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Safety and Radiation Protection at Swedish Nuclear Power Plants 2005

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Summary

The safety philosophy upon which the Swedish Nuclear Power Inspectorate's (SKI) supervisory and regulatory activities are based assume that multiple physical barriers will exist and that a plant-specific defence-in-depth system will be implemented at each plant *and that the licensee bears the undivided responsibility for safety.* The physical barriers are situated between the radioactive material and the plant personnel and surroundings. In the case of nuclear reactors in operation, the barriers comprise the fuel itself, the fuel cladding, the reactor pressure-bearing primary system and the containment. Defence-in-depth entails applying several layers of different technical systems and operational measures as well as administrative routines in order to protect the barriers and maintain their effectiveness during normal operation and during anticipated events and accidents. If this fails, a system for emergency preparedness should be in place in order to limit and mitigate the consequences of a severe accident.

An effective defence-in-depth approach is based upon sound management and control of safety, and an organisation with adequate financial and human resources and personnel with the necessary competence working under suitable conditions. This is the basis of a good safety culture.

When a facility is in operation, all the barriers should be intact. This means, for example, that a containment leak should normally result in the shutdown of a reactor, even if all other barriers are intact and safety is thereby not jeopardised.

Defence-in-depth systems are designed so that they can withstand deficiencies during the limited period of time required for corrective action. For example, a competence analysis or parts of a safety assessment may be lacking for a certain period of time without SKI requiring the facility to be shut down. When such deficiencies occur, SKI talks about reduced safety margins or about a need for improvement.

No Severe Events in 2005

In 2005, no severe events occurred which challenged the safety at the Swedish nuclear power plants. However, some events have been given a special focus.

The "Gudrun" storm, which occurred in January 2005, affected the operation of the reactors at Ringhals and Barsebäck 2. At Ringhals, the switchyards were affected by salt deposits and, at Barsebäck, the 400kV grid was subjected to interruptions.

Two events were classified as Level 1 events on the 7-point International Nuclear Event Scale. The events are described in the chapter, "*Operating Experience*".

Impact of Preventive Measures

In 2005, relatively little new damage and deficiencies were detected in the reactor barriers and safety systems. Previously identified problem areas have been followed up and analysed and new damage has been repaired. The replacement of existing material

by material that is less vulnerable to damage has been carried out as a measure to prevent damage at certain facilities. This means that SKI does not currently see any serious tendencies to age-related damage which would lead to a decrease in reactor safety.

The long-term trend is that the total number of fuel defects in Swedish reactors is decreasing. The damage that occurs nowadays has mainly been caused by small objects entering the fuel via the coolant and fretting holes in the cladding. To reduce the number of defects of this type, fuel with filters is successively being introduced to prevent debris from entering the fuel assemblies and cyclone filters in the facility which cleans the coolant. However, the most important factor is the fact that there is a greater awareness of the importance of keeping the coolant free from foreign objects which can wear holes in the cladding. The facilities have programmes to reduce the risk of harmful objects entering the systems.

Since the mid-nineties, the pressurised water reactors, Ringhals 2, 3 and 4, have had problems with fuel rod bowing in excess of the safety analysis calculations. Ringhals AB (RAB) has adopted measures to rectify the bowing. Followup work shows that the fuel rod bowing is continuing to decrease.

The followup in 2005 of damaged tubes in the Ringhals 4 steam generators indicates a continued slow damage propagation. Tubes with defects of such a limited extent that there are adequate margins to rupture and loosening have been kept in operation. Damaged tubes with insufficient margins have plugged.

During the year, previously observed minor leakage from the reactor containment in Ringhals 2 was investigated in greater detail and repaired. The investigations showed extensive corrosion attack caused by deficiencies in connection with containment construction.

The ageing of electrical cables and other equipment in the I&C systems has been examined by SKI. Regulatory supervision has so far shown that these issues are largely handled in a satisfactory manner by the licensees but that certain supplementary investigations and other measures need to be carried out.

Increase in Reactor Thermal Power

The licence granted by the Government for the operation of a nuclear power reactor states the highest thermal power at which the reactor can be operated as a licence stipulation. Thus, the licence only applies for this thermal power. In order to increase this power, the Government must decide to grant a new licence according to the Act (1984:3) on Nuclear Activities.

Forsmarks Kraftgrupp AB (FKA) has applied for permission for power uprates at the Forsmark 1-3 reactors, OKG (OKG) has applied for permission for power uprates at the Oskarshamn 3 reactor and RAB has applied for permission for power uprates at the Ringhals 1 and 3 reactors. SKI has reviewed the applications from OKG and RAB and has found that the necessary conditions exist for implementing the power uprates that have been requested. The Government has decided to grant permission for power uprates at Ringhals 1 and 3. SKI is currently reviewing applications from Forsmarks Kraftgrupp AB and a review statement will be submitted to the Government in May.

Requirements on Safety Improvements Lead to Major Challenges

SKI's regulations (SKIFS 2004:2) concerning the design and construction of nuclear reactors entered into force with certain transitional regulations on January 1, 2005. Through these regulations, SKI has developed and clarified the safety requirements for nuclear reactors.

The transitional agreements mean that the licensees concerned must be given the necessary time to plan and implement the measures at the reactors that are necessary in order to comply with the regulations. Based on the transitional regulations, the licensees concerned have described to SKI the measures that they consider need to be taken at each reactor and specified when these measures are to be implemented. SKI has reviewed and made a decision on the measures at the Forsmark 1-3 reactors. Similar reviews and decisions on measures at the Oskarshamn 1-3 and the Ringhals 1-4 reactors are expected to be made by mid-2006.

The regulations mean that extensive measures need to be conducted at the reactors, especially the older reactors, in order to further improve safety to the modern level that the requirements entail. The safety improvement work will be conducted for a relatively long period of time. During the same period, power uprates are being planned at several reactors. The nuclear industry is thereby entering a highly intensive and resource-intensive period, perhaps the most intensive since the facilities were constructed and taken into operation in the 1970's and 1980's.

During the year, SKI also decided on new regulations (SKIFS 2005:1) for the physical protection of nuclear facilities. These regulations will also have extensive consequences for the licensees, through more stringent regulations with respect to area protection, perimeter protection and access control. The regulations will enter into force on January 1, 2007 when most of the stipulated measures are also to be implemented. Certain more extensive measures are to be carried out by January 1 and October 1, 2008, respectively.

Both the licensees and their suppliers are facing considerable challenges in the future. SKI will also face considerable challenges in the form of regulatory reviews and other regulatory and supervisory actions which will be needed during the period. The authority has re-allocated priorities and concentrated resources on these issues.

Continued Development of Management Systems, Safety Documentation and Self-Assessment

During the year, SKI continued to follow up and promote the further development of the licensees' internal audit functions, management systems and competence assurance processes. SKI notes that continued improvements have been implemented and that the independent audit functions have been reinforced among other things. Additional reinforcement may be needed in the future as more and more changes are implemented at the reactors.

Up-to-date and documented safety analyses must be prepared and actively be included in both the preventive safety work and in connection with plant modifications. The licensees have implemented design analysis projects for a long period of time and clarified and stringent regulations for safety analyses have entered into force in 2005. As a result, updated safety reports exist for many of the facilities and schedules exist for the supplementary work that remains to be done. SKI is continuing to review work and provide the impetus for the licensees to continuously keep the central safety documentation updated as modifications are made and new knowledge emerges.

Closure of the Reactors at Barsebäck and Studsvik

SKI's reinforced supervision of Barsebäck 2 continued until the closure of the reactor on May 31, 2005. SKI's reinforced supervision entails a greater presence of inspectors than normal and more stringent reporting requirements. In SKI's opinion, Barsebäck Kraft AB (BKAB) mainly handled the lengthy facility closure in a satisfactory manner.

Nuclear Waste Handling

The handling of nuclear waste at the nuclear facilities has mainly functioned well. The same applies to the operation of the Repository for Low and Intermediate-level Operational Waste (SFR-1) and the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB).

Certain handling deficiencies have been observed and measures have been adopted to prevent a recurrence. Organisational changes are being prepared at CLAB. These changes will be reviewed by SKI.

Satisfactory Safeguards

In 2005, SKI, the IAEA and Euratom carried out inspections of how safeguards are handled at the nuclear power plants. A total of 89 inspections were carried out. The inspections have not found anything to indicate any safeguards deficiencies.

Good Radiation Protection Situation

The overall evaluation of the Swedish Radiation Protection Authority (SSI) is that radiation protection at Swedish nuclear power plants has functioned well in 2005. SSI cannot see any sign that the resources and the competence required to maintain a good radiation protection has decreased. However, SSI wants to point out that it continues to be important for the operations management of the nuclear power plants to give radiation protection a high priority to ensure a future positive development. As a result of plant modifications due to power uprates and plant modernisation, work at different units will vary from year to year. This could mean higher collective doses at the reactors concerned and the total radiation dose to the personnel at the Swedish nuclear power plants will be affected by this.

The total radiation dose to the personnel at Swedish nuclear power plants was 9.2 manSv, which agrees with the average value of the total radiation doses over the last five years (9 manSv). No-one received a radiation dose in excess of the established dose limits and the radiation levels in the facilities are largely unchanged compared with previous years.

The radiation doses to the public from the Swedish nuclear power plants continue to be low. SSI considers that continuous work is also needed in the future at the facilities to further reduce radioactive releases by applying the best available technique (BAT) and other measures. The control measurements that SSI is conducting on environmental samples from around the nuclear power facilities as well as on radioactive releases to water show a good agreement with the licensees' own measurements.

Continued Development of Emergency Preparedness

During the year, SKI and SSI have followed and provided the impetus for the development of emergency preparedness at the reactors. The issues that were paid special attention are the first phase after events occur and the contact with the authorities in connection with this. It also takes time to prepare and implement protective measures for people living in the vicinity, if this should be necessary. Therefore, it is important to ensure that there are well-developed, tried and tested emergency operating procedures at the facilities which ensure that situations can be handled and which can ensure a fast and adequate reporting to the authorities concerned.

Premises and evaluation criteria

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

Based on these stipulations, SKI must, in its regulatory and supervisory activities, clarify the details of what this responsibility means and ensure that the licensee is following the stipulated requirements and conditions for the activity as well as achieving a high level of quality in its safety work. Furthermore, the Ordinance (1988:523) with instructions for SKI, stipulates that SKI shall follow developments in the nuclear energy area, especially with respect to safety issues, as well as investigate issues concerning and take the initiative to implement measures to improve safety at nuclear facilities.

Defence-in-depth Principle

Safety at Swedish nuclear power plants must be based on the defence-in-depth principle 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 personnel and environment. In the case of nuclear power reactors in operation, the barriers comprise the fuel itself, 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 a 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 are provided with the right conditions for work.

A number of different types of engineered systems, operational measures and administrative procedures are applied in the defence-in-depth system in order to protect the barriers and maintain their efficiency during normal operation and under anticipated operational occurrences and accidents. If this fails, measures should be in place in order 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 is performed of the barriers that must function and the parts at different levels of the defence-in-depth that must function at different operating states. When a facility is in full operation, all barriers and parts of the defence-in-depth system must be in operation. When the facility is shut down for maintenance and when a barrier or part of the defence-in-depth system must be taken out of operation for other reasons, this is compensated for by other measures that are of a technical, operational or administrative nature.

Thus, the logic of the defence-in-depth system is that if one level of the defence system fails, the next level will take over. A failure in equipment or in 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 levels of the defence-in-depth system is essential in order to achieve this.

The requirements that SKI places on the different stages of the defence-in-depth system are stipulated in SKI's regulations and general recommendations.

Correspondingly, SSI has also stipulated radiation protection requirements in its regulations. Together, these legal acts 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

This chapter deals with operations at Swedish nuclear power plants in 2004. SKI presents the main work that was conducted during the year and describes the events and defects detected at each reactor. More details concerning operation and availability data are provided at each company's website and in the annual report of each nuclear power plant which, in accordance with SKI's regulations, is to be submitted to SKI. Certain events and conditions are described in greater detail in other sections of this report.

Two events have been classified as 1 on the International Nuclear Events Scale (INES) in 2005. These events, that occurred at the facilities at Forsmark and Oskarshamn, are described in the text under each facility's heading. None of the events was a threat to the safety of people living nearby.

The storm, "Gudrun", which affected Southern Sweden in January, resulted in interruptions in the operations of the facilities at Barsebäck and Ringhals.

Barsebäck

Barsebäck 1
Barsebäck 1 has been closed down since 1999. The main task for the personnel working with Barsebäck 1 is to build up decommissioning knowledge and to document plant status prior to the forthcoming dismantling as well as to support Barsebäck 2 with resources.

Barsebäck 2
In connection with "Gudrun" on January 8, interruptions occurred in the 400kV grid which led to partial scram. The facility changed over to dump operation at 54% reactor power. Automatic switchover to the 130 kV grid occurred. Early in the morning of the following day, the reactor returned to normal operation and was resynchronised to the external grid. As a result of a government decision, Barsebäck 2 was closed down on May 31. On June 10, all of the fuel was removed from the core and placed in the fuel pools.

Incorrect changes in system alignment in the fuel pool cooling system on June 20 resulted in a loss of pool cooling for about 17 hours. However, the event did not lead to operation exceeding the temperature limits stipulated in the Technical Specifications (STF).

On July 1, a new organisation was introduced which was adapted to the closure of Barsebäck 2. The main difference compared with the previous organisation is the reduction of personnel. However, the principles for the allocation of responsibilities and safety management are unchanged. Operational measures that have been underway since final shutdown are surveillance testing in accordance with STF and certain tests on systems which are not governed by requirements but for which BKAB would like to maintain a good status.

Forsmark

Forsmark 1
In October 2004, Forsmark 1 received indications of a fuel defect. During the autumn, the defect became successively larger but did not have a negative impact on operation during winter and spring 2005. However, in May, the facility was closed down for the replacement of the damaged fuel element. On July 17, the refuelling and maintenance outage started and included the replacement of low-pressure turbines, refurbishment work in the reactor cooling system and major replacement work in the switchyard. The refuelling and maintenance outage was the most extensive ever carried out at Forsmark. The facility was started up again on August 27.

During the year, as with Forsmark 2, Forsmark 1 had problems with neutron flux measurement. A number of neutron flux detectors were replaced during the 2005 outages at both Forsmark 1 and Forsmark 2. During the last months of the year operation was without disturbance.

Forsmark 2
The operation of Forsmark 2 was without incident during the first half of 2005. At the end of March/beginning of April an event occurred which Forsmark 2 classified as 1 on the 7-point INES-scale. An inner containment isolation valve in the system for drainage water was found not to be properly leaktight. The valve had an internal leak. The root cause is believed to be debris entering into the valve from the reactor containment sump. The outer isolation valve installed in series was leaktight.

On June 11, Forsmark 2 was shut down for a short, 12-day outage. Problems were encountered with neutron flux measurement during power reduction and power increase.

On July 1, a fire occurred in a rectifier. As a result of this event, SKI carried out a RASK investigation into Forsmarks Kraftgrupp AB's handling of the fire. With the help of the investigation, SKI determined that the event was handled according to the procedures for this type of event.

On July 28, a fault occurred in a valve position indicator on an isolation valve in the steam line system. During repair work, the valve closed which caused a second steam line to close. This resulted in a reactor scram. The problems were resolved and the facility was once again taken into operation shortly after.

On September 29, a partial scram and an automatic reduction to 36 per cent power occurred. The cause was a fuse failure in connection with maintenance work. Increase to full power was initiated the same day. During the last months of the year, no incidents occurred during operation.

Forsmark 3
In January 2005, Forsmark 3 detected a fuel defect. The defect was a primary defect and so minor that operation could continue without interruption. The damaged fuel was replaced during the refuelling and maintenance outage which occurred from May 28 to June 8. During the remainder of the year, no events occurred during operation.

