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Safety and Radiation Protection at Swedish Nuclear Power Plants 2006

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SKi

Summary and conclusions

The incident on July 25

Safety related problems in the electric systems of the Forsmark 1 reactor were the dominant event in Swedish nuclear power plants in 2006. The incident has had a significant impact on our attitude towards the reliability of how safety systems function both in Sweden and abroad. In connection with SKI's review of the incident it was found that the company's management system was not implemented correctly in conjunction with technical changes and tests. How well a licensee follows its quality assurance system is a important indicator of its safety culture.

As a result of the deviations which were discovered in Forsmark SKI has reconsidered its previously positive evaluation of safety related activities at the utility. This has amongst other things led to SKI placing Forsmark under intensified "special supervision"[1]. In a complementary recommendation to the government SKI on November 1 2006, SKI informed the government that in the event of approval being granted to Forsmark Kraftgrupp's application for thermal power increase, SKI does not intend to start the safety review, and thus will not approve trial operations at the increased thermal power whilst they are under special supervision.

The incident on July 25, 2006, did not result in any releases of radioactive substances to the environment.

Large safety related modernisations planned

The Swedish nuclear industry is in a very intensive period. It could be the most intensive period since the construction era of the 1970s. Extensive safety related modernisation are going to be carried, predominantly as a result of SKI's regulations, SKIFS 2004:2, concerning the design and construction of nuclear power reactors. These regulations are based on recent operational experience and the results of safety analyses, the results of research and development projects, as well as the most recent editions of the IAEA safety standards and industrial standards that were used during the construction of the plants. The regulations were intended to put pressure on the utilities and steer their modernisation programmes so that all Swedish nuclear power plants meet modern safety standards for the foreseeable future. This is in addition to the safety requirements that they already meet.

The new regulations require that a variable number of extra analyses and technical changes be implemented for the plants. These changes need to be specified, projected, purchased, safety evaluations performed and installation carried out, as well as being documented by the plant and included in the safety analysis reports. This is a process that will take several years to complete. It is important for the safety of the plant that the licensee has sufficient time to carry out the improvements so that high quality is ensured throughout the process. Therefore the Board of SKI has decided that the necessary measures to comply with some of the regulations

[1] Special supervision is normally used in connection with trial operations of new plants or after major changes to existing plants. Special supervision can also be enforced under other circumstances with safety significance. Special supervision involves an intensified inspection regime by SKI and additional reporting requirements for the plant. In some cases reporting is associated with the requirement to obtain SKI's approval.

must be completed at the latest by dates determined by SKI. The reason for this decision is the understanding that the plants will meet the current regulations for operation during the time required to carry out the modernisation programmes.

Initially licensees had until January 1 2006 to present reactor specific plans to comply with the new regulations. At the end of 2005 SKI published its decision on a time schedule for Forsmark. Corresponding decisions for the other plants were published on May 10, 2007. Some of measures are already completed, others are under way, and many more are planned. The programmes will be completed in 2013.

During 2006 significant measures have been taken by the plants to comply with SKI's regulations SKIFS 2005:1, concerning the physical protection of nuclear plants. These regulations came into effect, with some exceptions, on January 1 2007, and contain more stringent requirements for technical, organisational and administrative measures to prevent unauthorised access, sabotage or other such incidents.

Thermal power increases

The permitted thermal power for a reactor is stipulated in its license. Any increase requires permission from the government. Several of the Swedish reactors increased their thermal power during the 1980s. Further increases are now planned. The government has granted permission for three reactors (Ringhals 1 and 3, and Oskarshamn 3) to increase their thermal power and SKI has given permission for trial operation at the higher effect for two of these. Forsmark Kraftgrupp AB has applied for permission to increase the thermal power in reactors Forsmark 1 – 3. SKI has submitted its statement concerning these applications, but the government has not yet made its decision, amongst other things because the environmental impact evaluation is not complete, and also because Forsmark Kraftgrupp AB is under special supervision by SKI. Ringhals AB has announced their intention to apply late in 2007 for permission to increase the thermal power in Ringhals 4. There are also plans to increase the thermal power in Ringhals 1 in addition to the small increase which has already been approved by the government. OKG Aktiebolag has announced that it intends to submit an application to SKI for permission to increase the thermal power in Oskarshamn 2. The application is expected at the end of 2007 or the beginning of 2008.

In connection with the investigations SKI has performed in support of applications to increase the highest permissible thermal power output SKI has found that the principles for determining the thermal power during reactor operation need clarification. SKI has therefore imposed new requirements on the plants.

Overall evaluation of the status of the plants

The safety level of the plants is maintained at an acceptable level. There are no known deficiencies in the barriers which could result in discharge of radioactive substances in excess of the permitted levels. SKI has in its regulatory supervision during the year noted that there is, to varying degrees, the need for further improvement in the management, control and following up of safety work at the plants. This has been pointed out to the licensees, and in some cases SKI has imposed requirements that improvements be made.

At the Barsebäck plant all the fuel has been removed from Barsebäck 2. Both reactors have thus gone into the operational status “service operation”, and work has been started to adjust the organisation to the new situation.

At the Forsmark plant in addition to the incident that occurred on July 25 a number of incidents have occurred which indicate that there are deficiencies in quality assurance and in the attitudes to safety. Many years of production with very few disturbances have now ended. As a result of this SKI has planned special regulatory actions to follow up that the measures taken by the company to correct these problems have the necessary effect.

At the Oskarshamn plant extensive measures are being taken to comply with the more stringent regulations concerning physical protection. Oskarshamn 1 was shut down for a long period during the second half of 2006 to refurbish the electrical system since the unit had a similar construction to that Forsmark 1 of the uninterrupted electrical supply system. The alterations were complete by the end of January 2007 and SKI could grant permission for the plant to resume operation.

At the Ringhals plant extensive efforts are also being undertaken to comply with the more stringent safety requirements as well as the new regulations regarding physical protection. The control and monitoring systems of Ringhals 1 and 2 are being rebuilt. During 2006 preparations were made for trial operation of Ringhals 1 and 3 at the higher thermal power levels. SKI gave permission for the trial operations of both reactors in the first half of 2007. In November an explosive fire occurred in a transformer outside the containment of Ringhals 3. The reactor was scrammed and all the safety systems operated as they should.

Radiation protection status

Radiation protection of personnel at the nuclear power stations ensures that the individual and collective doses are maintained at a level which is comparable with international levels for the actual radiation environments and the work performed. No serious incidents resulting in the ingestion of radioactive substances or high does to personnel have been reported.

Radioactive releases from the plants are estimated to give doses to the critical group that are less than one hundredth of the current limit. For a number of years Forsmark has however had recurrent problems with the measurement of airborne radioactivity in particular. A review carried out by SSI has indicated that this is due to a combination of technical and organisational problems. On SSI’s initiative, FKA has developed a programme to address these problems and correct the erroneous measurement system.

In connection with the environmental impact evaluation of the thermal power increases the application of BAT after the increases has been assessed. SSI has imposed requirements that measures be taken to decrease the release of radioactive substances at the latest when the power increases come into effect, and also that the amounts released do not increase. The environmental courts in Vänersborg and Växjö have in their judgements accepted SSI’s point of view, and have stipulated that measures must be taken which will lead to a reduction of the total release of radioactive substances.

With regard to the requirements concerning submittals and reporting in accordance with SSI’s regulations, all the facilities comply with these regulations. The exception is Forsmark which on a number of occasions in connection with the measurement of release of radioactive substances has reported operational disturbances late.

SSI considers that the plants have shown an open attitude when reporting faults and incidents. The underlying reasons for the reported events have in the majority of cases been due to inadequate or non-existent instructions, as well as insufficient control that the instructions are followed. The plants have dealt with the events in a satisfactory manner and have described measures to avoid their recurrence.

Nuclear safeguards and waste management

During 2006 SKI as well as the international atomic energy organisation IAEA and Euratom have performed inspections to control how nuclear safeguards are managed by the nuclear power stations. In all 81 inspections have been carried out. Nothing has been found during these inspections to indicate that there are any deficiencies in the nuclear safeguard activities.

SKI and SSI consider that the treatment, interim storage and preparations for final disposal of nuclear waste have been carried out during the year in accordance with their regulations.

Emergency preparedness

SKI and SSI have throughout the year continued to follow and promote the development of emergency preparedness at the plants. The questions which have been in focus during the year are the efforts addressing training and the transfer of information to rescue organisations and the authorities that would be involved in the event of an emergency. SSI has also followed up how their new regulations, SSI FS 2005:2, are being complied with. The authorities note that emergency preparedness at the plants has improved, but that there is a need for further measures.

Premises and evaluation criteria

The Act (1984:3) on Nuclear Activities stipulates that the holder of a license to conduct nuclear activities has the full and undivided responsibility to adopt the necessary measures to maintain safety. The Act also stipulates that safety shall be maintained by adopting the measures required to prevent equipment defects or malfunction, human error or other such events than could result in a radiological accident.

In a corresponding manner, the Act (1998:220) on Radiation Protection stipulates that any person who conducts activities involving radiation shall, according to the nature of the activities and the conditions under which they are conducted take the measures and precautions necessary to prevent or counteract injury to people, animals and damage to the environment.

Against this background the authorities shall in their regulatory activities clarify the implications of the licensees' responsibility and ensure that they comply with the requirements and rules for these activities and also achieve a high degree of quality in their safety and radiation protection work.

Basic principles for nuclear safety and radiation protection

Safety at Swedish nuclear power plants must be based on the principle of defence in depth in order to protect humans and the environment from the harmful effects of nuclear operations. The defence in depth principle, see Figure 1, is internationally accepted and has been ratified in the International Convention on Nuclear Safety and in SKI's regulations, as well as in many other national nuclear safety regulations.

Defence in depth assumes that there are a number of specially adapted physical barriers between the radioactive material and the plant staff and the environment. In the case of nuclear power reactors in operation the barriers comprise the fuel itself (fuel pellet), the fuel cladding, the pressure-bearing primary system of the reactor and the reactor containment.

In addition the defence in depth principle assumes that there is good safety management, control, organisation and safety culture at the plant, as well as sufficient financial and human resources and personnel who have the necessary expertise and who have the right conditions for their work.

Defence in depth also assumes that a number of different types of engineered systems, operational measures and administrative procedures exist to protect the barriers and maintain their effectiveness during normal operations and under anticipated operational deviations and accidents. If this fails, measures should be in place to limit and mitigate the consequences of a severe accident.

In order for the safety of a facility as a whole to be adequate, an analysis must be performed to identify which barriers must function and which parts of the different levels of the defence in depth system must function during different operational conditions. When a plant is in full operation, all barriers and parts of the defence in depth system must be functional. When the plant is shut down for maintenance, or when a barrier or part of the defence in depth system has to be taken out of operation for other reasons, this must be compensated by other measures of a technical, operational or administrative nature. Thus the logic behind the defence in depth principle is that if one level fails, the next level will take over. A failure of equipment or a manoeuvre at one level, or combinations of failures occurring at different levels at the same time must not be able to jeopardise the performance of subsequent levels. The independence between the different barriers of the defence in depth system is essential in order to achieve this.

In Sweden radiation protection is also organised according to internationally accepted principles. These are based on the balance between usefulness and risk, and are:

the use of radiation must be necessary, that is to say, no unnecessary applications are permissible
the use of radiation must be optimised, that is to say, radiation doses must be as low as reasonably possible
doses to all individuals shall be below the doses levels stipulated by SSI.

The requirements that SKI imposes on the different levels of the defence in depth system are described in SKI's regulations and the associated general recommendations. Correspondingly SSI has also stipulated radiation protection requirements in its regulations. Together these legal documents comprise the essential premises and criteria for the evaluation presented by SKI and SSI in this report.

Necessary Conditions

- Several physical barriers successively placed between the radioactive material and the plant personnel and environment.
- Good safety management, control, organization and safety culture.
- Adequate financial and human resources as well as personnel with the necessary expertise and who are provided with the right conditions for work.

Level	Purpose	Main means
1	Prevention of abnormal operating occurrences and failures.	Robust design and high construction, operation and maintenance quality.
2	Control of abnormal operating occurrences and detection of failures.	High quality of the supervision and regulatory control of the facility through technical systems and administrative measures.
3	Control over conditions that can arise in connection with design basis accidents.	Efficient safety systems and emergency operating procedures.
4	Control over and limit of conditions that can arise in connection with severe accidents.	Technical measures prepared in advance and an efficient accident preparedness at the facility.
5	Mitigation of consequences in connection with the release of radioactive substances.	Measures prepared in advance for effective information to and protection of the population in the vicinity of the facility.

Figure 1. *The necessary conditions for a defence in depth system and the different levels of the system*

1. Operating experience

The event in 2006 which received considerable attention and put the focus on safety culture as well as receiving exceptional international interest was the incident in Forsmark 1 on July 25. SKI carried out a so-called "RASK-investigation"[2]. These investigations are implemented by sending an SKI analysis group to the specific site to obtain an independent picture of the incident, the sequence of events and the measures taken by the licensee during the first one to two days after the incident, or other serious situations. Two other RASK-investigations were carried out in 2006. In chronological order the following were investigated:

Errors in the equipment to determine the thermal power level in Forsmark 1.
The electrical disturbance in Forsmark 1 on July 25 which resulted in the malfunction of two of four safety systems.
Leakage from the containment in Forsmark 2, discovered during the restart of the plant after the annual refuelling outage.

During the year six events have be classified as level 1 or higher on the International Nuclear Events Scale (INES). The events are:

Forsmark 1 on July 25, risk for the loss of the battery secured net supply, level 2
Forsmark 2 **Fel! Ogiltig länk.**1
Forsmark 2 fast busbar-transfer failure, level 1
Oskarshamn 2 malfunction of the gas turbine, level 1
Ringhals 3 leakage from the reactor containment, level 1, and
Ringhals 3 loss of the external electrical distribution system, level 1.

These events are described in more detail in the following paragraphs concerning the different power plants.

Barsebäck (BKAB)
Barsebäck 1 has been closed down since 1999. The main task for the personnel working with Barsebäck 1 is to build up knowledge related to decommissioning and to document the status of the unit prior to its decommissioning as well as to support Barsebäck 2 (B2) with resources. As a result of a government decision, Barsebäck 2 was shut down on May 31, 2005. By June 10, 2005, the fuel had been removed from the reactor and placed in the fuel pools. Barsebäck 2 has since that date had the operational status "fuel free core". On July 1, 2005, a new organisation was established which was adapted to the closure of Barsebäck 2. The main difference compared to the earlier organisation is the reduction in the number of staff. However the principles for the allocation of responsibilities and safety management are unchanged. Operational measures that have been underway since the final shutdown are periodic testing in accordance with the Technical Specifications (STF) and some tests on systems not covered by these specifications but for which BKAB wants to maintain a good status.

On December 1, 2006, the last fuel from Barsebäck 2 left the site and Barsebäck 2 also transferred to the status "service operations".

[2] Rask Analys av Störningar i Kärnkraftverk (Quick analysis of disturbance in a nuclear power plant)

Since the decision to shut down the plants, BKAB has worked in accordance with a long term plan for decommissioning. In 2006 the highest priority has been to remove as much radioactive material as possible from the plant. BKAB has also had a project to convert the plant so that there is no need for continuous supervision of operations. The long term plan also includes personnel adjustments necessary to ensure that sufficient staff are available with the necessary competence during the different phases of the decommissioning process. At the turn of the year further reductions in staff were effected according to plan, which means that there are currently approximately 30 people involved with the operation of BKAB.

Forsmark (FKA)

Forsmark 1

The year has been dominated by several problems and disruptions.

Forsmark 1 is licensed to operate at 108 % which corresponds to 2928 MW thermal power. In the summer of 2005 Forsmark 1 replaced the low pressure turbines and in mid-March the manufacturer carried out measurements to check their performance. Preliminary results led to the suspicion that the plant was being operated at a somewhat higher power level than the permitted 108 % and SKI was informed of this at the end of March. Early in April the power level was reduced by 1 %. The reason for the erroneous measurements is thought to be connected with flow rate measurement in the feedwater system. SKI performed an incident related inspection, RASK-investigation, to elucidate how FKA had dealt with this situation internally. A week later the power was reduced by a further 1 %. This power level was maintained until coast-down was started shortly before the annual refuelling outage.

The refuelling outage started on June 11 and ended on June 19. Refuelling was the operation that dictated the length of the outage. Since the outage was short, the maintenance and plant alterations were minimised. The outage went well, but there were problems with the isolation valves and detectors for neutron flux measurement in the low power region. During start up there was a scram caused by high level indications in the reactor vessel when the feedwater piping was flushed. Better preparations and improvements to the outage planning are experiences which will be incorporated into the outage next year. The method known as “pre-job briefing” is considered to be very effective. Routines for register control of contractors have worked well. No disturbances were noted as a result of the introduction of this routine. Drug tests gave a couple of positive results. The fuel defect identified earlier was dealt with during the revision.

