SKI Report 2004:16
SSI-report 2004:04

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Statens strålskyddsinstitut
Swedish Radiation Protection Authority

ISSN 1104-1374
ISSN 0282-4434
ISRN SKI-R-04/16-SE

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STATENS KÄRNKRAFTINSPEKTION
Swedish Nuclear Power Inspectorate

Statens strålskyddsinstitut
Swedish Radiation Protection Institute

To the Government

Ministry of the Environment
103 33 STOCKHOLM

April 28, 2004

SKI 1.8-040456
SSI 2004/1658-20

Safety and Radiation Protection at Swedish Nuclear Power Plants 2003

In the directive for the 2004 budget year, the Government has charged SKI with the task of, together with the Swedish Radiation Protection Authority (SSI) and no later than May 1, 2004, reporting to the Government concerning the status of safety and radiation protection at Swedish nuclear power plants. SKI is to be responsible for ensuring that the joint report is submitted to the Government.

The report has been treated by SKI's reactor safety committee which has assisted SKI in the safety evaluations reported in the summary. SKI and SSI's Boards have been consulted on the matter in accordance with § 22 of the Agency Ordinance (SFS 1995:1322). Based on the comments submitted, neither Board has any objection to make to the safety and radiation protection evaluations reported in the summary.

The report on safety and radiation protection at the Swedish Nuclear Power Plants 2003 is hereby submitted.

SWEDISH NUCLEAR POWER INSPECTORATE

Judith Melin, Director General

SWEDISH RADIATION PROTECTION AUTHORITY

Carl-Magnus Larson, Acting Director General

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SUMMARY

The safety philosophy upon which the Swedish Nuclear Power Inspectorate's (SKI) supervisory and regulatory activities are based assumes that multiple physical barriers will exist and that a plant-specific defence-in-depth system will be implemented at each plant. 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 levels 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 system is based upon sound management and control of safety, an organization 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 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 jeopardized. Defence-in-depth systems are designed so that they can withstand deficiencies during a 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.

Safety Margins Challenged by Events and Detected Defects

In 2003, events occurred which jeopardized the safety systems at two nuclear power plants. However, the safety systems functioned as intended.

During stipulated inspection and testing which are largely conducted during the annual refuelling and maintenance outages, a number of defects were detected in the reactor pressure-bearing primary systems. As a result, extensive investigations and repair were conducted. In two cases, damage was detected when a leak occurred and this led to an unplanned outage at one of the units for repair work. Minor damage was also detected in the ultimate barrier, the reactor containment.

In SKI's opinion, the events and detected defects did not jeopardize safety although the safety margins were negatively affected through the weakening of parts of the defence-in-depth system. Before the reactors could be re-started, SKI required thorough safety analyses and controls to ensure that the barriers and safety margins were restored.

In the Swedish Radiation Protection Authority's (SSI) view, radiation protection at the Swedish nuclear power plants is good. Competence and an interest in radiation protection issues on the part of the plant operations management are vital for a continued positive development. In 2003, the collective dose at Swedish nuclear power plants was 11 manSv[1] which is on a par with the average value for the past five years. The events and detected defects mentioned above nevertheless resulted in higher doses than planned at some reactors. In 2003, the collective dose to people living in the vicinity of nuclear power plants were lower than one per cent of the dose constraint[2]. The control measurements conducted by SSI on samples taken from the environment around nuclear power plants and from releases to water show a good agreement with the licensees' own measurements.

SKI wishes to emphasize the importance of adequate radiation protection at the plants, also from the standpoint of safety. Low radiation levels facilitate maintenance, testing and repairs and allow these tasks to be conducted with a high level of quality.

SKI has criticized the way in which safety work has been conducted at Barsebäck Kraft AB and OKG Aktiebolag, the licensees for the units at which the two most severe events occurred. The investigations into the events have indicated deficiencies in safety management, safety review procedures, supplier control, experience feedback and decision-making procedures for safety-related issues. SKI has also criticized Ringhals AB for deficiencies in its safety reviews, experience feedback and the allocation of safety priorities in connection with plant modifications and detected defects of importance for safety. Corrective action has been adopted by the licensees to improve the quality of the safety work although additional measures are needed. SKI has not found any reason to criticize safety and safety work at Forsmarks Kraftgrupp in 2003.

Certain events have indicated deficiencies in the licensees' systems for experience feedback. SKI's investigations have found that some of the events could have been avoided if there had been a greater capability for taking timely and effective corrective action based on experience reported via the national and international experience feedback systems. SKI has required the licensees to implement more efficient experience feedback routines to evaluate events and conditions occurring at their own and at other plants. In addition, SKI has required the licensees to clearly allocate priorities relating to safety measures which must be implemented on the basis of experience.

On the basis of the year's events and detected defects, SKI concludes that a considerable improvement needs to be made in the licensee organizations' systems for handling internal information which can impact on safety. In SKI's view, the decision-making procedures for safety issues must be transparent. It is important that all information originating from operation, maintenance, safety analysis, project activities etc. should be handled in accordance with established procedures, documented and, without delay, be safety evaluated by the responsible line units. It is also essential that the internal safety review function should be strong, proactive and should be authorized by the senior management to intervene whenever it is found that safety issues are not receiving adequate attention or being prioritized within the organization. The licensees that have been deficient in this respect have adopted corrective action. SKI is continuing to review and follow up how safety-related information and safety reviews are handled within the organizations.

[1] manSv is the unit used for the collective dose which is the sum of the individual doses.
[2] Radiation dose from radioactive releases to a person living near a nuclear power plant may not exceed 0.1 mSv per year.

In its supervision, SKI will also monitor the licensees' activities to ensure that:

- the level of ambition in the damage prevention and correction work continues to be high and that the focus and scope of the control work is adapted to the lessons learned;
- the level of ambition in the safety analysis work is high so that new knowledge can be fed back into the safety reports and that all operating situations at the plants are analyzed, evaluated and documented.

Plant Modernization Continues

SKI has observed that extensive work is underway to renovate the units and further improve safety based on previous events and detected deficiencies. A large number of safety-improvement measures have been implemented at Swedish nuclear power plants since the TMI-2 accident in the USA in 1979. The strainer incident which occurred at Barsebäck in 1992 also resulted in considerable modifications at all nuclear power plants. This work is continuing and SKI will provide an impetus for work through new regulations etc.

The power companies are now strengthening the organizations with the aim of continuing work on improving safety and safety work at the plants as well as keeping a high level of quality in the radiation protection work. Safety issues in the industry include both the handling of ageing and technical development, organizational development, competence development, economic efficiency and environmental development. The organizations need to be able to handle a complex interaction between technology, humans, organization and financial aspects in order to maintain and continue to improve safety.

