Critical Review of the Swedish National Action Plan (NAcP)

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Content

1 Introduction

Following the accident at the Fukushima Dai-ichi nuclear power plant (NPP) in March, 2011 it became clear that it is impossible to exclude highly unlikely accidents from happening at any NPP, anywhere. In a prompt reaction to this catastrophic accident, the European Council concluded in March of the same year, that the safety of all EU NPPs 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.[1]

However, two months later the scope of the EU stress tests was reduced: The EU stress tests were defined as a targeted reassessment of the safety margins of nuclear power plants. The EU stress tests comprised three topics:

- The response of a nuclear power plant when facing different extreme situations (earthquakes, floods and extreme weather events, and the combination of events),
- The NPP's operator capabilities to cope with consequences of total loss of power (station black-out – SBO) and loss of heat removal via ultimate heat sink (UHS);
- The NPP's operator capabilities to prevent major radioactive emissions in case of a severe accident: the severe accident management (SAM).

All EU Member States operating nuclear power plants – plus Lithuania – and the neighbouring countries Switzerland and Ukraine, took part in the stress tests process.

The *first phase* of the EU stress tests started in June 2011 – the *operators* of the NPPs prepared a *self-evaluation* of their plants. Licensees had to provide a final report by 31 October, 2011.

In the *second phase,* the national regulator *reviewed the* final reports submitted by the operators. All final national stress tests reports were handed over to the EU Commission by 31 December, 2011.

Then the *third phase* started: the peer review, which was conducted by experts nominated by the national states to review the national reports. The peer review teams reviewed the national reports by desktop research. Each country was visited by one expert team. The peer review was completed with a main report that included final conclusions and recommendations at the European level regarding the three areas of research mentioned above, and 17 country reports including country-specific conclusions and recommendations. The report was endorsed and published by ENSREG on 26 April, 2012.

The EU Commission presented the ENSREG report in June 2012 to the European Council. However, the EU Commission did not see the Council mandate for stress tests fulfilled and demanded further testing; six additional fact-finding visits were undertaken.

One fact-finding team of four international experts and a representative of the Swedish regulatory body (SSM) visited the Ringhals NPP on 13 and 14 September, 2012 [ENSREG SE 2012].

The stress tests revealed a number of shortcomings regarding the plants´ capability to withstand several external hazards and its lack of ability to cope with the consequences.

[1] The introduction as well as this report based on the report: „Critical Review of the National Action Plans (NAcP) of the EU Stress Tests on Nuclear Power Plants" [BECKER 2013].

However, the outcomes of the stress tests consisted only of recommendations for "further improvements".

To implement the stress tests findings, an *ENSREG action plan* (published 1 August, 2012) was developed to track implementation of the recommendations. In line with this plan, each national regulator generated a *national action plan* *(NAcP)* to remedy the identified shortcomings revealed by the EU stress tests. By the end of 2012, the Swedish nuclear regulator (SSM) had provided the Swedish NAcP.

In October 2012 ENSREG published a compilation of recommendations to assist the preparation as well as the review of the NAcPs. A key issue which is still open is how comprehensively the ENSREG peer review of the NAcPs will be conducted. This might be seen as an opportunity to force the nuclear regulators to formulate mandatory requirements which need to be fulfilled in a rather stringent time schedule; in contrast to the years or even decades currently planned in many countries, in particular in Sweden. This could make operators decide to shut down old and unsafe NPPs rather than investing in extensive modernisation programs.

The ENSREG action plan specified the need to peer review these NAcPs via a common discussion at a dedicated ENSREG-workshop. This workshop took place in Brussels on 22 – 26 April 2013. The outcomes of the workshop will be presented to the public in the next ENSREG conference on 11 and 12 June 2013.

This report presents a critical review of the Swedish NAcP. It is the follow-up of the report "*Critical Review of the Swedish Stress Tests Reports*" published in September 2012 [BECKER 2012]. The report of 2012 discussed the main weaknesses as identified by operators, SSM and peer review team during the stress tests process and pointed out those issues and important shortcomings of NPPs not mentioned in the stress tests.[2]

This report has the aim to investigate whether the actions set out in the NAcP are sufficient to remedy the main weaknesses the stress tests revealed. It is important to understand that the EU stress tests could not take into account all key safety issues such as the capability to prevent accidents – the scope of these tests was not designed to deliver a comprehensive risk assessment. Too many factors were not taken into account, most importantly ageing, safety culture and design. Thus it is important to underline that the EU stress tests cannot be understood as a comprehensive safety check of the NPPs in Sweden. The public and independent experts were pointing out that the stress tests were mainly set up to improve the confidence in the safety of European NPPs.