At 13.20 on July 25, 2006, a short circuit occurred in the 400 kV switchyard at the Forsmark power plant. The reactor power was reduced through a partial reactor scram and the speed of the main circulation pumps was also reduced and transfer made to house load operation for a short period of time, that is to say electricity production for internal needs only. Shortly after this the reactor scrammed. The short circuit resulted in large power transients which were transmitted to several of the plant’s internal electrical systems. Two of the four electrical systems that should, using a battery secured supply, ensure uninterrupted supply to important safety systems, were affected. With the loss of offsite power an automatic signal is given to start the four diesel generators which should provide the reserve power to the plant’s safety systems. All the diesels started automatically. Since they are dependent on electricity from the secured power system to connect and supply their respective trains, two of the diesels stopped. Loss of the secured power supply also resulted in measurements, registration and monitoring possibilities partially disappearing in the control room.

After 22 minutes the operators manually reconnected offsite power to the two subs which should have been fed by the two diesels that had stopped. After about 45 minutes they confirmed that the operational condition warm shutdown was stable, that is to say that the reactor was subcritical and the reactor temperature was in excess of 100 ^{o}C.

Altogether the incident meant that important safety related equipment did not function because of a common cause failure, CCF. In addition the incident had not been foreseen and was therefore not an analysed postulate in the plant's safety analysis report. Throughout the incident there was sufficient core cooling and the reactor pressure vessel was not subjected to non-design base loads.

SKI was informed of the incident within one hour of the scram.

At that time Forsmark 3 was in full power operation and was not affected by the incident since it was connected to another switchyard. Forsmark 2 was shut down for its refuelling outage.

A RASK-investigation was carried out to determine how FKA had coped with the situation and to enable SKI to obtain an independent picture of the sequence of events and how FKA had dealt with the events. The incident has been classified as a category 1 incident according to SKIFS 2004:1 which requires that extra investigations be performed and that SKI must grant permission for the reactor to restart. The incident was classified as INES-2 on the seven-level international INES scale. The reactor was restarted on September 29 after SKI had granted permission.

SKI's decision of September 29 meant that the whole of FKA was put under special supervision, which in this case means extra requirements concerning daily reporting, submission of internal decisions to restart the reactor prior to the actual restart, as well as increased regulatory effort by SKI. The decision is in effect until further notice.

In connection with a turbine load shedding test on October 11 Forsmark 1 could not reset the partial scram because some relays were set wrongly. Whilst trying to remedy this, the control rods started to enter the core and the operators scrammed the reactor manually. One lesson from this event is that tests following plant modification should be more comprehensive, since this event was the result of a plant modification and was not detected in connection with the accompanying tests.

In the middle of December the reactor was shut down for a couple of days to remedy a steam isolation valve which had fastened shut after a routine test. When shutting down the reactor an unexpected power surge occurred since the regulating system for the main recirculation pumps malfunctioned, which resulted in the pumps increasing the coolant flow rate through the core to correspond to full power effect. During the Christmas weekend power was reduced to repair an oil leak in one of the turbine systems.

Forsmark 2 (F2)
The refuelling outage started on July 16, and was the longest and most extensive in Forsmark 2's history (78 days) and meant that most of the measures taken in Forsmark 1 in 2005 were implemented in Forsmark 2. The outage went well, but was extended because of the incident in Forsmark 1 on July 25. Major plant modifications had dictated the outage time for Forsmark 2, amongst other things the replacement of the low pressure turbines, rebuilding the 6 kV switching system and remodelling the electric panel in the central control room, CKR,

installation of a cyclone filter to trap particles in the feedwater system, as well as replacement of the upper toroid of the reactor containment.

As a result of the incident in Forsmark 1 on July 25, and because the construction was identical in Forsmark 2 the Forsmark 1 incident was classified for Forsmark 2 as a level 1 on the seven level international INES scale.

While restarting the reactor after the refuelling outage a neutron flux detector short circuited and gave the maximum reading, 500 %. This made such a large contribution to the mean level measurement that it exceeded the level for connection from the low power monitoring to full power operation. This meant that monitoring of the low power region could not initiate safety measures. Forsmark 1 and Forsmark 2 have now taken compensatory measures to guarantee the safety function in the event of a short circuit in the neutron flux detectors in the low power region.

During the start up after the outage of 2006 an alarm was activated for a leak in the reactor containment of Forsmark 2. Subsequently the leak was identified as coming from defects in the upper toroid of the reactor containment which were introduced in connection with the replacement during the outage. SKI carried out a RASK-investigation of this event on October 11. The toroid was repaired and SKI required that all test protocols be checked before the reactor could be restarted.

Whilst testing switching between different reconnection alternatives to the 6 kV busbars, faults were found which would have meant that under some transients the automatic switching would not have happened. This fault had not been detected during normal testing. The event was classified as a level 1 on the seven-level international INES-scale.

Forsmark 3 (F3)

The refuelling outage was started on May 28 and ended on June 9, one day later than planned. The extension was due to unplanned measures needed to remedy a leaking valve which was observed during the start up. During the outage apart from refuelling, routine maintenance and inspection of a large amount of equipment was carried out. During a tightness test of a main steam isolation valve an internal leak in excess of that which is permissible was observed. The leak was reported in accordance with regulations and was remedied before upstart.

Tests performed during a planned shutdown in September erroneous connections in the reactor safety system for room surveillance were detected. This showed that there had been deficiencies in the tests which had been performed in connection with rebuilding during the refuelling outage.

On December 7 a 10 kV switch to the main circulation pump supply, HCP, disconnected which resulted in both the pumps supplied from the A-train stopping. The reactor power level correspondingly sank from 109 to 100 %.

The fuel defect that was identified after the refuelling outage developed into a secondary fuel defect in December. The plant was shut down for a few days to replace the defect fuel bundle with a new one.

Oskarshamn (OKG)

Oskarshamn 1 (O1)

On January 24 a scram occurred in Oskarshamn 1. The reason was overfilled floor drains when draining water after a test. The plant went back into operation on January 26.

The refuelling outage started on May 15. It was planned to last until June 4. Some of the work which was carried out in addition to the annual refuelling was service and preventative maintenance to the valves and control rod drive mechanisms. Start up after the outage was started on June 3. During the start up measurements of the phase sequence of the generator were planned. In connection with these measurements two scrams were initiated. Both were caused by the planned measurements on the generator. On the third attempt the measurements were performed without problem, and after that the generator was phased in on June 7.

Analysis following the incident in Forsmark 1 on July 25 showed that the design of the secured net supply in Oskarshamn 1 was similar to that in Forsmark 1 and 2. OKG decided to shut down Oskarshamn 1 and on August 3 it was in the cold shut down operational condition. Following extensive analyses extensive reconstruction was carried out to improve and strengthen the protection of the secured net supply. The plant was restarted on January 20 2007.

Oskarshamn 2 (O2)

The refuelling outage started on August 3, 10days earlier that planned in order to check the situation after the incident in Forsmark 1 on July 25. Apart from refuelling, two large transformers were replaced as well as the main generator and support equipment. Problems with the oil supply to a bearing and problems with a thermocouple in the new generator resulted in delays and the plant became operational again, not as planned on September 15, but on October 1.

At the end of October the plant was shut down for a week in order to complete outstanding measures on the new generator and the malfunctioning of the control rod mechanism indicator as well to repair a small leak in the reactor containment. Between November 17 and 20 there was another short stop to rebalance the generator and carry out other measures because of a steam leak in the turbine system.

In connection with a periodic test on one of the two gas turbines on November 7 a start interlock error occurred. At the same time an alarm for high oil temperature in the generator's main bearing occurred. The start interlock error happened because of a faulty thermocouple. The thermocouple was returned to the manufacturer for a root cause analysis. The event was classified as level 1 on the seven-level international INES scale.

Oskarshamn 3 (O3)

In the middle of March a small fuel defect was indicated in Oskarshamn 3. The fuel defect remained stable until the reactor was shutdown for the annual outage, which started on June 25.

The outage ended on July 7, after the shortest refuelling outage ever for Oskarshamn 3. Apart from short reductions in power because of a main circulation pump which stopped, problems with the safety relief valves and routine tests, the reactor experienced smooth operations until October 28 when a new fuel defect was detected. Oskarshamn 3 achieved a new production record in 2006 of 96.2 % energy exploitation.

Ringhals (RAB)

Ringhals 1 (R1)

On January 1 a steam leak occurred in a pressure relief line to a valve in the feedwater system. In order to repair it, a turbine was taken out of operation and the reactor power was reduced to 55 %. At the end of April there was a hitch when connecting in a measurement instrument which resulted in one of the turbines stopping, loss of supply from the 400 kV switchyard and partial scram of the reactor. After identifying the fault the reactor could be restarted and reconnected to grid in less than two hours.

There were small reductions in reactor power at times during July and August because the seawater coolant temperature was high. On July 12 a scram occurred because of a steam leak which affected the feedwater flow rate. The reactor was restarted on July 14.

The refuelling outage was started on August 25. The planned restart was delayed because of problems with the newly installed safety relief valves. The reactor was restarted on September 28. There was a short stop on October15 for maintenance to the generator. During the restart a change in the power level was observed. The measurement of the feedwater flow rate was investigated and a transmitter was found to be giving erroneous readings.

Ringhals 2 (R2)

During the spring the reactor power was reduced to 98.7 % because an intermediate heat exchanger was taken out of operation since it leaked internally. On two occasions there were problems with the heating system for boric acid injection. These were quickly remedied.

The refuelling outage was carried out between June 20 and July 18 when the intermediate heat exchanger which had been taken out of operation in the spring was repaired. A small leak, about 20 ml/day, was detected from the bottom plate of the reactor containment during the outage. SKI has granted permission for continued operation on conditions that Ringhals reports continuous monitoring of the leak and performed a programme of tests during the autumn of 2006.

Ringhals 3 (R3)

The refuelling outage occurred between May 26 and June 30 and amongst other things the low pressure turbines were replaced. According to the original plan the reactor power level should have been increased to 108 % immediately after the outage. SKI had however had required further revision of the safety analysis report, SAR, before taking the decision to approve trial operation. Thus the thermal power was limited to the original level of 100 %. During the outage a leak from the reactor containment was discovered because a safety isolation valve in a pipe to a pressure gauge had been mounted incorrectly. The event was classified as level 1 on the seven-level international INES scale. The start up after the outage was delayed, amongst other, things because of the trial operation of the new turbines which entailed shutdown to balance them. 100 % was achieved on July 8 but a short circuit in the switchyard required a short shutdown for repair of the isolation switch on July 10.

On November 14 a local transformer exploded and caused the oil which ran out to ignite and the fire spread to the adjoining location of the main transformer. The fire was extinguished within two hours. Since there was loss of power two busbars in the plant which are supplied by the local transformer the connecting diesels started automatically. The reactor scrammed and all the safety systems functioned as expected. When restarting the system it was found that one of the main coolant pumps to one of the turbine condensers and a coolant pump to an intermediate coolant system had been damaged in connection with the short circuiting. After overhauling the electric systems and the replacement of the transformer and the damaged pumps the reactor could be restarted on December 10. The event was classified as level 1 on the seven-level international INES scale.

Ringhals 4 (R4)
On February 24 two valves were given maintenance which required that power was temporarily reduced to 80 %. Under a short period of time there was an error in the control rod indication system because of an erroneous circuit board. There were however alternative indication possibilities and the safety significance was determined to be small. On two occasions a diesel generator was disconnected for short maintenance work. Otherwise operations have been uneventful with the reactor at full power. There is a trend of increasing leakage from the primary to the secondary side of the steam generators which has been observed since the previous refuelling outage. This is being monitored more closely. The leak is however well below the limit. A return to the lower pH-value that had been used prior to the refuelling outage has, in a preliminary evaluation, been deemed to have a positive effect.

A small power reduction, to approximately 95 %, occurred in July because of the high seawater temperature. The refuelling outage was carried out between August 3 and 29 and included amongst other things a helium leak test of the steam generators because of the increased internal leakage during the year.

Problems with damp in a generator resulted in a shutdown between September 3 and 9 to replace the rotor. On September 26 a manual reactor scram occurred due to human error in connection with the test of a safety system. The plant was restarted the same day.

2. Technology and ageing

Requirements for more extensive ageing management programmes at nuclear facilities

The Swedish nuclear power plants are getting older. They were constructed in the 1960s and 1970s. The oldest plant, Oskarshamn 1, was taken into operation in 1972 and the youngest, Forsmark 3 and Oskarshamn 3, were taken into operation in 1985. Different aspects of ageing must therefore be taken into account and ageing phenomenon must be taken into consideration in order for the safe operation of the plants. This is particularly important in the current situation where the licensees are planning to operate several of the plants for longer than they were originally technically designed for, which was approximately 40 years.

Normally ageing management refers to components and building structures which form part of the plant barriers or defence in depth concept. This type of ageing involves a continuous process in which the physical properties change in some way as a function with time or use under normal operating conditions. In order to maintain control over the physical ageing it is therefore necessary for the licensee to be well prepared through well planned preventative measures, such as replacement of components that are sensitive to degradation, extensive monitoring and inspection of the plant barriers and its defence in depth systems, and subsequent mitigation and repair measures in the event that damage or degradation is detected. In addition validated models for the analysis and safety assessment of such components that can be kept in service for a limited period of time despite degradation are essential.

Ageing of nuclear power plants has received more and more attention internationally. In many countries better defined requirements have been enforced for the establishment of ageing management programmes and more systematic management and supervision measures necessary to retain control over problems associated with ageing. SKI has introduced corresponding more stringent requirements concerning ageing management in the regulations SKIFS 2004:1 concerning safety in nuclear facilities. According to the transitional regulations, licensees had until the end of 2005 to prepare a complete programme for ageing management.

A programme for the management of ageing related deterioration and degradation is, according to SKI's regulations, a programme that in a coordinated manner demonstrates how these questions are dealt with at the plant. The programme thus coordinates the plant efforts in other already existing programmes such as maintenance, periodic inspection, and environmental qualification. This interpretation, which is presented in SKI's report concerning ageing management programmes[3], has international support, for example in the guidelines from the International Atomic Energy Agency, IAEA[4], and in the European nuclear regulatory authorities organisation, WENRA, in its document on revised reference levels[5]. This means that a programme for the management of ageing related deterioration and degradation must include all the building structures, systems and components of importance for the safety of the plant.

[3] Ageing management programmes – need and content. SKI report in Swedish. 2006-09-07.
[4] Implementation and review of a nuclear power plant ageing management programme. Safety Reports Series No.15. International Atomic Energy Agency. Vienna 1999.
[5] Harmonization of reactor safety in WENRA countries. Report by WENRA reactor harmonization group. January 2006

In order to obtain sufficient control, management, coordination and following up of the ageing management programme it is necessary that these activities are included in the quality assurance system in a clear manner. This is particularly important since the constituent activities are performed by different parts of the organisation and by different categories of personnel. The overall processes impose specific requirements on coordination, clear lines of authority and responsibility, and so forth. For the same reason it is necessary that the pant safety analysis reports are revised to included information on the organisation and principles for the management and control of the management of ageing related deterioration and degradation.

SKI has in 2006 evaluated the programmes for ageing management submitted by the plants using the principles described above and has found that there is to varying degrees a need for improvements and further effort. SKI has therefore decided to require that the plants make the necessary revisions to both the programmes and the quality assurance systems to ensure effective, comprehensive and appropriate ageing management.

Overall development of degradation and the influencing factors

Mechanical components which are part of the barriers and defence in depth

Extensive replacement of components that have been found to be susceptible to degradation has been carried out by the Swedish nuclear power plants. Many of these replacements have been performed preventatively as more knowledge has been acquired about the causes of the damage and the degradation mechanisms. In other cases the components have been replaced when damaged. In 2006 relatively few new cases of degradation and defects have been reported. Previously identified problem areas have been followed up and analysed.

SKI continuously follows the development of degradation in the mechanical components and building structures that form part of the barriers and defence in depth of the plants. SKI also follows up the programmes for monitoring the ageing of electrical cables and instruments. This work includes both evaluation of the development of the damage overall and for the individual plants. The work also covers efforts to follow up under which conditions the various degradation mechanisms occur.

An overall evaluation which covers all the cases of damage in mechanical components since the first plant was commissioned confirms that the preventative and mitigation measures taken have had the intended effect. This conclusion is valid even after the damage that has occurred up to the end of 2006 is included. As shown in Diagram 1 below, there is no tendency to an increase in the number of defects as the plants become older. The overall evaluation also shows that most of the damage to date has been found through periodic in-service inspection before safety has been affected. Only a small proportion of the defects have led to leakage or more serious conditions as a result of the cracks or other types of degradation remaining undetected.