Oskarshamn

Oskarshamn 1
Operation at Oskarshamn 1 was smooth until April 27 when scram occurred as a result of a fault in the turbine governing system. On May 14, the facility was shut down due to high vibrations in the turbine. For this reason, OKG decided on May 23 to bring forward the date of the refuelling and maintenance outage (the original start date was scheduled for the beginning of June). The high vibrations were found to come from the high-pressure turbine and were caused by a loose support in the first turbine stage. During the refuelling and maintenance outage, the high-pressure turbine rotor was replaced.

The refuelling and maintenance outage was somewhat prolonged and followed by a test period to balance the new high-pressure turbine. At the beginning of August, a short outage occurred for two days for the repair of a steam leak. This had been caused by a leaking gasket in a flange on a drainage pipe from the high-pressure turbine.

At the end of August, the quantity of jellyfish in the coolant intake increased. Power was reduced and measures adopted to improve the filtering in the intake. During this reduction, a scram occurred when the throttle valves failed to regulate the steam flow fast enough. On December 8, the facility was shut down to repair a leak in connection with one of the main circulation pumps.

At the end of 2004, Oskarshamn 1 applied for permission to terminate SKI's special supervision of the facility. The special supervision was introduced following the major modernisation work which was implemented in 2001 and 2002. SKI rejected the application with the justification that certain supplementary work on the facility Safety Analysis Report (SAR) was necessary, primarily the analysis sections.

Oskarshamn 2
Operation until the refuelling and maintenance outage was mainly incident-free. A couple of minor disturbances occurred which affected production. In January, a salt water leak to the turbine condenser was repaired. In February, the power was once again reduced to repair a valve in the preheater system. For short periods in June, power was reduced by a couple of per cent due to high voltage levels in the Swedish power grid. The refuelling and maintenance outage was started on July 31 and continued for 24 days. During the outage, the power control and feedwater control system was replaced, in addition to routine servicing.

Operation after the refuelling outage was also incident-free. At the end of August, Oskarshamn 2, like Oskarshamn 1, had problems with jellyfish in the cooling water intake. For this reason, power was reduced to 80 % and measures were adopted to improve the filtering in the intake. At the beginning of September, turbine power reduction occurred as a result of a high level in a drainage vessel on the reheater. The cause was an instrument valve that was not completely open.

During the year, no unplanned outages occurred at Oskarshamn 2.

Oskarshamn 3
In January, a loss of load occurred at Oskarshamn 3 with subsequent partial scram caused by a fault in the excitation equipment. In January, a saltwater leak to the condenser and a fuel defect were also detected. In February, the power was reduced to carry out a routine isolation valve test in the steam and feedwater system. The valves functioned as intended but, in connection with the valve test, partial scram was activated in connection with the removal of a feedwater temperature measurement point block.

During the refuelling and maintenance outage which started on May 1, refuelling and preventive maintenance as well as testing were carried out. In connection with re-start, a valve leakage was detected in a small pipe in the feedwater system. On June 2, the refuelling and maintenance outage was completed and the facility was re-started. During shorter periods in June, the power was reduced by a couple of per cent due to high voltage levels on the grid.

In the beginning of July, the facility was shut down temporarily for a couple of days in order to repair a defective control valve on a main steam line. In September, partial scram occurred due to a defect in a measurement point in the feedwater system.

In October, a short five-day outage occurred to replace defective fuel. Two fuel elements were replaced due to damage. An additional fuel element was replaced since it had become contaminated.

On November 1, indication of a fuel defect recurred. The primary fuel defect developed into a secondary defect. A short outage occurred during the Christmas break to replace the damaged fuel element.

Ringhals

Ringhals 1
In connection with the storm “Gudrun”, on January 8, salt deposits occurred in the switchyard and could not be removed by the spray system. Both generators became disconnected from the grid due to flashovers in the switchyard. The reactor once again operated at full power on January 10. On March 9, Ringhals 1 reduced its power to cold shutdown for increased testing of a leak in the reactor coolant cleaning system. The leak was temporarily repaired and the reactor was once again at full power on March 15. (See also “*Technology and Ageing*”). Following this operating event, uninterrupted operation at full power continued until May 28 when the reactor was shut down to repair leakage inside the reactor containment. The leak occurred in a flange in the reactor pressure vessel flange spray system. During re-start, a leak from the reactor pressure vessel pressure relief system was detected and was repaired before re-start continued at the beginning of June. During re-start, a scram occurred in Ringhals 1 due to turbine problems.

On September 2, the refuelling and maintenance outage started. Extensive testing and replacement measures were carried out. New high-pressure turbines and new mixers in the feedwater system were installed. Insulation on the reactor pressure vessel bottom was replaced as well as the damaged pipe components in the cleaning system. The flag relay system in the control room, which is a part of the alarm system, was replaced by a computerised alarm system. In addition, preparations were made for future major modernisation work. The refuelling and maintenance outage had to be extended due to several different problems at re-start. No incidents occurred during the rest of the year.

Ringhals 2
Ringhals 2 was affected by the "Gudrun" storm in the same way as Ringhals 1. Both generators disconnected from the grid due to flashovers in the switchyard. The reactor was once again operating at full power on January 11.

The reactor was subsequently operated at full power until February 15 when it was shut down for the repair of previously detected leakage from the bottom of the reactor containment. Initial investigations showed extensive corrosion damage on the toroid plates. Repair work was started and it was decided to schedule the refuelling and maintenance outage for an earlier date. (See "*Technology and Ageing*"). This work continued until the beginning of May.

After the outage, no events occurred during operation until December 6. Ringhals 2 then reported that, in connection with work the previous day, errors had been made which had led to two auxiliary feedwater pumps not being ready for operation. The pumps had been covered with plastic to protect them from dust during work. However, a third pump was available. This pump has a double capacity compared with the two other pumps. The capacity is enough to dilute two steam generators. This would thereby make it possible to handle the residual heat in connection with a possible operating event. In connection with such an event, the covered pumps would also have functioned as intended for a short period of time. The event was preliminarily classified as one on INES-scale.

Ringhals 3
Ringhals 3 was also affected by "Gudrun". Changeover to house load operation failed. The reactor was then taken to hot standby. On January 10, the reactor was once again operating at full power. On January 26, a spurious power reduction occurred due to a fault in the turbine regulating system. In connection with the decrease, seals in two condensate system pumps of one of the turbines failed. The fault was repaired on January 27 and the reactor was then operated at full power.

No incidents occurred until the power decrease for the refuelling and maintenance outage which started at the end of May. The outage lasted for about one month. Major work carried out included reactor pressure vessel head replacement and new equipment for control rod manoeuvres.

On August 16, a reactor scram occurred due to the spurious closure of a valve in the feedwater system. The cause was a fault in the new control equipment which had been installed during the outage. The unit was re-started and full power was reached the following day.

At the beginning of November, an internal leak occurred in one of the reheaters on one of the turbines. This resulted in a slight power reduction from November 8 to 21 when the turbine was shut down for repairs. In connection with turbine re-start, regular testing of the turbine valves was conducted. During testing, a fault operated at full power on November 27. No events occurred during the rest of the year at Ringhals 3.

Ringhals 4
As was the case of the other reactors, Ringhals 4 was affected by “Gudrun”. Power decreased to about 25 % for a few hours. In the morning of January 9, the unit returned to full power operation.

On May 20, a short power decrease was carried out in order to repair a leaking low-pressure preheater drainage pump in the condensate system in one of the turbines. Apart from this, no incidents occurred until the refuelling and maintenance outage. The outage started early in August and lasted for about one month. In connection with reactor re-start, problems with the turbines occurred. Both turbines were shut down for different periods in order to correct the problem. During the rest of the year, no incidents occurred at Ringhals 4, with the exception of three occasions when power was reduced somewhat in connection with the shutdown of a main coolant pump. The pump was shut down to correct vibrations.

2. Technology and Ageing

More Stringent Requirements on the Handling of Ageing

The Swedish nuclear power facilities are ageing. They were constructed in the 1960's and 1970's. The oldest facility, 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 the ageing phenomenon must be taken into consideration in order for operation to be safe. This also applies in the current situation where the licensees are planning to carry out extensive additional safety improvements and modernisation.

Ageing of nuclear power plants usually refers to the ageing of devices, components and building structures that are included in the barriers and in the defence-in-depth system of the facilities. This type of ageing refers to a process where the physical properties change in some respect over time or through use. However, there are other aspects of ageing that need to be taken into account by the licensees and by SKI. The Committee on Nuclear Regulatory Activities, CNRA, has pointed out that both the nuclear industry and the authorities need to maintain a broader perspective on ageing[1]. In addition to the physical ageing of mechanical and electrical components and building structures, ageing may include:

- technological ageing of, for example, instrumentation and control equipment which work but which may be difficult to repair or for which spare parts may be difficult to find since they are no longer manufactured or on the market.
- ageing of the detailed design requirements which applied when the facilities were constructed and which then changed as new knowledge was acquired or the approach to safety became more stringent. It is not unusual that these older design requirements are still being referred to in the facilities' safety reports and that no assessment has been made of the new requirements or how plant components meet these requirements.
- ageing of the personnel who were in the organisation during the design, construction and startup phases and whose broad experience may be difficult to replace without systematic work to transfer knowledge to new generations.
- ageing of formal or informal organisational structures where the organisational culture has been formed by the older personnel and is not accepted by the younger generations.

These different ageing aspects are addressed in SKI's regulations and are included in the supervision since compliance is monitored through inspections, reviews and other followup work. The regulations (SKIFS 2004:1) concerning safety in certain nuclear facilities place requirements on management systems that are fit for purpose, measures for human resources and competence assurance, up-to-date safety analyses and safety reports as well as the retention of technical facility documentation. SKI's supervision and evaluation of the licensees' organisations, management systems and competence assurance measures are reported in Chapter 5 "*Organisation and Safety Culture*".

[1] Regulatory Aspects of Ageing Reactors. 1998 CNRA Special Issue Meeting. OECD Nuclear Energy Agency, Committee on Nuclear Regulatory Activities. NEA/CNRA/R(99)1.

In addition, according to the requirements of SKIFS 2004:1, requirements clarifying that documented programmes for the handling of age-related degradation of systems, devices, components and building structures apply from December 31, 2005. The purpose of such programmes ("Ageing Management Programmes"), which are also starting to be increasingly applied internationally, is to improve advance planning of safety work through a systematic identification and quantification of all of the ageing mechanisms that can occur. These clarifying requirements also facilitate SKI's supervision of how the facilities are handling ageing-related issues.

SKI's SKIFS 2004:2 regulations, concerning the design and construction of nuclear reactors, stipulate that for additional measures must be implemented in order to maintain and develop safety. These regulations mean that considerable modernisation and safety improvement has to be carried out in the coming years in several reactor facilities. See also Chapter 4, *"Safety Improvements of the Reactors."*

Physical Ageing of Mechanical Devices and Building Structures

Nuclear facilities in Sweden, as in other countries, were designed and built on the basis of the requirements and knowledge that prevailed at the time and on the basis of applying the best available technique and high quality requirements. The aim was to have safe facilities with a good defence-in-depth system which also required little maintenance, inspection and testing. However, in the case of technically complex facilities, it is not possible to anticipate and observe all of the conditions and circumstances that can arise. After only a couple of years in operation, damage started to occur. Vibrations and thermal loads had been underestimated during the design phase. Design limits were exceeded and cracks occurred. In spite of tried and tested and stringently controlled welding processes, greater materials changes and residual stresses occurred than were expected in some devices during the manufacturing and installation phase and these then led to stress corrosion attacks after a period of operation. It started in stainless steel austenitic pipes with relatively small dimensions and in steam generator tubes made of the nickel-based Alloy 600. Several years later, stress corrosion damage also started to occur in thicker pipes and other components made of stainless austenitic steel. The same applied to components and devices manufactured from the nickel-based Alloy 600 and the type used for welding, Alloy 182. Stress corrosion damage has also occurred in materials of the X-750 type which is a high durability steel.

Over the years, thermal fatigue has continued to be a problem. It has been difficult to predict how hot and cold water become mixed in the facility process systems. Furthermore, changes in the operating modes of the facilities result in such damage. The accepted design rules in order to obtain adequate safety margins to thermal fatigue have also started to be reviewed.

Erosion corrosion is another damage mechanism which has resulted in problems in many facilities all over the world. Aggressive flow conditions have been underestimated with damage as a result.

In the reactor containments, it is mainly the metallic parts that have been affected by damage in the form of corrosion attack.

As damage is detected in the facilities, different types of measures have been adopted. Research has been initiated to obtain increased knowledge of the damage-affecting factors. On the basis of this knowledge, the inspection and testing programmes have been revised, the replacement material has been developed and major system components have been replaced. The research has also led to changes in the chemical environment at the facilities. In addition, both operating experience and research have led to requirements for more extensive qualification of new materials and of the testing processes that are to ensure that damage is detected in time.

Preventive Measures Have Had an Impact

In 2005, relatively few new defects and deficiencies were detected. Previously identified problem areas were followed up and analysed. Currently, SKI does not envisage any serious tendencies towards age-related damage which caused a deterioration in safety at the Swedish facilities.

An overall evaluation which covers all cases of damage[2] in mechanical devices since the first facility was taken into operation, confirms that the adopted preventive and corrective measures have had the intended effect. This conclusion also applies when the damage that occurred up to the end of 2005 has been taken into account. As shown in the figures in Diagrams 1 and 2 below, there is no tendency to an increase in the number of defects as the facilities become older[3]. The overall evaluation also shows that most of the damage has so far been detected in time through periodic in-service inspection and testing before safety was affected. Only a small portion of all of the damage has led to leakage or other more serious conditions as a result of cracks and other types of degradation which remained undetected – see *diagram 3*.

It is mainly different types of corrosion mechanisms that have given rise to the defects that have occurred, see *diagram 4*. These account for about 70 % of the cases with intergranular stress corrosion as the most common damage mechanism, followed by erosion corrosion. Stress corrosion damage has most often occurred in primary pipe systems and in safety systems. Erosion corrosion is more common in more secondary parts, such as steam and turbine parts. Thermal fatigue, which is the third most common cause of damage, and which is responsible for about 10 % of the cases, has largely occurred in primary pipe systems and in safety systems. Additional cases of thermal fatigue have been reported in 2005. These cases are described in detail below.

The positive development where the number of cases of damage in the mechanical devices do not increase as the facilities become older require a high level of ambition in the preventive maintenance and replacement work. SKI will therefore continue to promote the licensees so that they maintain a high level of ambition and a good preparedness to evaluate and assess damage when it is detected. This is important since

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[2] *Damage*: One or several cracks or other defects detected in a certain part of a device and at a certain point in time. The damage has had different degrees of severity and importance to safety.

[3] Note that the large number of cases of damage that occurred between 1986-87 (see diagram 2) after 13-14 operating years (see diagram 3) were caused by stress corrosion in cold-worked pipe bends. These were subsequently replaced by bends that were not cold-worked.

experience shows that once the planning is deficient, significant problems may arise when damage occurs and the impact of the damage on safety must then be assessed.

Furthermore, SKI does not see any general tendencies for severe age-related damage which can cause the deterioration of the safety of the reactor containments and the other building structures. The damage and deterioration which has occurred shows that these were mainly caused by deficiencies in connection with building or subsequent facility modifications. This type of damage has been observed at Barsebäck 2, Forsmark 1, Oskarshamn 1 and Ringhals 1. During the year, additional damage of this type has led to extensive repair work at Ringhals 2, which is further described below. However, with respect to the difficulty of reliably inspecting the reactor containments and other vital building structures, it is important for the licensees to continue to study possible ageing and damage mechanisms that can affect the integrity of the components and safety.