To show a more complete picture of the respective safety risks of the Sweden NPPs, some important safety issues not included in the stress tests are again explained. These evaluations do not claim to be exhaustive, but the findings contribute to a more comprehensive understanding of the risk of nuclear power plants in Sweden.

The overall aim is to assess whether an accident comparable to the Fukushima accident could happen in Sweden even after the stress tests.

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[2] Information that was provided in the report of 2012 are not quoted again.

2 Nuclear Power Plants in Sweden

There are ten reactors in operation at three NPP sites (Forsmark, Oskarshamn and Ringhals). The seven boiling water reactors (BWRs) were designed by the domestic vendor ASEA-ATOM (later ABB Atom, now Westinghouse Electric Sweden AB); and the three pressurised water reactors (PWRs) by Westinghouse (USA). The PWRs are 3-loop standard Westinghouse design reactors.

OKG operates the Oskarshamn NPP, which is majority owned by E.On and minority owned by Fortum. Forsmark and Ringhals NPPs are majority-owned by Vattenfall, with E.On as the minority owner in Ringhals and one of the minority owners in Forsmark.

Table 1: Swedish reactors still in operation [IAEA 2013]

Reactor	Operator	Type	Net capacity [MWe]	Design net capacity [MWe]	Commercial operation
Oskarshamn-1	OKG	BWR	473	440	06 Feb, 1972
Oskarshamn-2	OKG	BWR	638	580	01 Jan, 1975
Oskarshamn-3	OKG	BWR	1400	1050	15 Aug, 1985
Forsmark-1	Vattenfall	BWR	984	900	10 Dec,1980
Forsmark-2	Vattenfall	BWR	996	900	07 Jul, 1981
Forsmark-3	Vattenfall	BWR	1170	1050	18 Aug, 1985
Ringhals-1	Vattenfall	BWR	878	760	01 Jan, 1976
Ringhals-2	Vattenfall	PWR	865	820	01 May, 1975
Ringhals-3	Vattenfall	PWR	1064	915	09 Sep, 1981
Ringhals-4	Vattenfall	PWR	940	915	21 Nov, 1983

3 Swedish National Action Plan (NAcP)

The Swedish NAcP listed the measures in three different categories –2013, 2014 or 2015 – according to the year when the measures have to be completed [SSM 2012b]. The deadline is always the 31 December of the year. If the measures are described as investigations the deadline refers to the report of this investigation. The deadline in these cases does not include any technical or administrative measures that the investigation reports are expected to propose. All necessary actions resulting from the investigations are to be fully implemented not early than 2020.

SSM stated that the site-specific action plans form the basis of the NAcP, but not each individual site or unit-specific measures have been reviewed yet.

The NAcP does not present a comparison of the ENSREG recommendations and the actions to be taken. Plant specific actions are not mentioned at all, which makes the understanding of the action plan very difficult. It is out of the scope of this study to analyse whether all shortcomings indentified at the Swedish NPPs during the stress tests process and all general ENSREG recommendations are addressed adequately. However there are indications that this is not the case.

4 Efforts to Remedy the Weaknesses the Swedish Stress Tests Described

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 Swedish reactors became subject to general requirements imposed on resilience against earthquakes when the Swedish Nuclear Power regulations, entered into force in 2005 (SSMFS 2008:17). However, the required improvements have not been implemented immediately. In order to allow licensees sufficient time to fulfil the requirements, the deadline for taking measures is 31 December, 2013. That means: There are known weaknesses that could cause a severe accident during an earthquake, e.g.:

- 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.
- 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.

The peer review team criticized the situation and recommended the implementation of identified back-fitting measures in timely manner (i.e. as soon as possible).

But also after finishing the back-fitting measures, the protection will not be adequate, because the peer review revealed that the methodology used for seismic hazard assessment (SHA) is not fully compliant with current international standards and research results.

Following the advice of the peer review team, SSM will start a research project concerning the influence of paleoseismological data on the existing model regarding frequency and strength of earthquakes in 2013.