It is mainly different corrosion mechanisms that have given rise to the defects that have occurred, see Diagram 2. These account for approximately 60 % of the cases with intergranular stress corrosion cracking as the most frequent degradation mechanism followed by flow accelerated corrosion. Stress corrosion cracking is a degradation mechanism that in nuclear systems occurs for the most part in austenitic stainless steels and nickel base alloys when these are exposed to tensile stresses and corrosive environments. The susceptibility of the material to cracking depends partly on the chemical composition, partly on the heat treatment and the metal working processes used during manufacture and installation in the plants. Despite the fact that considerable knowledge of the factors which affect degradation has been built up over the past few decades, this is not sufficient to completely avoid problems or always to predict which of the components will be affected.

Whilst stress corrosion cracking has most often occurred in the primary piping and safety systems, flow accelerated corrosion has been more common in secondary parts such as steam and turbine components. Thermal fatigue, which is the third most prevalent cause of damage (and which is responsible for about 10 % of the damage), has largely occurred in primary piping and safety systems. The positive development, with no increase in the number of cases of damage in mechanical components as the plants become older, requires a continued high level of ambition with regard to the preventative maintenance and replacement efforts. SKI will therefore continue to pressure the licensees to retain this high level of ambition and the preparedness to evaluate and assess damage when it is detected.

SKI also follows up the condition of the reactor pressure vessels. The requirements, specified in SKI's regulations SKIFS 2005:2 concerning mechanical components, partly cover in-service inspection of the material and weldments in the vessel, and partly the recurrent testing of the mechanical properties of the vessel material. The latter involves irradiated samples which are mounted in the pressure vessel being removed in accordance with a specific programme approved by SKI, and then the ductility of the samples is monitored by impact testing which also enables the transition temperature between ductile and brittle behaviour to be determined. These data are then used to establish the highest reactor pressure at different temperatures which is permissible during operation of the reactor. SKI currently sees no tendency to irradiation embrittlement of the material in the reactor pressure vessels.

Reactor containment

Further studies and development work is still necessary in order to achieve adequate monitoring of the ageing related damage that can decrease the safety of the reactor containment and other building structures. The damage and deterioration which have occurred to date have for the most part been caused by deficiencies in connection with the erection of the structures or their subsequent modifications. This type of damage has been observed in, for example, Barsebäck 2, Forsmark 1, Oskarshamn 1, Ringhals 1 and Ringhals 2. The damage has primarily been the result of corrosion of the metallic parts of the reactor containment. Similar experience has been reported from other countries. Considering the difficulties associated with the reliable control of the reactor containment and other important building structures SKI considers it important that the licensees continue to study possible ageing and degradation mechanisms that can affect the integrity and safety of these structures.

SKI is continuing with its own study and research concerning the damage and other degradation mechanisms that can affect the reactor containment. Mechanisms that can affect the concrete itself are amongst others chemical reactions, leaching, sulphate attack, cement ballast reactions and carbonation. With regard to these damage mechanisms SKI's own studies and research to date have shown that the environmental conditions in the Swedish containments are such that the risk for damage caused by the environment is in general considered to be small. On the other hand the damage which has occurred shows that deviations from the construction drawings have led to damage at a later stage. Therefore the risk for the occurrence of different damage mechanisms cannot be assessed entirely on the basis of operational conditions and the nominal design, but must also be based on the reported damage.

SKI's studies and research work therefore also cover questions to identify control programmes and methods that need to be developed to be able to meet the threat of containment leak tightness and integrity over time, and also additional analysis methods that should be developed to more thoroughly assess the tolerance and tightness under different upset and emergency conditions. The results of the studies to date have resulted in SKI issuing more stringent requirements for in-service inspection of the metallic parts of the reactor containment. The more stringent requirements have been issued by an addition to the regulations, SKIFS 2005:2 concerning mechanical components in nuclear facilities. The new regulations concerning the control of the reactor containment became effective on July 1, 2006. SKI is planning further extensions and more stringent requirements in the regulations so that they also include the concrete parts.

Instrumentation and monitoring equipment

In recent years ageing of instrumentation and control systems has been paid more and more attention both in Sweden and internationally. Ageing phenomena in this type of component differ considerably from the type of ageing of materials and structures which has been described above. One reason is that this type of component is often replaceable, and therefore is replaced if defects are detected, without raising the question of ageing. Some of the defects are detected in components shortly after installation, so-called "infant mortality". The subsequent development depends on the type of component or system in question. Since instrumentation and control systems include sensors, transmitters, displays and systems to present measured data the conditions, and therefore the possible degradation mechanisms, will vary considerably. Different types of deterioration in the physical properties of a component will depend on the loads to which the component is or has been subjected, and these are to some extent time dependent.

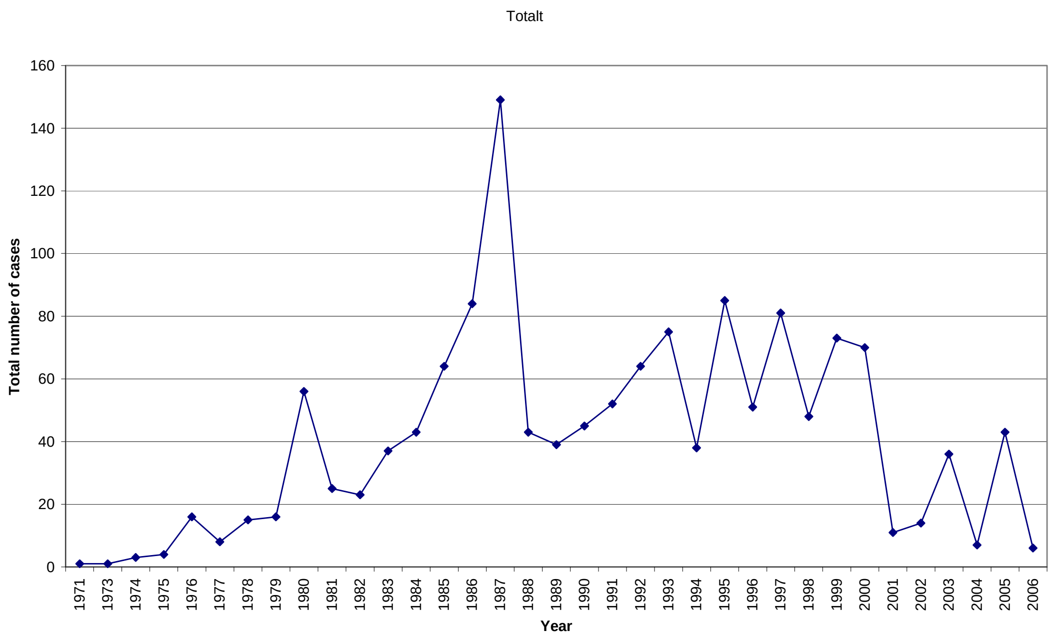
Another type of ageing, and for instrumentation and control systems, a very important one, is something that is often called "technological ageing". This means that systems and components become obsolete because of the technological advances and that they are correspondingly difficult to replace, or that there are problems of compatibility, that is to say it is difficult to replace a limited part. Evolution and the increased use, not least the anticipated increased use, of digital equipment, "clever" sensors and suchlike, obviously affect this situation. Another aspect which can be relevant to note for instrumentation is what can be called "functional ageing". This means that a measurement or monitoring system has become "irrelevant" as a result of other alterations to the plant. Conditions have simply changed in such a manner that the measurement system no longer gives information in the manner envisaged when it was installed. One example of this is leak detection systems which depend on the measurement of gaseous radioactivity in the containment atmosphere. These systems depend in some cases are on a higher concentration of radioactivity in the coolant than is normal today, and therefore they cannot be attributed their original functionality.

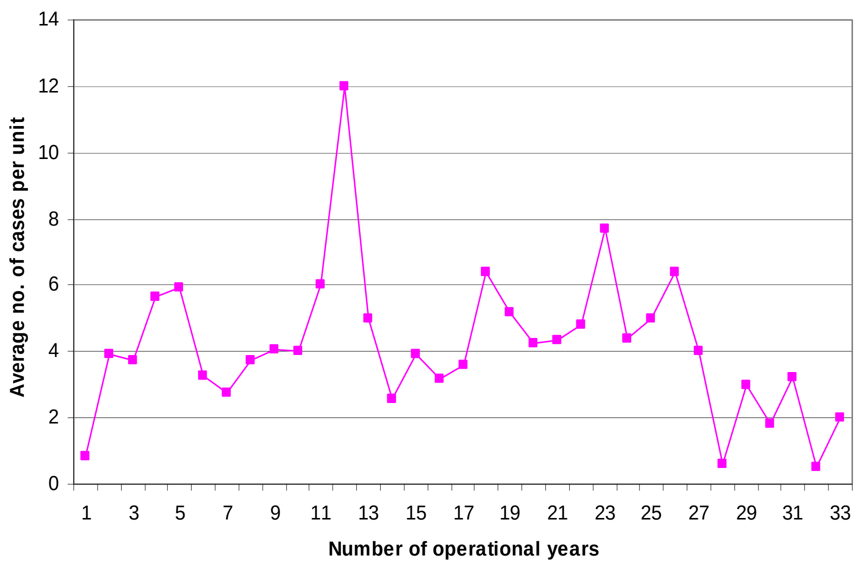
Electrical equipment

In contrast to mechanical components and building structures the condition of electrical cables cannot be followed by in-service inspection and testing. In these cases it is necessary to qualify the cables and equipment in specific testing programmes to ensure that the equipment functions as expected throughout its planned life. The qualification programmes must include both normal operational conditions and also accident conditions, as well as take into consideration the mechanisms that can affect for example degradation of polymer materials.

The factors which have the most effect are normally high temperature and ionising radiation. High humidity and vibrations can also play a large role in the ageing of electric cables and other electrical equipment. The question as to how these environmental factors should be simulated in the accelerated tests of the qualification programmes has been the subject of considerable discussion for a long time. Different national and international standards for the qualification of electrical equipment vary with regard to which acceleration factors can or should be used. For example, in the case of ageing resulting from ionising radiation the discussion has centred on how high the dose rates can be during accelerated testing, without risking that the degradation will be less than that which will occur in the environments in which the equipment will be used.

With respect to Swedish plants SKI has previously required that they provide information describing how they are managing ageing phenomena and environmental qualification. SKI’s assessment of the material provided to date is, that the for the most part, the situation is satisfactory but that the licensees need to perform certain complementary investigations. The continued efforts by the licensees will be followed by SKI within the scope of the regulations in SKIFS 2004:1 concerning the ageing management programmes.





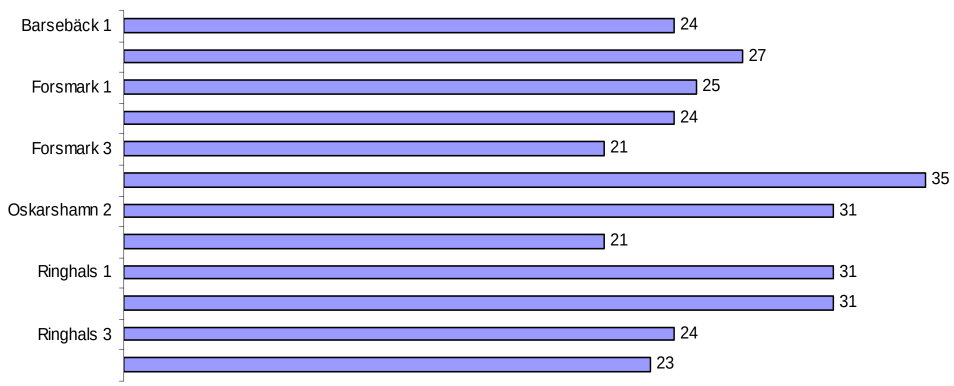


Diagram 1. *The upper of the two diagrams shows the total number of events per year. The middle diagram shows the average number of reported events per plant and operational year for all the Swedish plants. The diagram includes events in pressure vessels, piping, and other mechanical components except steam generators. The lowest diagram shows the operational age of the plants.*

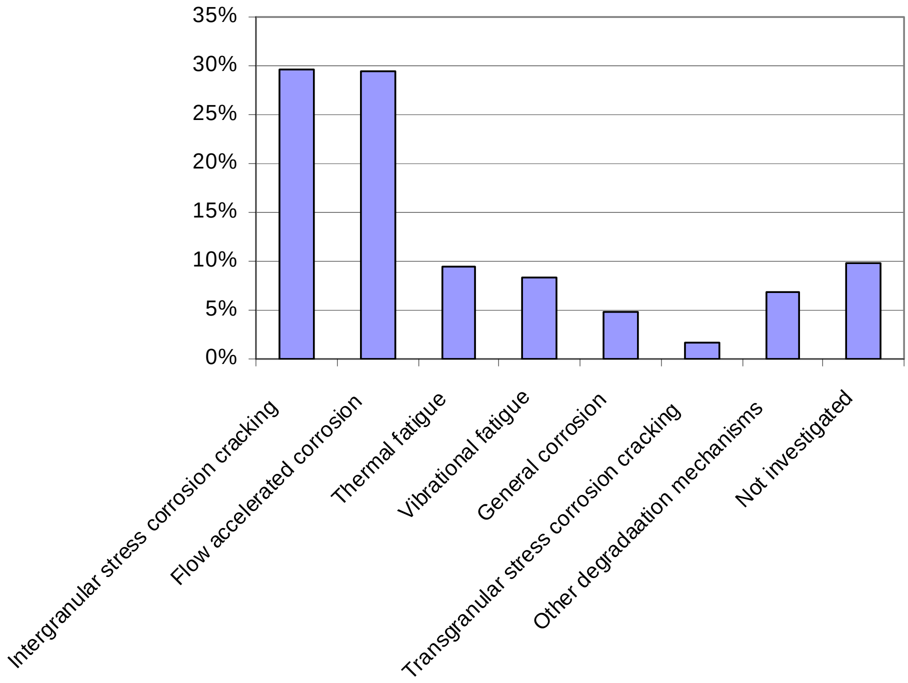


Diagram 2. *Causes of damage according to degradation mechanism.*
(The category "other" includes damage caused by grain boundary attack, corrosion fatigue and mechanical damage.)

Following up the damage in steam generator tubing

Nickel based alloys have been a relatively common construction material in nuclear facilities around the world, but they have been found to be susceptible to stress corrosion cracking. This is particularly true for Alloy 600 and the corresponding welding alloys known as Alloy 182 and 82. Extensive measures have been taken in the Swedish plants to replace these susceptible materials with other less susceptible materials.

Examples of remaining problems with stress corrosion cracking in nickel based alloys are the steam generator tubes in Ringhals 4. These tubes are manufactured from Alloy 600 and comprise a major portion of the pressure boundary of the primary system in the plant. The damage evolution is therefore followed very carefully through annual inspections and other investigations in accordance with SKI's regulations. The inspections and tests performed during the year have as previously included damaged regions of the tube support plate, support plate intersections, preheated parts and the U-bends. A number of tubes were found to contain new stress corrosion cracks in the region of the tube support plate as well as some growth of previously detected cracks. No new defects were found in the U-bend region of the tubes during the inspections and tests performed during the year.

Tubes with such limited damage that there are safe margins to rupture and flaring have been kept in operation in Ringhals 4. Damaged tubes with insufficient margins were fitted with plugs in the ends and thus removed from service and crack propagation was thus halted. During the year a total of 49 tubes were plugged. The total number of steam generator tubes which have been taken out of service now corresponds to 3.03 % of all the tubes.

RAB has now decided to replace the damaged steam generators in Ringhals 4. In addition to the safety and maintenance advantages of such replacement the prerequisites will exist for increasing the thermal power in Ringhals 4. RAB is planning such an increase.

As discussed above, Ringhals 2 and 3 have replaced their steam generators with generators of a partially different design and with tubes manufactured from material less susceptible to cracking. During the periodic in-service inspections there have been no signs of environmentally induced degradation. Operating experience so far gained with the new steam generators, installed in 1989 in Ringhals 2 and in 1995 in Ringhals 3, is still good. Some minor wear damage caused by foreign objects has, however, been observed on the secondary side of the steam generators.

Evolution and optimisation of the in-service inspection programme

The in-service inspection of mechanical components and building structures is an important part of the defence in depth in order to capture damage and other deterioration in time before safety is jeopardised. The controls are aimed at regular confirmation of the condition of vital components, and that the properties and design prerequisites remain.

According to SKI's regulations (SKIFS 2005:2) the extent and direction of the in-service inspection should be determined by the relative risks for core damage, release of radioactive substances, unintentional chain reactions and deterioration in the safety levels as a result of cracking or other degradation. The practical application of these regulations in Swedish plants has since the end of the 1980:s used a qualitative risk model. This is a risk model with indicators that qualitatively measure the probability that cracking or other degradation will occur in the specific part and the probability that degradation will result in core damage or other deterioration in the safety levels.

This qualitative risk model for determining the direction of the in-service inspection has proved to be relatively effective at detecting damage in important plant components at an early stage before safety is affected. As described in the section on the overall assessment of the damage evolution, most of the damage to date has been detected in time by the in-service inspection. Only a small portion of all the damage has resulted in leakage or other serious consequences because of cracking or other degradation not being detected.