SKI and SSI share the licensees' view that it is necessary that the organizations should be reinforced, especially taking into account the considerable challenges of maintaining a high level of safety and adequate radiation protection conditions during operation and, at the same time, conducting major projects to upgrade the plants. This places considerable demands on the licensees' resources and competence. Experience from the year's events and from the modernization of Oskarshamn 1 indicate that the resources and competence required for project management, safety review and supplier control should not be underestimated. SKI and SSI are reinforcing their supervision in this area within their own areas of competence.

Increased Protection against Terrorist Attacks

SKI has identified a need to promulgate new regulations concerning the physical protection of nuclear facilities partly in view of the recent years' terrorist attacks. During the year, SKI also established a new set of design basis threat scenarios. This is the basis for the licensees' design of physical protection at each nuclear facility. Compared with the previous set of scenarios, SKI has assumed a more violent attacker whose main purpose may be to damage a facility.

Loss of Offsite Power, September 23, 2003

The event occurring at Oskarshamn in connection with the major power outage in southern Sweden in September indicated the importance of high availability of the offsite power grid. The nuclear power plants have their own independent power sources which can handle the safety functions. However, a loss of offsite power can result in reduced margins in the defence-in-depth system, especially in connection with lengthy power outages. SKI intends to ensure that this issue is dealt with by the licensees.

Special Supervision

SKI is continuing the reinforced supervision of Barsebäck Kraft AB for as long as the uncertainty surrounding the continued operation of the reactor remain. This means a more frequent inspection presence in Barsebäck in order to observe the safety work on site. SKI cannot exclude that the problems that have occurred at the facility are partly due to the uncertainty. However, SKI’s view is that Barsebäck Kraft AB is continuing to manage the situation satisfactorily.

BACKGROUND

Reports concerning the safety and radiation protection situation have been prepared by the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Agency (SSI) since 1990. The reports are jointly written by both authorities on behalf of the Swedish Government. SKI is responsible for co-ordinating the preparation of the reports and for ensuring that they are submitted to the Government no later than May 1 of every year. In the reports, the authorities provide an overall evaluation of safety and radiation protection, based on what has emerged from the regulatory and supervisory work or in other ways during the course of the year. The review is based on relevant legislation and regulations promulgated by the authorities.

SKI consults the reactor safety committee and the Board on its review. SSI consults its Board. The reports are addressed primarily to the Government and the Riksdag (Swedish parliament) as well as to the licensees concerned. It has also been found that the reports have a considerable value in terms of information. For this reason, the media also comprises a target group.

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.

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, organization 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 jeopardize 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 as well as in the stipulations that the Government and SKI establish in the licences to conduct nuclear activities.

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 2003. 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 in the annual report of each nuclear power plant which, in accordance with SKI's regulations, is to be submitted to SKI or made available on the company's website.

Barsebäck

Barsebäck 1

Barsebäck's first reactor has been shut down since 1999. The main tasks for the personnel working with Barsebäck 1 was to develop expertise in decommissioning and to document the status of the unit prior to future dismantling. To some extent, the personnel provides support for other activities at the facility. The Technical Specifications (STF) have been adapted to the operating status.

Barsebäck 2

During the refuelling and maintenance outage[3] in 2002, Barsebäck Kraft AB (BKAB) replaced the thermal mixers in two of the reactor's operating and safety systems. During autumn and winter the same year, operating disturbances occurred and the reactor was shut down for inspection in January 2003. Extensive damage was found in the thermal mixers. Some damage was also found in connecting systems. In order to restore the reactor, extensive measures were required. All of the fuel had to be removed from the reactor and the reactor had to be cleaned. All of the drive mechanisms were inspected and cleaned to restore their functionality and eliminate suspicions that parts of the damaged components had become stuck in the mechanisms.

New thermal mixers were installed and the pipe components in question were replaced. BKAB initiated two human factor investigations, one focusing on the thermal mixer incident and the other focusing on the decision-making chain which led to the shutdown. The event, which was classified on the International Nuclear Event Scale (INES) is discussed in detail in Chapters 2 and 5.

The reactor was re-started and synchronized to the grid on March 7. However, already on March 9, the reactor scrammed due to turbine-related problems. On March 11, the reactor was once again operating at full power. Power operation then continued until July 17, when the reactor was shut down for the annual outage.

The annual refuelling and maintenance outage largely comprised preventive maintenance and recurrent inspections. The outage was extended when inspections revealed a number of crack indications in the level measurement and bottom nozzles in the reactor pressure vessel which required further investigation.

On account of the above-mentioned thermal mixer event, SKI decided that Barsebäck 2 was not allowed to be started up after the outage until SKI had approved the measures

[3] A *refuelling and maintenance outage* is an annual shutdown of a nuclear power reactor during which the reactor containment and reactor pressure vessel are opened. During this period, refuelling is conducted and planned inspections and repair are conducted on the reactor, service and operating systems.

that SKI required that the company should implement. SKI gave permission for the reactor to be started up on October 17.

In connection with inspections prior to startup, the personnel at Barsebäck detected a minor water leak which was subsequently found to originate in the reactor containment condensation pool. For several weeks, work was conducted to identify the leak route through the containment. The cause was a weld defect which had developed corrosion attack. The damage was repaired and the containment was then judged to be leaktight. The reactor was re-started and synchronized to the grid on December 11, after which no operating disturbances were reported. The shutdown period, including the refuelling and maintenance outage, was 147 days.

Forsmark

Forsmark 1

On April 8, the reactor scrammed due to a turbine plant failure. On July 27, the annual refuelling and maintenance outage started. The main work during the outage comprised the renovation of the emergency core cooling systems which entailed the removal of the core spray system nozzles. An extensive reactor pressure vessel and internals testing was also conducted. The outage lasted for 26 days. On October 17, the reactor was taken to hot shutdown in order to repair a leaking pipe in the containment.

Forsmark 2

The annual refuelling and maintenance outage was started on May 10, a few hours earlier than planned due to a scram during power reduction prior to shutdown. The scram was caused by electrical connection errors prior to switchgear replacement. As with Forsmark 1, the main work conducted during the outage was the upgrading of the emergency core cooling system and an extensive testing of the reactor pressure vessel and internals. During startup after the outage, the reactor scrammed twice due to incorrect alignment of the reactor safety system. The outage lasted for 35 days. Apart from this, no disturbances occurred during operation throughout the period, although a minor interruption occurred at the end of November when a leak was repaired in a turbine plant cooling system.

Forsmark 3

The annual refuelling and maintenance outage started on June 23 and, in addition to refuelling, also involved component servicing and stipulated testing.

During isolation valve testing, the personnel detected a major leak in one of the feedwater system isolation check valves caused by the wearing of the valve seat and stem. The quantity of leakage exceeded the measurement range of the measurement equipment. The event was classified as one on INES. The refuelling and maintenance outage lasted for ten days.