Unlike mechanical devices and building structures, the state of primarily electrical cables and certain instrumentation and control equipment cannot normally be followed up through periodic in-service inspection and testing. Instead, in these cases, cables and equipment must be qualified through special testing programmes to ensure that the equipment will function as intended throughout the entire period of service. Qualification programmes must include both normal operating conditions and accident conditions and must take into consideration the mechanisms that can affect used polymers and other materials.

Ageing of electrical cables and other equipment in the facilities' instrumentation and control systems has gained international attention. Observed and possible problems have been identified and reported within the framework of an international co-operation project with the participation of both the nuclear industry and the regulatory authorities. The purpose has been to acquire an overall international experience and assessment of ageing phenomena as a basis for in-depth risk analyses and the analyses of necessary measures. With respect to the situation in the Swedish nuclear reactors, SKI has previously required information on the facilities' handling of ageing and environmental qualification. SKI's evaluation of the information that has so far been reported shows that these issues are largely being handled in a satisfactory manner by the licensees but that they need to carry out certain supplementary investigations. This continued handling of issues at the licensees will be followed up through the prescribed ageing handling programmes which are now being developed. Furthermore, SKI has requested special reports and investigations into how ageing can affect the reliability of certain instrumentation. See "*Control of the Dynamic Response of Measurement Systems*" below.

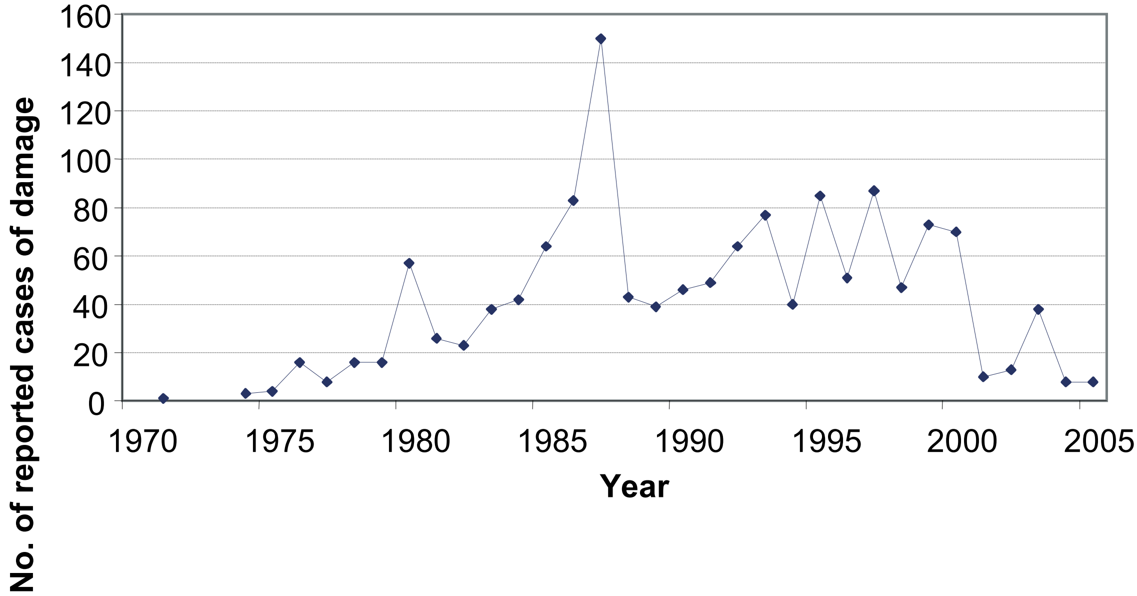

Diagram 1. *The total number of reported cases of damage per year at Swedish nuclear power plants. Damage in steam generator tubes is not included.*

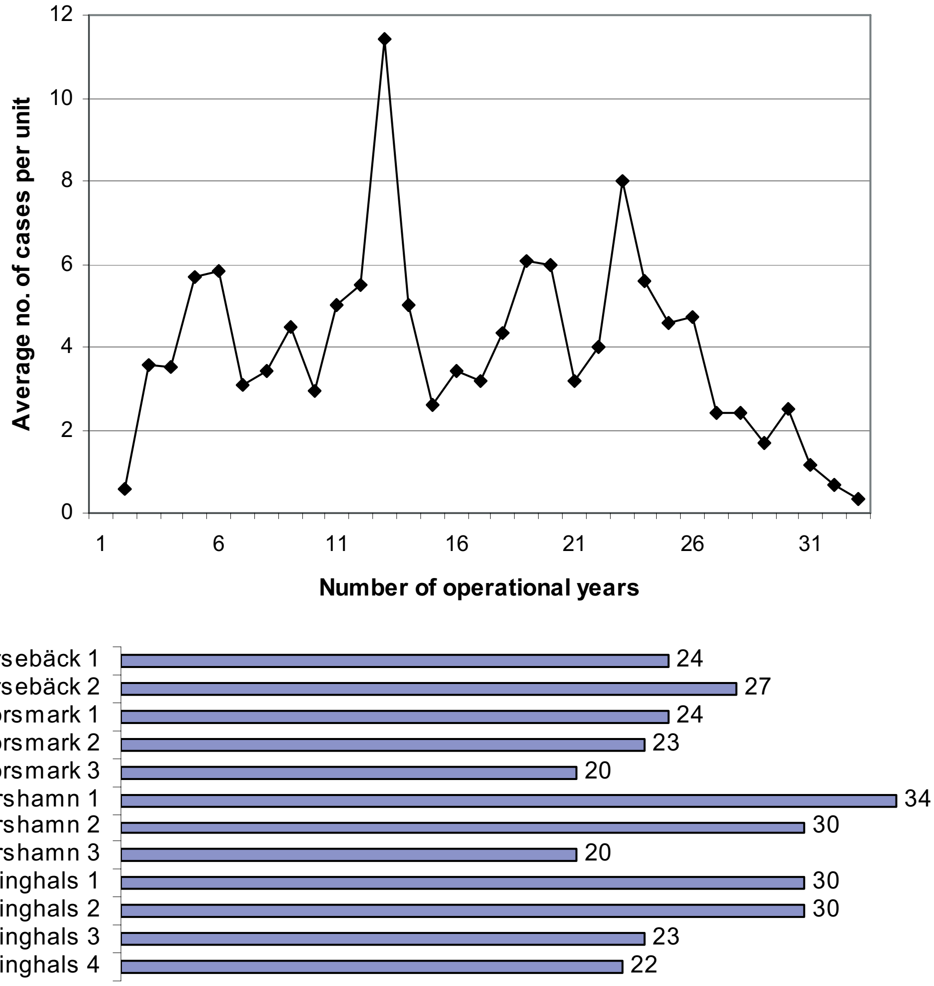

Diagram 2. *The uppermost of the two diagrams shows the average number of reported cases of damage per unit and operating year for all Swedish nuclear power plants. The diagram comprises damage to pressure vessels, pipelines and other mechanical devices apart from steam generator tubes. The diagram below shows the number of operating years for diffeent units.*

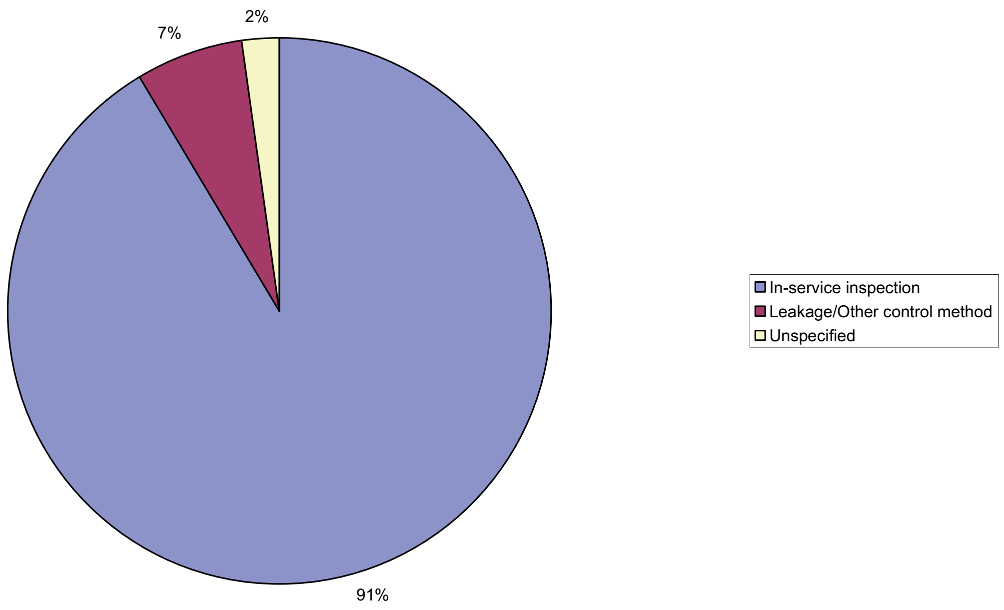

Diagram 3. *The number of cases of damage detected through periodic in-service inspection and testing and the number of instances of damage that have resulted in leakage or that have been detected in some other way.*

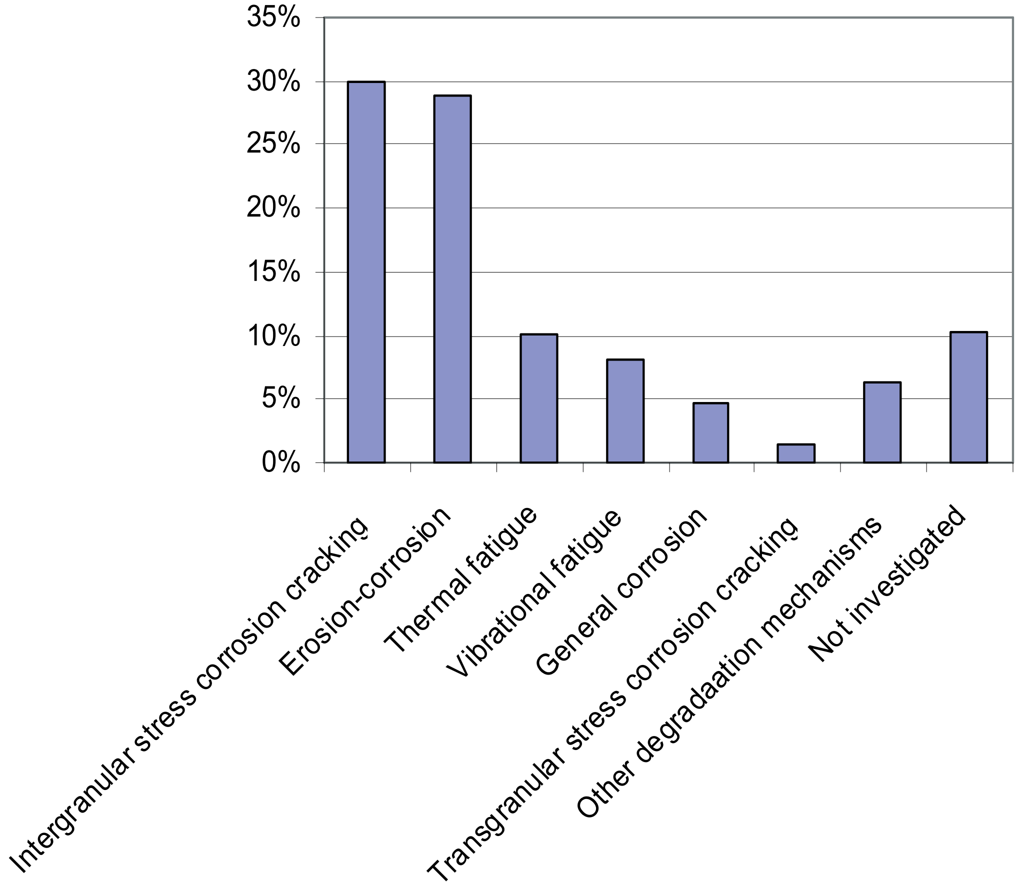

Diagram 4. *Cases of damage distributed according to damage mechanism. ("Other damage mechanisms" includes cases of damage caused by grain boundary attack corrosion fatigue and mechanical damage).*

More Leakage from Reactor Containments Leads to More Stringent Requirements

The reactor containment is the outermost barrier to the release of radioactive substances from a nuclear reactor. The main task of the containment, for both boiling water reactors and pressurised water reactors, is to:

- in the event of a maximum design basis accident inside the containment, absorb the design basis overpressure and, through the built-in containment liner, prevent the dispersion of radioactive substances to the environment
- contain the reactor primary system
- provide protection for the reactor primary system against external events.

Consequently, stringent requirements on materials strength and leaktightness are placed on the containment. The leaktightness is to be tested on a recurrent basis through global pressure tests and other measures. Furthermore, certain more local investigations, inspections and testing are carried out.

In July 2004, Ringhals AB informed SKI that Ringhals 2 had detected probable leakage through the toroid ring in the reactor containment. This toroid ring is a leaktight connection between the leaktight sheet plate in the cylindrical wall and the leaktight sheet plate in the bottom plate. The toroid ring consists of an inner and outer sheet plate with a leak monitoring device between the plates. Minor leakage from the inner toroid plate has existed since the facility was taken into operation. In connection with leakrate testing in 2004, leakage from the outer plate was also detected.

Ringhals AB carried out a number of investigations and leak measurements in order to be able to verify the readiness for operation of the reactor containment. The leak was considered to be within the design basis assumptions made in the safety report for Ringhals 2. In September 2004, after reviewing the data and analyses that had been submitted, SKI gave permission for Ringhals 2 to remain in operation until the refuelling and maintenance outage the following year, on condition that the size of the leakage did not increase. In addition, SKI required additional investigations and studies as well as regular leak investigations.

In November 2004 and February 2005, followup leak measurements and chemical analyses of the leak water were carried out. Certain measurement problems were detected in connection with the measurements in November. In February, a significantly higher flow was measured than that upon which SKI's decision was based regarding operation until the refuelling and maintenance outage. In accordance with SKI's evaluation, uncertainties in the measurements could not account for this increase. Therefore, the facility was shut down at the end of February for further investigation. These indicated relatively severe corrosion attack, which had occurred due to failure to follow building and installation drawings. In addition, harmful pollutants were found on the inner toroid. The observations led to decisions regarding major replacement and repair measures. Both the inner and outer toroid plates were replaced. The investigations also showed that there were significant uncertainties in both the leak measurements conducted and the chemical analyses of the leak water.

Several cases have been reported over the past fifteen-year period, both from Swedish facilities and from facilities in other countries, where deviations from drawings and building instructions have created conditions that led to severe corrosion attack a long time later. After the first events in the mid-nineties, SKI requested that all nuclear facilities should conduct systematic inspections of the containments in order to identify potential problem areas, also taking into account the possibility that constructions that deviate from the design drawings can occur. These inspections caused the facilities to expand their inspection and testing programmes. SKI also started its own investigations into issues concerning both ageing aspects and inspection, testing and safety evaluation aspects. Furthermore, as a support for the investigations, SKI initiated and participated in research projects on reactor containment ageing.

The results obtained so far have resulted in more stringent SKI regulations (SKIFS 2005:2) on mechanical devices and increased requirements on containment inspection and testing. The requirements on measures after damage and leakage are detected have also been made more stringent. This primarily applies to the metallic components. When additional results of the ongoing investigations and research projects are obtained, it is expected that the regulations will be further expanded in order to cover the containment concrete parts. The events that occurred have also led SKI and SSI to jointly decide to investigate and review leaktightness requirements which will apply to reactor containments. This investigation is expected to be ready at mid-year 2006.