Furthermore, especially for Ringhals and Forsmark NPPs, there is a need to carry out more detailed analyses of earthquake-induced flooding, because, for instance, leakage from broken water storage tanks and cracks in the cooling water channels can aggravate an accident. However, the NAcP demands only the investigation regarding these secondary effects of earthquakes by 2014.

The analysis of the maximum earthquake severity which the plant still can withstand without loss of fundamental safety functions or severe damage to the fuel becoming unavoidable was not performed yet. The NAcP asked for an investigation of seismic margins; an evaluation of structures, systems and components (SSCs) against ground motions exceeding DBE is to be performed by 2015.

The operators are obliged to review the procedures and training program for seismic monitoring, followed by implementing them by 2014.

Further studies regarding the structural integrity of the reactor containments, scrubber buildings and fuel storage pools are to be performed; the pipes between the reactor

[3] The consequence of relay chatter may be that objects are given incorrect signals.

containment and the filtered venting system are to be evaluated further[4] (deadline 2013).

The Fukushima accident highlighted the need of sufficient **flood protection.** All Swedish NPPs are situated near the sea, making the threat posed by flooding a key consideration. Only at the Oskarshamn NPP the safety margin between the calculated design base flood (DBF) and the site elevation seems to be adequate (about one meter).

Ringhals NPP has only small safety margins and Forsmark NPP has not safety margins at all between the calculated sea water level and the site elevation. This is a concern particularly because the detailed methodology for the definition of high sea level is identified as an open issue by SSM. Despite the fact that historical extreme sea levels were associated with storms, at Ringhals and Forsmark NPPs, the effect of waves had not been considered while calculating the design basis flood (DBF).

An analysis of the combined effects of waves and high water including potential dynamic effects is to be performed by 2015.

However the peer review team recommended carrying out more detailed flooding risk analysis including studying the combination of high sea water level and other external phenomena such as swell and organic material. But this is not mentioned in the NAcP.

Forsmark NPP: The ground elevation is a few decimetres above the not appropriately calculated DBF. In case of a water level higher than the ground elevation of the site, the water level in the respective buildings rises to the same level. The safety systems are not protected against water, thus damage to the core is likely (if no manual action is taken). At Forsmark-1-2 even a seawater level below the calculated DBF can jeopardize the emergency diesel generators (EDGs).

Ringhals NPPs**:** 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. After having visited the plant, the ENSREG fact-finding team concluded: ‘The definition of high sea level for assessment of the margin against flooding remains an issue. In connection with this issue the team underlined the importance of re-assessing the vulnerability of the emergency control centre (ECC) [ENSREG SE 2012]’.

An evaluation of the protection against flooding as recommended by ENSREG (volumetric approach) is scheduled for completion by 2014. This study is necessary to identify critical areas and spaces regarding flooding of the sites, and considers the need for further protection of the buildings containing safety related equipment located in rooms at or below ground level.

The NAcP requires a flooding margin assessment, an analysis showing step by step increased flood levels beyond the design basis and identification of potential improvements, by 2014. In conjunction with this flooding margin assessment, a formal assessment of margins for all external hazards (including seismic, flooding and severe weather), plus identification of potential improvements is to be performed by 2015.

All in all, the flood protections at Forsmark and Ringhals NPP are insufficient, but it will take at least eight years to remedy this dangerous situation.

[4] A return frequency of 10^{-5}/year shall be used.

Both the frequency and the intensity of **extreme weather events** have increased during the last decades. Extreme weather events can trigger or aggravate an accident at nuclear power plants. However, the current Swedish regulation addresses extreme weather without quantification of the loads.

SSM plans to initiate a study with the target of a more precise assessment of extreme weather conditions, in 2013. The study will be performed as a research project in cooperation with industry. Time schedule for this study is not announced.

The effects of extreme weather events have not been adequately analysed, but some shortcomings have been already identified during the stress tests process (e.g. vulnerability of the reactor building of Ringhals-1 against tornado and heavy snow load[5]).

It is likely that further analyses will identify additional deficiencies. Ice storms are of particular interest. An ice storm could be a danger for a NPP, because it could knock out the offsite power and also block the ventilation systems. However, only investigations of plant characteristics in extreme weather conditions are to be performed by 2015.

The peer review team recommended implementing appropriate early warning systems. But only investigations of improved early warning systems are currently required (deadline 2013).

