO 2012]. But the important weakness of the EDGs remains: The EDGs depend on seawater cooling, and will fail, if the ultimate heat sink fails. Instead of remedy this weakness, the operator is continuing the work to implement power uprates. The technical upgrading work has been carried out, and now the operator hopes to get permission for a trial operation with higher reactor power at Forsmark-2 [SO 2012].

Obviously it is planned to operate the Swedish NPPs for the next years with the known shortcomings. In view of the existing risk, the units have to stop operation or at least operate with reduced power until the implementation of the necessary back-fitting measures will be performed. However, the operators plan to increase the power of the reactors – and thus will increase the existing risks.

5 Conclusion

The evaluation of the Swedish NPPs in the light of the Fukushima accident and in accordance with the ENSREG stress tests has revealed a number of shortcomings.

In the current status, all four Ringhals units, Forsmark-1,-2 and Oskarshamn-1,-2 are not able to withstand a design basis **earthquake** (DBE). Additionally, the earthquake risks are not assessed according to the international state of the art. Thus, for Forsmark-3 and Oskarshamn-3 the resistance against earthquake is probably also not sufficient.

The stress tests point out that for the Ringhals and Forsmark units the protection against flooding is inadequate, **flooding** events could cause core melt accidents at these NPP sites. Further evaluations to assess the flood hazards according to the state of the art are necessary.

Extreme weather events (e.g. ice storms, heavy rainfall) could initiate or aggravate an accident, but the effects have not been adequately analyzed until now.

Currently, there are several design shortcomings regarding the prevention of **loss of power or ultimate heat sink** (UHS) situations. A serious safety issue is the lack of an alternate ultimate heat sink. Any problem with the ultimate heat sink (e.g. blocking of the water intake) will affect all units at the site.

In case of flooding or earthquake, the off-site power supply, but also parts of the back-up on-site power supplies could get lost. For Forsmark e.g., the gas turbine (GT) could not withstand an earthquake. If this earthquake also damages the ultimate heat sink, all emergency diesel generators (EDG) fail. The staff has to restore power supply for Forsmark-1 and -2 with mobile diesel generators within 35 minutes, for Forsmark-3 within 60 minutes otherwise core melting is unavoidable. Because of the expected conditions at the site after an earthquake, this seems very impossible.

Currently, measures for **severe accident management** (SAM) to mitigate major release of radioactive substance show nearly the same weaknesses as in Fukushima: The filtered venting systems are not as reliable as estimated; hydrogen explosions at the reactor building are possible; the number of competent staff is insufficient, the capacity of battery (e.g. for instrumentation and controlling) is too limited, there are no appropriate measures to cope with spent fuel pools or with more than one unit simultaneously.

The stress tests have identified a number of areas of improvement, respectively weaknesses. Despite this fact, SSM's assessment is that these "areas of improvement" are of such a nature that the continued operation of the facilities does not need to be questioned.

This assessment of the Swedish regulator is not understandable, especially because there are other safety concerns that the stress tests have not evaluated.

Shortcomings of **safety culture** have been a serious problem for many years. More cases of undetected sloppiness, like the scrap in Ringhals-2 and -4 cannot be excluded, respectively has to be expected. These latent defects could result in a partly or total failure of safety systems during an accident.

Ageing of materials is a safety issue in all units, but especially for the oldest Ringhals-1,-2 and Oskarshamn-1,-2. Ageing related effects – direct by material degradation or indirect by defective mounting of changed equipment – could significantly aggravate an accident situation.

Power uprates (e.g. at Oskarshamn-2 and -3) could lead to unexpected failures of safety systems. Additionally, in case of severe accident, the intervention time will be decreased and the potential radioactive release will be increased.

Due to the insufficient protection against natural hazards and the high number of latent faults the probability of a loss of power and/or loss UHS situation is relative high, but appropriate measures to cope with such accident situations are lacking, thus the **risk of a core melt accident with major radioactive releases is relative high**. All Swedish units should stop operation as soon as possible – for comprehensive backfitting measures or to shut down permanently.

5 References

ENSREG 2012 European Nuclear Safety Regulator Group (ENSREG): Peer review country report, Stress tests performed on European nuclear power plants, Sweden; 2012; www.ensreg.eu/sites/default/files/Country%20Report%20SE%20Final.pdf

IAEA 2010 International Atomic Energy Agency (IAEA): Report of the OSART Mission to the Oskarshamn NPP, SWEDEN 16 February – 5 March 2009 and OSART FOLLOW UP VISIT 30 November – 3 December 2010; www.stralsakerhetsmyndigheten.se/Global/Nyheter/2011/Oskarshamn%20OSART%20mission%20report%20FU%20finish%20rev3%20%287%29.pdf

IAEA 2011 International Atomic Energy Agency (IAEA): Power Uprate in Nuclear Power Plants: Guidelines and Experience; IAEA Nuclear Energy Series; No NP-T-3.9; Vienna; January 2011; www-pub.iaea.org/MTCD/publications/PDF/Pub1484_web.pdf

NEI 2011 Nuclear Engineering International (NEI): Pipe work, 20 September 2011; www.neimagazine.com/story.asp?storyCode=2060628

NW 2010 The McGraw-Hill Companies: Nucleonics Week 51, March 25, 2010, p.3

NW 2011 The McGraw-Hill Companies: Nucleonics Week 52, September 29, 2011, p.12

NW 2011a The McGraw-Hill Companies: Nucleonics Week 52, December 1, 2011, p.8

NW 2012 The McGraw-Hill Companies: Nucleonics Week 53, February 2, 2012, p.7

NW 2012a The McGraw-Hill Companies: Nucleonics Week 53, March 8, 2012, p.4

OKG 2012 OKG: Valve problems delay final testing at unit Oskarshamn 3 Press release 2012-08-29 www.okg.se/templates/NewsPage____1272.aspx

SO 2012 Second opinion: Forsmark hoppas på provdrift för effekthöjd reactor; 12 September 2012; http://www.second-opinion.se/energi/view/2646

SSM 2011	Swedish Radiation Safety Authority (SSM): European stress tests for nuclear power plants, Swedish National Report; December 29, 2011; www.ensreg.eu/sites/default/files/Swedish%20national%20report%20EU%20stress%20tests%20111230.pdf
SSM 2012	Swedish Radiation Safety Authority (SSM): Kärnkraftsindustrin har redovisat åtgärdsplaner, 18 September 2012; http://www.stralsakerhetsmyndigheten.se/Om-myndigheten/Aktuellt/Nyheter/Karnkraftsindustrin-har-redovisat-atgardsplaner/
WENISCH 2012	Wenisch, A.; Becker, O.: Critical Review of the EU Stress Test performed on Nuclear Power Plants; Study commissioned by Greenpeace; Wien, Hannover, May 2012; www.greenpeace.org/eu-unit/en/Publications/2012/stress-tests-briefing/
WISE 2008	Nuclear Monitor: Sweden: Cracked Control Rods; Gaping Holes in the Culture of Safety; No. 679; November 13, 2008
WNN 2007	World Nuclear News (WNN): Forsmark under scrutiny, 30 January 2007; www.world-nuclear-news.org/newsarticle.aspx?id=12800
WNN 2010	World Nuclear News (WNN): Swedish uprates postponed, 24 November 2010; www.world-nuclear-news.org/IT-Swedish_uprates_postponed-2411107.html
WNN 2011	World Nuclear News (WNN): Swedish focus on earthquake protection, 04 November 2011; www.world-nuclear-news.org/RS_Swedish_focus_on_earthquake_protection_0411111.html