Oskarshamn

Oskarshamn 1

At the end of 2002, startup was initiated after modernization work. On January 2, 2003, the reactor was connected to the grid. In connection with testing, the facility started up and shut down a number of times. On January 3, the reactor scrammed due to a turbine plant malfunction. During turbine testing on January 7, reactor scram occurred due to a high level in the reactor pressure vessel and during valve testing in the feedwater system, scram occurred on January 25.

A short outage occurred at the end of January in order to repair an oil leak in the turbine plant. In early February, OKG Aktiebolag decided to operate the plant at reduced power due to vibrations in the turbine plant. Early in March, the plant was shut down for almost a week to correct the undesirable vibrations.

On June 8, scram occurred due to a leak in a safety valve outside the containment. The reactor was started up the following day and full power was reached a couple of days later. On July 22, a reactor scram occurred due to a malfunction in the voltage feed to computer equipment. On August 13, an oil leak was detected in the turbine. During power reduction prior to shutdown to repair the leak, scram occurred.

On August 23, the unit was shut down for the annual refuelling and maintenance outage. The outage was planned to last three weeks but at the end of August particles were found in the reactor pressure vessel. Analyses showed that they were probably caused by oxide flaking from the fuel boxes. The reactor was started up after an outage of 43 days. In connection with startup, two scrams occurred. The first occurred in connection with turbine testing and was caused by faults in the turbine speed governing system. The second scram occurred when the turbine was being shut down due to smoke caused by oil in the pipe insulation. On December 25, manual shutdown was conducted due to oil leakage in the turbine plant. Scram was initiated in connection with the shutdown. The unit was started up again on December 27.

Oskarshamn 2

The annual refuelling and maintenance outage was initiated on May 11. In connection with the shutdown, scram occurred, initiated by a signal from the turbine plant. The outage was the most extensive ever for the reactor and included the replacement of material in reactor pressure vessel and other pipe connections. During the outage, the core shroud head and core spray nozzles were also replaced.

As at Barsebäck 2, reactor pressure vessel pipe connection inspections revealed defects which had to be corrected. When the repair work was done, the personnel found that the core grid had been damaged during the work. The repair work was approved by SKI at the end of September. The outage lasted 139 days. During startup, steam leakage and turbine shaft imbalance were detected. Two scrams occurred during the adjustment work and restoration to power operation.

At the end of October, the unit was affected by electromagnetic solar winds which caused the temperature of the main transformer to increase. Power was reduced in order to correct the problem.

Oskarshamn 3

On June 15, the unit was shut down for the annual refuelling and maintenance outage. The reactor was started up after 29 days. During the outage, when the generator was disconnected from the grid, an automatic turbine trip occurred in connection with overspeed testing and resulted in a reactor scram.

At Oskarshamn 3, inspections of the reactor pressure vessel pipe connections were also conducted. The inspections showed that no immediate measures needed to be adopted but that followup inspections were necessary.

During maintenance work in the turbine plant on September 23, water leakage resulted in a reactor scram. Shortly afterwards, a major power outage occurred in large parts of southern Sweden and this had a major impact on the reactor. In connection with power restoration prior to startup, a rapid temperature increase in the reactor caused the Maximum Permitted Limit Value (MPLV) for temperature changes in the reactor pressure vessel to be exceeded. In such a situation SKI's regulations require that the unit should not be started up until it can be shown that the unit is not adversely affected by the event and permission for startup is required from SKI. SKI gave its permission on November 14. The reactor was started up on November 16. The event was classified as one on INES.

Ringhals

Ringhals 1

On April 19, the reactor was shut down for three days to repair leaking isolation valves in the auxiliary feedwater system. On June 16, the reactor was shut down as a result of an external leak inside the containment. The leak was located in a level measurement nozzle below core level. Other level measurement nozzles were inspected and found to be defect-free. The refuelling and maintenance outage started on August 30. During the outage, a diesel-backed emergency power generator and connected busbar was not energized due to two malfunctioning contacts in the maneuvering system. An inspection showed that the same malfunction would have resulted in the redundant busbar not being energized. The event was classified as one on INES. During the outage, normal maintenance work and refuelling were conducted and a new core shroud head and core spray system nozzles were installed. The refuelling outage lasted for 48 days.

On December 30, a suspected breach of containment integrity was reported to SKI. A leak in the toroid plate which connects the pool bottom with the containment liner had been found. The defect is being investigated.

Ringhals 2

On April 22, a reactor scram occurred due to incorrect equipment in connection with the replacement of a relay protection in the internal electrical system. During startup, a second scram occurred. The reactor was again synchronized to the grid on April 23. In connection with shutdown prior to the annual refuelling and maintenance outage on May 23, scram occurred as a result of a fault in the dump control system. In connection with this event, the annual refuelling and maintenance outage started with refuelling and normal maintenance.

On June 15, the refuelling and maintenance outage was concluded after 24 days and the reactor was synchronized to the grid. On October 23, the reactor scrammed due to malfunctioning equipment. On the following day, full power was attained. Since then the reactor has been operated without interruption and at full power.

Ringhals 3

The reactor was shut down for the refuelling and maintenance outage on April 24. The outage was extensive and included the rebuilding of pressure relief valves from the pressurizer safety valves and the repair of materials defects in the reactor pressure vessel connections. The outage lasted for 52 days.

On September 20, the reactor was shut down briefly to replace the insulation on a valve in the reactor containment. It was found that, during the annual outage, the valve had been insulated with mineral wool instead of reflective metallic insulation which is the material that must be used. In connection with the major power outage on September 23, the turbine changed over to house load operation which means that the unit only supplies electricity for its own needs. Consequently, the generator was disconnected from the offsite grid and reactor power was automatically reduced. Rapid power reduction places considerable demands on the turbine governing equipment. Since there was a malfunction in the turbine valve governing equipment, which maintains house load operation, scram was initiated shortly afterwards. On September 25, full power was once again attained and the unit continued operating at full power throughout the rest of the period.

Ringhals 4
On July 31, the reactor was shut down for the refuelling and maintenance outage. The outage also included rebuilding of the pressure relief lines from the pressurizer safety valves. During the outage, a penetrating crack was detected in a pressurizer level measurement nozzle. In accordance with normal procedures an investigation into the cause of the damage was conducted and a repair method was formulated which was approved by the inspection and testing organization and SKI. As a result of the measures to repair the crack in the nozzle, the outage was extended, lasting for 36 days.