In recent years more and more interest has been expressed by Swedish and foreign plants to optimise the inspection programmes using quantitative risk oriented models. In these models probabilistic fracture mechanics models are combined with probabilistic safety analyses of the plant. Since the primary motive for using these models is to reduce the costs of inspection and testing SKI must ensure that the changes are introduced without increasing the risk for core damage and the release of radioactive substances. SKI has therefore, as have authorities in other countries where these models are beginning to be used, imposed stringent requirements on the input data to the models and that the models, themselves are validated.

During 2006 SKI has completed a renewed review of an application from Ringhals AB to use an inspection programme for the piping systems in Ringhals 2 which is based on a risk informed selection (RIVAL) according to a procedure developed by the Westinghouse Owners Group (WOG). SKI noted that in general application of this procedure has provided a good description of the risks represented by the passive mechanical components. SKI has on the other hand had a number of criticisms of the original application from Ringhals using the WOG method in particular on the occurrence of different degradation mechanisms, validation of the probabilistic fracture mechanics models used, the model for the selection of samples and the lack of a method to treat risk outliers. SKI has decided on a number of conditions for the further application and development of RIVAL in Ringhals 2. A corresponding change in the current in-service inspection programmes using the RIVAL-application is expected in 2007 for Ringhals 3 and 4.

Investigation of consequences to the surroundings of radiological release in the event of upset conditions or an accident

In connection with SKI's evaluations and decisions related to events with water leakage from reactor containments in recent years the question has arisen on the analysis prerequisites and reference values for radiological consequences to the surroundings in the event of upset conditions and design base accidents. The question of safety analyses has also been raised in connection with a review of the plant safety analyses and applications to increase the thermal power of several plants.

The questions concerning the analysis prerequisites and reference values relate to events which are included in the design basis events, unexpected events and improbable events which in accordance with SKI's regulations, SKIFS 2004:2 concerning the design and construction of nuclear power reactors, are designated H2, H3 and H4. For transients during normal operations, H1, according to SSI's regulations (SSIFS 2000:12) the effective dose to an individual in the critical group of one year of releases of radioactive substances to air and water from all facilities located in the same geographically delimited area shall not exceed 0,1 millisievert (mSv). For very improbable events, H5-events, (sometimes called severe accidents) government decisions, from 15 October, 1981, concerning filtered pressure relief for Barsebäck and from 27 February, 1986, for the other nuclear power plants, are in force. According to these government decisions certain guiding principles are applicable for the measures to be taken to limit the release of radioactive substances in the event of severe nuclear accidents. The guiding principles are considered to be met if the release of radioactive substances is limited to a maximum of 0.1 % of the core content of the caesium isotopes 134 and 137, not including noble gases, in a reactor core of the size of Barsebäck, i.e. 1800 MW thermal power, on condition that other nuclides of relevance from the use of the land are separated to the same extent as caesium.

For events and courses of events in categories H2, H3 and H4 there are no clear Swedish requirements for the reference values and analysis prerequisites. SKI and SSI have therefore carried out a joint study to provide the basis for the analysis prerequisites and reference values to cover H2, H3 and H4 events. The report[6] describes the background, consideration and recommendation concerning the analysis prerequisites and reference values for the consequences to the surroundings of a radiological release in the event of upset conditions or a severe accident. The study has included an assessment of the current requirements in Sweden and the USA, an assessment of some of the results of analyses that the nuclear power plants have in their safety analysis reports (SAR) and a brief comparison of the internationally

[6] "Consequences to the surroundings of radiological release in the event of upset conditions or an accident. Suggestion for reference values and analysis prerequisites" dated 6 December 2006 (SKI 2006/573, SSI 2006/1759-250). (In Swedish).

applied analysis and acceptance criteria. The study has also included work to identify a recommended method that can form the basis for Swedish reference values and illuminate essential analysis prerequisites and which requirements should be imposed on methods to calculate the dispersion radioactive substances released as a result of a severe accident.

The survey made in this study of the analyses of the consequences to the environment in the safety analysis reports of the Swedish nuclear power plants has shown that there is a relatively large variation between the assumptions and calculation bases for the different reactors. This is in respect to both the assumed fission product release from the fuel and the sequence of events in the containment, and also to some extent the methodology and assumptions for the dose calculations. Against this background, and also since there is improved knowledge concerning the sequence of events during a severe accident and radiological source terms, the analysis group considers that it is motivated to recommend both that generic analysis prerequisites should be taken into account by the licensees and also that there should be some sort of reference value that can be used in the analysis capacity of the plant barriers and defence in depth to prevent radiological accidents.

In order to retain the robustness of the barriers, the analysis group considers that the consequences to the environment should in the future be analysed for two sorts of case, one realistic and one conservative hypothetical case. This is of prime importance for the reactor containment with its high requirements for tightness. It is also important to obtain as good an understanding as possible of the capacity of the barriers and defence in depth to prevent radiological accidents and mitigate the consequences.

Both the release of fission products from the fuel and the internal and external source terms for the realistic case should be determined using a realistic best estimate analysis of the sequence of events during the accident. The analysis should be performed with the best methods available and based on current knowledge. An assessment of the uncertainties should be performed for the analysis models, methods and the input data and parameters assumed. Amongst other things the permissible limiting values in the technical specifications should be used for relevant parameters.

For the conservative case the analysis group considers that the analysis prerequisites recommended by US NRC should continue to be used. This ensures that the stringent requirements concerning the tightness of the reactor containment are applicable, both for the so-called design basis events (H4 events) and for the initial phases of a severe accident (H5 events) before the rupture disc ruptures and the pressure relief accident filter is activated.

In the near future SKI and SSI are intending to make decisions within their respective areas of responsibility concerning the prerequisites and reference levels which should be used by licensees in their work with deterministic safety analyses.

3. Core and fuel issues

Foreign debris continues to cause fuel defects

Fundamentals

Leaktight fuel cladding is essential to prevent the release of radioactive substances in and from the plants. Therefore, stringent quality requirements exist for the manufacture of fuel cladding with low acceptable frequencies for defects. The quality requirements have led to the number of manufacturing defects of the order of one fuel rod out of 100,000. Stringent requirements are also imposed on the fuel cladding to, as far as possible and reasonable, withstand the radiation and other environmental conditions to which the fuel can be exposed. Furthermore the design must be well tried and tested and there must be appropriate programmes to follow up and check the behaviour of the nuclear fuel after it has been taken into operation.

During the 1980’s and a bit into the 1990’s a large number of fuel failures caused by stress corrosion cracking were reported, where the fuel cladding did not meet the requirements concerning tolerance to the environment. No damage of this type has been reported in recent years since operating rules have been employed and more resistant cladding material has been developed. The long-term trend is that the number of fuel failures in Swedish reactors is decreasing, see Diagram 3. All of the reactors have had the odd failure in recent years, but a couple of reactors (Forsmark 1 and Oskarshamn 3) have had more than one fuel failure per annum on several occasions over the last ten years.

The failures that occur nowadays are primarily caused by small objects that enter the fuel bundles via the coolant and then wear holes in the cladding. To reduce the number of this sort of failure, fuel assemblies with filters to prevent the debris from entering the bundles, as well as cyclone filters to clean up the coolant, are successively being installed. It is however essential that there is a greater awareness of the importance of keeping the coolant free from debris that can wear holes in the fuel cladding. The plants have programmes in place to reduce the risk for debris getting into the systems.

More and more plants are now also applying a strategy to avoid a fuel failure developing to the extent that uranium leaches into the reactor water. This strategy involves restrictions in operations that will worsen the damage, and shutting down the reactor to remove failed fuel if there are indications of uranium leakage. In this manner the plants avoid contaminating the primary system with radioactive isotopes with long half-lives which result in deterioration of the radiation environment, and in turn make maintenance, inspection and testing more difficult.

Over the last five years a total of three to nine fuel failures due to wear have been reported each year. In 2006 six fuel failures were reported in all. Most of the reactors were, however, free from fuel failures in 2006. Three of the fuel failures occurred in Forsmark 3, two in Oskarshamn 3, and one in Forsmark 1. The fuel failure frequency over the past five years has stabilised at a relatively low level. However, since a few reactors account for several failures it should be possible to reduce the failure frequency further if all the reactors employ effective corrective measures to avoid fuel failures.

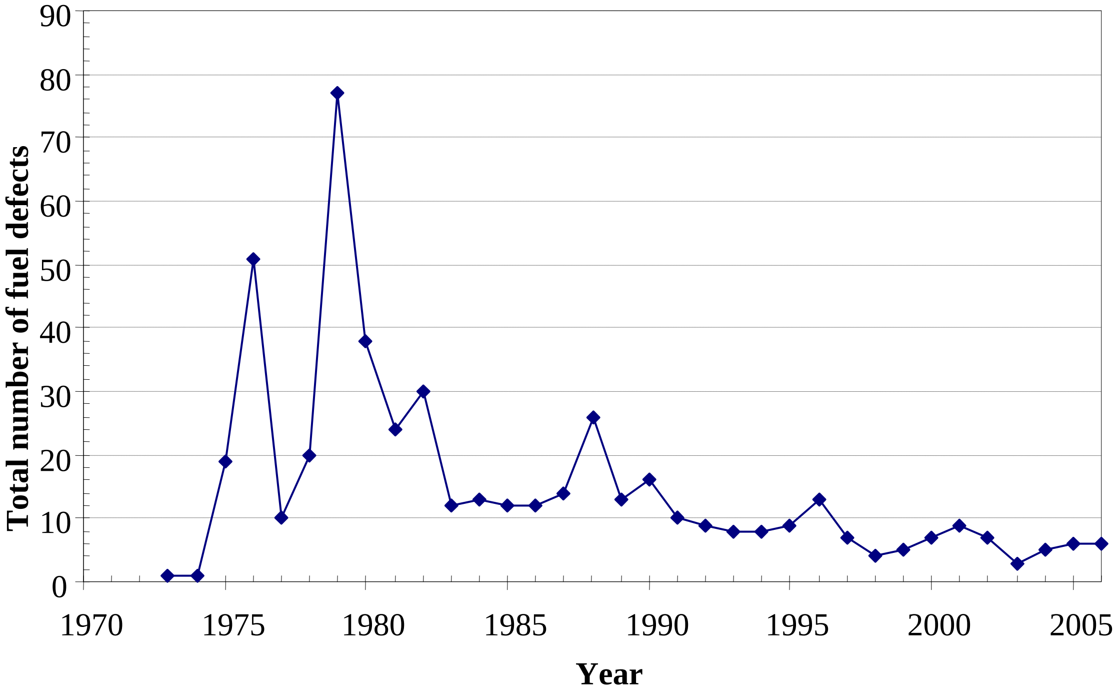


Diagram 3. *Total number of fuel failures reported per annum in Swedish nuclear power plants*

Continued follow-up of bowed fuel

Since the mid-1990's the pressurised water reactors, Ringhals 2, 3 and 4, have had problems with fuel bowing beyond the limit postulated in the safety analysis. The safety related aspects of this are to ensure that the control rods can be inserted as necessary and that the thermal limits are not exceeded. RAB has implemented measures to restore the straightness of the fuel and to analyse the impact of the bowing on the thermal margins. SKI has evaluated these measures and the methods used to follow-up the bowing and is continuing to monitor the progress through annual reports in which RAB describes the status of the bowing. The direction of the bowing is unchanged in the upper part of the fuel whilst it is more diffuse in the lower part of the assemblies. A number of constructive measures have been taken to improve the situation gradually even if the positive trend has been broken in the past year in Ringhals 2 and 4.

Increased burnup and enrichment

Work has been underway internationally for several years to improve the economic margins through core optimisation, improved fuel utilisation, new fuel designs and increase operating flexibility. There is an ambition to modernise the core loading strategy so that fewer new fuel assemblies are needed. The maximum fuel burnup is also a factor in the optimisation efforts.

In Sweden there is a general limit of 60 MWd/kgUO_2 for the highest local fuel pellet burnup which was introduced through a decision made by SKI in 1995. Previously there was no incentive to go to higher fuel burnup. However the licensees have revised their cost optimisation for fuel and have found that a somewhat higher burnup should be aimed at. In 2004 BKAB and RAB were granted permission to increase the local fuel pellet burnup in the reactors Barsebäck 2 and Ringhals 1 from 60 MWd/kgUO_2 to 65 MWd/kgUO_2. In 2006 applications have been submitted by OKG and RAB to increase the burnup for a few specific fuel assemblies in Oskarshamn 3 and Ringhals 2. SKI has evaluated these applications and decided to grant permission for the current burnup limits to be exceeded by a small amount. SKI is of the opinion that this higher local pellet burnup can be allowed with sufficient safety margins. In Oskarshamn 3 the reason for the irradiation is to gain information on a new fuel material (ADOPT-pellet) which is of interest for this reactor.

Further applications to increase the fuel burnup are expected. SKI is therefore following these discussions in detail and is preparing for future reviews by amongst other things participating in research which will provide a basis for verifying the safety limits for fuel with high burnup. Amongst the issues that are important to follow in this respect is how existing failure mechanisms are affected and if new ones will occur at the higher burnup levels.

As part of the plans to increase the thermal power (see below) at several plants higher enrichment of the fissile material (uranium-235) per fuel assembly is also being discussed. When the thermal power is increased in a reactor the fuel consumption will increase to the same extent, if no other measures are taken. That means that an increase in thermal power of 1 % results in approximately a 1 % increase in fuel consumption. An increase in thermal power can be achieved by consuming more fuel assemblies.

By increasing the enrichment of fissile material the need to consume more fuel bundles can however, be reduced or even eliminated. Modifications to the fuel design can also be expected to reduce the need for more fuel assembles to a limited extent. The licensees will probably use a combination of increased consumption and enrichment to increase the thermal power. The choice of method depends on an economic evaluation in which, amongst other things, the cost for increased enrichment and the larger quantity of uranium and final disposal are influencing factors.

Continued work with thermal power increases

The government license for the operation of a nuclear power reactor includes stipulations for the maximum thermal power which may be taken out of the reactor. The license is thus valid only for that thermal power. In order to increase the thermal power, the government must grant a new license in accordance with the Act (1984:3) on Nuclear Activities.

The thermal power of a reactor can, as described above, be increased by loading more fresh fuel assemblies or by loading more highly enriched fuel assemblies, or by a combination of these measures. The average heat rating of the fuel assemblies will increase. The power can however be evened out by letting the fuel assemblies that are currently operating at a lower power load take a larger portion of the load increase than the highest rated fuel assemblies.

In a boiling water reactor the higher power in the core is dealt with by increasing the flow rates of feedwater and steam. It is possible to choose between retaining the recirculation flow rate, which results in a higher steam concentration in the core, or increasing the recirculation flow rate and maintaining the steam concentration. A combination of these measures can also be used.

In a pressurised water reactor the higher power in the core is dealt with either by increasing the water flow through the core, or by increasing the temperature difference over the core. A combination of these measures can also be used. The higher thermal energy generated on the primary side results in more steam being produced on the secondary side. The higher steam flow is then transported to the turbine systems in which increasing the opening of the throttle valves results in the generator producing more electrical power.

Most of the Swedish plants power implemented uprates in the 1980's, see Table 1. Most of the previous power uprates were achieved by utilising the large safety margins which existed, improved analysis methods and improved fuel. In several cases these increases in thermal power could be made without major plant modifications. In recent years the licensees have investigated the possibilities of further increases in thermal power. These include both larger and smaller uprates. The incentive is that thermal power increases are a relatively cost-effective means of creating extra electrical production capacity.

Table 1. *Thermal power increases carried out in Swedish plants. The table shows that the total increase in electrical power is 727 MWe.*

Reactor	Original thermal power (MW_{th})	New thermal power (MW_{th})	Increase (%)	Original thermal power (MW_e)	New thermal power (MW_e)	In-crease (%)	Year for increase
Barsebäck 2	1700	1800	5.9	580	615	6.0	1985
Forsmark 1	2711	2928	8.0	900	1006	11.8	1986
Forsmark 2	2711	2928	8.0	900	1006	11.8	1986
Forsmark 3	3020	3300	9.3	1100	1200	9.1	1989
Oskarshamn 1	1375	-	-	460	490	6.5	2003
Oskarshamn 2	1700	1800	5.9	580	630	8.6	1982
Oskarshamn 3	3020	3300	9.3	1100	1200	9.1	1989
Ringhals 1	2270	2500	10.1	750	870	16.0	1989
Ringhals 2	2440	2660	9.0	820	910	11.0	1989
Ringhals 3	2783	-	-	-	-	-	-
Ringhals 4	2783	-	-	-	-	-	-

An increase in the thermal power can affect a plant in a number of different ways and to a varying degree depends on the magnitude of the increase. The conditions and parameters which can affect safety must therefore be identified and analysed to determine if the safety requirements are met with the necessary safety margins.