If **loss of off-site power** occurs, power is to be supplied by emergency diesel generators (EDG) [6]. Most of the emergency diesel generators (EDG) depend on seawater cooling, and will fail, if the ultimate heat sink fails. To cope with the situation in which all EDGs fail, gas turbines (GTs) are installed as alternate AC power sources. But the GTs are in most cases not fully protected against external hazards (e.g. earthquake) and thus could fail in case of an external event.

The ultimate heat sink (UHS) removes heat from the primary cooling circuit and other vital systems necessary to avoid a core melt accident. In case of a **loss of the ultimate heat sink** , fuel damage can occur in the reactor core and/ or spent fuel pool quite rapidly. None of the Swedish BWRs has an alternate UHS. The PWRs Ringhals-2, -3 and -4 have the option to release residual heat to the atmosphere via the steam generators. However, this procedure is dependent on the water sources available for the auxiliary feed water system, and is thus, limited.

All in all, there are several weaknesses that could result in the total loss of power supply (station black-out SBO) and loss of heat removal, but the time to prevent fuel damage in such situation is very short:

- At the Forsmark NPP, all EDGs are dependent of the sea-water cooling and thus loss of UHS (e.g. by blocking of the water intake channel) all EDGs are expected to fail. The gas turbine (GT) could not withstand an earthquake. Without power supply, for Forsmark-1,-2 damage to the fuel is calculated to be unavoidable after 35 minutes, for Forsmark-3 after 1 hour.
- For Oskarshamn-1, two EDGs are cooled by sea water and two by a roof-mounted air-cooling system. However, it is possible that the cooling system could be covered in snow and the capacity of the system might be reduced. Without power supply, fuel

[5] If no snow removal takes place, a collapse of the buildings could cause damage to the fuel.

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

damage in the reactor core is calculated to occur within 3 hours. In case of an earthquake the emergency condenser is assumed to be unavailable, damage to the fuel is calculated to begin within 1 hour.

- For Oskarshamn-2, two GTs and two EDGs serve as power supply in case of loss of off-is site power. None of them is seismically qualified. Without power supply, fuel damage in the reactor core is calculated to occur after around 2 hours.
- 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. Without power supply, fuel damage in the reactor core is calculated to occur after around 1 hour.
- In case of loss of off-site power, manually action for Ringhals-1 is necessary to connect to the GTs. Without power supply, fuel damage becomes unavoidable after approximately 16 hours for Ringhals-1 and after approximately 9 hours for Ringhals-2,-3,-4.[7]
- In case of loss of UHS, fuel damage becomes unavoidable at Ringhals-2 after 11 hours, and Ringhals-3,-4 after 8 hours. But if manual actions are delayed damage to fuel will be unavoidable within 2 hours.

However, to prevent a station black-out (SBO), the robustness of the on-site, off-site power and alternative supplies and corresponding power distribution systems is only to be evaluated by 2014.

The EC recommended the reducing of the common cause of failures in the EDGs, this issue is not addressed directly in the NAcP [EC 2012].

The robustness of the DC power supplies and corresponding power distribution systems (including batteries discharge time and the capabilities to recharge batteries) is to be evaluated by 2014.

If all power supply fails, only mobile diesel generators (DGs) can be used. However, the stress tests revealed that the capacity and number of mobile units are insufficient, especially when several reactors are affected simultaneously.

The fact finding team underlined needs for the additional mobile power resources with fixed connection points, as well as increased robustness of existing power sources. However, the NAcP asks only for investigations: the robustness of existing mobile power supplies, pumps and air compressors as well as the need for additional mobile devices with prepared quick connections, procedures, and staff training is to be evaluated and reassessed by 2015.

In the event of a total loss of power (SBO), there is no way to supply water to the reactor pressure vessel (RPV) of the BWRs. The Swedish strategy for dealing with a core melt in BWRs is to let the core debris fall into a large volume of water in the lower regions of the containment. Since the strategy is somewhat unique, the international research related to the special phenomena associated with this strategy is fairly limited. There are still some open

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

issues identified related to steam explosions which could occur when the core melt interacts with the water and the coolability of the core debris in the containment. Both issues could result in a containment failure and thus in a major radioactive release.

Alternative means of cooling and residual heat removal for the reactor core as well as alternative means of cooling the safety systems will be evaluated and reassessed by 2015. Furthermore the fundamental design principles of an independent core cooling system for injection of water to the reactor pressure vessel to handle SBO are to be defined by 2013; however, no decision about the measures are made nor the schedule for implementing any of the necessary measures set.