Damage in the Containment Pressure Relief Filters

After the Three Mile Island accident, in the eighties the Swedish reactors were equipped with a system for pressure relief and filtering which is operated in the event of severe accidents. For example, in the event of a LOCA in the containment and safety system malfunction, it must be possible to depressurise the containment in a controlled manner and limit the release of radioactive substances to the surroundings to a maximum of 0.1 % of the core inventory of cesium isotopes 134 and 137 in a 1,800 MW thermal power reactor core, assuming that other nuclides of importance from the standpoint of land use are removed in a corresponding proportion to cesium. The filter equipment must operate when the pressure in the containment exceeds the design basis pressure.

At the Ringhals reactors, a passive system, called PMR (Post Mitra Ringhals) was installed and taken into operation in 1989. Pressure relief occurs automatically via a rupture disc. The radioactive gases continue to a water scrubber where radioactive particles and iodine are bound. The water scrubber is a stainless steel construction with desalinated water to which sodium carbonate and sodium thiosulphate have been added in order to react with radioactive iodine in an accident situation.

During the refuelling and maintenance outage at Ringhals 2, clear traces of leakage on the outside of the PMR building were noted. Subsequent inspections and testing showed corrosion damage and cracks in the bottom of the water scrubber. The cause of the damage was the aggressive environment in the water scrubber in combination with certain unsuitable manufacturing methods which resulted in stress corrosion. The damage cause analyses have not given any unambiguous answers to how the leakage occurred. The observations at Ringhals 2 resulted in expanded inspections and testing in several facilities with similar accident filters. These inspections and tests also indicated damage to Ringhals 3 and Ringhals 4.

Damaged parts of the PMR systems at Ringhals 2, 3 and 4 were repaired during the annual refuelling and maintenance outages. Thorough chemistry control programmes have been introduced as have improved programmes for periodic in-service inspection and testing of affected building parts. Other measures may also be relevant in the future in order to ensure that the accident filters continue in perfect condition.

Vulnerable Materials Result in More Replacements

Nickel-based alloys are a relatively common building material in nuclear facilities which have been found to be sensitive to stress corrosion. This specifically applies to Alloy 600 and the type of this alloy which is used for welding, Alloy 182.

The vulnerability of the materials and damage found led to steam generator replacement in Ringhals 2 and 3 as well as a new reactor pressure vessel head in Ringhals 2. The latter replacement was made due to stress corrosion cracking in the control rod mechanism penetration pipes in the head which were manufactured from Alloy 600 and welded with Alloy 182. The penetration pipes in the reactor pressure vessel heads of Ringhals 3 and 4 had similar types of cracks. In these facilities, the extent of the damage and crack growth was followed up for many years through periodic in-service inspection and testing. The results from the most recent years of followup show that the extent of damage there was limited and that propagation was slow. However, Ringhals AB has now replaced the Ringhals 3 and 4 reactor pressure vessels in order to, as in the case of Ringhals 2, avoid future problems. The replacement of the Ringhals 4 head was carried out in 2004 and that of Ringhals 3 in 2005.

Continued Slow Increase in Damaged Steam Generator Tubes

Examples of remaining problems with stress corrosion in nickel-based alloys are the steam generator tubes in Ringhals 4. These tubes are manufactured by Alloy 600 and are a major part of the pressure-bearing primary system of these plants. The damage propagation is therefore being closely followed up through extensive annual tests and other investigations in accordance with SKI's requirements. The inspections and tests for the year have, as before, included damaged parts at the tube plate, support plate intersections, preheater parts and U bends. A further number of tubes with indications of stress corrosion cracks at the tube plate were detected as was minor growth of previously noted cracks. During the followup inspections and testing during the year, two tubes with new defects in the U bend area were detected.

Tubes with such limited damage that there are secure margins to rupture and loosening have been kept in operation at Ringhals 4. Damaged tubes where the margins were inadequate were repaired by plugging the ends of the tubes in order to remove the tubes from operation and thereby prevent continued crack propagation. During the year, a total of 41 tubes were plugged. The total number of steam generator tubes that are out of operation at Ringhals 4 has thereby increased somewhat and now corresponds to 3.03 % of the total number of tubes. The results from inspection and testing over the past few years thereby show that the rate of damage increase has levelled off at a relatively low level.

Ringhals AB is now discussing replacing the damaged steam generators at Ringhals 4. In addition to the safety and maintenance benefits from such replacement, this action would also create the necessary conditions to increase the thermal power at Ringhals 4. As described above, Ringhals 2 and 3 have replaced steam generators by generators of a new and partially different design and by tubes manufactured of less crack-sensitive material. During the periodic in-service inspections and testing, no signs of environmental damage were observed. The operating experience so far gained from the new steam generators, which were installed in 1989 at Ringhals 2 and in 1995 at Ringhals 3, is still good. However, minor wear has been observed on a few tubes. This wear is believed to have been caused by foreign objects found on the secondary side in the steam generators.

Case of Thermal Fatigue

Thermal fatigue occurs when a device is subjected to more or less regular temperature cycling. This type of temperature cycling can occur in plant systems where water flows of different temperatures meet. Thermal fatigue results in cracking which, under certain conditions, can grow relatively quickly. Most of the damage which has so far occurred in Swedish facilities has arisen in connection with temperature differences between flows of 100 ºC or greater. However, in a number of cases, the temperature differences were smaller, decreasing to 55 ºC. Several cases of thermal fatigue have arisen due to different types of design differences and some have arisen after operational modifications. A number of cases of thermal fatigue have also occurred due to leaking valves.

A further case of thermal fatigue occurred at Ringhals 1 during the beginning of the year. The damage was located in a high energy line belonging to one of the facility cleaning systems and it was found in connection with a round that was made when the facility was in operation. The leaking pipe part was kept in operation during monitoring and until a temporary repair method was developed. The situation where a leaking high energy line was kept in operation during a certain period of time led to a special supervision by SKI which concerned issues concerning the facility's own safety evaluation and possible lack of clarity in SKI's regulations. The damaged pipe part was replaced during the refuelling and maintenance outage and SKI's regulations were clarified with the conditions that are to apply in order to keep damaged devices in operation for a certain time.

New Investigations into Issues concerning Pipe Break Protection

The view of pipe breaks and how they are prevented as well as of how protection against the consequences of pipe breaks can be achieved has varied over the years. From the beginning, LOCAs were considered to be a purely hypothetical event in order to calculate the loss of coolant that had to be replaced by the emergency core cooling systems. LOCAs therefore became a design basis accident for the containment and emergency core cooling systems. At a later stage, the possibility of sudden pipe breaks actually occurring gained attention and this led to requirements on consequence-mitigating measures. The prime concern was pipe whip and this is an example of a local, dynamic effect of a pipe break. A large number of pipe break reinforcements were installed in order to keep any broken pipe ends in place.

During the latter part of the 1970's, in the USA, the focus was on the consequences of asymmetrical blowdown loads as well as certain disadvantages of pipe break reinforcements, in the form of an increased risk for locking in certain load situations as well as difficulties with respect to periodic in-service inspection and increasing radiation doses in connection with maintenance. For these reasons, analyses and supporting pipe break experiments were conducted which indicated that the probability of a large sudden large break on a large pipe which lacked an active damage mechanism was very small. These analyses resulted in the Leak Before Break (LBB) concept which was also formalised in the US regulations for nuclear power reactors.

Issues concerning pipe break protection and the application of the LBB concept have also been discussed in Sweden for many years. SKI previously conducted a number of investigations into issues that are relevant in this context. The requirements on reinforced pipe break protection, which are now required by SKI's regulations, SKIFS 2004:2 concerning design and construction, were based on these investigations. If it can be demonstrated that LBB is met, this could be an alternative to other measures aiming at protecting the facility against local dynamic effects, such as via pipe break reinforcements and missile protection. In the regulations, SKI has clarified that LBB means that the pipe break system in question is designed in such a way, and has such operating and environmental conditions that the probability of a break is sufficiently small and that measures have been adopted so that damage, which in spite of this could arise, would most likely lead to detectable leakage long before the break occurred.

In 2005, SKI carried out a new investigation which included an inventory of the view of LBB in the light of the most recent developments in fracture mechanics. The investigation resulted in proposed guidelines which are mainly to be used as a basis for SKI's decisions in connection with its regulatory reviews of applications to apply LBB which are expected to be submitted to SKI in 2006.

A basic condition for the application of LBB is that it should be possible to detect leakage long before a pipe break occurs. Therefore, SKI has also carried out an investigation into the leak monitoring systems to identify possibilities and limitations. In the LBB context, it is particularly important to pay attention to the reliability of the systems, the uncertainties with which the measurements are associated and to ensure that clear and documented requirements on readiness for operation are made on the systems that must perform so that the reliable measurement can be carried out on all occasions. The leak limits and related measures (such as power reduction requirements) to be applied must be specified and documented. In cases where there is uncertainty regarding whether the size of the measured leakage correctly reflects the actual leak flow from a defect in the primary system, such as leakage which may be expected to remain under the pipe insulation, the installation of a local leak monitoring system should be considered.

Control of the Dynamic Response of Measurement Systems

The measurement systems in a nuclear reactor are necessary for the facility's operation and safety. The measurement systems provide input signals to the reactor safety systems, the alarm systems, instrumentation and control systems and for control room display. Therefore, it is of considerable importance that the components in the measurement systems, such as impulse lines, transmitters, density converters etc. are reliable, that they are sufficiently accurate and that they have sufficiently rapid response times.

Signals from a measurement system comprise a static and a dynamic part. The static parts of the signals are thoroughly investigated in connection with calibration which occurs in connection with each annual shutdown of a nuclear reactor. SKI does not consider that the dynamic part is investigated to the same extent. A certain dynamic response time is postulated in the safety analysis. This response time must be kept in order for the safety analysis results to apply.

Previous tests conducted in Swedish nuclear reactors have indicated deficiencies in the dynamic response of measurement points that are of importance for safety, for example, level and pressure measurement in the reactor pressure vessel. These deficiencies were not detected in connection with the static tests conducted during the refuelling and maintenance outage. The deficiencies resulted in practical measures in the facility as well as in event reporting to SKI. International experience has also shown the importance of ensuring that age-related deficiencies such as sensors and measurement systems are properly followed up. This experience shows that sensors and measurement chains can, to a greater extent than other systems, be affected by age-related deterioration.

Based on experience so far gained, SKI has communicated to the licensees the importance of ensuring that thorough, periodic in-service inspections and testing is carried out, especially in terms of dynamics. SKI has also requested that the licensees at the facilities should implement additional improvement measures and investigations.

Additional Measures for Consequence Mitigation

It has been known for some time that iodine accounts for a large part of the radiological consequences of a radioactive release to the environment after a severe accident. In recent times, it has also become clear that the pH of the reactor containment water phase could have a decisive impact on iodine chemistry and, thereby, on the quantities released in connection with an accident.

Studies show that dissolved iodine at acid pH values can to an increased extent be converted into volatile, elementary iodine which can be released to the containment gas phase and leak into the environment. The elementary iodine can also react with organic pollutants such as methane and other hydrocarbons, both in the gas and water phases, and form volatile, organic iodine, such as methyl iodide. The rate for these reactions in the water phase is strongly pH dependent. Organic iodine is particularly difficult to handle since, compared with elementary and particulate iodine, it is removed to a significantly lesser extent in the scrubber which is included in the reactors' accident filters. Both SKI and SSI therefore consider that the quantity of organic iodine that is released is important for the calculation of the environmental consequences of an accident.

In the light of this, SKI has requested information from the licensees about how the improved understanding of the formation of organic iodine has been evaluated and about whether the licensees intend to adopt measures for pH control and if so which measures. From the information submitted, SKI has drawn the conclusion that if the licensees, with well-supported analyses of different accident situations, can show that the pH in the reactor containment water phase will continue to be alkaline, no additional measures to raise pH will be necessary. In order to achieve this, any uncertainties must be handled with appropriate conservatism and a reasonable margin to neutral pH must be achieved. However, SKI has also reached the conclusion that the diverging results from analyses so far carried out of pH after severe accidents indicate, if nothing else, the need for and advantage of conducting a specific study of the containment pH for each facility. SKI has therefore requested such analyses from the facilities and intends to make a decision on measures to be taken in 2006.

Measures against Hydrogen Gas Deflagration in the event of PWR accidents

During the TMI accident in 1979, a large quantity of hydrogen gas was generated in connection with the core damage that occurred. A sudden pressure increase was registered in the containment which indicates that the hydrogen gas caught alight and that a deflagration occurred. Since the TMI accident, considerable research has been focused on the hydrogen gas issue and phenomena such as hydrogen gas production, distribution in the containment and combustion have been identified. Furthermore, different types of agents to neutralise hydrogen gas have been developed and installed in several facilities all over the world.

SKI has continuously followed international research and development in the area. In a newly conducted investigation, SKI notes that a number of neutralising agents currently exist which, theoretically, could be used against the hydrogen gas that can be present/produced in PWR containments during severe accidents. However, most have several clear disadvantages and cannot be considered to be applicable in practice. The method that experts consider to be the best solution is passive autocatalytic recombiners, PAR. SKI also observes that the containments in the Swedish PWRs at Ringhals have a large volume and an open, internal geometry. The design thereby creates good conditions to avoid severe hydrogen gas deflagration and to mitigate consequences if they nevertheless occur. In an analysis from 1994, based on a previous probabilistic safety assessment (PSA), the probability for a rupture in the Ringhals 3 containment due to deflagration was estimated at below 10^{-7} per year. This probability was thereby in the residual risk range and no measurements were therefore required. However, in a new study, Ringhals AB reached the conclusion that the probability could be somewhat higher than 10-7 and that a hydrogen gas fire with subsequent deflagration could be a dominant cause of a large, early containment rupture if a severe accident were to occur. Ringhals AB has therefore decided to introduce an agent to neutralise hydrogen gas in its PWRs.

3. Core and Fuel Issues

Foreign Debris Cause Fuel Defects

A leaktight fuel cladding is essential to prevent the release of radioactive substances in and from the facilities. Therefore, stringent quality requirements, with low acceptable defect frequencies, are made in connection with fuel cladding fabrication. The quality requirements have meant that the number of fabrication defects is on the order of 1 fuel rod out of every 100,000 rods. Stringent requirements are also made 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, it is required that the design should in all other respects be tried and tested and that there should be functional programmes to follow up and check the behaviour of the nuclear fuel after it has been taken into operation.

In the 1980’s and some time into the 1990’s, a large number of defects were reported as a result of stress corrosion and where the fuel cladding did not correspond to the environmental permissibility requirements that were made. No damage of this type has been reported in later years since the operating regulations were introduced and more damage-resistant cladding material was developed. The long-term trend is that the total number of fuel defects in the Swedish reactors is decreasing, see diagram 5. All of the reactors have had individual defects for one or two years but a few reactors (Forsmark 1 and Oskarshamn 3) have had more than one defect in one year on several occasions over the last ten-year period.

The damage which occurs nowadays has been primarily caused by small objects entering the fuel via the coolant and wearing holes in the cladding. To reduce the number of this type of defect, fuel with filters which prevent debris from entering into the fuel assemblies and cyclone filters to clean the coolant are successively being introduced. However, the most important aspect is that there should be a greater awareness of the importance of keeping the coolant free of debris which can wear holes in the cladding. The facilities have programmes to reduce the risk of debris entering the systems.

Nowadays, facilities are increasingly also applying a strategy to avoid the damage from becoming degraded so that uranium leaches into the reactor coolant. This strategy involves restrictions in operation in order to avoid making the damage worse and having to shut down the reactor to remove the damaged fuel if there is a sign of uranium leaching. In this way, the facilities avoid contaminating the primary system with long-lived radioactive isotopes which degrade the radiation environment which, in turn, make the maintenance work, inspections and testing difficult.