A number of components and systems in a nuclear power plant must be verified as having the capacity corresponding to the higher power rating. The impact on safety is principle in that the core will contain more reactivity. The inventory of radioactive substances in the fuel will increase. The neutron irradiation of components around the reactor core will increase. The residual heat of the reactor is proportional to the operating power and therefore will also increase. The systems that supply coolant to the reactor and remove the residual heat must have increased capacity. Since the total energy production from the core will increase the consumption of fissile material (U-235) will increase. At the most the increase will be proportional to the thermal power increase. The increased residual heat will also result in certain sequences during operational disturbances or in the event of a severe accident happening faster.

Permission to operate with increased thermal power can be supported by SKI on condition that it can be shown, through analyses and other measures, that the plant can be operated at the higher power in such a way that the safety requirements are met. In addition any known deficiencies or open issues affecting safety must be handled in an acceptable manner. SKI's supervision also includes acting to ensure that possibilities for safety improvement are considered in connection when planning different types of changes.

SKI's review of power increase applications is performed in several stages. Initially SKI carries out a broad safety review which forms the basis of the comments submitted to the government prior to their decision concerning the power increase. If the license is granted the subsequent stages are initiated, starting with evaluation of more detailed investigations and analyses submitted by the applicant covering the necessary plant alterations and their operational modes. SKI then follows up the alterations in the plant and makes decisions regarding test operation and routine operation at the higher power level. SKI's process for handling applications for increased power levels is described in "*Regulatory review and other supervision of the thermal power in nuclear power plants*"[7].

The following thermal power increases are currently under consideration:

Forsmarks Kraftgrupp AB

On September 29, 2005, FKA submitted an application to SKI, in accordance with the Act on Nuclear Activities, to increase the thermal power rating from 2,928 MW to 3,253 MW for both Forsmark 1 and Forsmark 2, and from 3,300 MW to 3,775 MW for Forsmark 3. After reviewing the application and the supporting documentation SKI has concluded that the necessary conditions are met for FKA to increase the thermal power in such a way that the safety requirements can be met. SKI has therefore in its comments submitted to the government dated April 26, 2006, supported the application and recommended that the government grant permission in accordance with the Act (1984:3) on Nuclear Activities for FKA to operate the reactors Forsmark 1, 2 and 3 with the highest thermal power as specified in their application.

On September 28, 2006, the government asked SKI to supplement its comments from April 26, 2006, in the light of the incident in Forsmark 1 of July 26, 2006, and the special conditions that SKI had imposed as a result of the incident. In an additional statement SKI informed the government that SKI's conclusions have not changed with regard to the technical basis for increasing the thermal power in the reactors Forsmark 1, 2 and 3 in such a way that the safety requirements can be met. In this statement SKI also informed the government that it considered that FKA has the prerequisites to correct the deficiencies in the management of the company and its safety culture that have been identified in connection with the incident on July 25, 2006. SKI further informed the government that in the event it were to grant permission and make a decision with regard to the proposed license conditions, SKI does not intend to begin its review of the preliminary safety analyses and thus not grant permission for test operation at a higher thermal power level as long as the conditions for operation of the plants in accordance with the decision of September 28, 2006, are in force.

[7] Regulatory review and other supervision of the thermal power in nuclear power plants. SKI-PM 04:11. Swedish Nuclear Power Inspectorate. 2004-11-01.

Ringhals AB
On October 20, 2005, the government granted permission for RAB to increase the thermal power in Ringhals 1 from 2,500 MW to 2,540 MW. A stipulation of this decision is that SKI must approve trial operation and the routine operation of the reactor at the increased thermal power level. On May 11, 2006, RAB submitted an application for the trial operation of Ringhals 1 at a thermal power level of 2,540 MW. As the basis for this application RAB has amongst other things performed a number of new safety analyses. SKI is currently reviewing these and other documentation supporting the application and a decision concerning trial operation is expected during the spring of 2007.

On October 20, 2005, the government also granted permission for RAB to increase the thermal power in Ringhals 3 from 2,783 MW to 3,160 MW. A stipulation of this decision is that SKI must approve trial operation and the routine operation of the reactor at the increased thermal power level. RAB is planning to increase the thermal power in two steps. On December 23, 2005, RAB applied to SKI both for approval of the preliminary safety analysis report (PSAR) and permission for trial operation of Ringhals 3 at a thermal power level of 3,000 MW. SKI has reviewed the PSAR and associated safety analyses, and pointed out a number of areas in which measures must be taken before trial operation can be started. RAB has therefore prepared a new safety analysis report (SAR) in which the deficiencies and need for improvement are resolved. In addition during the annual outage in June, RAB adjusted the control and safety systems of the reactor for operation at the increased thermal power level. In SKI's opinion however the need for some improvements remained to be dealt with prior to trial operation at 3,000 MW thermal power. Whilst waiting for this, RAB therefore applied for permission to replace the current SAR with the revised version, and then to operate the plant in the modified state for the higher thermal power rating at the current thermal power of 2,783 MW. On June 26, 2006, SKI granted permission for the use of the revised SAR and operation in accordance with RAB's application. RAB has carried out further measures and submitted further complementary analyses. After reviewing these, SKI approved the revised SAR and granted permission on January 22, 2007, for the reactor to start trial operation at 3,000 MW thermal power.

OKG Aktiebolag
On June 8, 2006, the government granted permission for OKG to increase the thermal power in Oskarshamn 3 from 3,300 MW to 3,900 MW. A stipulation of this decision is that SKI must approve trial operation and the routine operation of the reactor at the increased thermal power level. OKG is planning to submit an application to SKI in the spring of 2007 for approval of both a preliminary safety analysis report (PSAR) for operations at the higher thermal power rating and also for trial operation at 3,900 MW thermal power.

Highest permissible thermal power clarification

The thermal power that is produced during the operation of a nuclear reactor is for natural reasons subject to small fluctuations. The thermal power is not measured directly but is calculated during operation using a number of parameters. Determining the thermal power is always associated with some uncertainty. In the safety analyses these uncertainties are taken in account by an additional allowance which is normally 2 % of the thermal power cited in the license.

In connection with the studies that SKI has carried out because of the applications for increased thermal power output of several plants, SKI has found that the principles for determining the thermal power of an operating reactor need to be clarified. A study of this has been performed[8] and the report describes the power limitations applicable for Swedish nuclear power plants, the existing requirements for the power levels used in the analyses, how the thermal power is measured and followed up, which types of calibrations and controls are made, as well as the expected uncertainty in the determination of the power level. On the basis of this SKI decided on new licensing requirements for the reactors Forsmark 1, 2, and 3, Oskarshamn 1, 2, and 3, and Ringhals 1, 2, 3 and 4. The purpose of these is to ensure that the stipulated maximum permissible thermal power produced by the reactors is not exceeded.

SKI also decided that the affected licensees must, by March 1, 2007, at the latest, have revised the safety analysis reports and technical specifications with information on the new regulations and how, with the help of specific monitoring systems, inspection programmes, inspection methods, inspection interval and analyses, they are met.

[8] Determination of the thermal power and power limitations. Swedish Nuclear Power Inspectorate report dated 2006-11-06.

4. Reactor safety improvement

New regulations concerning the design and construction of nuclear power plants

Safety improvements at the Swedish nuclear power plants have to date been conducted through successive alterations to the plant and special measures as a result of events which have occurred and problems that have been identified in the plants. The basis of these successive modifications has been new reactor designs which have indicated possible safety improvements and the emergence of new knowledge through analyses and research.

Examples of problems that have led to this sort of plant modification is the so-called strainer incident in Barsebäck in 1992 when it was found that the emergency core cooling system in boiling water reactors with external main cooling pumps did not function as postulated in the safety analysis report. The incident led to the refurbishment work in the other Swedish plants and re-evaluation of earlier analyses.

With the new regulations (SKIFS 2004:2) SKI has developed and clarified important safety requirements for nuclear power plants. The requirements are based on operational experience from Swedish and foreign plants, recent safety analyses, results from research and development projects as well as the development of IAEA[9] safety standards and the industrial standards which were applied in connection with the construction of the plants. The requirements comprise the design principles that are to apply, which monitoring and manoeuvring functions must be possible from the control room and the emergency control room as well as the safety and incident classification that should form the basis of amongst other things the analyses. In addition, regulations concerning the core design and operation are included.

The regulations came into force on January 1, 2005. In order to give the licensees sufficient time to plan and implement the necessary measures, SKI is issuing decisions on interim requirements. In these the implementation plans that the licensees must follow are decided in order that they meet the regulations in full by 2013 at the latest. For the older plants in particular extensive measures are needed to improve the safety further, and bring them up to the modern level in accordance with the more stringent requirements. Both SKI and the licensees will face major challenges since more thermal power increases are also planned during this period of time.

SKI has made the first decision concerning the nuclear power plants Forsmark 1 – 3 and this will be followed by the corresponding decisions for Oskarshamn 1 – 3 and Ringhals 1 – 4 in May 2007.

Modernisation projects

Some time ago the licensees identified the need for extensive and radical modernisation. Many of the safety improvements will be steered by the regulations in SKIFS 204:2. There are

[9] International Atomic Energy Agency, Vienna.

however other reasons for these measures, for example, operational cost-related considerations such as the increased need for maintenance and testing of older equipment, technical equipment that needs to be replaced because it is outdated and difficulties in locating spare parts or competence for their maintenance. Control room electronics and equipment are an example of the latter, where older equipment will be replaced by more modern equipment based on digital technology.

The larger modernisation projects of the older Swedish power plants are being carried out in stages and will last several years. Some examples are:

Oskarshamn 1 was the first Swedish nuclear power plant to undergo very extensive modernisation. The work was completed in 2002 and involved amongst other things a new design of the safety systems, new instrumentation and control equipment, as well as a new control room.

Oskarshamn 2 is planning to rebuild the safety systems, instrumentation and control equipment and the control room. Procurement is under way and, according to the plans, the modernisation will be completed in 2012.

Preparations are under way in Ringhals 1 to install a new reactor protection system, RPS. The major part of the work is planned for 2008.

Modernisation of Ringhals 2 has to date been concerned with the switchyard and waste systems, and will in future include modernisation of the control equipment and the control room.

A project, FIMP (Fire Improvement Project), is under way in Ringhals to modernise and make more effective the fire protection systems in all the plants so that they meet modern design requirements. The project includes the installation of new, redundant diesel operated fire fighting pumps, a new ring circuit for the fire fighting water with new risers and distribution piping in all the units.

SKI is supervising the ongoing modernisation work and has identified the need for considerable efforts over several years to supervise and regulate future modernisation.

Updating safety analysis reports and technical specifications

As a result of the strainer incident in Barsebäck in 1992, which identified deficiencies in the design requisites, in the mid 1990’s the utilities started reviewing the original design prerequisites and safety analysis reports. These reviews have identified some deficiencies in both the design and the analyses. SKI’s revised regulations (SKIFS 2004:1) concerning the safety in nuclear facilities the requirements have been clarified and made more stringent with regard to the safety analysis report and the safety analyses.

Ringhals 1 undertook a revision of the safety analysis report (SAR) in the project REDA at the end of the 1990’s. Prior to the plant alterations that are planned in both the projects Reactor Protection System (RPS) and Safety Package 2 (SP2), which are mainly aimed at modernising the reactor protection and the residual heat removal systems, a preliminary safety analysis report (PSAR) has been prepared. The PSAR for these projects will be reviewed by SKI in 2007 and 2008.

Ringhals 2 has revised its SAR as part of the DART project. Ringhals 2 DART-SAR was submitted to SKI on June 1, 2005. SKI will complete its review in the autumn of 2007 in conjunction with the submission of PSAR and the project TWICE.

In 2006 SKI reviewed the preliminary safety analysis report (PSAR) for Ringhals 3 in connection with the application for the thermal power increase. SKI considered that the PSAR was not up to the standard expected for a modern safety analysis report in accordance with the requirements in chapter 4, § 2 of SKIFS 2004:1. There is thus the need for further improvement to varying degrees and importance for safety.

Ringhals 4 has not yet submitted a revised safety analysis report to SKI.

Forsmark 1 – 3 has continued its modernisation of the safety analysis reports and revisions have been submitted to SKI successively. FKA considers that the modernisation of the SAR:s are complete in principle.

OKG has worked on safety analyses in accordance with their confirmed plans which are in part the result of requirements imposed by SKI. One of the important efforts has been the revision of the SAR for all three plants. These will be reviewed in connection with the reviews planned for the thermal power increases for Oskarshamn 2 and 3. In the case of Oskarshamn 1, SAR will be reviewed in connection with the transfer to routine operation.

Probabilistic safety assessments

The original reactor design and safety analysis reports have essentially been based on deterministic requirements and analyses. According to SKI’s requirements in SKIFS 2004:2, reactor safety development is still based on deterministic requirements and safety analyses. However, requirements are also made to conduct probabilistic safety analyses (PSA) in order to verify and develop safety. The purpose is therefore to obtain a description of risk and safety that is as comprehensive as possible by using both deterministic and probabilistic analyses. PSA is thus an important tool for identifying possible weaknesses and the need for measures to improve safety. This applies to both the design and construction of the plant, the technical specifications as well as the instructions for upset and accident conditions.

PSA methods and areas of application have been the subject of considerable development, both in Sweden and internationally. A complete PSA must cover upset and accident conditions as well as external effects on systems such as the fire protection and flooding systems. It should also cover all operational conditions including start up, shut down and the annual outage.

PSA is being used more extensively, not only for safety development but also for different optimisation measures, such as optimisation of the maintenance and inspection and testing programmes. These applications impose new demands on the scope, coverage, quality and validity of the models and also on the input data and parameters that are used.

Previous PSA models developed for the Swedish plants have some deficiencies in this respect that are being dealt with successively. SKI through its supervision is providing impetus to the work so that the licensees will supplement and complete the PSA in accordance with current regulations. SKI also considers that a comprehensive PSA is an important part of the analysis work to assess the need for measures resulting from the requirements in SKIFS 2004:2.

During the year the PSA for Ringhals 2 has been reviewed and a decision will be taken during the spring of 2007. In December Ringhals 1 also submitted a revised PSA that SKI has decided to review. In December completely revised analyses were submitted for all of the Forsmark plants; these should comply with the requirements concerning comprehensiveness, according to SKIFS 2004:1.

It should also be mentioned that SKI has initiated a two year research project aimed at coupling the results from PSA to the different barriers.

5. Organisation, competence and resource assurance and safety culture

The ability to handle a complex interaction between technology, people, organisations and economic aspects is essential to maintain and continuously improve safety. This section deals with how the nuclear power plants, in SKI's view, have worked with questions concerning, amongst other things, organisation, management systems, investigation of incidents, competence assurance and safety culture in 2006.

Safety culture in focus

All organisations that work with high safety requirements have a safety culture. An organisation can have a pronounced desire that all employees shall see safety as the most important overall goal and that everyone sees safety as their responsibility. But even the best organisations can become risky if there are conflicts in the goals of the operations and there are attitudes and behaviour in the safety culture that are directly contradictory to each other. Then an organisation can rapidly go from a safe behavioural pattern to a less safe one. Such shifts in behaviour can be caused by pressure from top management which is too concentrated on production results.

At other levels in an organisation people continually interpret rules and procedures. Most do their best to do a good and efficient job with the existing conditions, and this can result in the development of habits to circumvent the rules, or find creative solutions which can have a surprisingly negative effect, despite the fact that from the individual's point of view they appear to be consistent with safe behaviour and the way to solve a task. Some of the functions of the safety management system are, however, to detect such departures from the expected safe behaviour.

Part of the safety culture is maintenance of the discussion of risk, and that one can deal with risk by learning continuously from the experience of others. Earlier success can foster self-righteousness and the challenge is to maintain a thought process about what could happen on both the organisational and individual levels. Leadership is of course an important aspect in the codes and values that are established in a place of work – leadership at all levels in the organisation.

Organisations with high requirements for safety have different ways of handling and controlling risks in their activities that is to say, the things that are actually done to keep the activities safe, such as up to date instructions and procedures, open communication, well defined responsibilities, conservative decision making, and processes for evaluation and improvement.

The whole idea and goal with systems and processes for safety and for the continuous work with the safety culture, is that the organisation as a whole and the individuals in it, will, in all situations, focus on safety and threats to safety. This must be reflected in the daily behaviour in the local work place. A creative organisation needs to have watchful and questioning attitude. It is not fruitful for organisations only to try and stuff their employees with knowledge. It is not sufficient to rely on good practices and that written rules are interpreted and followed mechanically. The operations require a large portion of common sense, care and reflection. It is therefore important that management can stimulate creative thinking and actions in the continuous work concerning the improvement of safety. When an organisation can create a forum for people at all levels in the organisation to air different opinions regarding safety openly it is possible to have an effect. But one has to be aware that it takes time to have an effect on a culture.

The safety culture of FKA has been debated extensively over the past year. Following the incident on 25 July – when several safety systems were rendered non-functional by a power failure – FKA has carried out a number of technical alterations to prevent the recurrence of a similar incident. SKI reviewed an approved the alterations, but stipulated a number of conditions in connection with the resumption of operations. The conditions SKI imposed for continued operation contain criticism of how activities are managed, and that there are deficiencies in the safety culture. Permission to resume operations is associated with a number of requirements that the management of FKA improves the safety culture at the nuclear power plant. SKI's role is amongst other things to ensure that the licensee under no conditions give priority to production at the expense of safety. Therefore it is important to ensure that the organisation has a strong safety culture and a management that has an active safety oriented attitude. SKI has reviewed the measures that FKA plans to undertake to resolve the deficiencies that SKI has identified.