In case of a total loss of power (SBO) or loss of ultimate heat sink (UHS), no system is currently available for cooling the spent fuel pools (SFP). The only usable source for the preparation of make-up water necessary for the pools is fire fighting water. Manual actions must be performed before the onset of harsh conditions (humidity, temperature, radiation) in the spent fuel area. The installation of permanent pipes for make-up water from a protected location is to be considered by 2014. Instrumentation for measurement of necessary parameters in the spent fuel storage (water level, temperature) is to be investigated by 2014.

The evaluation and reassessment of alternative means of cooling for the spent fuel pools is to be done by 2015.

Despite the fact, that none of the Swedish NPPs is able to cope with an accident at two or more units simultaneously SSM does not address this issue adequately. A thorough plan for managing several, simultaneously affected units (including staffing and procedures) is to be developed not earlier than 2014. The effects of simultaneous events affecting all reactors at the site are to be investigated by 2015.

Measures for **severe accident management** (SAM) were introduced in Swedish NPPs in the 1980s; 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. However in most cases the schedule for the implementation of necessary measures is not set. It will take at least eight years to remedy the known weaknesses.

The peer review team identified several areas for further safety improvements (i.e. the need of measures) including multiple unit accidents; long term performance of filtered venting system; the treatment of hydrogen outside the containment area, including spent fuel pools (SFP); enhanced monitoring of parameters in SFPs; enhancement of severe accident management guidelines (SAMGs) for all plant sites; training and drills for extended scope of SAMGs.

The fact finding team pointed out: The Ringhals NPP is advised to reflect more explicitly in the action plan for the areas for improvements listed above, and demonstration of feasibility of SAMGs under harsh radiological situations and severely damaged infrastructure. This will also apply for Forsmark and Oskarshamn NPPs.

After and during a core melt accident, the filtered venting system aims to capture the majority of the radioactive substances. 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. However, necessary back-fitting measures are not required yet, only the reassessment is to be done by 2014.

Furthermore, at Oskarshamn-1,-2 the performance of the common system for filtered venting (which is probably not sufficient in case of an accident that affecting both unites) is to be investigated by 2014.

The risk of hydrogen leakage to reactor buildings in the BWRs has not been dealt with sufficiently, thus hydrogen explosions are possible. Hydrogen explosions can cause damage to concrete buildings, as happened in Fukushima. The possibilities and consequences of hydrogen accumulating in the reactor building and suggestions for necessary instrumentation and management are to be investigated by 2014. Furthermore the handling of hydrogen in a long-term perspective in the containment area has to be improved; analyses for this issue are to be performed by 2014.

There are no SAM measures in place for the loss of the containment integrity. A containment area failure leads to radioactive emissions that can affect regions some hundreds of kilometres away. Strategies for managing loss of containment integrity are to be developed by 2014.

To prevent a severe accident or to mitigate its consequences, a lot of further actions are necessary, however only evaluations and reassessments are required by SSM:

- The reassessment of the integrity of the primary system (including the definition of technical and administrative measures) is to be done by 2013. This especially includes reassessments of the primary pump seal for the PWR units.
- The reassessment of the integrity of the spent fuel pools (including the definition of technical and administrative measures) is to be performed by 2013.
- The use of severe accident mitigation systems as a heat sink is to be assessed by 2015.
- The accident management programmes (emergency operating procedures and severe accident management guidelines (SAMGs) for all plant states including spent fuel pools and multi-units events are to be evaluated by 2014.
- The training and drills for this extended scope of accident management (including multi-unit accidents under conditions of infrastructure degradation) are to be considered by 2014.
- The risk of criticality and/or re-criticality is to be reassessed by 2014. Furthermore the strategies for handling re-criticality, both for detection and countermeasures are to be reassessed by 2014.
- The instrumentation and monitoring systems to ensure reliable and adequate monitoring and measurements of essential parameters in the plants (including the spent fuel pools) is to be reassessed by 2015.
- The operability and habitability of the main and emergency control rooms as well as the emergency control centre are to be reassessed by 2013.
- The accessibility of important areas at the site and inside the reactors units during accident scenarios, especially following natural phenomena and other events is to be evaluated and reassessed by 2015.
- The necessary resources (including personnel and equipment) to handle prolonged extreme situations as well as the need and possibility for external support is to be evaluated by 2015.
- The need for means to manage large volumes of contaminated water is to be investigated by 2015.