Over the past five-year period, a total of 3-9 cases of damaged caused by wear per year have been reported. In 2005, a total of six fuel defects were reported. However, most of the reactors were defect-free in 2005. Five of the six defects were found in Oskarshamn 3 and the remainder in Forsmark 3. The damage frequency over the past five years has stabilised at a relatively low level. However, a few reactors account for a number of defects, which indicates that it should be possible to reduce the damage frequency further if all of the reactors manage to correct the damage through effective measures.

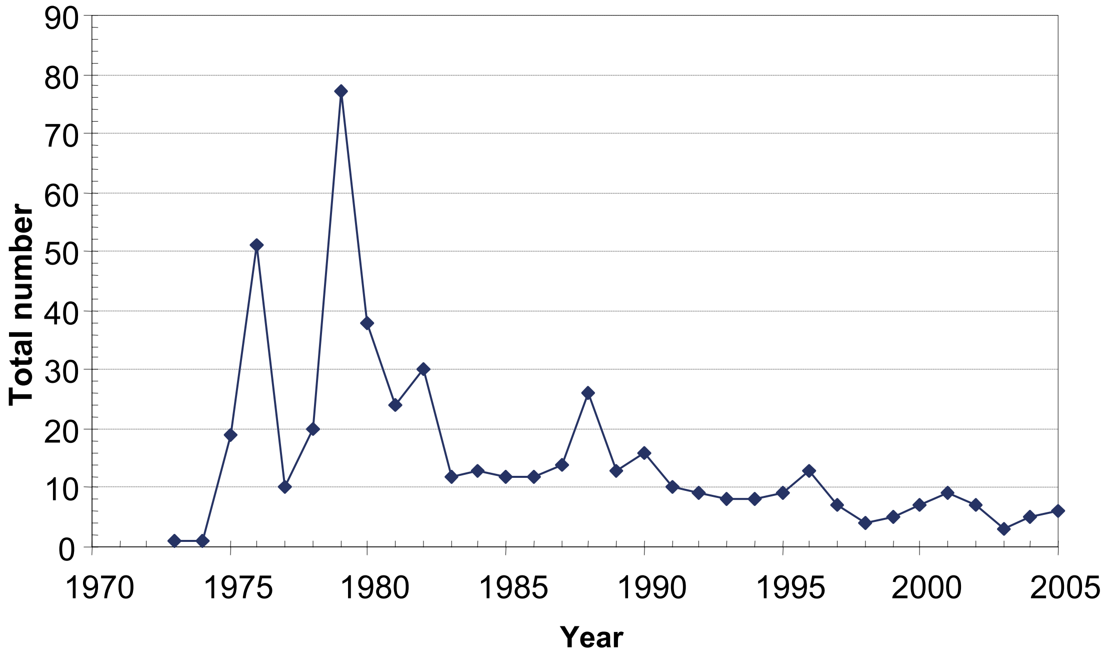

Diagram 5. *Total number of reported fuel defects per year at Swedish nuclear power plants*

Followup of Bowed Fuel

Since the mid-1990's, the Ringhals 2, 3 and 4 pressurised water reactors have had problems with fuel bowing beyond the limit postulated in the safety analysis. The safety-related aspects are to ensure that the control rods can be inserted when necessary and that the thermal limits are not exceeded. Ringhals AB has implemented measures to restore the straightness of the fuel and has developed methods to measure bowing and to analyse the impact of the bowing on the thermal margins. SKI has evaluated the measures implemented and the followup methods used and is continuing to monitor progress via annual reports where Ringhals AB describes the status of the bowing. The followup work shows that the bowing is continuing to decrease. The direction of the bowing is unchanged in the upper part of the fuel assembly while it is more diffuse in the lower part. This may be the first sign that design-related measures are having an impact.

Increased Burnup and Enrichment

On the international front, development work has been underway for several years to improve economic margins through core optimisation, improved fuel utilisation, new fuel designs and increased operating flexibility. The aim is to modernise the loading strategy so that fewer new fuel bundles need to be loaded into the core. The maximum fuel burnup is also a factor in the optimisation work.

In accordance with an SKI decision from 1995, a general limit of 60 MWd/kgUO_2 applies in Sweden for the highest local fuel pellet burnup. Previously, there was no incentive to change over to high fuel burnups. However, the licensees have revised their cost optimisation for the fuel and found that a somewhat higher burnup should be aimed for. In 2004, BKAB and Ringhals AB were given permission to exceed this general limit and to increase the local pellet burnup in the Barsebäck 2 and Ringhals 1 reactors from 60 MWd/kgUO_2 to 65 MWd/kgUO_2. Additional applications for permission to increase the burnup levels can be expected. SKI is therefore following these discussions in detail and is preparing future reviews by participating in research which will provide a basis for verifying safety limits for fuel with a high burnup. Issues that are important to monitor in these respect include how existing damage mechanisms, such as stress corrosion, are affected and how new damage mechanisms arise when a transition is made to a higher burnup.

Through the plans to increase the thermal power (see below) at several reactors, a higher enrichment of fissile material (uranium-235) per fuel bundle is also being discussed. When the thermal power is increased in a reactor, the fuel consumption, if no further measures are implemented, will increase to the same extent as the power increase. This means that a 1 % increase in power will result in an additional fuel consumption of about 1 %. However, by increasing the enrichment of fissile material, the need for several fuel bundles can be reduced or eliminated. Modifications in the fuel design can also reduce the need for several fuel bundles.

The licensees will probably use a combination of increased consumption and enrichment to increase the thermal power. The choice of method depends on the financial valuation where the cost of increased enrichment, a greater quantity of uranium and the repository are factors influencing the choice.

Increase in the Thermal Power of the Facilities

The government licence for the operation of a nuclear reactor carries stipulations for the highest thermal reactor power. The licence applies only for this thermal power. In order to increase the thermal power, the Government must decide on a new licence in accordance with the Act (1984:3) on Nuclear Activities.

The thermal power of a reactor can, as described above, be increased by loading several fresh nuclear fuel bundles or by loading fuel with a higher enrichment by combining the measures. The average heat rating of the fuel bundles will increase. However, the power can be evened out by letting the fuel bundles that are currently operating at lower power take a greater portion of the power increase than the highest rated fuel bundles.

In a boiling water reactor, the higher power in the core is then dealt with through an increased feedwater flow and steam flow. The choice can be made to either maintain the recirculation flow which leads to a higher steam concentration in the core or increase the recirculation flow while maintaining the steam concentration. A combination of these measures can also be applied.

In a pressurised water reactor, the higher power in the core is dealt with either by increasing the water flow in the core or through a higher temperature increase over the core. A combination of these measures can also be applied. The higher thermal energy generated on the primary side will then lead to an increase in steam formation on the secondary side. The higher steam flow is then taken to the turbine plant where increasing the opening of the governor valves can result in the generator generating a higher electrical power.

In several Swedish nuclear reactors, power uprates were implemented in the 1980's, see *Table 1*. Most power uprates which were previously implemented have largely been made through the use of existing large safety margins, improved analysis methods and improved fuel. In several cases, it has been possible to make these increases without major facility modifications. Over the past few years, the licensees have investigated the possibilities of further power uprates. This includes both large and small power uprating. The incentive is that the power increases are a relatively cost-effective way of creating extra electricity production capacity.

Table 1. *Power increases carried out at Swedish facilities. 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	-	-	-	-	-	-

A power increase can affect the facility in a number of different ways and to a varying degree depending on the size of the increase. The conditions and parameters which can affect safety must therefore be identified and analysed in order to establish whether 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 a capacity corresponding to the higher power. The impact on safety mainly occurs from the fact that the core will contain more reactivity. The inventory of radioactive substances in the fuel is increasing. The neutron radiation of components around the reactor core is increasing. The reactor's residual heat is proportional to the operating power and will therefore increase. The systems that supply coolant to the reactor and remove the residual heat must have an increased capacity. Since the total energy generation from the reactor will increase, the consumption of fissile material (U-235) will increase. At most, the increase will be in proportion to the power increase.

The increased residual heat will also mean that certain sequences during abnormal operation or an accident will occur at a faster rate.

A licence to operate a reactor at increased power can be approved by SKI on condition that, through analyses and other measures, it is shown that the facilities can be operated at the higher power levels in such a way that the safety requirements will be fulfilled. In addition, possible known deficiencies or open questions relating to 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 with the planning of different types of changes.

SKI's review of a power uprating case comprises several steps. To begin with, SKI carries out an initial, broad safety evaluation which is the basis of its statement to the Government prior to the Government's licensing decision. If the licence is granted, subsequent stages are initiated with the evaluation of the in-depth investigations and analyses that the applicant has presented for the changes that are needed in the facilities and in their operating modes. SKI then follows up the changes in the facilities and their operating modes. SKI then follows up changes in the facility and decides on issues concerning test operation and routine operation at the higher power. SKI's process for handling power increase issues are more closely described in the report, "*Regulatory Review and Other Supervision of the Thermal Power in Nuclear Reactors*"[4].

The following power uprating cases are currently being handled:

In December 2004, SKI submitted its statement on applications from Ringhals AB concerning permission in accordance with the Act on Nuclear Activities for a thermal power uprating at Ringhals 1 and 3. On October 20, 2005, the Government decided to allow Ringhals AB to increase the thermal power at Ringhals 1 from 2,500 MW to 2,540 MW and at Ringhals 3 from 2,783 MW to 3,160 MW. As a condition for the decisions, SKI is to approve that the reactors are to be taken into trial operation and routine operation at the higher power ratings. Ringhals AB has submitted analyses and other supporting data as well as an application for trial operation at Ringhals 3 at a higher power level. SKI has initiated reviews of this data.

On October 6, 2004, OKG submitted an application for permission to increase the thermal power at Oskarshamn 3 from 3,300 MW to 3,900 MW. After reviewing the application and supporting documents, SKI has found that the necessary conditions exist to increase the thermal power at Oskarshamn 3 and to operate the facility at the higher power in such a way that the safety requirements are met with the necessary safety margins. Therefore, in its statement to the Government, SKI has proposed that the Government grant OKG permission, in accordance with the Act on Nuclear Activities, to operate the reactor at Oskarshamn 3 at the higher power level. SKI has also proposed to the Government that the permission should carry stipulations which specify that the reactors are not allowed to be taken into trial operation or routine operation at the new highest approved thermal power without SKI's approval.

[4] Regulatory Review and Other Supervision of Thermal Power Uprating of Nuclear Power Reactors. SKI-PM 04:11. Swedish Nuclear Power Inspectorate, November 1, 2004.

On September 29, 2005, Forsmarks Kraftgrupp AB submitted an application to SKI for permission to increase the thermal power from 2, 928 MW to 3,253 MW at Forsmark 1 and Forsmark 2 and from 3,300 MW to 3,775 MW at Forsmark 3. SKI has now carried out its main review of this application. Certain issues still have to be clarified. SKI expects to be able to submit a statement on the application to the Government in spring 2006.

In all of these cases, an environmental licensing is being carried out by the relevant environmental court.

4. Reactor Safety Improvement

New Regulations on the Design and Construction of Nuclear Power Plants

Safety improvements at the Swedish nuclear power plants have so far been conducted through successive facility modifications and special work as a result of events which occurred and problems identified in the facilities. Furthermore, these successive modifications have been based on 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 type of facility modification include the “strainer incident” at Barsebäck in 1992 when it was found that the emergency core cooling systems in the BWRs with external reactor recirculation pumps did not perform as postulated in the safety analysis reports. The event led to refurbishment work in other Swedish facilities and re-evaluations of previous analyses.

Through SKI’s regulations (SKIFS 2004:2) concerning the design and construction of nuclear power plants, the situation has partially changed. With these regulations, SKI has developed and clarified important safety requirements for nuclear reactors. The requirements are based on Swedish and foreign operating experience, recent safety analyses, results from research and development projects and the development of IAEA[5] safety standards and the industry standards that were applied in connection with the construction of the facilities. The requirements comprise the design principles that are to apply, the improved tolerance of certain malfunctions and events, environmental qualification, necessary functions for monitoring and manoeuvring from the control room and emergency control room and requirements on the safety and event classification on which different types of analyses are to be based. In addition, regulations concerning reactor core design and operation are included.

With certain transitional provisions, the regulations entered into force on January 1, 2005. According to the transitional provisions, licensees concerned are to be allowed the necessary time to plan and implement the measures in the reactors that are required to comply with the regulations. Based on the transitional regulations, the licensees concerned have reported to SKI the measures that have to be adopted at each reactor and when these measures should be implemented. SKI has reviewed and decided on the measures for the reactors at Forsmark 1-3. Corresponding reviews and decisions on measures to be implemented at Oskarshamn 1-3 and Ringhals 1-4 are expected to be completed by mid-2006.

The regulations entail that extensive measures need to be implemented at many reactors, especially in the older reactors, in order to thereby further improve safety to the modern level that results from the stringent requirements. The safety improvement work will be conducted for a relatively long period of time, up to about 2013. During the same period, power uprates are also planned at several reactors. (See the “*Core and Fuel Issues*”) section. Altogether, this work will entail major challenges for the licensees and

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[5] International Atomic Energy Agency (IAEA), Vienna.

their suppliers in the future. SKI will also have to face major challenges with reviews and other supervisory work which will be needed during the period.

Modernisation Projects

Some time ago, the licensees identified the need for major and extensive modernisation and Oskarshamn 1 was the first Swedish reactor to undergo a very extensive modernisation. The work was completed in 2002 and involved a new safety system, instrumentation and control equipment design as well as a new control room.

Even if many instances of reactor safety improvement and modernisation will be regulated by SKIFS 2004:2 in the future, there are other reasons for measures. These may include operating cost-related considerations, such as the possibility of old equipment placing greater requirements on maintenance and testing, technical equipment needing to be replaced because it is outdated and because it may be difficult to locate spare parts or competence for maintenance. Control room electronics and equipment are examples of the latter, where older equipment will be replaced by modern equipment, based on digital technology.

The licensees both have extensive modernisation plans and ongoing modernisation projects. Several of these plans entail modernisation work in stages which will last many years in the future. For example, Oskarshamn 2 has presented modernisation plans that extend until 2012. The plans for Ringhals 2 have so far concerned switchyards and waste systems and, in the future, it will include the modernisation of control equipment and control rooms. Ringhals 1 is preparing to refurbish and supplement its control equipment.

A project is underway at Ringhals called FIMP (Fire Improvement Project), where all of the facilities' fire protection systems are being modernised and made to operate more effectively in order to comply with modern design requirements. The project also includes installing completely new, redundant diesel-operated fire-fighting pumps, a new water circuit for the fire-fighting system around the plant with new riser and distribution pipes at all reactor units.

SKI is supervising the ongoing modernisation work and is planning to conduct multi-year and extensive supervisory and regulatory work for future modernisation.

Updating of Safety Analysis Reports and Technical Specifications (STF)

In the mid-nineties, the power utilities initiated reviews of the original design basis and reactor safety reports. The reviews were initiated after the "strainer incident" at Barsebäck in 1992 when deficiencies in the design basis were detected. Considerable work has been conducted, especially for the oldest reactor types. The reviews have identified certain points in the original designs which have been corrected or which will be corrected. Through SKI's amended regulations (SKIFS 2004:1) concerning safety in nuclear facilities, the requirements on safety analysis were clarified and made more stringent.

As a result, updated safety reports currently exist for Barsebäck 2, Oskarshamn 2, Ringhals 1 and Ringhals 2. SKI's review of the new safety report for Ringhals 2 will be carried out in autumn 2006. Oskarshamn 1 also submitted a revised safety report after its modernisation work. In the case of the more modern reactors, Forsmark 1, Forsmark 2, Forsmark 3 and Oskarshamn 3, the consequences of the design reviews and the more stringent requirements will be less.