Ringhals 4 also switched over to house load operation mode in connection with the loss of offsite power on September 23. When the grid was considered to be stable, Ringhals 4 was synchronized to the grid. A few hours later, the unit once again changed over to house load operation while the National Grid Authority reconnected equipment in the switchyard in Horred. Twenty minutes later, both generators were once again synchronized to the grid. The reactor reached full power on September 24.

2. Technology and Ageing

Overall Evaluation of Damage Evolution

Swedish nuclear power reactors are between 18 and 32 years old. Oskarshamn 1, Sweden's oldest nuclear reactor, was taken into operation in 1972. The most recently constructed reactors, Oskarshamn 3 and Forsmark 3, were started up in 1985. Possible damage and degradation that may be due to ageing, namely time-dependent damage mechanisms, must be kept under constant surveillance. The licensees must be good at planning ahead and at implementing preventive measures in order to avoid damage for as long as possible. Furthermore, suitable periodic inspection and testing programmes are required to detect damage and other degradation on a timely basis before safety is jeopardized.

Extensive replacement of parts which were found to be susceptible to damage was conducted at the Swedish facilities. Much of this replacement work was conducted for preventive purposes as a greater understanding was obtained of damage causes and mechanisms. In other cases, replacement work was conducted when damage occurred. During the year, relatively few new cases of damage and deficiencies were detected. Previously identified problem areas have been followed up and analyzed. Taken as a whole, as a result of these measures, SKI does not see at present any serious tendencies towards age-related damage which may have degraded safety at the plants.

SKI is continuously following the evolution of damage in the mechanical devices and building structures included in the plant barriers and defence-in-depth system. An overall evaluation made by SKI[4] and which covers all cases of damage[5] in mechanical devices since the first unit was taken into operation in 1972 up to 2000, confirms that preventive and corrective measures have had the intended effect[6]. This conclusion applies even when the cases of damage that occurred up to the end of 2003 are taken into account. As shown in *Diagrams 1* and *2* below, there is no tendency towards an increase in the number of cases as the plants become older. The overall evaluation also shows that most of the damage that has occurred so far was detected in time through periodic in-service inspection and testing before safety was affected. Only a small part of all of the damage has led to leaks or other serious conditions as a result of cracking and other degradation which remained undetected, see *Diagram 3*.

It is mainly different types of corrosion mechanisms that have resulted in the cases of damage which 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 is a mechanism that mainly occurs in stainless austenitic steel and nickel alloys when they are subjected to stresses and corrosive environments. The materials' susceptibility to damage is due to their chemical composition and to the thermal treatment and machining that they have been subjected to during manufacturing and installation in the facility. In spite of the fact that

[4] Damage in the mechanical devices of Swedish nuclear facilities, 1992-2000. SKI-Report 02:50. Swedish Nuclear Power Inspectorate, December 2002 (in Swedish).

[5] Case of damage: One or more cracks or other defects detected in a certain device component and at a certain time. There have been different degrees of severity and safety importance of damage.

[6] Note that most of the cases of damage that occurred from 1986 to 1987 (see Figure 2) after 13 to 14 years of operation (see Figure 3) were caused by stress corrosion in cold-worked pipe bends. These were subsequently replaced by bends that were not cold-worked.

considerable knowledge of factors affecting damage has been developed in recent decades as well as how these factors interact, our understanding of the issue is not yet sufficiently developed to completely avoid the problems or to predict which of the existing plant components can be damaged.

While stress corrosion damage has most often occurred in primary pipe systems and in safety systems, erosion corrosion usually occurs in secondary components, such as in steam and turbine parts. Thermal fatigue, which is the third most common damage mechanism (and which accounts for about 10 % of the cases) has mainly occurred in primary pipe systems and safety systems.

The positive trend where the increase in the number of damage cases does not increase as the plants become older requires a continued high level of ambition in terms of preventive maintenance and replacement work. Therefore, SKI will continue to provide impetus to the licensees to maintain a high level of ambition and a good level of preparedness to evaluate and assess damage when it is detected. This is important, since experience shows that when there is a lack of adequate advance planning, significant problems arise when damage occurs and must be evaluated in terms of its impact on safety. The lack of data and of suitable analysis and testing methods leads to uncertainty regarding margins and, thereby, regarding the safety importance of the damage.

At present, SKI does not see any serious tendencies towards age-related damage which can lead to the degradation of the safety of the other building structures. The damage and degradation that have occurred show that these have mainly been caused by deficiencies in connection with plant construction or subsequent modifications. This type of damage has been observed in Barsebäck 2, Forsmark 1 and Oskarshamn 1. During the year, additional damage of this type has been reported and this is described in detail below. However, in SKI's view, taking into account the difficulty of reliably testing 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 and safety of components. For its part, SKI is conducting investigations[7] and research into damage and other types of degradation that can affect the containments in the long term as well as into the inspection and testing methods that must be developed in order to deal with possible threats to containment leaktightness and integrity on a timely basis.

The ageing of electrical cables and other equipment in plant instrumentation and control systems has attracted international attention. Work on identifying observed and possible problems has started within the framework of a joint international project with participants from the nuclear industry and the regulatory authorities. The objective of the project is to compile international experience, for example, the risk of cable fires due to ageing, to obtain a better basis for conducting relevant risk assessments and implementing measures. With respect to the situation at Swedish plants, SKI has required information from the licensees concerning their handling of the ageing phenomenon and environmental qualification of these components. The report will provide a basis for SKI to continue to deal with these issues.

[7] Investigation into reactor containments – design, damage, inspections and testing. SKI-Rapport 02:58. Swedish Nuclear Power Inspectorate, February 2003 (in Swedish).

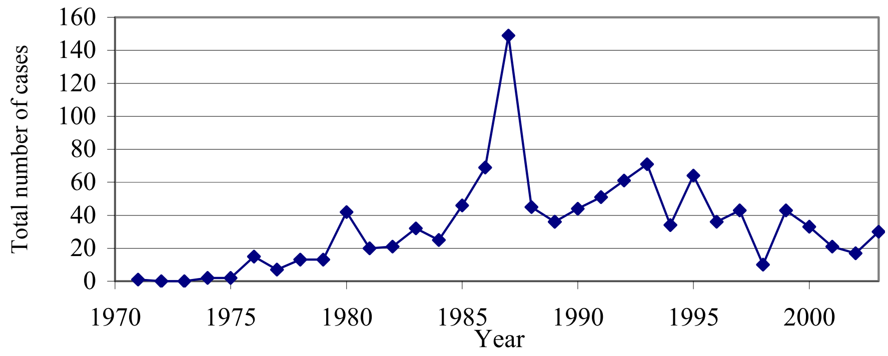
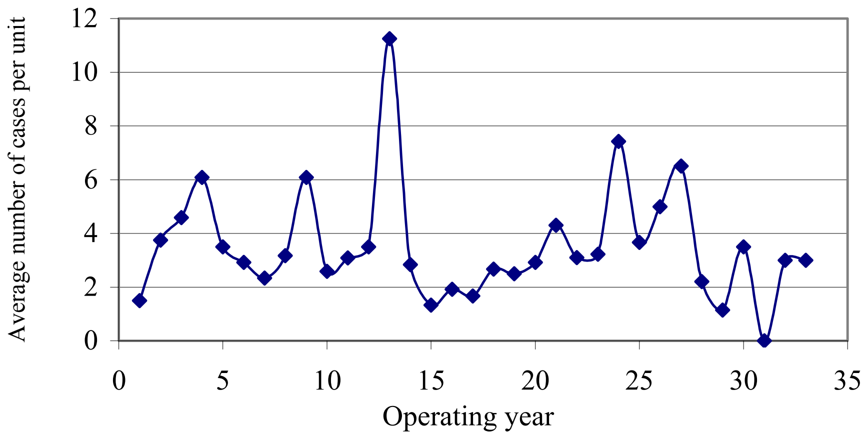