However, it can be said that all the licensees work with safety culture and the concept is well known and needs to be given a high status at Swedish nuclear power plants. In order to maintain a good safety culture it is very important and decisive to react quickly to signs of deficiencies, since if deficiencies in the safety culture are not corrected they can jeopardise the organisation's capability to deal with diffuse and difficult situations and maintain safety. SKI's role is, amongst other things, to ensure that licensees mantle the responsibility necessary for active safety leadership, and SKI expects that licensees develop and maintain a strong safety culture.

For some years the licensees have used a questionnaire to carry out an internal survey of the status of their safety culture. In 2006, a revised version of this was used. SKI is very positive to the fact that the licensees are working with their safety culture, and note that there are a variety of efforts underway in this area, such as seminars and inter-organisational discussions. In 2006 SKI carried out an inspection to follow the work with safety culture in OKG and RAB and has found that both licensees have made good progress in their ongoing programmes. SKI has as part of the special supervision of FKA, also carried out an inspection to find out about FKA's evaluation of the seriousness of incidents and their categorisation. The aim of the inspection was to clarify if FKA has appropriate support in the quality assurance system and technical specifications, as well as other necessary prerequisites to perform these evaluations.

SKI has carried out inspections at OKG and FKA with the overall goal of assessing if these licensees have a system to ensure that conditions which become apparent are evaluated without undue delay with respect to their impact on safety. SKI found that Oskarshamn and Forsmark have systems for dealing with unclear conditions that are discovered. They have routines to deal with this in accordance with current requirements through various forms of meetings, information channels, decision making processes, as well as the relevant documented instructions. Thus there are the prerequisites for discovering and dealing with unclear conditions in the plants. In 2006 SKI followed up on the inspection with the aim of seeing how the licensee had responded to the inspection results. The follow up showed that OKG had acted on several of the recommendations for improvement from the inspection, such as documentation of the decisions in safety issues, and feed back to the organisation. Overall SKI considers that OKG has the prerequisites to detect and deal with unclear conditions. The corresponding inspection of Forsmark will be followed up as part of the special supervision effort.

Organisational changes and how management and safety review activities are conducted

SKI has found that all the nuclear power plants have routines to handle organisational changes and activities. The nuclear power plants have routines for the early identification of the safety aspects in changes and to ensure that they are taken into account throughout the entire process.

In 2006 SKI carried out two inspections regarding the internal control of organisational changes by the licensees, one inspection at FKA and one at RAB. SKI found that both FKA and RAB meet the requirements in SKI’s general regulations (SKIFS 2004:1) with regard to organisational changes and the requirements concerning management, quality assurance and development, with the support of a management system including the necessary routines and documentation, periodic review of the management system, defined and documented responsibility, authority and collaborative conditions, that experience of relevance for safety in their own nuclear activities and from similar operations are continuously taken into account and the personnel involved are informed. SKI also found that the licensees comply with the regulations concerning the internal safety review of organisational changes, that is to say the requirements that organisational changes which can have an effect on the safety analysis report are to be subjected to an internal safety review in accordance with § 3 and that they are submitted to SKI, as well as the requirements concerning the extent and depth of the internal primary and independent safety reviews and their documentation. SKI found further that the licensees have learnt from their experience of previous organisational changes and have improved their routines in this area. During the inspections SKI identified a minor need for improvement of negligible safety significance at both licensees.

SKI has reviewed the reports regarding the documentation of professional competence requirements for personnel performing the independent safety reviews. This complementary effort was directed to the licensees RAB and OKG (FKA was considered after a review in 2004 to have almost complete documentation of the professional requirements with the need for one minor measure, which FKA has carried out and reported). SKI’s review was also directed towards the competency of the personnel who perform the independent safety reviews at FKA, RAB and OKG. The goal with this review was partly to assess if the complementary measures were sufficient, and partly if gap-analyses had been performed systematically, and if they were documented so that the requirements concerning sufficient resources and competence are met. SKI considers that RAB and OKG have the prerequisites to comply with the regulations in SKIFS 2004:1 regarding competence, and that this is documented for the personnel carrying out the independent safety reviews, in that the licensees have sufficient and documented requirements concerning the professional competence of the staff who perform the independent safety reviews. SKI has found that the three licensees have identified gaps in the competence of their staff. In consideration of the extensive measures regarding modernisation and thermal power increases that are planned over the coming years at the OKG, FKA and RAB nuclear power plants, SKI deems that the competence gaps should be remedied without delay. Further SKI judges that the licensees have the prerequisites to meet the requirements concerning sufficient personnel resources for the staff performing the independent safety reviews through the documented competence and resource analyses for both the near and longer term, as well as through the recruitment process that was underway at the time of the inspection. Finally, SKI has noted that the licensees are expanding their groups for independent safety reviewing.

Continued development of quality assurance systems and internal audits

In 2006, SKI has continued to follow OKG's work to develop its quality assurance system. The global approach to develop and implement a process oriented quality assurance system was abandoned in the autumn of 2006. Instead on November 1, 2006, a revised quality assurance system was introduced which is known as the management system. Altogether this means that the top documentation which steers the system has been restructured to make it more lucid.

SKI has also carried out an inspection to follow up on the work in Forsmark with its quality assurance system. SKI has found that FKA still have a well disposed quality assurance system with clearly defined responsibilities. However the system needs some improvements in respect of its user friendliness and its ready availability for the staff. Further it was discovered that FKA allows work instructions be written in the form of directions. These are not part of the quality assurance system and their use is therefore voluntary. SKI sees a concern that an increasing number of directions will be produced that should have been instructions. SKI has communicated this concern to Forsmark and they are going to reconsider this and the requirements regarding instructions will be clarified.

With respect to FKA it can be noted that, in the light of the incident in FORSMARK 1 last year and what was discovered then, it is clear that FKA does not use its quality assurance system to the full. It is thus not sufficient to have a good quality assurance system if is not used in practice. This is very serious and SKI has therefore required improvements in the decisions for its use and is monitoring this as part of the special supervision.

SKI also notes that RAB has a quality assurance system that fulfils its purpose appropriately and is readily accessible. Work continues to complete the implementation of the system for deviations, questions and experience feedback, known as "AvÅrS". The next step is to incorporate event reporting (RO) into the system. Outstanding residual items have become more visible after the introduction of the AvÄeS system and this has contributed to measures being carried out in time to a greater extent. Separation of the quality assurance systems of Ringhals and Barsebäck continues as planned.

SKI can also report that the licensees of the nuclear power plants are continuing to develop their operations through the use of internal audits. Once a year SKI meets the different licensees to obtain an impression of how the internal auditing work functions, and which audits have been performed and with which results. SKI can report that all of the licensees have a process for carrying out the internal audits as part of the quality assurance system, and that there is an established practice for the internal auditing work. SKI considers that all the plants maintain high quality in the management and work pertaining to internal audits. In 2006 SKI noted, however, that OKG has made alterations concerning the internal auditing activities. The reason for this was partly the extensive changes in the management system and partly the result of a observation made by SKI. The changes relate mainly to the areas (processes) for audit and the audit frequency.

MTO-aspects of modernisation activities *(Man-Technology-Organisation)*

SKI's supervision of this area is aimed in part at assessing that the licensees have instructions to steer the work, and in part to determine if the approved processes and routine are used in the work with alterations and modernisation of the control rooms. Supervision is amongst other things directed towards the technical constructions being designed and that they are adjusted to provide the conditions for the staff to safely monitor and manage the plant under both normal operations and during upset conditions.

During the year SKI has performed several reviews of the control room modernisation projects, amongst other things the plans of RAB and OKG concerning the transitional regulations related to SKIFS 2004:2. During the year a review of the flag- relay function in Ringhals 1 was completed, and SKI considered that Ringhals had taken sufficient measures in accordance with SKI's earlier decision. SKI assumes that Ringhals will continue to update the instructions in connection with the plant alterations and will follow this work as part of the normal supervision.

In addition SKI has performed reviews of the processes for plant alterations in RAB, with the focus on the MTO aspects. The overall criticism was that there was insufficient support in the form of routines and instructions in this area. SKI will make a decision that RAB must complement and develop documentation which steers up the process in a systematic manner and provides the prerequisites for the planning, realisation and following up of plant alterations, and which provide the licensee with the means to ensure that the plant design is appropriate for staff capacities. SKI considers that competence in the MTO area has fairly limited resources in RAB.

A review of the changes to the control room equipment was carried out at OKG within the project "TURBIC". In connection with this, a review of the quality assurance system revealed structural deficiencies with regard to the organisational affiliation of the MTO resources as well as the responsibilities and powers of authority regarding MTO. During the year OKG has taken measures in a satisfactory manner to clarify how this is shared among the different functions.

Incident reporting and experience feed back

Following up the 2005 inspection of OKG concerning the investigation of incidents and experience feedback SKI found that several of the needs for improvement identified in the inspection had not been remedied, and SKI therefore made a decision regarding a plan to implement the necessary measures. After a review of the plan, SKI still considers that OKG needs to improve its work on the investigation of incidents.

SKI has carried out an inspection of FKA and OKG concerning their MTO-related reportable events (RO). SKI found that FKA works well in classifying and following up the incidents. FKA has made efforts to improve the quality of the investigation, and has identified the need for further improvement. SKI considers it very important that they solve the problems regarding the detail of the investigations and the recommendations, so that neither the area of MTO nor the investigation methodology is discredited due to lack of competence. The fact that FKA is working in a broad manner with MTO aspects as a result of the WANO audit can act as a lever for the depth and breadth of MTO throughout the organisation. With regard to OKG, SKI found that they work with classification and the follow up of incidents, but pointed out that OKG needs to work more to evaluate trends with time.

Competence and resource assurance

Early in 2006, SKI completed an inspection concerning the competence and scheduling of operational staff at FKA. The inspection resulted in a decision in which SKI required an analysis of the staff availability both in the short and long term, an up to date gap analysis for operational staff, a plan to develop documented criteria of acceptable performance with regard to actual tasks of importance for safety for each individual position, what measures have been taken to improve the system of certification of proficiency, as well as the current staff availability at three separate times during the year. SKI has reviewed the reply and the proposed measures that FKA was submitted. The reply was however considered to be insufficient to meet the requirements in SKI's decision. A new decision was made in which SKI clarified the points which were deemed to be insufficient, and required that the response and planned measures are to be reported to SKI in January 2007.

SKI has reviewed the plan to remedy the needs for improvement that were identified during the inspection of OKG in 2005 within the area of ensuring that contractors have sufficient competence. SKI found that the plan was adequate with the implementation of the measures. SKI intends to follow up the inspection in 2007 when all the measures should be implemented in the organisation.

6. Physical protection

SKI considers that all the nuclear power plants have physical protection which meets current requirements. This assessment is based on supervisory activities such as inspection, event reports and notification of plant alterations concerning the physical protection of all the plants. SKI's supervision during the year has concentrated on following the work the licensees are undertaking to meet the new regulations (SKIFS 2005:1) concerning the physical protection of nuclear facilities and which came into force on January 1, 2007.

All the licensees have started extensive projects to plan and implement the measures needed to meet the requirements. For some of the measures which have taken longer than originally intended the licensees have applied for and been granted limited exceptions. SKI has also resumed work to complement the new regulations with requirements concerning the protection of so called vital areas in the nuclear power plants.

During the year SKI has continued its dialogue with the National Criminal Investigation Department and police authorities in the counties with nuclear power plants, as well as with the licensees for the nuclear power plants to ensure, as far as possible, that preparedness is adequate in the event of an attack or serious threat situation.

SKI has reviewed the report submitted by a task force comprised of representatives from local and central police authorities as well as the licensees with recommendations for measures for improving the state of preparedness in the event of a criminal attack on a nuclear power plant. SKI considers that the recommendations should be implemented as soon as possible and has agreed with the National Criminal Investigation Department that an implementation plan should be developed. The plan will then be presented to both the police authorities which are affected as well as the licensees.

In conclusion, it can be noted that in 2006 SKI has held a staff training course for representatives from police authorities, licensees and county authorities in the counties which have nuclear power plants. The goal was to give the participants improved prerequisites to act in the event of a criminal attack on a nuclear facility, and thus contribute to shortening the response time. The course was financed by the Swedish Emergency Management Agency and was a free-standing continuation of a previous course. SKI is planning to hold similar courses in 2007.

7. Nuclear safeguards

The facilities work with nuclear safeguards is satisfactory. In 2006, SKI, IAEA and Euratom have conducted inspections of how nuclear safeguards are handled at the facilities. 81 such inspections have been carried out at the nuclear power plants. The criteria used by IAEA and the Commission require that the inspection interval for facilities with irradiated nuclear fuel may not exceed three months. Furthermore, each facility must carry out a physical inventory once a year. For nuclear power plants this is carried out in connection with the annual refuelling outage. The results of this inventory are verified by SKI, IAEA and the Commission. Nothing has emerged during the inspections in 2006 to indicate deficiencies in nuclear safeguard work at the nuclear power plants.

The updates of the facility descriptions submitted to SKI by the plants in 2006 for the supplementary protocol to the safeguard agreement with IAEA, have been forwarded to IAEA in advance of the stipulated date of May 15. The supplementary protocol requires that the signatory must provide IAEA with more information than previously concerning nuclear activities and activities concerned with the nuclear fuel cycle. The supplementary protocol also gives IAEA extended rights of inspection. IAEA has not exercised this right in 2006.

8. Radiation protection

Summary and evaluation

Occupational radiation protection at the nuclear power plants is performed so that the individual and collective doses are maintained at a level which is comparable with international levels for the actual radiation environments and the work performed. No serious incidents resulting in intake of radioactive substances or high does to personnel have been reported.

Radioactive releases from the plants are estimated to give doses to the critical group that are less than one hundredth of the current limit. For a number of years Forsmark has however had recurrent problems with the measurement of airborne radioactivity in particular. The review carried out by SSI has indicated that this is due to a combination of technical and organisational problems. At SSI's initiative FKA has developed a programme to address these problems and correct the faulty measurement system.

In connection with the environmental impact evaluation of the thermal power increases the application of BAT after the increases has been assessed. SSI has imposed requirements that measures be taken to decrease the release of radioactive substances at the latest when the power increases come into effect and also that the amounts released do not increase. The environmental courts in Vänersborg and Växjö have in their judgements accepted SSI's point of view and stipulated that measures must be taken which will lead to a reduction of the total release of radioactive substances.

With regard to the requirements concerning submittals and reporting in accordance with SSI's regulations all of the facilities comply with these regulations. The exception is Forsmark which on a number of occasions in connection with the measurement of the release of radioactive substances has reported operational disturbances late.

SSI considers that the plants have shown an open attitude when reporting faults and incidents. The underlying reasons to the reported events have in the majority of cases been due to inadequate or non-existent instructions as well as insufficient control that the instructions are followed. The plants have dealt with the events in a satisfactory manner and have described measures to avoid their recurrence.

Occupational exposure and radiation protection organisation

Common issues

During 2006 the total collective dose (effective dose to personnel, including contractors) at the Swedish nuclear power plants was 9.3 manSv. The dose is the same order of magnitude as the average for the past five years (9.7 manSv). Diagrams 4 and 5 show the collective doses at the Swedish nuclear power plants and an international comparison for BWR and PWR plants. The choice of has countries been made taking into consideration reactors comparable to the Swedish plants with respect to design and age. Diagram 6 shows the dose trend for occupational exposure at the nuclear power plants over the period 1996 – 2006.