Corresponding reviews are underway for Ringhals 3 and 4. In the case of Ringhals 3, a preliminary safety analysis report (PSAR) was submitted at the end of 2005 as a part of the application for power uprating. SKI's review of this report is being carried out in spring 2006.

Ringhals AB has carried out a project for pressurised water reactors which aims at modernising and simplifying the Technical Specifications (STF) of each reactor, based on a principle called MERITS. The principle was developed in the USA and is partially based on risk-based criteria. SKI has evaluated and approved, with certain reservations, of the application of the new STF in summer 2005. At year-end 2005 and the beginning of 2006, the reviews are being conducted of the reports and supplementary information that SKI requested in the decisions mentioned.

Probabilistic Safety Assessments

The original reactor design and safety analysis reports have essentially all been based on deterministic requirements and analyses. According to SKI's requirements in SKIFS 2004:1, reactor safety development is still based on deterministic requirements and safety analysis. However, requirements are also made on conducting probabilistic safety assessments (PSA) in order to verify and develop safety. The purpose is therefore to obtain, through both deterministic assessments and PSA, a description of risk and safety that is as comprehensive as possible. PSA is therefore an important tool to identify possible weaknesses and the need for safety-improvement measures. This applies to both the reactor design and construction and the Technical Specifications as well as the Emergency Operating Procedures.

Both deterministic assessment and PSA must be based on a systematic inventory of the events and conditions that can result in a radiological accident. This means that the PSA of a reactor should comprise all abnormal events and accident sequences that can arise during different operating conditions including power increase and reduction as well as the refuelling and maintenance outages. Furthermore, external events need to be included in a PSA as well as fire and flooding.

In Swedish and foreign facilities, PSA is being used to a greater extent, not only for safety development but also for different types of optimisation measures. For example, this may apply to the optimisation of maintenance, inspection and testing programmes. These applications make new and increased demands on the scope, coverage, quality and validity of the models as well as on input data and parameter values that are used.

PSAs that have been previously developed for Swedish reactors have some deficiencies in these respects which are successively being corrected. Through its supervision, SKI is giving impetus to the licensees' work on supplementing and completing PSAs that comply with the requirements. In SKI's opinion, comprehensive PSAs are important in the work on analysing and evaluating measures that result from the requirements in SKIFS 2004:2.

5. Organisation and Safety Culture

The ability to handle a complex interaction between technology, people, organisation and economy is necessary in order to maintain and to continue to improve safety. This section deals with how nuclear power plants, in SKI's view, have worked with questions relating to organisation, management systems, investigation of events, competence assurance and safety culture in 2005.

Organisational Changes and How Control and Safety Reviews of Activities are Conducted

No major organisational changes were implemented in 2005. However, Studsvik AB has been reorganised as a result of the closure of the company's reactors and the new organisation entered into force on July 1, 2005. Barsebäck 2 was closed down on May 31, 2005 after a government decision. The personnel force was then reduced and shutdown operation is currently in effect at the plant (Barsebäck 1 and 2).

In other respects, SKI observes that routines to handle organisational changes and activities are in place at all nuclear power plants. The nuclear power plants have routines so that the safety aspects in the change work are identified at an early stage and are dealt with throughout the process.

SKI conducted an inspection in autumn 2005 as a part of its work in following up how OKG evaluated the major organisational change implemented in 2002. Furthermore, the inspection included followup work to ensure that OKG carried out necessary measures and further developed its internal control of the handling of organisational changes including primary and independent safety review. In SKI's opinion, OKG meets the requirements in SKI's general regulations (SKIFS 2004:1) with respect to the following: an organisation designed to maintain safety, a defined and documented responsibility, authority and conditions for co-operation between the key functions that were subjected to the reorganisation. Furthermore, SKI considers that the nuclear activity is being managed, controlled, evaluated and developed with the support of a management system focusing on the handling of organisational changes. SKI also considers that the focus, scope and documentation of the primary and independent safety review with respect to organisational changes comply with the regulations. SKI identified two minor improvement needs which were considered to be of negligible importance for safety.

A new review of the documented professional competence requirements for the personnel which carry out independent safety reviews at OKG and Ringhals AB nuclear power plants has been conducted in 2005 after a request for supplementary work in 2004. SKI's review resulted in requirements for additional supplements to the documented competence requirements. SKI also requested a report on the competence situation in the form of gap analyses of the independent safety review function from OKG, Ringhals AB and Forsmarks Kraftgrupp AB. The supplementary information and the descriptions of the competence situation have been submitted to SKI and a review is underway of measures that have been undertaken and of the competence situation. At a first glance, SKI finds that the content of the industry's competence requirement documents has considerably improved.

SKI carried out two inspections during the year – one at Oskarshamn and another at Forsmark – with the overall purpose of judging whether these licensees have a system for ensuring that detected conditions are evaluated from the standpoint of safety without unnecessary delay. SKI intended to identify how detected deficiencies are handled, how information channels and decision processes in connection with undetected deficiencies look and if routines are in place to ensure that detected deficiencies are handled in a suitable manner in relation to the requirements. SKI observed that Oskarshamn and Forsmark have a system to handle unclear detected conditions. They have routines to ensure that this work is handled in accordance with the requirements that apply through different forms of meetings, information channels, decision processes and documented instructions for these.

Furthermore, SKI has carried out two inspections of investigations into events relating to MTO at OKG and Ringhals AB during the year. The overall purpose of the inspections was to evaluate their systems for investigating events through the evaluation of the management of the quality system and through random sampling. SKI did not identify any deviations from the requirements in SKIFS 2004:1 at OKG or Ringhals AB. On the other hand, SKI identified improvement needs within all inspected requirements. At OKG, SKI found that the structure of the quality system needed to be improved. Both Ringhals AB and OKG lacked documented routines for how they intend to conduct followup work to ensure that implemented measures had the intended impact and how they should evaluate the event investigation activity.

SKI has conducted inspections at Forsmark and Ringhals with respect to their MTO-related LERs. SKI found that Forsmarks Kraftgrupp AB's way of working with the classification and followup of LERs was adequate. In SKI's opinion, Forsmarks Kraftgrupp AB needed to improve the quality of the LERs so that the underlying root cause of the LERs could be distinguished and understood from the text. In the case of Ringhals, SKI can observe that Ringhals AB works, to some extent with the classification and followup of LERs, primarily in connection with the annual report. SKI can observe that the classification of LERs is being conducted in different areas, but considers that Ringhals should, to a greater extent, make the classification and trend followup more systematic in order to improve learning from the events that have occurred.

Continued Development of Management Systems and Audits

In 2005, SKI carried out a review of Forsmarks Kraftgrupp AB's management system. The review showed that Forsmarks Kraftgrupp AB has a management system that is established, documented and covers all of the activities. However, SKI identified a few minor improvement needs. SKI considered that Forsmarks Kraftgrupp should clarify the connection between the management system and the programme of activities and to review the management of the departments with respect to the general tasks of managers so that these are more uniform. In SKI's view, in its review, these measures clarify the management of the activity and that the input data to the management followup should be improved. In letters, Forsmarks Kraftgrupp AB has responded to SKI's review and the improvement needs that SKI has identified have been dealt with in an acceptable manner. Furthermore, SKI carried out an inspection at Forsmarks

Kraftgrupp AB with the aim of, in practice, verifying the structure, management and the routines and working procedures that are established and documented in the management system of Forsmarks Kraftgrupp AB. During the inspection, it was found that Forsmarks Kraftgrupp AB has safety targets and guidelines for how safety should be maintained and developed and that those working in the activity are acquainted with the goals and guidelines. Furthermore, SKI found that the activity is routinely monitored and followed up, deviations identified and handled so that safety is maintained and continuously developed in accordance with the goals and guidelines that apply to the activity. However, SKI identified the following needs for improvement that Forsmarks Kraftgrupp AB should take into account in order to clarify the management of the activity. These were:

- A clearer connection between Forsmarks Kraftgrupp AB's goal to each activity area
- A clearer goal formulation so that followup can be improved
- Clearer plans of action to achieve the goals

In 2005, SKI continued to follow OKG's work on developing the management system. OKG adopted a holistic approach in the work on redesigning the management system. This entails the preparation and implementation of a process-oriented management system. The time-schedule was constrained and this meant that the introduction of the new process-oriented management system was delayed and will be introduced by June 2006 at the latest. The requirements made by SKI in the decided followup review of the management system have been met. The difference is that the measures were introduced in the existing management system and not in the new, which was specified in the programme of measures.

In the Ringhals group, work is continuing to develop the activity management system and process development which was started a few years ago. During followup work in 2005, Ringhals presented the overall process map. Furthermore, Ringhals presented the way in which the work on process development is being conducted at Ringhals. Ringhals's ongoing process development made a good impression and should be able to result in further efficiency improvements, also within safety-related work.

SKI finds that the licensees at the nuclear power plants are continuing to develop their activities by carrying out internal audits. Once a year, SKI meets each licensee in order to understand how their internal audit activity works, which internal audits have been conducted and the result of these audits. SKI finds that all have a process for conducting internal audits in the management system and that there is an established tradition of working with internal audits. In SKI's view, all nuclear power plants maintain a good level of quality with respect to management and work with internal audits. However, in 2005, SKI was able to observe that OKG did not manage to conduct all of the internal audits that were planned due to the fact that substantial resources were allocated to the work on developing the new process-oriented management system.

Decommissioning Situation at Barsebäck and Studsvik

The reinforced supervision of Barsebäck continued during the year up to and including the closure of Barsebäck 2 on May 31, 2005. SKI's supervision has focused on following up whether BKAB adopted adequate measures for safe operation up to the closure of Barsebäck 2. In SKI's view, BKAB has mainly handled the prolonged decommissioning situation in a commendable manner. BKAB has adopted many measures to keep ensure that the personnel is competent and motivated. However, certain problems have characterised the time period from the closure of Barsebäck 1. These are primarily problems and deficiencies that SKI detected after the loose thermal sleeves event in Barsebäck 2. SKI has subsequently followed the measures that that BKAB has adopted to correct the deficiencies that SKI had identified. In several inspections, reviews and in its facility monitoring work, SKI has found that many good measures have been adopted.

SKI reviewed Studsvik Nuclear AB's staffing plan prior to the closure of the R2 and R2-0 reactors up to June 18, 2005. In SKI's opinion, Studsvik had the necessary conditions to operate the reactors in a safe manner based on the situation they were in. SKI also considered that Studsvik had a clear and well-thought out plan to motivate its personnel and to handle uncertainties and difficult issues that can occur in connection with the personnel redundancy situation. However, SKI considered that NQ should have a clearer strategy and decide on the need for reinforced reviews of activities that are important for safety. In SKI's opinion, it was of the utmost importance that the management should be visible in the organisation both with respect to communicating information and with respect to capturing the motivation of the personnel and ensuring that work is being conducted at a high level of safety.

Competence and Resource Assurance Focussing on Operating Personnel

Previously, SKI followed up the plant's competence assurance system and found that all of the facilities had documented, systematic methods to ensure that personnel and competence were adequate for the present and several years into the future. Bearing in mind the responsibility and importance of the operating personnel for operating safety at a reactor facility, operating personnel must comply with special requirements. The regulations, SKIFS 2000:1, concerning the competence of operating personnel at reactor facilities, have been in operation since January 2001. After this date, SKI has conducted inspections at Oskarshamn, Ringhals and Barsebäck in order to judge how the nuclear power plants comply with the requirements in SKIFS 2000:1 and has found that measures are necessary. In 2005, SKI considered that Oskarshamn, Ringhals and Barsebäck had all implemented adequate measures in order to meet SKI's requirements.

SKI conducted an inspection concerning competence and staffing of operating personnel at Forsmarks Kraftgrupp AB in December 2005. This inspection is currently being compiled.

Another area that it is of considerable importance to review is the licensees' competence assurance of sub-contractors. In June 2005, SKI conducted an inspection at OKG in the area of competence assurance of sub-contractors as a step in its supervision in order to establish whether OKG meets SKI's requirements. In SKI's opinion, OKG complied with the basic requirements but SKI considered that OKG's competence assurance process with respect to sub-contractors in all areas covered by the inspection needed improvement measures of varying scope. The need for measures largely applied to the extent to which work, documentation and the application of operating procedures and routines were systematically conducted. OKG agreed with SKI's findings and described its plans to implement corrective action in the identified areas where improvements were necessary.

SKI has found that the inspections have given impetus to the work of the nuclear power plants which have implemented their measures and reported major improvements with respect to all operations management levels. The competence assurance work has been accorded a high priority at the nuclear power plants and the facilities have adopted a systematic approach to how they ensure that they have adequate competence and staffing.

Continued Development of the Safety Culture

For some years, the licensees have had a safety culture questionnaire which they use to conduct internal, survey-based measurements. SKI is very positive to the fact that the licensees are working on safety culture and have found that many efforts are underway in this area, such as seminars and inter-organisational discussions.

In an ongoing research project, Approaches to Safety Culture Enhancement, SKI tried to enhance knowledge of methods and possibilities to reinforce the safety culture at the licensees' facilities. The focus of the project is on the management's view and understanding of safety and safety culture. The research project is based on a model to create awareness of different views of the organisation's safety and safety work. During the year, Westinghouse Electric Sweden was involved in the project. Previously, Oskarshamn and Ringhals participated in this project.

The project was conducted in the form of action research where the participating licensees directly receive help and the possibility of finding methods of continuing their own work on reinforcing their specific safety culture. The purpose of the entire project is also to ensure that SKI has an overall and coherent view of the status of safety culture in the Swedish nuclear industry.

In 2005, SKI has continued to follow up the measures that BKAB has implemented as a result of the mixer event. BKAB has, until the time that Barsebäck 2 was closed on May 31, 2005, reported its experience of the organisational and administrative measure that were implemented in the areas of bringing the reactor to a safe level, design basis and safety review. In addition, BKAB described the measures that were conducted within the framework of the safety culture programme which was developed. SKI has found that many good efforts were made and considered that BKAB handled and developed the activity in a satisfactory manner.

6. Physical Protection and Nuclear Safeguards

In SKI's view, all of the nuclear power plants have a physical protection which meets the applicable requirements. The evaluation is based on supervision activities such as plant monitoring, event reporting, notifications about plant modifications and annual reports concerning the physical protection at each facility.

During the year, new regulations (SKIFS 2005:1) for the physical protection of nuclear facilities were decided. The new regulations will have extensive consequences for licensees, including through more stringent requirements on area protection, perimeter protection and access control. The regulations enter into force on January 1, 2007 when most of the prescribed measures are to be implemented. Certain, more extensive measures are to be implemented on January 1 or October 1, 2008. With these transitional regulations, the licensees are being given the necessary time to implement the measures that are necessary at each facility. SKI intends to supplement the recently adopted regulations with provisions concerning the protection of vital and protected areas in nuclear reactors.

The concept for physical protection which is established and which is expected to also apply in future is based on the licensees adopting necessary measures to prevent sabotage, attack or other similar conscious action from leading to a radiological accident. Furthermore, in connection with a criminal attack, the police is expected to quickly act to, in connection with the licensee, protect the facility and avert an attack.

During the year, SKI intensified its dialogue with the National Criminal Investigation Department and the police authorities in the counties with nuclear power plants as well as with the nuclear power plant licensees in order to, as far as possible, ensure that the preparedness is adequate in the event of attack or a serious threat situation at a nuclear facility.

The background is the central role of the police authorities in the event of a criminal attack on a nuclear facility, for example, a nuclear power plant. The police is the armed incident-response force with the aim of primarily providing the licensee with assistance in maintaining reactor safety and, in the event of an occupation, regaining control of the plant and regaining control of the necessary operator areas.

A task force comprising representatives from local and central police authorities and licensees have, in a report, submitted a proposal to SKI describing measures to improve preparedness in the event of a criminal attack on a nuclear facility. SKI has not yet reviewed the report.