Diagram 1. Total number of reported cases of damage per year at Swedish nuclear power plants. Damage in steam generator tubes is not included.



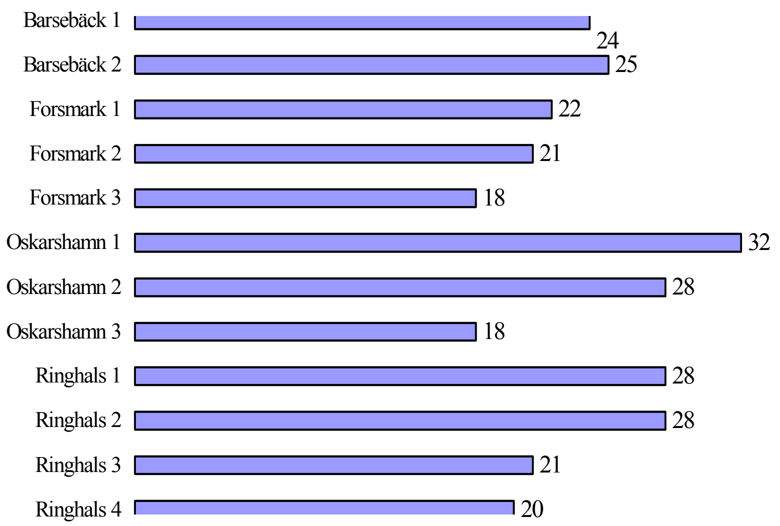


Diagram 2. The uppermost of the two diagrams shows the average number of reported cases of damage per unit and operating year for all Swedish nuclear power plants. The diagram comprises damage to pressure vessels, pipelines and other mechanical devices apart from steam generator tubes. The diagram below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

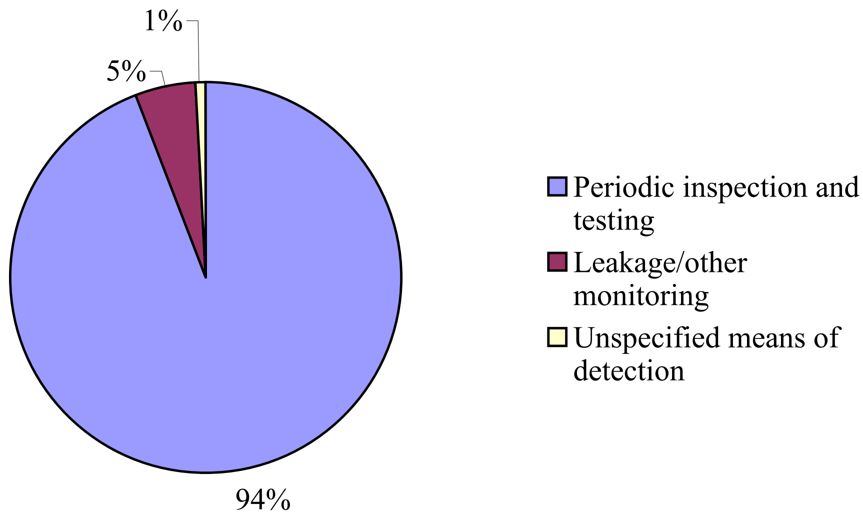


Diagram 3. The number of cases of damage detected through periodic in-service inspection and testing and the number of instances of damage that have resulted in leakage or that have been detected in some other way.

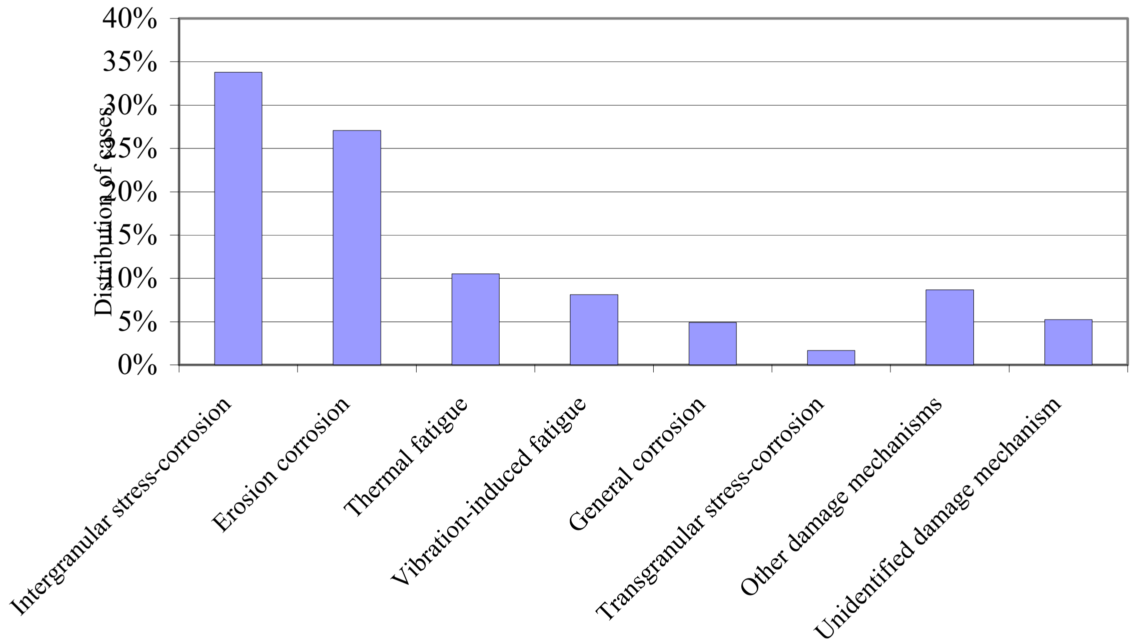


Diagram 4. Cases of damage distributed according to damage mechanism. ("Other damage mechanisms" includes cases of damage caused by grain boundary attack, corrosion fatigue and mechanical damage).