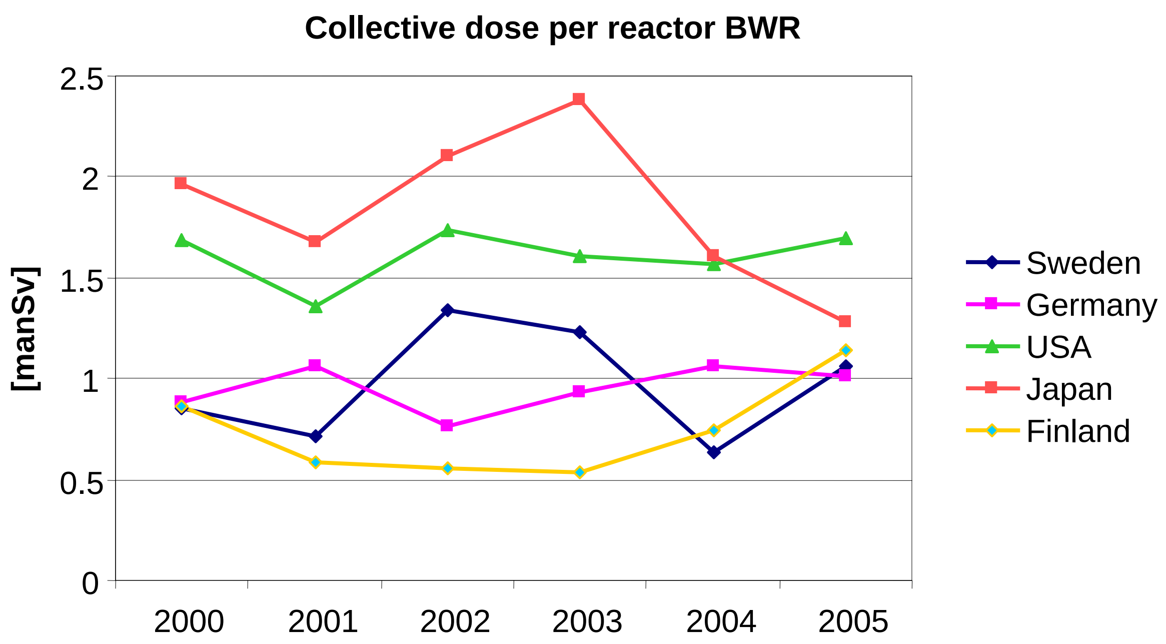


Diagram 4: Swedish collective doses for BWR (boiling water reactors) in an international comparison. Source: OECD/NEA, Information System of Occupational Exposure.

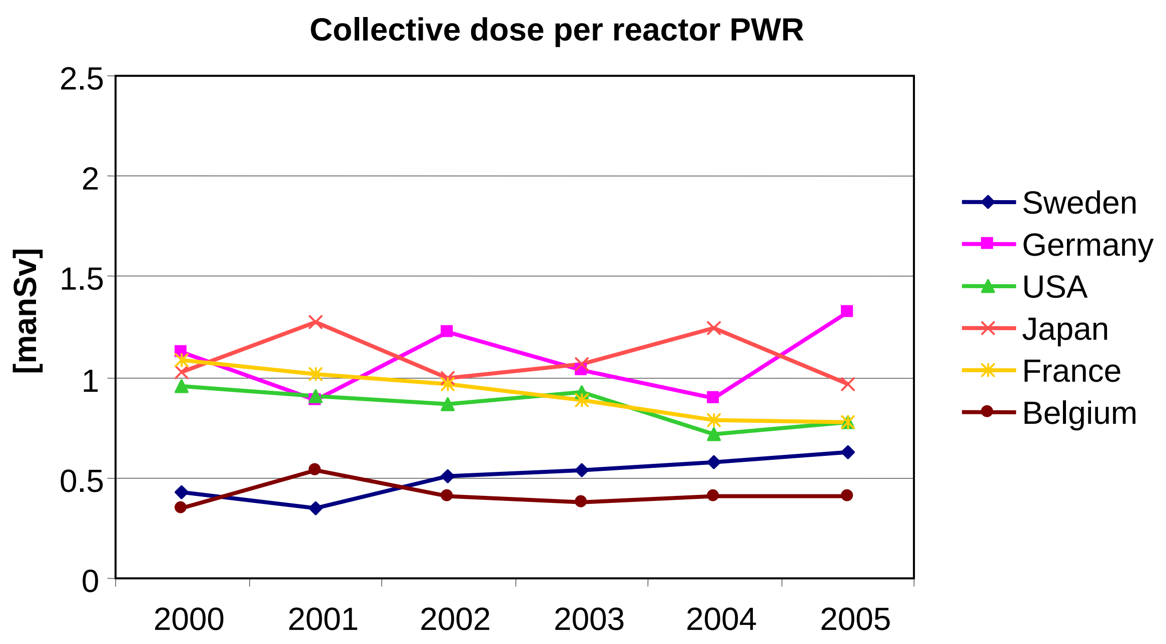


Diagram 5: Swedish collective doses for PWR (pressurized water reactors) in an international comparison. Source: OECD/NEA, Information System of Occupational Exposure.

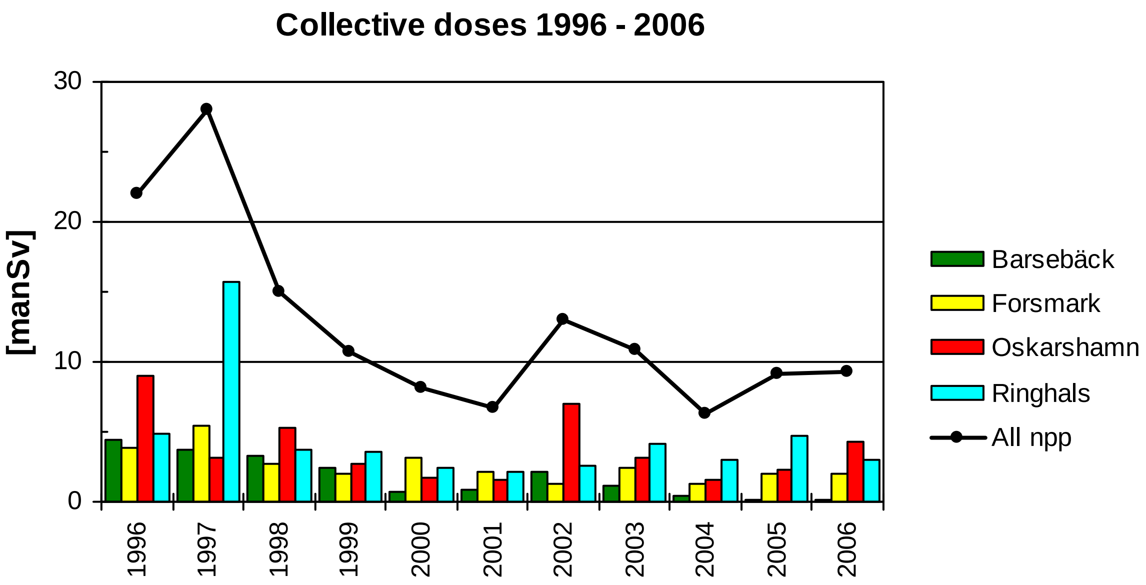


Diagram 6: Annual total collective doses (manSv) to personnel at the Swedish nuclear power plants.

During the year 4,238 people have received a radiation dose > 0.1 mSvfrom occupational exposure. The average dose for these people was 2.2 mSv, which is similar to that in 2005. The largest registered dose which has been received during work at any of the nuclear power plants is 19.7 mSv. The largest individual dose received in 2006 was however 25 mSv. Nobody has received a dose in excess of the established dose limits. Monitoring of internal contamination as a result of intake of radioactive substances has been carried out in accordance with established rules, and nobody has been reported to have received internal doses of > 0.25 mSv during the year.

Table 2 shows more personnel doses for the Swedish nuclear power plants in 2006. Note that since some individuals can work at more than one plant, the highest individual dose per plant differs from the highest total individual dose quoted above. For the same reason the sum of the number of individuals per plant differs from the total number of people who have received a reportable dose.

Table 2: Summary of doses to personnel at the Swedish nuclear power plants in 2006

Plant	**Total annual collective dose** (manSv)	**Average individual dose** (mSv)	**Largest individual dose** (mSv)	**No. with registered dose >0.1 mSv**
Barsebäck	0.10	1.0	8.8	104
OKG	4.28	2.9	1.7	1471
Forsmark	1.95	1.3	12.1	1455
Ringhals	2.94	1.7	16.4	1751

Plant specific

Barsebäck Kraft AB
Activities at the Barsebäck facility in 2006 have been concentrated to both technical measures and the management and organisational changes required for the final closure of Barsebäck 2. The amount of work on system technical measures has been limited during the year, and the most extensive effort has been the removal of all the spent fuel from the site to the interim storage facility for spent fuel (CLAB). Further the detection probes in the reactor vessel have been taken care of, as well as medium level waste in the form of ion exchanger resins cast in bitumen, which has been removed to the final depository in Forsmark (SFR).

The staff at the Barsebäck facility has been successively adjusted to the current activities and has been reduced from about 130 at the beginning of the year to about 65 by the end of 2006.

The collective dose to the staff during the year was the same as in the previous year: 0.1 manSv. No incidents of importance for radiation protection have been reported during the year. Nor have any noteworthy deviations been noted in connection with SSI's inspections. Reporting from BKAB with regard to occupational radiation protection in accordance with SSI's regulations has worked well during 2006.

SSI considers that the work related to radiation protection of personnel at the Barsebäck facility has been carried out to a good standard and in accordance with current regulations. The doses received in recent years are considered to reasonable under the circumstances prevalent at the facility.

Forsmarks Kraftgrupp AB
A large reorganisation was carried out in 2001 in which the protection and maintenance personnel, amongst others, were transferred from the individual plants to a common maintenance department. Responsibility for planning and resources remain with the individual unites F1 – F3, but the resources and personnel are supplied by the maintenance department. SSI considers that the joint protection organisation has resulted in improved coordination and improved performance of the occupational radiation protection activities at FKA.

The collective dose was in total 1.95 manSv in 2006 and approximately 0.6 manSv per unit, which is internationally a good result for a boiling water reactor. Modernisation of several reactor systems in recent years has in combination with better control of the water chemistry resulted in lower radiation levels in the plants. The external radiation levels around the Forsmark site are also monitored on a continuous basis, and nothing noteworthy has been observed. The Forsmark plants do not dose hydrogen water chemistry (HWC) and this means that the radiation levels in the vicinity of the turbines and surroundings are 3 – 4 times lower during operation than in the reactors which operate with HWC.

Three fuel failures occurred at FKA during 2006. The fuel failures have not affected the contamination levels in the reactors or the reactor systems. SSI carried out an inspection of the fuel failure policy in November 2006 and concluded that they meet the requirements in SSI's regulations (SSI FS 2000:10 § 31).

Two contamination incidents have been reported to SSI in 2006. One was in connection with immobilisation of ion exchange resin and the other was when a piece of pipe that had not been properly cleaned was being machined. The incidents have been followed up by inspections performed by SSI, and resulted in the introduction of clearer instructions by FKA.

The incident which occurred during the summer of 2006 with a short-circuiting in the switch yard resulting in serious disruptions in the electricity supply in Forsmark 1, did not lead to any consequences with respect to radiation protection, neither for doses to personnel nor the release of radioactive substances to the surroundings.

Reporting from FKA in accordance with SSI's regulations concerning occupational radiation protection has been satisfactory during 2006. SSI's evaluation of how current regulations and rules are met has not resulted in any criticism or sanctions. SSI has not in its supervisory efforts noted any remarkable deviations or incidents within the area of radiation protection of personnel at FKA in the last year. SSI therefore considers that the work addressing the occupational radiation protection at FKA is carried out in a satisfactory manner.

OKG Aktiebolag
The total collective dose to personnel at the Oskarshamn facility in 2006 was 4.3 manSv. This was the result of normal outage activities and necessary safety measures.

The radiation environment in the plants is comparatively favourable following the decontamination campaigns between 1998 and 2003. OKG has described on-going work to further reduce the radiation doses to personnel. The programme includes, amongst other things, follow-up of radiation levels in the plants, measures to keep the reactor systems clean, reducing the input of stellite to the reactor systems and prevention of the occurrence of fuel failures.

The radiation levels around the Oskarshamn site are monitored on a continuous basis, and nothing remarkable has been observed in the results.

O3 had two small fuel failures in 2006. One of the failures was dealt with during the refuelling outage when the damaged fuel was replaced. It is planned that the other failure will be dealt with during Easter 2007. SSI has assessed that the consequences from these failures to radiation protection are minimal.

Two other incidents occurred in 2006. Both of the incidents have been investigated and the deficiencies that were identified have been rectified. One incidence occurred at O2 in connection with radiography work which was being performed by a contractor. One person received a radiation dose which was in fact small, but he was subjected to unnecessary risk which is unacceptable. One reason for the event was indistinct division of responsibility between the licensee and the contractor. In the other incident a load of contaminated components slid off a trolley inside the enclosed area of unit 3. None of those involved received any dose, but the incident showed that there were deficiencies in internal instructions and how they are followed. No other notable deviations or incidents have been observed by SSI in connection with its supervision of OKG.

Reporting from OKG in accordance with SSI's regulations concerning the radiation protection of personnel has been satisfactory during 2006. Reports have been submitted in time and have been sufficient. SSI's evaluation of how current regulations and rules are met has not resulted in any criticism or sanctions.

SSI therefore considers that the work addressing the radiation protection of personnel at OKG is carried out in a satisfactory manner.

Ringhals AB
For some years the activities of Barsebäck and Ringhals have been integrated but following the shutting down of Barsebäck 2 preparations are under way for their separation, which will be carried out at turn of the year 2006/2007. SSI has not had any viewpoints concerning the organisation of the radiation protection work at Ringhals AB.

The collective dose at Ringhals in 2006 was 2.94 manSv. During the year considerable testing and rebuilding activities have been carried out on the reactors in Ringhals. The radiation levels are still low or decreasing, with the exception of R4, for which a slight increase has been noted. The doses received at the Ringhals facility are considered to be reasonable with regard to the work which has been carried out and the radiation environment.

No incidents concerning occupational radiation protection have been noted in 2006.

SSI carried out a detailed inspection in connection with the annual outage for maintenance and refuelling of Ringhals. During the inspection SSI found a number of areas in which a revision of current routines are needed, and for which there is a potential for improvement. These include, amongst other things, how dose targets are followed, experience feedback from contractors, feedback and responses to safety reports, as well as the management of information concerning radiation protection. RAB has reported on how they are working with measures to rectify SSI's observations. SSI considered overall that the work with radiation protection as a whole is conducted well and that there is an open and constructive dialogue between management, employees and hired contractors.

The reporting required by SSI has been carried out by RAB without deviations or incompleteness. SSI's evaluation of how current regulations and rules are met by RAB has not resulted in any criticism or sanctions.

SSI therefore considers that the work addressing the radiation protection of personnel at RAB is carried out well.

Environmental impact evaluation

Barsebäck Kraft AB
BKAB received in 2006 permission according to the environmental ordinance to carry out shutdown and service operations as preparation for the decommissioning of the nuclear power plant and harbour activities. Permission is limited in time until the end of 2012, since it was not considered that it has been determined if there were the prerequisites to commence demolition earlier than originally planned.

Forsmarks Kraftgrupp AB
SSI in its statement to the environmental court in Stockholm has not supported FKA's application to operate the reactors F1, F2 and F3 at higher thermal power. The lack of support is directed to those areas concerning the use of the best applicable technique (BAT) for limiting the release of radioactive substances for activities with increased thermal power.

An important aspect for SSI's evaluation if BAT is being applied in connection with the power increase is that the measures to reduce releases should be introduced at the latest when the increase is implemented, and that the releases should not increase. SSI therefore considered that it is not acceptable that the measures that are planned to reduce the release to the water from F1 and F2 are first planned to be introduced in 2013, when the last thermal power increase is planned for 2011. Further SSI considered that it was unacceptable that FKA did not present any plans at all for measures to reduce the release of radioactive substances from F3 and no measures to reduce the release to the atmosphere from F1 and F2. The releases are instead calculated to increase by 14 percent from F3, and by 11 percent to the air from F2, and SSI does not consider that this is acceptable.

OKG Aktiebolag
SSI did not support OKG's application to operate the reactor O3 at increased thermal power in its statement to the environmental court in Växjö. This was based on the first hand on the question of the use of the best applicable technique (BAT) for the release limiting systems for OKG's reactors, but also the application of BAT for the steam content of the primary steam. SSI considered that the measures presented by OKG for O1 and O2 concerning releases to the atmosphere complies with SSI's assessment of what can be considered to be BAT with the addition that the investigation of carbon columns should be implemented within 2 years. On the other hand SSI is of the opinion that OKG should seriously consider the use of evaporisers in order to reduce the release to the water, since this is an accepted method used by many reactors around the world. An important basis for SSI's evaluation if BAT is used in connection with thermal power increases is that the measures to reduce releases should be introduced at the latest at the implementation of the increase in thermal power of the unit and that the release should not increase.

The environmental court in Växjö granted permission on 2006-08-16 for OKG to operate the reactors with thermal power levels of 1,375 MW for O1, 1,800 MW for O2 and 3,900 MW for O3, and that they can take the necessary steps to increase the thermal power in O3 from 3,300 to 3,900 MW. A condition for this permit is that OKG must take the measures to reduce releases as described in the appendices to OKG's response or other measures which will result in the same reduction in the total release of radioactive substances expressed as radioactivity (Becquerel) from theoperations. These measures take into account the points raised by SSI in the above named statement.

Ringhals AB
SSI did not support RAB's application to operate the reactors R1, R2, R3 and R4 at increased thermal power in its statement to the environmental court in Vänersborg. This was directed to the use of the best applicable technique (BAT) for limiting the releases from operations after the thermal power increases. An important aspect in SSI's evaluation as to whether BAT is applied in connection with the thermal power increase is that the release reducing measures should be introduced, at the latest, at the time that the thermal power increase the reactor is implemented and that the releases should not increase.