In conclusion, it can be stated that SKI, in consultation with the Swedish Security Service and the National Criminal Investigation Department have reviewed the design basis threat situation which is the basis of SKI's regulations concerning the physical protection of nuclear facilities. The review resulted in the evaluation that the design basis threat situation continues to be relevant and, therefore, does not need to be changed.

The Facility Safeguards are Satisfactory

In 2005, SKI, the IAEA and Euratom have conducted inspections of how nuclear safeguards are handled at the facilities. 89 inspections were conducted at the nuclear power plants. According to the criteria that the IAEA and the Commission have followed, the interval between two inspections at a facility which has irradiated nuclear fuel may not exceed three months. Furthermore, each facility is to conduct a physical inventory once a year. In the case of nuclear power plants, this occurs in connection with the annual refuelling and maintenance outage. The result of the inventory is then verified by SKI, the IAEA and the Commission. Nothing has emerged from the inspections in 2005 to indicate deficiencies in nuclear safeguards at the nuclear power plants.

In 2005, the updates submitted to the SKI of the facility descriptions for the supplementary protocol to the safeguard agreement with the IAEA were submitted to the IAEA before the stipulated deadline of May 15. In line with the supplementary protocol, the state must give the IAEA more information than before about nuclear activities and about activities relating to the nuclear fuel cycle. During summer, the IAEA requested supplementary information to and clarification of the basic declaration submitted in 2004. After information was submitted to the utilities, a response was submitted to the IAEA in December. The supplementary protocol also gives the IAEA an expanded inspection right. In 2005, this was used for supplementary access by IAEA to a nuclear power plant on one occasion. A new Euratom ordinance on safeguards entered into force in March 2005. The ordinance gives the European Commission the right to require that any information be submitted that the Commission needs to meet the requirements in the supplementary protocol and also involves requirements on certain changes in reporting to the European Commission.

7. Radiation Protection

Summary and Evaluation

SSI's overall evaluation is that radiation protection at the Swedish nuclear power plants has been good in 2005. SSI cannot see any signs that the resources and the competence required to maintain a good radiation protection have decreased. However, SSI would like to emphasize that it is still important that radiation protection questions should have a high priority in the nuclear power plants' operations management for a positive future development.

The collective dose to the personnel at Swedish nuclear power plants was 9.2 manSv[6], which agrees with the average of the collective radiation doses over the past five years (9 manSv). Several of the units had long refuelling and maintenance outages[7] as a result of major renovation and modernization work while other units had short outages since they only carried out refuelling and certain maintenance work. No individual received a radiation dose which exceeded the established dose limits, although three individuals received a radiation dose greater than 20 mSv[8].

As a result of plant modifications due to power increases and modernization work of the stations, the work to be conducted at different units will vary from year to year. This could result in higher collective doses at the units concerned and SSI finds that the collective dose to the personnel at the Swedish nuclear power plants will be affected by this.

SSI is following the resource and competence issues relating to resignation of personnel and the nuclear power plants' use of external resources. In SSI's opinion, there is scope to improve the co-operation between contracted and own personnel and thereby also continue to maintain adequate radiation protection.

The radiation levels in the facilities are largely unchanged, compared with previous years. A few fuel defects occurred in 2005 but they have not resulted in any negative radiation protection effects worth mentioning.

Radiation doses to the public from Swedish nuclear power plants continued to be low. SSI requires continuous work to be conducted at the nuclear power plants, also in the future, in order to further reduce radioactive releases by applying the best available technique[9] (BAT). The measures to achieve the target values[10] that the nuclear power

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[6] ManSv (mansievert) is the unit used for the collective dose which is calculated as the average dose to the individual in a group, multiplied by the number of individuals in the group.
[7] A refuelling and maintenance outage is an annual shutdown of a nuclear reactor when the reactor containment and reactor pressure vessel are opened. During this period, refuelling is carried out as well as planned inspections, testing and repair work on reactor, service and operating systems.
[8] The value of 20 mSv (millisievert) originates in the fact that an individual's total dose may not exceed 100 mSv during five consecutive years.
[9] "Best Available Technique" is the use of the most effective method for limiting radioactive releases and mitigating the impact of releases on human health and the environment and which does not entail unreasonable costs.

plants report indicate, in most cases, a satisfactory level of ambition. The control measurements that SSI is conducting on environmental samples from the area surrounding the nuclear power plants and on the water released show a good agreement with the licensees' own measurements.

Radiation Protection at the Nuclear Power Plants

In 2005, the collective dose to the personnel, including contractors, at the Swedish nuclear power plants was 9.2 manSv. The collective dose is thereby somewhat larger than in 2004 (6.4 manSv) but agrees with the average value, 9 manSv, for the past five years. Diagram 6 shows the dose trend for the personnel at the nuclear power plants during the period from 1994-2005.

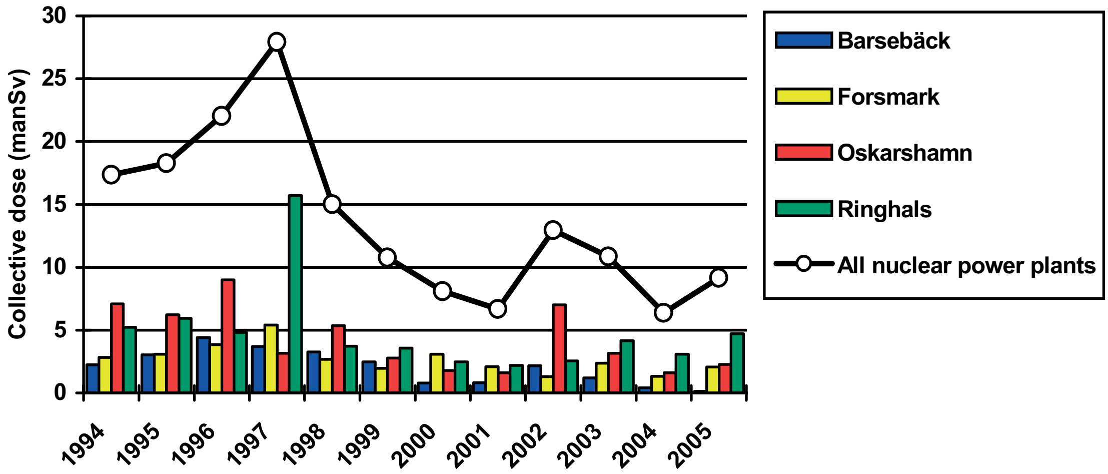

Diagram 6: *Annual collective dose (manSv) at Swedish nuclear power plants.*

During the year, 4,195 people received a registered effective dose. The average dose for these individuals was 2.2 mSv, which is somewhat higher than the corresponding figure for the previous year (1.7 mSv). The largest registered individual radiation dose was 23.6 mSv. These figures should be related to the fact that three-quarters of the personnel received radiation doses below 2.5 mSv. No individual received a radiation dose that exceeded the established dose limit[11]. Two individuals were internally contaminated during the year as a result of the intake of radioactive substances. The committed effective doses were 0.8 mSv and 0.5 mSv. The reporting limit is 0.25 mSv. Table 2 below shows the dose data from the Swedish nuclear power plants for 2005.

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[10] The target value must be seen as a measure of the release level that can be achieved during a certain period.

[11] The dose limit for a separate year is 50 mSv. I In five consecutive years the sum of an individual's radiation doses shall not exceed the dose limit 100 mSv.

Table 2: *Summary of individual doses at the nuclear power plants in 2005.*

	Collective radiation dose (manSv)	Largest individual dose (mSv)	Average dose (mSv)	Number of individuals[1] with a registered dose > 0.1 mSv
Barsebäck	0.1	5.7	0.7	172
Forsmark	2.1	15.5	1.7	1 225
Oskarshamn	2.3	19.2	1.9	1 188
Ringhals	4.7	21.2	2.1	2 280

1) Since an individual can work at several plants during a single year, the numbers in the columns cannot be added in order to obtain the total amount of persons having received a registered dose.

The nuclear power plant personnel receive most of their radiation dose during the refuelling and maintenance outages. This is the time when the personnel conduct work on the areas near to the reactor and turbine systems. During operations, these areas are normally not available due to the high radiation level. SSI's supervisory work therefore includes receiving information about the planning of a refuelling and maintenance outage, especially with respect to radiation protection optimization, inspecting the activity during the outage and inspecting special tasks that result in or can result in high radiation doses and reviewing the evaluation after an outage. The following text summarizes the radiation protection activities conducted at the nuclear power plants in 2005 and, in particular, the outcome of the year's refuelling and maintenance outages from a radiation protection perspective.

Barsebäck Nuclear Power Plant

Radiation protection activities at Barsebäck nuclear power plant went well during the year. With the government decision in December 2004 that the Barsebäck 2 nuclear reactor would be closed down no later than by May 31, 2005, the situation changed drastically for the facility. The original planning of a normal maintenance and service shutdown at Barsebäck 2 in 2005 was changed to a simplified outage for the necessary shutdown and maintenance work at the unit. SSI is monitoring radiation protection activities during the phase-out phase that Barsebäck 1 and Barsebäck 2 are now undergoing.

The work at Barsebäck 2 during the refuelling and maintenance outage has mainly consisted of a final fuel unloading, system flushing and maintenance of systems that will be used during the subsequent shutdown and service operation. The spent nuclear fuel at Barsebäck 2 is placed in the unit's fuel pool until transportation to CLAB can be carried out.

In 2005, the radiation doses at Barsebäck nuclear power plant were small. The collective dose to the personnel was 0.1 manSv and no abnormal individual doses were reported.

Forsmark Nuclear Power Plant
In 2005, radiation protection was good, without accidents or serious incidents. During the operating year, a minor fuel defect was detected at Forsmark 3. The damaged fuel was replaced during the outage.

In late autumn 2005, a request for a review statement was submitted to SSI by SKI concerning power uprating at Forsmark 1, Forsmark 2 and Forsmark 3. SSI is following work on these planned power uprates and is monitoring work to ensure that the plants' current radiation protection activity is maintained and develops favourably.

The annual refuelling and maintenance outage at Forsmark 1 was long and extensive in terms of work accomplished. The corresponding shutdowns at Forsmark 2 and Forsmark 3 were short and comprised refuelling and maintenance. In terms of radiation protection, the refuelling and maintenance outages went well without any significant deviations from the schedules.

The refuelling and maintenance outage at Forsmark 1 lasted for almost 41 days and the collective dose was 1.3 manSv, which was somewhat higher than the predicted dose. During the outage, a number of major plant modifications, including the replacement of low-pressure turbines, were carried out. Furthermore, extensive testing was conducted. The turbine replacement project resulted in larger doses than expected due to the fact that the quantity of man hours spent in areas with high dose rates had been underestimated.

The radiation levels in the reactor containment and in the turbine plant declined slightly compared with previous years.

The refuelling and maintenance outage at Forsmark 2 lasted for 11 days and the collective dose was 0.2 manSv, which was somewhat lower than the expected dose. The radiation levels in the facility were somewhat higher than the levels measured during the refuelling and maintenance outage in 2004.

The refuelling and maintenance outage at Forsmark 3 lasted for 10 days and the collective dose was, as expected, 0.13 manSv. The radiation doses in the reactor containment were unchanged and the radiation levels in the turbine plant declined slightly compared with the previous year.

Oskarshamn Nuclear Power Plant
In 2005, radiation protection at Oskarshamn nuclear power plant was satisfactory. The collective dose was 2.3 manSv and no severe incidents occurred. Two individuals were internally contaminated as a result of the intake of radioactive substances. In 2005, five minor fuel defects occurred at Oskarshamn 3 and the plant is now working actively to reduce the damage frequency.

During the year, SSI reviewed an application for power uprating at Oskarshamn 3 and subsequently submitted a statement to SKI. On the basis of the information that SSI has so far received, SSI considers that, from the radiation protection standpoint, the necessary conditions exist for Oskarshamn 3 to be allowed to increase power.

The refuelling and maintenance outage at Oskarshamn 1 lasted for 52 days instead of the planned 29 days. The cause was the balancing of the turbine and the fact that the replacement and repair of the high-pressure turbine took longer than expected. In addition to refuelling and maintenance, work was conducted on the reactor systems. The collective dose for the outage was 1.0 manSv, which was somewhat higher than the forecasted 0.7 manSv and the cause was the extension of the outage. The radiation levels in the facility have increased moderately since the decontamination in 2003.

Refuelling and maintenance at Oskarshamn 2 lasted for 24 days and the collective dose was 0.34 manSv, which is somewhat higher than estimated due to several additional tasks. The decontamination that was carried out during the refuelling and maintenance outage in 2003 and the zinc dosing which was introduced have affected the dose rates at the facility more favourably than expected. The increase in radiation levels is less than in previous years. During the outage, Oskarshamn 2 carried out refuelling and maintenance as well as testing. Furthermore, work was carried out on the reactor systems and low-pressure turbines.

The refuelling and maintenance outage at Oskarshamn 3 lasted for 32 days. The emphasis of the outage was on refuelling, preventive maintenance and testing. The collective dose was 0.6 manSv, somewhat higher than the expected dose due to additional work. The radiation levels in the facility are unchanged compared with previous years.

Ringhals Nuclear Power Plant

During 2005, the radiation protection work at Ringhals nuclear power plant has been satisfactory. No accidents or serious incidents occurred. The collective dose during the year was 4.7 manSv which was higher than in 2004 (3.1 manSv). The reason was extensive work during the outages, especially at Ringhals 1. In connection with that an employee at a firm of sub-contractors reporting that she was pregnant, Ringhals AB detected deficiencies in the routines for minimizing radiation risks to fetuses, which led to a change in routines and in information to those concerned.

During the previous year, the Government gave Ringhals 1 and Ringhals 3 permission for a power uprating. SSI asked additional questions about radiation protection during normal operation, refuelling and maintenance outages and accidents after a power uprating at Ringhals 3 and Ringhals nuclear power plant answered these questions satisfactorily. SSI is continuing to monitor that the plant's current radiation protection activity is being maintained and that it is developing in a positive direction.

During the refuelling and maintenance outage at Ringhals 1, extensive work was carried out, such as reactor pressure vessel and reactor pressure vessel head testing as well as replacement of high-pressure turbines. Work lasted for 46 days. Stable or lower radiation levels and good radiation protection work in several sub-projects led to a collective dose for the refuelling and maintenance outage of 2.5 manSv, compared with the anticipated 3.5 manSv. In SSI's view, additional work would have been possible to better deal with the large number of sub-contractors and to maintain an orderly workplace.

Ringhals 2 was shut down as early as on February 15 for repair of the reactor containment. The refuelling and maintenance outage was rescheduled for a later date and lasted 77 days as a result of complex repair work. The collective dose for the outage was 0.8 manSv. In spite of the fact that the reactor operated with fuel leakage during part of the operating year, measurements indicated lower levels of radiation.

At Ringhals 3, the refuelling and maintenance outage lasted for 27 days and the collective dose was 0.4 manSv. During the annual refuelling and maintenance outage, the reactor pressure vessel head was replaced, maintenance was carried out on steam generators and intake strainers (water) for certain safety systems were replaced. The radiation levels at Ringhals 3 are low. Recurrent measurements show lower or the same values as in 2003 and 2004.

The collective dose during the outage at Ringhals 4 was 0.5 manSv. External measurements show lower or unchanged radiation levels compared with 2004. During the refuelling outage, which lasted for 29 years, maintenance was carried out on the steam generators, the steam relief valves were improved and intake strainers in certain safety systems were refurbished.