5 Action Plans of the Operators

On 15 September 2012, the Swedish regulator SSM published the operator´s actions plans for the remedy of the deficits found in stress tests [SSM 2012a]. A short glance to actions plans of the operators shows:

Ringhals NPP: The main strategy of the operator is to introduce flexible mobile systems to prevent a severe accident in case of loss of power supply. 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 a review of instructions for severe accident situations (e.g. regarding refuelling of diesel in the exiting mobile units).

After having visited Ringhals NPP in September 2012, the ENSREG fact-finding team concluded: 'The plant is advised to update the action plan taking into account the full set of ENSREG recommendations. The plant and SSM should establish the processes to ensure that the plan is implemented in accordance with the established schedule, and in particular that the important safety modifications will be implemented in the near future [ENSREG SE 2012]'.

Forsmark NPP: 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 enhance 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 NPP: 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: 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.

The operators show 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.

6 Weaknesses the Swedish NAcP Ignored

Safety culture

In July 2009, the Ringhals NPP was placed under special investigative measures by the Swedish Radiation Safety Authority (SSM) to address the shortcomings in safety culture after a series of failures jeopardising reactor safety since 2005.

In May 2011, a short circuit in a vacuum cleaner forgotten in the containment area caused a fire[8]. The fire generated a substantial amount of ash that was difficult to remove. But the cleaning work revealed a worrisome sloppiness: old scrap from welding work was found in important safety systems (containment sprinkler systems) at Ringhals-2 and later in Ringhals-4. Comprehensive modernisation work was conducted at those units in the 1980s and 1990s and it is possible the scrap had been there since then. That the scrap was not detected earlier is alarming and shows that the safety systems were not tested properly over many years. Checking and maintenance of safety systems is 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. Obviously the dangerous situation at Ringhals NPP has not changed sufficiently. On 22 November 2012, SSM announced it would continue its special oversight [NW 29/11/2012].

Recently, on 20 December, 2012, the Swedish Radiation Safety Authority (SSM) also put the Oskarshamn NPP under special oversight as a result of problems at the plant. SSM made this decision because it saw too many deficiencies in the organization, how they were handling safety issues in a lot of different areas. Oskarshamn-1 has been almost continuously offline since 30 October, 2011 because of a variety of problems including damage to the high pressure turbine. The backup diesel generators failed to start as they should have 25 times in a row during testing [NW 21/02/2013].

Oskarshamn-2 was taken offline in early December 2012, under order from SSM to shut the unit immediately for safety reasons. According to the safety regulations[9] which took effect already in 2005, the operator OKG should have replaced the two existing backup diesel generators and installed two additional diesels by the end of 2012, but OKG asked for and received an extension until December 2014 to complete the work [NW 12/13/2012]. However, SSM ordered OKG to perform maintenance and testing on the backup diesel generators. SSM underlined this work should have been done without SSM having to issue the order [NW 21/02/2013].

SSM's oversight decision means that plant management must file special reports with the agency and meet with regulators after those reports are submitted. SSM will also conduct special inspections at the plant. In addition, after any planned or unplanned shutdown, OKG must get permission from SSM before a reactor can be restarted. The special oversight is of indefinite duration. By April 1, OKG had to submit a report on its internal quality control audit system and how it will be improved [NW 10/01/2013].

SSM underlined, that having two plants under special oversight at the same time puts quite a

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[8] The management decided to start a containment pressure test three days earlier than scheduled, but forgot to inform the personnel.

[9] The regulations SSMFS 2008:17 and the general advice on their interpretations entered into force on 1 January 2005. A significant share of identified measures has been implemented, but there are also a lot of measures remain to be performed at all units, but especially for Oskarshamn 2 and Ringhals 2.

lot of pressure on SSM and its resources. There is a risk to focus on the oversight and take away resources from other things [NW 10/01/2013]. This statement is very worrisome regarding the considerable amount of necessary work resulting of the stress tests process.

Oskarshamn and Forsmark NPPs: In October 2008, a routine control at Oskarshamn-3 turned up a control rod that had broken off. On closer inspection other rods were found to be cracked.[10] An investigation ordered by the safety authority found cracks at Forsmark-3, as well. Both the Oskarshamn and Forsmark NPPs have repeatedly been faulted for poor safety routines.