The environmental court in Vänersborg granted permission on 2006-03-22 for Ringhals to operate the reactors with thermal power levels of 2,550 MW for R1 (an increase from 2,500 MW), 2,710 MW for R2 (an increase from 2,660 MW), and 3,159 MW for R3 and R4 (an increase from 2,783 MW). The environmental court chose to postpone making a decision as to which conditions should be imposed with regard to reactor safety and radiation protection for a trial period. During this trial period Ringhals is required to carry out a number of measures to reduce releases, as specified in the annex to the judgement, or to carry out other measures which will result in the same reduction of the total release of radioactive substances expressed as radioactivity. These measures take into account the viewpoints raised by SSI in the above named statement.

The release of radioactive substances to the environment

Common issues

Nuclear power plants release small amounts of radioactive substances to both the atmosphere and water. These releases are measured continuously. The radiation dose to the public from these releases is calculated using models which are plant-specific, and which take into account, amongst other things, the meteorological conditions, and the local land and water environments. The measurement and reporting of releases are to be conducted in accordance with SSI FS 2000:12, *The Swedish Radiation Protection Authority's Regulations on the Protection of Human Health and the Environment from the releases of Radioactive Substances from Certain Nuclear Facilities.*

Diagram 7 shows the radiation doses calculated from the release of radioactive substances from nuclear power plants in 2006. The radiation doses (quoted in Sv) are for people living close to a nuclear power plant and who are expected to receive the highest doses, *the critical group*. The permissible dose to a person the critical group is 0.1 mSv per annum (100 Sv). The doses were in all cases less than one hundredth of the permissible dose, and also show a decreasing trend over the years covered in the diagram.

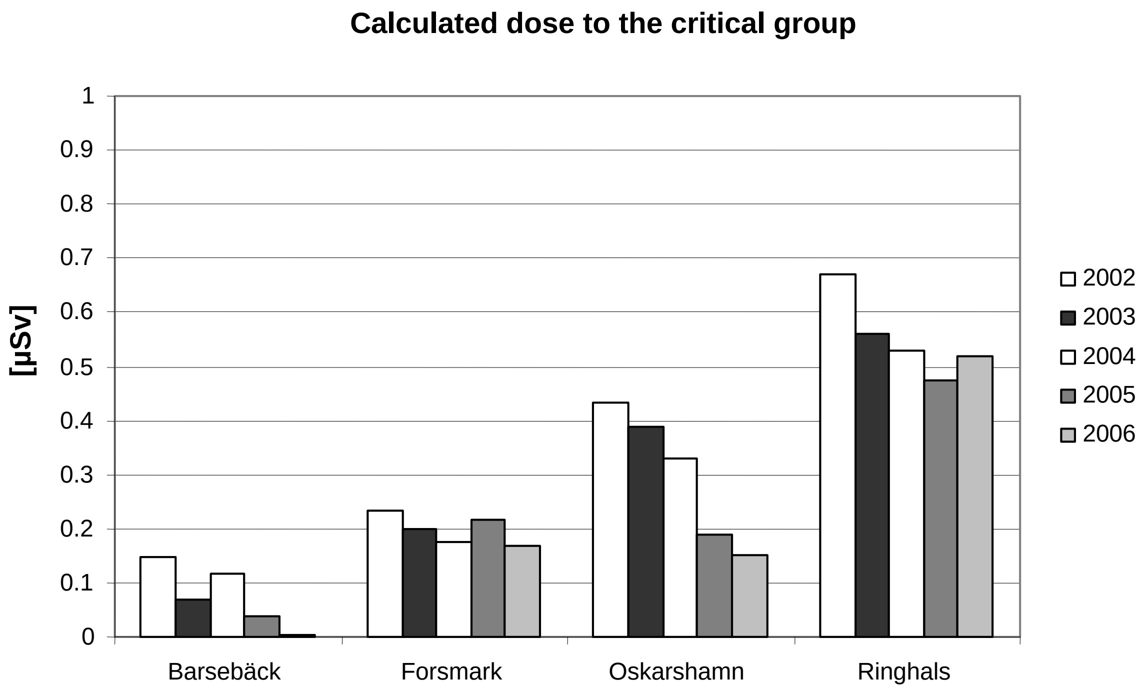


Diagram 7: Release of radioactive substances to the atmosphere and water from nuclear power plants 2002 – 2006 shown as the dose to the critical group. The results from Forsmark are not corrected for the measurement error detected in December 2006.

Reporting release data and new target and reference values

SSI's regulations contain requirements that the licensees of nuclear power plants report *reference values* for the release of individual or groups of radionuclides. These values are intended to show the normal optimised release level that it is possible to achieve during the operations of each unit. The reference value is a measure of the different reactors' ability to limit releases during operation. The decisive factor for determining the reference value is operating experience and knowledge of the magnitude of the release in an historical perspective.

The regulations also contain the requirement to report a *target value*. The target value is the level to which the release of radioactive substances from a reactor can be reduced over a given time under normal operating conditions. Work to reduce the releases is thus steered by the established targets. The regulations require that the licensees report their ambitions and strategies for both the short and long term with regard to the reduction of the release of radioactive substances. The target values that have been used for the past five years are valid until 2006, which means that the evaluation will be made using these values.

Barsebäck has met all the target values. At the other facilities a few target values have been exceeded, partly because of fuel failures and partly because the target values were in some cases chosen so that they did not correctly reflect the licensee's ambitions to reduce releases. Forsmark does not mention anything in their report about the measurement problems they have had and that are described below.

That the target values have been exceeded does not mean that the public has received significantly higher doses or that any dose or release limits have been exceeded.

All the facilities have submitted new suggestions for tartet and reference values for the next five years, and SSI is intending to take into account the assessment of how they met the goals in 2006 when evaluating the new target and reference values.

Incidents and deviations

Repeated problems with monitoring release to the atmosphere in Forsmark

For a number of years FKA has had repeated problems with the measurement of, on the first hand, releases to the atmosphere from Forsmark. The problems have been both technical and organisational. Amongst the technical problems are faulty detectors, errors in communication between the detector and the computer, as well as problems with the software, which has led to problems with data collection from the detectors. The organisational problems include, for example, deficiencies in operational monitoring, regulations that reports should be submitted to SSI when there are operational disturbances which have not been followed, and the lack of routines for the back-up of stored data. SSI has continually followed up and evaluated specific events, and, on the initiative of SSI, FKA has prepared a plan for rectifying the erroneous measurement system.

Errors in the measurement of particulate release to the atmosphere in Forsmark

In December 2006 FKA discovered that the release to the atmosphere of particulate radioactivity from F1 had been measured in an erroneous manner since the middle of 2004. The errors in the measurements mean that only a quarter of the releases have been measured. Since the releases have not been measured correctly, FKA have not complied with the requirements in SSI FS 2000:12 (release regulations) with respect to continuous measurement of the release of radionuclides from nuclear power plants.

SSI has, in a decision dated February 5, 2007, required that FKA investigate the incident and report to SSI by March 31, 2007, at the latest, amongst other things, the reason for the erroneous measurements and the actual releases based on assumptions, as well as how FKA can ensure that similar errors in measurement have not occurred on other occasions than for the specified time period at F1, or at one of the other two plants. The same sort of equipment is used in the other two units.

Contaminated sediment at Barsebäck

On September 22, 2006, BKAB stated that when they were about to remove the sediment from a cooling channel it was found to contain 6 kBq of various nuclides. Work was stopped, and BKAB started an investigation. Just over a week later BKAB came with new information about the sediment. Based on § 2 item 5 in the Radiation Protection Act they had determined that the material could be disposed on their own tip since the sediment was considered to be *"material which had been contaminated with radioactive substances as a result of a release approved by the Swedish Radiation Protection Authority, and which the authority had declared need not be controlled any further"*

Environmental surveillance

According to SSI:s regulations SSI FS 2000:12, facilities must perform monitoring and take samples in the environment following a programme set up by SSI. A limited selection of the samples taken should also be measured by SSI. Cesium-137 from the Chernobyl accident in 1986 still dominates the samples taken in the control programmes, in particular in soil samples. In the samples taken from the water environment in the vicinity of the nuclear power facilities a number of other radioactive substances are detected, such as Cobolt-60, amongst other things in samples of algae and the bottom sediment.

Decommissioning

Inspection of plans prior to decommissioning

In 2004 and 2005 SSI carried out an inspection of the plans for decommissioning at all the nuclear facilities in accordance with the regulations in SSI FS 2002:4.

None of the nuclear facilities were considered to meet the requirements concerning the analysis of different decommissioning alternatives. Further SSI considered that the compilation of the inventory of radioactive material was inadequate in BKAB, OKG and RAB.

SSI stipulated that the facilities complement their decommissioning plans in this respect. All of the facilities have complemented their decommissioning plans and SSI has assessed the revisions and considered them to be acceptable.

Reporting in accordance with the requirements in SSI's decommissioning regulations after the final closure of a facility

In May, 2006, BKAB submitted decommissioning plans, in accordance with 9 § SSI FS 2004:2 after the final closure of the facility.

SSI considers that the submission by BKAB is far too stereotyped and must be complemented, in particular with respect to the future decommissioning measures and the waste logistics. The submission should also be revised to ease readability. SSI intends to stipulate complements to the submission.

9. Waste management

Treatment, interim storage and disposal of nuclear waste

Different forms of treatment of radioactive operational waste are conducted at the nuclear power plants so that the waste can be disposed of or placed in interim storage pending disposal. Low level waste is disposed in landfills on site at Forsmark, Oskarshamn and Ringhals, or is sent to Studsvik for treatment. More radioactive waste is disposed in the repository for operational waste, SFR-1, which is located near the Forsmark nuclear power plant. Very low level waste can be exempted from the regulations (free-classed) concerning the Radiation Protection Act and the Act on Nuclear Activities and can then be used without restriction, incinerated or disposal on municipal dumps. Waste containing long-lived radioactivity is placed in interim storage at the nuclear power plants or in CLAB, the Central Interim Storage Facility for spent nuclear fuel, pending a suitable repository.

In addition to the treatment of normal operational waste, the following can be reported for 2006:

At Barsebäck work is underway to deal with the waste from the operational period. Amongst other things about 100 tons of oil from the shut-down reactors has been free-classed. During 2006 the last remaining drums of bitumen sealed waste have been sent for disposal in SFR-1. In connection with this, it was discovered that there are errors in the database of the waste in Barsebäck. Investigations have been started to ensure that the waste has already been disposed in SFR-1. The planned cement immobilisation of ion exchange resin may not be started until SKI and SSI have approved its disposal in SFR-1.

An incident occurred at Forsmark in November 2006, in connection with cleaning and emptying a tank at the waste handling facility in Forsmark 3. After changing the cleaning agent the wrong routines were used, which meant that the immobilisation locality had to be decontaminated. This event demonstrates that they are deficiencies in the routines for experience feedback. The replacement of the low pressure turbine in Forsmark 2 generated after treatment approximately 410 of tons scrap metal which was free-classed. This has been well handled in accordance with the waste plan. Evaporator concentrate is still being stored whilst a method is developed to increase the capacity for its treatment.

In the underground storage facility (BFA) at Oskarshamn preparations are underway for the interim storage of long-lived waste such as reactor vessel internals from the Swedish nuclear power plants. The aim is to use the underground storage facility until the final repository for long-lived waste is available, which is expected to be in 2045.

At Ringhals waste handling is affected by the prohibition for the disposal of certain PWR waste in SFR-1. The waste is being stored at Ringhals until SKB (Swedish Nuclear Fuel and Waste Management Co) submits the statement that the authorities required as a result of the review of the safety report for SFR-1.

In 2006, the treatment of the steam generators from Ringhals 3, which were sent to Studsvik in 2005, is almost completed with good results. Some waste remains to be treated before the final report can be submitted to the authorities SKI and SSI. Similar treatment is planned for the other steam generators that are currently being stored at Ringhals.

As in previous years, scrapped components have been sent from the nuclear power plants to Studsvik for treatment in the melting facility. In 2006 Barsebäck has sent 9 tons, Oskarshamn 44 tons, and Forsmark 416 tons.

No waste has been disposed in the landfills at the plants. A campaign at Ringhals has been postponed because of requirements imposed by SSI that certain nuclides which are difficult to measure must be reported. It is probable that the permission granted for landfills must be reconsidered before disposal can be resumed.
The existing landfill at Forsmark has been fitted with a new roof in 2006 because of earlier water penetration. In 2001, the licensee, FKA, applied for permission to establish a new landfill. A renewed application was submitted in 2005. Additional information must be submitted before SSI, after consultation with SKI, can make a decision.
In 2006 waste packages corresponding to 294 m^3 have been disposed in SFR-1. Since SFR-1 became operational, a total of 31,101 m^3 has been disposed. The leakage of radioactivity from drums with waste in the BMA portion of the facility has ceased and the concentrations in the drains have returned to normal levels,

SKI and SSI consider that other waste treatment, interim and final storage of nuclear waste at the nuclear facilities have been conducted in a satisfactory manner in 2006.

Spent nuclear fuel

Spent nuclear fuel and remains of reactor vessel internals that are classified as long-lived waste are placed in interim storage in Clab which is located close to the Oskarshamn nuclear power plants. OKG conducted the day-to-day operations under contract to SKB up to 2006-12-31. From 2007 SKB will take over the operation of Clab, which will mean considerable adjustment for SKB. During the year SKB has made considerable efforts aimed at taking over the responsibility for operating the facility themselves. As a result of this SKI is performing a review of the organisational changes effected by SKB.

During the year 116 fuel transport containers, with a total of 312 tons of uranium in the form of spent fuel from the nuclear power plants, have been received at Clab. At the end of the year there were 4,552 tons of uranium in the Clab storage pools. During the year a total of 222 reserve positions for fuel have been utilised.

10. Emergency preparedness

During the year the authorities have continued to follow and promote the development of emergency preparedness at the nuclear power plants. In particular the work concerning exercises has been in focus, both the preparations and the execution of the comprehensive exercise “FALKEN”.

In 2006 SSI has concentrated on efforts connected with the introduction of their regulations concerning emergency preparedness at certain nuclear facilities (SSI FS 2005:2). The nuclear power plants have had the ambition to introduce all the measures necessary to meet the requirements during 2006. SSI plans to carry out inspections of all nuclear facilities in 2007 for a detailed assessment of how the regulations are met.

In 2005, SKI performed reviews and inspections of all the nuclear power plants to determine to what extent the licensees meet the requirements in SKI’s regulations, SKIFS 2004:1 concerning safety at nuclear facilities, with regard to the planning of emergency preparedness and information transfer to SKI. The supervisory effort showed that there is a need for improvement of both the planning and the transfer of information. SKI therefore issued a decision that required that the plants to carry out improvements. The measures are currently being reviewed and will be followed up further in 2007.

SSI, in cooperation with the plants, has strengthened the possibilities for SSI’s personnel communication in the control centres at the nuclear power plants. SSI personnel at the plant can now communicate in a secure manner with SSI via the internet and get access to the information system in the internal network at the authority. This improvement has been implemented at Forsmark and Ringhals. The upgrade is planned for 2007 in Oskarshamn. Corresponding measures have been implemented in the protected control centres of the relevant counties.

SKI, in consultation with SSI, has started a research project concerning the technical alarm criteria at the nuclear power plants. The alarm criteria form the basis for setting the alarm levels which in turn form the basis for organisations outside the plant to take initial measures in the event of an accident. The project is also to investigate the possibility of further improvements in harmonisation of the scope of the alarm criteria at the different nuclear power plants.

Experience has shown the importance of well defined criteria and routines for when and how a plant should contact the authorities in the occurrence of incidents. In connection with the incident in Forsmark in July 2006, SSI was not contacted by the plant in the early stages, which should have happened according to the routines in the event of an incident of interest to the media. Forsmark contacted SKI within one hour of the incident. SSI was however contacted at an early stage by SKI, through the established information channels between the authorities.

SKI and SSI have participated in a project group which has investigated the requirements concerning special emergency preparedness for the county administrative board of Skåne after all the nuclear fuel has been removed from Barsebäck. The final report from the group has not yet been approved, but the conclusion is that the plant will probably be classed as category 3 according to SSI’s regulations (SSI FS 2005:2) concerning emergency preparedness at certain nuclear facilities. The requirement for special emergency preparedness in Skåne would thus be revoked in accordance with the regulations SFS 2003:739 concerning protection against accidents.

SKI and SSI have participated in a number of exercises of varying size and complexity, ranging from liaison tests to exercises at units of nuclear power plants.

On October 4, 2006, the national nuclear exercise FALKEN was held with the county administrative board of Halland and Ringhals nuclear power plant as central participants. Both SKI and SSI participated in the exercise and sent representatives to the county administrative board, press centre in Varberg and the control centre at the plant. Coordination between SKI/SSI headquarters, and their representatives at the different locations worked well throughout the exercise.

The exercise was preceded by extensive collaboration between SSI and the nuclear power plant in order to develop the radiological scenario that was used for the exercise.