Continued Problems with Nickel-based Alloys

Nickel-based alloys are a relatively common material in nuclear power plant construction. This is particularly the case for Alloy 600 and the weld variety of the material, called Alloy 182. The reason is that it is a highly durable material with better corrosion resistance than stainless austenitic steel. This material has been used for the manufacturing of nozzles, tubes and safe-ends (the transition between a nozzle and the connecting pipe). However, both Alloy 600 and Alloy 182 are sensitive to stress corrosion in certain environments and temperatures. In the 1980's, several cases of damage in boiling water reactor nozzles and tubes in pressurized water reactor steam generators were reported. The reported cases led to requirements by SKI for increased inspection and testing of components and parts manufactured from Alloy 600 or welded with alloy 182.

The sensitivity of the material and the damage found resulted in the replacement of steam generators in Ringhals 2 and 3 as well as a new core shroud head in Ringhals 2. The latter replacement was carried out due to stress corrosion cracking in the drive mechanism penetrations in the head. The penetrations were manufactured of Alloy 600 and welded with Alloy 182. The penetration pipes in the reactor pressure vessel heads of Ringhals 3 and 4 show similar cracking. In these units, the extent and propagation of the damage have been followed for many years through periodic inspection and testing. The results from the most recent follow-ups show that the damage is limited in scope and that propagation has been slow. In spite of this, Ringhals AB has now ordered new reactor pressure vessel heads for Ringhals 3 and 4 in order to counteract future problems, as was the case with Ringhals 2. The replacement of the head in Ringhals 4 will be conducted in 2004 and in Ringhals 3, in 2005.

During the refuelling and maintenance outage, defects and cracks were also detected in a number of level measurement, core and boron spray nozzles in Oskarshamn 2 and 3 as well as in Barsebäck 2. In these cases, it has not been possible to clearly determine whether the detected cracks were caused by stress corrosion or whether thermal cracking occurred already in connection with the manufacturing and was then overlooked during the manufacturing inspections. In Oskarshamn 2, the detected cracks in the level measurement nozzles were removed as was most of the Alloy 182 weld material. This material was replaced by another weld metal which is less sensitive to stress corrosion. After safety analysis and review by SKI, other cracks in the units concerned were left for the following year's outages when new testing and inspection will be conducted.

At Ringhals 1 and 4, damage has also been detected during the year in nozzles manufactured of Alloy 600 and welded with Alloy 182. Also in these cases, the level measurement nozzles were affected. The extent of the damage was such that leakage occurred and meant that affected parts had to be replaced.

Nozzle Welds Repaired

Pipe connections to the reactor pressure vessel nozzles are another example of problems with cracking in Alloy 182 weld metal. Stress corrosion cracking was detected in these connections in Ringhals 3 and 4 during the refuelling and maintenance outages in 2000. In Ringhals 4, the observed cracks were removed through the removal of boat-shaped specimens without any subsequent repair before the facility was once again taken into operation. This was conducted in order to obtain improved knowledge of possible causes of damage and in order to prevent further propagation. After in-depth safety analysis, a number of crack indications were left in Ringhals 3. The followup work conducted in 2001 showed signs of propagation in the remaining cracks. Therefore, Ringhals AB decided to also remove these without any subsequent repair work. Based on the inspections conducted and safety analyses submitted, both Ringhals 3 and 4 obtained permission from SKI to operate the facilities until the 2002 refuelling and maintenance outages. Crack-sensitive material which was exposed to the reactor coolant was then removed from the connections in Ringhals 4 and replaced by less susceptible material.

The followup work in Ringhals 3 in 2002 showed signs that minor cracks had occurred at the bottom of the pits that had formed after the boat-shaped specimens had been removed. The cause could not be determined. However, after in-depth safety analyses with pessimistic assumptions, SKI gave permission for a further year of operation without any additional measures. During the shutdown, the same repair work which was conducted the previous year in Ringhals 4 was conducted. In connection with this repair work, additional boat-shaped specimens were taken in order to investigate in detail the minor cracks that had arisen. However, the results were difficult to interpret. It cannot be excluded that the microcracks were caused by the machining method used and that the cracks then propagated as a result of stress corrosion. SKI will discuss these results further with the licensees and the independent testing organization which evaluates repair methods.

The type of repairs that are now being conducted at Ringhals 3 and 4 have previously been carried out on the nozzle connections to Forsmark 1-3. The measures implemented at Forsmark were largely preventive. Similar measures are now under consideration for additional facilities in order to avoid future problems.

Slow Increase in Damaged Steam Generator Tubes

An additional example of problems with stress corrosion in nickel-based alloys is the steam generator tubes in Ringhals 4. These tubes are manufactured of Alloy 600 and are a large part of the pressure-bearing primary system in these facilities. The damage is therefore being closely followed up through comprehensive annual testing and other investigations in accordance with SKI’s requirements. The inspections for the year have as before comprised damaged parts at the tube plate, support plate intersections and U bends. An additional 70 tubes with indications of stress corrosion cracks at the tube plate were detected as well as minor growth of previously detected cracks. The number of tubes with cracks in these areas have increased, on average, by 0.5 to 0.7 % per year. The followup inspections during the year did not detect any new defects in the U bend area.

Tubes with damage that is so limited that secure margins for rupturing and flaking exist have been kept in operation. Damaged tubes with inadequate margins were dealt with by the installation of plugs in the tube ends in order to take the tubes out of operation and, thereby, prevent further crack growth. However, during the year, no tubes were repaired by installing sleeving in order to prevent continued crack propagation and to restore tube mechanical strength. The total number of steam generator tubes that have been taken out of operation at Ringhals 4 has therefore increased somewhat and now corresponds to 2.15 % of the tubes.

As described above, Ringhals 2 and 3 have replaced their steam generators by generators of a new and partially different design and by tubes manufactured by less crack-sensitive material. In connection with the periodic inservice inspections and testing conducted, no signs of environmental damage were noted. The operating experience so far obtained from the new steam generators, which were installed 1989 in Ringhals 2, and in 1995 in Ringhals 3, is still good. However, minor wear-related damage was observed on a couple of tubes. It is believed that this damage was caused by foreign objects on the secondary system side of the steam generators.

Core Spray Systems Replaced and Removed

The core spray systems at Barsebäck 2, Oskarshamn 2 and Ringhals 1 are also plant components which have been affected by stress corrosion damage in nickel-based alloys. During the 1999 refuelling and maintenance outages, extensive stress corrosion cracking was observed in core spray pipe brackets and stays in Barsebäck 1 and 2 as well as in Oskarshamn 2. Similar damage, but not as extensive, was found in Ringhals 1. The damaged brackets and stays were manufactured from a nickel-based alloy called X-750. In certain heat treatment conditions, this alloy is very susceptible to stress corrosion.