Forsmark NPP: In January 2007, an internal document revealed safety concerns at Forsmark NPP. A report described a poor safety culture among staff. 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, but the discovery of the design fault was a shock to the Swedish nuclear industry. The very old reactors with similar systems (Forsmark-2, Oskarshamn-1,-2) were shut down as a precaution. Changes have been made but only to protect against similar conditions. The stress tests revealed that the safety systems remain vulnerable in case of lost of power supply.

Power uprates

In parallel with necessary modernization programs, power uprates have been conducted or planned at nearly all Swedish reactors during the period 2005-2015. In general, power uprates caused unexpected failures in safety systems that could aggravate accident situations. Power uprates could 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 considerably higher.

The experience in Oskarshamn-3 has shown the occurrence of several unexpected deficiencies 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. In 2005, a project for a power uprate under licensed safety (PULS) was initiated. The goal was to achieve around a 30% increase in thermal power so that the electric power could be increased to 1450 MWe, as well as to extent the plant´s operation time to 60 years. This was approved by SSM in April 2010. The power uprate project was completed in December 2009, but during a test period a number of deficiencies were detected. Up to now, deficiencies related to the power uprate occurred in August 2012 when a defected valve in a system controlling the water influx to the reactor vessel caused a standstill.

At Oskarshamn-2, a project to extend the operation time to 60 years and to increase the power began in 2007. The project completion is expected in 2015. The uprate, and a new turbine will increase the unit's generating capacity by almost 38%. Thus, even more unexpected problems during normal operation and accident situations have to be expected compared to Oskarshamn-3.

Power uprates planned for Forsmark-1 and -3 have been postponed; the units had been

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

scheduled for power uprates in 2011 and 2014, respectively. It is necessary to develop a solution for issues with high-pressure turbine control valves that caused problems during similar work at Forsmark-2 in 2010.

Ringhals-3 applied for a major uprate; in May 2009 SSM approved test operation at 1045 MWe. A further uprate to 1105 MWe is envisaged. Ringhals-4 had a 30 MWe uprate to 935 MWe following the replacement of its low pressure turbines in 2007. Exchange of high-pressure turbines and steam generators in 2011 and other work is expected to yield a further 240 MWe [WNA 2013].

Ageing effects (direct and indirect)

The age of the Swedish reactors is between 28 years and 41 years (see table 1). This means that ageing of materials, which starts in general at about 20 years of operation, 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 had not been investigated during the stress tests. 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 accident sequences. 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 stress tests took for granted that all the structures, systems and components (SSC) assessed are in place and without faults, but the operational experience at the Swedish NPPs has shown (see for example above) that this is not the reality.

Terror attacks

Sweden's nuclear utilities have begun preparing to upgrade security and improve routines for finding intruders at their plants after Greenpeace activists broke into Forsmark and Ringhals NPP sites in October 2012. Several persons managed to evade police and security guards at both plants and spend the night on the sites. It was the second time since June 2010 that Greenpeace activists broke into Forsmark. Vattenfall said that "one of the most important things they have learned" from the Greenpeace break-in is that security routines must be improved [NW 22/11/2012].

In addition to the plant modifications, the licensees need to implement measures to comply with the regulator's new regulations on security and physical protection (SSMFS 2008:12). These measures are not described in the NAcPs. However the design weaknesses of the old reactors (particular Oskarshamn-1,2 and Ringhals-1,-2) increase the "success" of a terror attack, but the implementation of for example more stringent measures of passive protection (alarm systems, fences, and video surveillance) at nuclear sites cannot compensate these facts.

An airplane crash is not required 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 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.

7 Conclusions

The evaluation of the Swedish NPPs in light of the Fukushima accident, and in accordance with the ENSREG stress tests, has revealed a number of shortcomings. But the national action plan (NAcP) does not aim to remedy theses weaknesses immediately. The next years will be a prolongation of the status quo. Almost all planned "actions" of the Swedish NAcP are more or less only investigations that are scheduled to be finished by the end of 2014 or 2015. The envisaged deadline for the implementation of resulting back-fitting measures is 2020. Obviously the Swedish Nuclear Authority (SSM) and the operator plan to have the Swedish NPPs operating for eight more years with the known 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), reinforcement is ongoing. However, the earthquake risks are not assessed according to the latest international standards. Thus, also after finishing the back-fitting measures, the protection will not be adequate. The earthquake resistance at Forsmark-3 and Oskarshamn-3 is probably also not sufficient.