Environmental Qualification

Ringhals nuclear power plant was the first to submit an application for licensing, in accordance with the Environmental Code, for existing and expanded activities. The hearing in Court was held in February 2005. The application of best available technique (BAT) which is a central feature of the Environmental Code and SSI's regulations concerning releases from nuclear facilities, was an important issue in the negotiations. With the emissions reductions that Ringhals AB, during the negotiations, undertook to achieve successively during a five-year period, SSI concluded that BAT will be met. In April 2005, the Environmental Court in Vänersborg submitted its statement which entailed handing over the case to the Government to decide on the environmental permissibility of the activity with respect to spent nuclear fuel, nuclear safety and energy conservation. In October, the Government announced its decision that existing and increased activities at Ringhals nuclear power plant were permissible. Vänersborg's district court announced a partial verdict on the case on March 22. According to the verdict, during a trial period of five years, the commitments with respect to reduced emissions that Ringhals made during the hearing in Court must apply as provisional regulations. The Environmental Court thereby postpones for a trial period of five years the decision concerning stipulations with respect to radiation protection.

In 2005, the application from OKG concerning permission under the Environmental Code for existing and expanded activities has been dealt with in the form of a written process. SSI has submitted a number of statements relating to, among other things, the application of BAT for the release of radioactive substances. As a result of this SSI approved OKG's application in its entirety at the start of the main negotiations in February 2006.

In the case of Forsmarks Kraftgrupp AB, the application process in accordance with the Environmental Code started in 2005. In the case of BKAB, the environmental qualification process, which focuses on the plant closure, is currently in progress.

Radioactive Releases to the Environment

Nuclear power plants release small quantities of radioactive substances to both air and water. These releases are continuously measured. The radiation dose is calculated using models that are plant-specific, which take into account meteorological conditions and the local land and water environment. The measurement and reporting of releases are to be conducted in accordance with the regulations established by SSI, the *Swedish Radiation Protection Authority's Regulations on the Protection of Human Health and Environment from the Releases of Radioactive Substances from Certain Nuclear Facilities* (SSI FS 2000:12).

The regulations also contain requirements that the licensees must report the reference values for the releases of individual or groups of radionuclides. The aim for these values is to show the normal optimized release level, which can be attained during the operation of each reactor. The reference value is a measure of different reactors' ability to limit releases during operation. The decisive factor for determining the reference value is the operating experience and knowledge of the size of the release in a historical perspective.

In 2005, the reference values were exceeded in some cases. This does not mean that the public has been exposed to significant increased dose, but that the plant's release-mitigating system did not perform optimally for some reason. The reference value can also be exceeded as a result of maintenance work, which results in increased releases. The regulations also contain requirements on reporting the target values.

The target value is the level to which the radioactive substances released from a reactor can be reduced during a certain given time, under normal operating conditions. The release mitigating work is therefore controlled by the targets that have been established. According to the regulations, the licensees must annually report their aims and strategies with respect to mitigating releases in the short and in the long-term work.

The difference between the reference value and the target value is that a reference value shows the situation at the current time while a target value indicates what can be achieved in the future. In the annual reporting to SSI, the measures implemented or planned with respect to achieving the target value are specified. Examples of measures are:

Barsebäck

- Measures to reduce airborne activity in connection with pool handling and cleaning,
- The reduction of activity levels in release water after extensive cleaning of the pipe system
- The reduction of the volume of released water.

Forsmark

- Reduced releases of water from Forsmark 1 and 2, which means reduced total consumption of water, released volume of water as well as released amounts of radioactive substances
- Renovation of evaporators, separators and centrifuges to increase capacity to deal with the waste water

- Measures for preventing foreign objects from entering the primary system and causing fuel damage.

Oskarshamn

- Reduced activity on system surfaces through zinc dosing
- Low core contamination and avoidance of fuel defects
- Locating sources and creating routines to promote clean systems
- Low offgas flows with the help of oxygen dosing
- Modernization of the waste facility
- Administrative measures to reduce radioactive releases to water
- Reduction of the water flow load to the waste facilities by redirecting the water and repairing leaks
- Decision to introduce recombiners in Oskarshamn 1 (2007) and Oskarshamn 2, changed from 2006 to 2007 due to technical difficulties
- Reduction of releases of I-131 through control of operating filters without I-131 dosing.

Ringhals

- Damage-free cores
- New cleaning steps for releases of waste water from the laundry
- New technology to reduce water consumption combined with methods to handle waste products from the cleaning steps
- Preventive sludge suction
- Frequent replacement of pre-filters for process water cleaning
- Partial sorting of water for cleaning and direct releases as well as re-direction of water from PWRs to the waste station at R1

In 2006, the target and reference values for the first four-year period will be evaluated by the plants. In certain cases, it can be expected that these values will be subsequently changed to better reflect reality. They will then be reported to SSI.

Diagram 7 shows the radiation doses that resulted from radioactive releases from the nuclear power plants in 2005. For purposes of comparison, the figures for 2002-2004 are also included. The radiation doses (specified in mSv) concern people living close to a nuclear power plant who are estimated to receive the highest dose, known as the *critical group*. The dose constraint for an individual in the critical group is 0.1 mSv per year. The doses were all less than one-hundredth of the dose constraint and, in several cases, also show a downward trend for the years reported.

The plants conduct environmental monitoring in accordance with SSI's instructions. A limited selection of the samples taken is also measured by SSI. Cesium-137 from the Chernobyl accident, which occurred in 1986, still dominates the samples taken in the control programme. A number of other radioactive substances can also be detected in the samples taken from the water environment in the vicinity of the nuclear power plants, including samples of algae and bottom sediment.

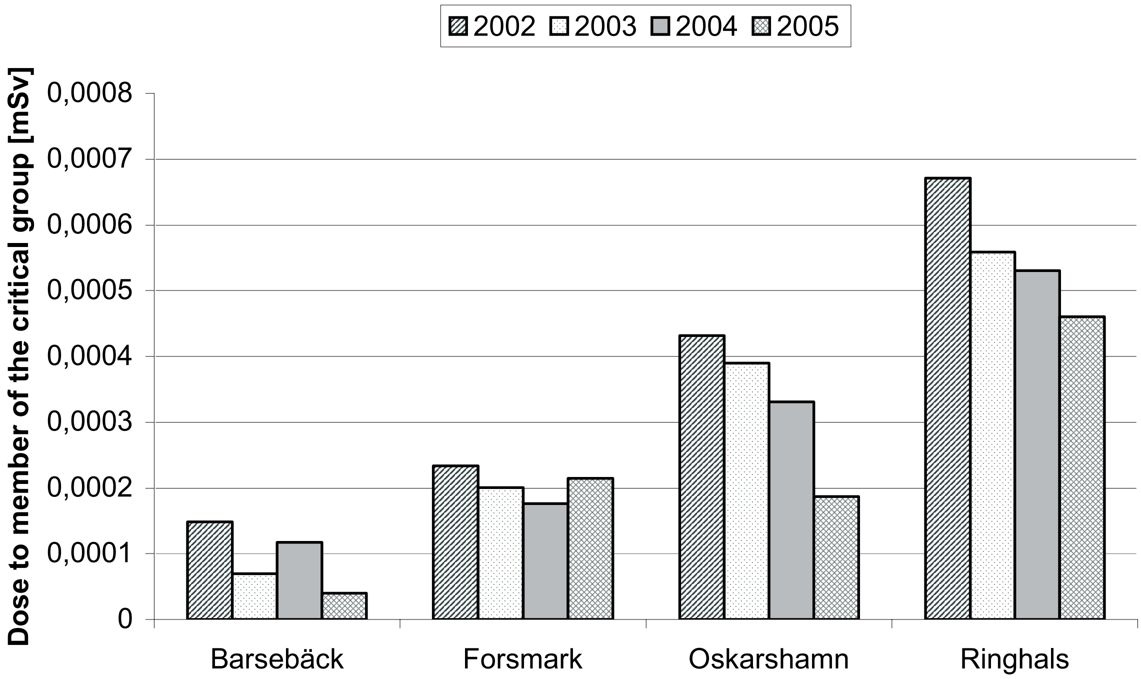

Diagram 7: Radioactive releases to air and water from nuclear power plants in 2005, shown as the dose to the critical group.

8. 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 deposited in local landfills at Forsmark, Oskarshamn and Ringhals or is sent to the facilities at Studsvik for treatment. Waste with a higher level of activity is deposited in the repository for radioactive operational waste (SFR-1), which is located at Forsmark nuclear power plant. Waste with very low activity can be exempted (free-released) from the regulations of the Radiation Protection Act and the Act on Nuclear Activities and then used without restriction, incinerated or deposited in municipal waste dumps. Long-lived waste is placed in interim storage at the nuclear power plants or CLAB pending a suitable repository.

In addition to the treatment of normal operational waste, the following can be noted for 2005.

At Barsebäck, trial operation of a facility for immobilizing waste to be deposited in SFR-1 was completed. The test results have been submitted to SKI and SSI. Work is underway at BKAB to, together with SKB, prepare a type description which, after regulatory approval, will comprise part of the revised safety analysis report (SAR) which should apply for Barsebäck 1 and 2 after closure. Even if these reactors have been closed down, the waste facility has to be operational, bearing in mind future system decontamination at the plant and other aspects.

At Forsmark, 115 m^3 of turbine oil from unit 3 was removed from the controlled area without performing control measurements. This action was in breach of SSI's regulations concerning the removal of goods and oil from a zone-classified area, SSI FS 1996:2. SSI considered the risk of contamination of the oil to be low, but has required Forsmarks Kraftgrupp to describe the event and measures taken against a possible recurrence. A license from SKI to remove the oil from a controlled area was also lacking. However, an application for an exemption from the provisions of the Act on Nuclear Activities had been submitted to SKI before this, although SKI had not managed to make a decision on this issue. Forsmarks Kraftgrupp then investigated the matter and reported the event to SKI.

A similar event occurred at Oskarshamn. The removal of 57.5 m^3 of oil from Oskarshamn 1 was carried out in spite of the fact that the amount that can be removed every year was limited to 35 m^3. The fact that the quantity of oil removed exceeded the permitted amount was detected in connection with OKG's preparation of its annual report on the transfer of exempted quantities of nuclear waste. OKG subsequently reviewed its procedures for preventing similar events from occurring. It can be noted that the waste was free-released in accordance with SSI's regulations (1996:2) concerning the removal of goods and oil from zone-classified areas at nuclear facilities.

At Ringhals, a steam generator from the Ringhals 3 reactor, which was previously placed in interim storage at the nuclear power plant, was sent to Studsvik for waste treatment in the form of decontamination, melting and recycling of materials. For this work, Ringhals prepared a plan of action to describe the transportation and handling of these types of waste.

During the year, no waste was disposed of at the facility landfills. A campaign at Ringhals was postponed for later years due to the requirement to report certain nuclides which were difficult to measure.

In 2005, waste packages corresponding to a volume of 486 m^3 were deposited at SFR-1. Since SFR-1 was taken into operation, a total of 30,930 m^3 has been deposited. During the year, a low increase in activity was detected in the drainage water from the BMA interim storage facility. An investigation carried out by the Swedish Nuclear Fuel and Waste Management Co (SKB) detected an activity leakage from waste drums. However, the activity level was far below the permitted values for radioactive releases. SKB implemented measures to prevent a recurrence. The leak had no impact on safety.

Other treatment, interim storage and disposal of nuclear waste at the nuclear facilities were conducted in a satisfactory manner during the year.

Spent Nuclear Fuel

Spent nuclear fuel and scrapped reactor internals which are classified as long-lived waste, are placed in interim storage at CLAB which is located in the vicinity of the Oskarshamn nuclear power plant. OKG conducts the day-to-day operation at the facility on behalf of SKB which is the licensee. In 2005, SKB's board made a strategic decision that SKB should take the operation of CLAB under its own auspices as of October 1, 2006. Extensive work has been initiated at SKB for this purpose and a new safety department is being established.

During the year, 89 transport containers with a total of 92.2 tonnes of uranium in the form of spent nuclear fuel and 21 transport containers with core components from the nuclear power plants were received at CLAB.

SKB has noted deficiencies in the design of a joint in the transport channel between an existing part of CLAB and the extension part of CLAB. Currently, fuel is being stored in the reserve positions at the existing part of CLAB since SKI has not granted permission to SKB to start nuclear operation (namely, spent fuel handling) at the extension part of CLAB (stage 2).

9. Emergency preparedness

During the year, the authorities have followed and promoted the development of emergency preparedness at the nuclear power plants. The issues that have received special attention are the first stage following an event and the contact with the authorities in connection with this. The preparation and adopting of protective measures for those living in the vicinity of the facility, if it should be necessary, also takes time. Therefore, well-developed and rehearsed routines must be in place at the nuclear power plants for the first stage following an event.

In 2005, SKI conducted inspections and monitoring at all of the nuclear power plants to determine whether the licensees meet the requirements of the Swedish Nuclear Power Inspectorate's regulations, SKIFS 2004:1 concerning safety at nuclear facilities with respect to emergency preparedness planning and information transfer to SKI. The supervisory work was conducted in the light of the clarified requirements in the preparedness area that were introduced into SKIFS 2004:1. In SKI's opinion, all of the nuclear power plants comply with the requirements that were made. However, there are areas in which all of the licensees can improve. The measures that are now to be adopted as a result of SKI's findings will be followed up in 2006 and 2007.

The work on preparing SSI's regulations for emergency preparedness at certain nuclear facilities has progressed as planned during the year. The regulations were decided in April 2005. In autumn, all of the nuclear facilities were visited with the aim of verifying the application of regulations and to evaluate the plans for the introduction of measures that must be adopted at the facilities.

The nuclear facilities are classified as threat category 1 in accordance with IAEA's regulations. This entails increased radiation protection requirements in connection with emergency situations with respect to continuous radiation monitoring at the facility site and the handling of meteorological data.

SKI and SSI have also participated in minor exercises at the nuclear power plants and have participated in training. Furthermore, the authorities participated in a joint exercise with the county administrative board of Umeå, where one of the features was a radiological event on the Kola penninsula. Representatives from SKI and SSI also participated in an exercise with the Cabinet Office and ministries as well as in an exercise with the county administrative board of Malmö and a number of municipalities in Skåne.

Three staff exercises were carried out during the year. At one of the exercises, the scenario involving an accident at a Swedish nuclear power plant was exercised. The exercise had been jointly planned by SSI and SKI with the aim of testing the working methodology and establishing ways of SKI and SSI to work together, where SKI's crisis organization is established at SSI's management centre. The exercise had been preceded by a joint SSI/SKI three-day course in staff work methodology.

In addition to the staff exercises, the on-duty radiation protection inspector (TSI) and the on-duty decision-maker (VB) participated in several minor exercises at the plants.

The purpose of the exercises was for VHI and TSI to practise making contacts and exchanging initial information.

The Generalen crisis information system, used by SSI, SKI and counties with nuclear power plants for the documentation and exchange of operational crisis information, has been developed during the year and a new version has been created. The new version is based on the latest web technology and follows current standards in the ware. This means that information can be exchanged between Generalen and other information systems which follow applicable standards. The new Generalen will be launched in mid-2006.

Within the Generalen concept, a new website for crisis information to the public has also been completed and launched. The websites have been verified in accordance with the W3C standard.

Joint work between the authorities within the areas of the Proliferation of Hazardous Substances, Protection Rescue and Care and Technical Infrastructure has been further developed. In the Proliferation of Hazardous Substances area, a working report has been prepared as a basis for risk and vulnerability analyses and priorities have been clarified for the continued work. The authorities have also prepared their own risk and vulnerability analyses.

This year, SSI and SKI have also, in co-operation with other actors in the preparedness area, continued to develop and make preparedness more efficient in the event of nuclear accidents. One of the starting points of this work has been the IAEA's recommendations in the preparedness area. These recommendations were also the object of Nordic co-operation. Within the Nordic co-operation, the focus has been on the mutual agreements on information in connection with events.

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