Most of the damaged stays were replaced before the facilities were started up. However, individual damaged stays which were difficult to repair were left unrepaired after in-depth analyses of their impact on the core spray system nozzle mechanical strength and stability.

The followup inspections that were conducted between 2000 and 2002 showed that no new cracks had occurred but that some of the cracks that had been left unrepaired in Barsebäck 2 and Oskarshamn 2 had propagated, although without jeopardizing the necessary safety margins. The core spray nozzles in Oskarshamn 2 and Ringhals 1 were replaced by new nozzles of a partially different design during the annual refuelling and maintenance outages. The nozzles are also manufactured of less crack-sensitive material. SKI has reviewed the design basis for the new nozzles and has reviewed other aspects of the design, including the necessary core spray flow capacity. In Barsebäck 2, followup inspections have once again been conducted. These inspections show that new cracks have formed and that cracks left unrepaired have propagated. However, the analysis of these cracks shows that the safety margins are intact. SKI has no information on how Barsebäck Kraft AB intends to handle the problems in the long term, besides annual followup inspections.

In 2003, the core spray nozzles in Forsmark 1 and 2[8] were removed. Forsmarks Kraftgrupp AB (FKA) implemented this modification to avoid future crack-related problems in stays and in nozzle pipe systems. The condition for the modification was that FKA had to show that the core can be cooled under all conditions and that heat generated can be taken to heat sinks of an adequate size. Before the modifications were

[8] Unlike Barsebäck 2, Oskarshamn 2 and Ringhals 1, these units have internal reactor recirculation pumps without external main recirculation loops. Internal pump reactors do not have the same demands on an even spray distribution in the event of emergency core cooling, which means that other solutions are possible. This condition has been investigated by SKI as a basis for its review of the measures implemented. (Feasibility study of the possibility of changing the core spray function in internal pump reactors. SKI-PM 01:27. Swedish Nuclear Power Inspectorate, January 27, 2001). In Swedish.

implemented, extensive investigation and review work was conducted by both FKA and SKI, involving calculations and analyses of postulated accidents within the facilities' Safety Analysis Reports (SAR) as well as calculations and analyses of critical cases in addition to these postulated accidents.

The modifications which have been implemented mean that all water from the emergency core cooling system and auxiliary feedwater system is fed into the downcomer instead of, as before, via the core spray nozzles mainly over the core inside the core shroud. A similar plant modification is being planned at Forsmark 3.

Damaged Thermal mixers Due to Deficient Management and Control

In summer 2002, major plant modifications were conducted at Barsebäck 2, involving the replacement of stress corrosion-sensitive pipe parts and components. In addition, three T pipes where hot and cold water are mixed in the feedwater and auxiliary feedwater system were replaced. The purpose of the pipe replacement was to achieve a better thermal mixer design with less risk of thermal fatigue. Another aim was to improve the possibility of periodic inservice inspection.

From the beginning of September 2002 until the end of the year, a rising differential pressure was observed between trains 1 and 2 in the feedwater system. Furthermore, an increasing backpressure was observed after the feedwater pumps. A decision was therefore made to shut down the reactor and to investigate the cause of the observations. These investigations showed that thermal liners in the thermal mixers which protect the pressure-bearing walls at the mixing points from thermal loads had become detached from their reinforcements and, in one of the trains, had become displaced and had moved into the next T pipe in the feedwater pipe. The dislodged thermal mixer had partially blocked the feedwater flow. Furthermore, it was found that a thermal mixer of the same type in the auxiliary feedwater system had been damaged.

The root cause analyses showed that the reinforcement design was too weak and that the load dimensions had been misjudged. This indicated that the performance of the design review that must be conducted before plant modifications are made was unsatisfactory.

After initial investigations, SKI decided to require Barsebäck Kraft AB to conduct an in-depth analysis of the cause of the damage. Furthermore, the investigations would comprise all of the activities adopted by BKAB from the time that the design specifications for the thermal mixers had been prepared until the time that the extent and nature of the damage was established after reactor shutdown.

SKI's review of the investigation and the event sequence indicated major deficiencies in management and control as well as deficiencies in the views and attitudes that are essential to a good safety culture. This is discussed in detail in Chapter 5. The review also showed that BKAB had deviated from SKI's regulations which require that a facility should be brought to a safe state without delay when it is not functioning as intended or when it is difficult to determine the safety importance of a specific deficiency.

Therefore, in August, SKI decided to require BKAB to implement a number of measures to correct the deficiencies and to prohibit the startup of Barsebäck 2 after the refuelling and maintenance outage 2003 until the measures had been implemented. Furthermore, SKI decided to lodge a suspicion of crime notification with the Office of the Public Prosecutor in Malmö in connection with the operation of Barsebäck 2.

SKI subsequently conducted reviews and inspections of the measures implemented by BKAB to correct the deficiencies in the management and control of operations, maintenance, modification and safety work at the facility. On October 17, SKI gave permission for BKAB to restart Barsebäck 2 under special supervision. However, SKI has required that BKAB implement an additional number of improvements and SKI has therefore continued with its evaluations and follow-ups of relevant activities at Barsebäck 2.

The events occurring in connection with the incorrectly designed thermal mixer have also indicated a need to expand and supplement SKI's regulations (SKIFS 2000:2) concerning mechanical devices. This work is currently in progress.

Excessive Temperature Loads in the Reactor Pressure Vessel

In connection with the loss of offsite power on September 23, 2003, the reactor pressure vessel in Oskarshamn 3 was subjected to major temperature loads. The initiating event was a malfunctioning changeover switch in the condensate filtering system which resulted in scram and reactor recirculation pump runback. The pumps were then shutdown when the loss of offsite power occurred shortly afterwards at the same time that the residual heat removal system continued for a certain time to supply the drive mechanisms in the reactor pressure vessel bottom with flushing water with a temperature of about 60ºC. This meant that the nether region of the pressure vessel was gradually filled with colder water and was, therefore, cooled down from the operating temperature of about 275ºC to 135ºC. However, other parts of the pressure vessel remained at operating temperature. When power was restored, two reactor recirculation pumps started up and the warmer water in the upper parts of the pressure vessel was rapidly pumped to the cooler nether region. This resulted in severe temperature loads and caused the Maximum Permitted Limit Value (MPLV) for Oskarshamn 3 to be exceeded.

The event was classified as a category 1 event in accordance with SKI's regulations, SKIFS 1998:1. After such an event, investigations conducted and measures implemented must be evaluated by the facility from the standpoint of safety and reviewed and approved by SKI before the facility can be restored to normal operation.