The stress tests pointed out that for the Ringhals and Forsmark NPPs the flood protection is inadequate, **flooding** events could cause core melt accidents at these NPP sites. Obviously neither the operator nor the regulator is aware of the flooding hazard. The design basic flood (DBF) is not calculated according to the latest international standards. Furthermore, the NAcPs does not comply with the ENSREG recommendations of re-calculating the flooding hazard.

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

Should an external event affect all units simultaneously, staff at the NPP will not be able to cope with a severe accident at all units.

Currently, there are several design shortcomings regarding the prevention of **loss of power.** 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. In case of loss of power, the staff have only a very short time span to prevent core melt accidents with insufficient mobile devices. According to the stress tests results this is nearly impossible.

All Swedish NPPs are dependent on sea water as the ultimate heat sink. Any problem with the ultimate heat sink (e.g. blocking of the water intake) will affect all units at the site. It seems that SSM does not aim to remedy this situation. The implementation of an independent alternate heat sink (e.g. a well), which could improve the situation to a certain extent, is not required by SSM.

Currently, measures for **severe accident management** (SAM) to mitigate major releases of radioactive substances 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. This might result in very serious consequences - large radioactive releases from the reactor cores and the spent fuel pools.

The operators presented the use of mobile pumps or diesel generators as a satisfying solution to compensate deficiencies of the safety systems. Up to now, the regulator SSM has not required appropriate safety improvements.

In general, there are two different possibilities for operator and nuclear authorities to remedy.

The stress tests revealed: a quick response, but without any guarantee that the measures are sufficient, or comprehensive back-fitting measures including thorough evaluations of possible hazards and protections measures, but this will take about ten years.

However in Sweden, neither a quick response nor comprehensive plant modifications are envisaged.

The safety of the Swedish NPP relies heavily on mobile equipment, which is a cheaper solution compared to comprehensive plant modifications. But under severe accident conditions, it is very unlikely that the mobile equipment can be put to work as quickly as necessary; to rely to such a large extent on manual actions in light of the consequences of a severe accident is irresponsible.

Limited backfitting measures do not significantly improve the safety level because they cannot compensate the increasing threat of hazards (e.g. by climate change) and of ageing effects. Furthermore, experience shows that back-fitting measures could cause new faults (e.g. because of defective mounting, forgotten scrap etc.).

More expensive, but more effective measures are the implementation of a new independent core cooling system, a diversified alternate heat sink to ensure 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 core melt accidents, such measures should be implemented as soon as possible, but SSM does not require any of these measures yet.

In October 2012, TEPCO admitted that the company had failed to prevent the Fukushima accident, reversing its earlier statement that the accident could not have been foreseen. The management assumed a severe accident was extremely unlikely in Japan, and feared that retrofitting safety systems would increase anxiety among the public; it was also feared that safety retrofitting would require a costly shutdown period [NW 18/10/2012].

In the Sweden the situation is similar: the risk of natural hazards exists, but the operators insist on the low probabilities to avoid high investments and anti-nuclear activities of the public.

The stress tests have identified a number of areas of improvement, and 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. In particular, because, there are further safety concerns that are out of the scope of the stress tests, but which are obviously known by SSM.

Shortcomings of **safety culture** have been a serious problem for many years. This problem results in several undetected faults that could cause a partial or total failure of safety systems in course of an accident. It is worrisome that problems with safety culture persist, but SSM failed to take appropriate measures. The only reaction is to place the plants under special oversight. But on the one hand this measure does not change the dangerous situation sufficiently, and on the other hand puts quite a lot of pressure on SSM and its resources.

Ageing of materials is a safety issue in all units, but especially for the oldest reactors (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. But the operators aim to extend the operation time to 60 years.

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

Besides natural hazards, also **terror attacks** could cause a severe accident.

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 of heat removal is relatively 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 relatively high**.

In view of the existing risks, it is not acceptable to have the plants on the grid in their current status for many more years, while evaluations and assessment are under preparation. The very obvious solution – permanent shut down – needs to be considered.

All Swedish units should stop operation as soon as possible for comprehensive backfitting measures to be carried out or to shut down permanently.

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