SKI has reviewed the investigations conducted by OKG Aktiebolag, both with respect to how the reactor pressure vessel and internals could have been affected by the substantial temperature loads and the conditions that preceded the event. After reviewing the information, which showed that no damage had been sustained, SKI granted permission, on November 14, for Oskarshamn 3 to be started up. However, in the light of similar events which have occurred previously at foreign facilities and the observations made in connection with the review, SKI also required that OKG Aktiebolag should implement measures to safeguard the safety culture and to correct the deficiencies relating to experience feedback, the role of the safety department, the lowering of project priorities as well as role uncertainty in decision-making when unforeseen events occur. This event is analyzed from an organizational perspective in

Chapter 5. Furthermore, SKI required that possibilities and conditions should be investigated to find a technical solution which would prevent the startup of the reactor recirculation pumps in similar situations.

SKI also initiated an investigation into the more general conclusions that can be drawn from the event. This investigation will concern equipment for monitoring and alarm in connection with major temperature loads as well as administrative control via instructions and decision-making in connection with this type of event.

Design Basis and Load Data

In connection with the repair of the level measurement nozzles in Oskarshamn 2 (see above), an unsuitable work method caused a local mechanical defect to occur in the upper part of the core grid. In addition, parts in other nearby core grid positions were deformed. OKG Aktiebolag removed some of the damaged and deformed parts by machining. However, the analyses upon which the application for continued operation was subsequently based were not based on up-to-date design basis and load data. As a result of this, SKI required supplements and criticized the facility's own safety review work.

Corresponding deficiencies in design basis and load data were observed in connection with a modification which was implemented in Ringhals 1 to temporarily repair damage in the scram system. In this case, SKI also required that supplementary work should be conducted and criticized the safety review work at the facility.

SKI has for a long time observed and called attention to problems with the design basis of the plants and plant load data. As early as in the late 1980's, SKI pointed out that the design basis and data were incomplete in certain respects and needed to be reviewed in the light of the knowledge gained since the plants were taken into operation. SKI also expected such reviews in connection with the major design analysis projects that were initiated after the "strainer incident" in Barsebäck in 1992. However, the completion of the design analysis projects and the subsequent transfer of results to the safety reports have been substantially delayed at some plants. In addition, some of the projects have been limited in scope. This also applies to the work on conducting new mechanical integrity calculations in cases where differences are observed between the new and the old design basis.

SKI will continue to urge the licensees to complete their work on preparing an up-to-date and suitable design basis and load data. These issues will also be highlighted when SKI reviews major plant modifications, such as power increases.

Problems with Wedge Gate Valves

As early as during the trial operation of the pressurized water reactors in Ringhals, the problem of pressure blockage and thermal valve locking was identified. Since 1988, Ringhals AB (RAB) has conducted a project which aims at verifying the functionality of isolation valves and other safety-related valves. About 700 valves are involved and these have resulted in a separate project dealing with pressure blockage. During the 2002 refuelling and maintenance outage at Ringhals 3, a valve became stuck and it was found that the problem was caused by hydraulic pressure blockage. The previous year, the same valve had become stuck and was damaged as a result. Furthermore, a similar valve in Ringhals 4 had become stuck in a closed position during power reduction prior to the start of the 1997 refuelling outage.

After an overall evaluation of the safety importance, in spring 2003, RAB reported the measures that it intended to implement to correct the problem. SKI's evaluation resulted in a decision that RAB was allowed to continue to operate Ringhals 2 to 4 with temporary measures until the refuelling and maintenance outages. SKI also required that the short-term solution should be robust. SKI's decision meant that RAB had to report and implement temporary solutions that take into account the environment that can arise in connection with a design basis accident. RAB then implemented a temporary solution with air cooling of certain valves and water filling of sumps to protect other valves. With these solutions, Ringhals continued operation until the 2003 refuelling and maintenance outage when more permanent measures were implemented.

However, these measures were limited to eliminating the risk of pressure blockage. The problems with thermal locking had not been analyzed and corrected. Therefore, SKI has decided to require RAB to further investigate the risk of such locking and to implement the necessary corrective action.

With respect to the safety importance of the problem and the evident international and Swedish experience available, SKI also found that RAB gave a low priority to the handling of the problems. SKI has therefore proposed that RAB should analyze and evaluate its system for experience feedback, safety prioritization of measures which have to be implemented and followup of these measures.

Importance of Stable Offsite Power

Stable electrical systems are important for a nuclear power plant from two standpoints – safety and production.

From the perspective of safety, a nuclear reactor and its fuel pools are always dependent on cooling due to the fact that the fuel always generates residual heat. Residual heat is the name of the energy which is generated after the chain reaction has stopped. Energy is emitted as a result of the decay of unstable fission products in irradiated fuel. When the chain reaction ceases, no new fission products are formed. The residual heat decreases relatively quickly during the first day and then continues to be fairly stable for many years. As a result of the residual heat, a nuclear power plant is dependent on electricity to operate its cooling systems, even when the plant is not in operation, and this must be done for a long time. Even if the cooling systems have several auxiliary power supply systems of its own – both diesel-backed and gas turbines – they must normally be supplied with energy from the offsite grid.

From a production perspective, the nuclear power plants provide the base load. This means that they are normally operated at full power and are not involved in the power balancing that continually occurs in the system. Power balancing is usually accomplished with hydro power. This means that the nuclear plants are dependent on the availability of balancing capacity in the system which can counteract changes in system loads. There must be capacity available to compensate for the greatest production capacity in the system if, for any reason, capacity falls off. At the same time, large production facilities, such as nuclear power plants, account for the stability in the system since they have a stabilizing effect, because of their size. Abnormal events in one plant can affect another plant via an unstable or deficient power grid.

The Ability of Swedish Reactors to Withstand Plane Crashes

After the events in the USA of September 11, 2001 when terrorists attacked the World Trade Center in New York and the Pentagon in Washington, SKI requested that the licensees should conduct supplementary investigations and analyses of the nuclear reactors' ability to withstand plane crashes. These analyses and investigations have been conducted and reviewed[9] by SKI.

When the plants were constructed, they were designed to withstand the consequences of different types of events. These events included a small plane crashing into the plants by accident. The licensees' analyses show that the ability of the plants to withstand external events is greater than previously described. The plants are considered to more than adequately meet the requirement of withstanding a plane crash which was made when they were commissioned. In SKI's opinion, the plants can also withstand a crash involving the types and sizes of civil aircraft that usually occur in the air around nuclear power plants, without any radioactive releases to the environment. The reactor containments, and consequently the radioactive fuel, are particularly robust. The design and construction of the reactor safety systems are also important from the standpoint of robustness. In addition, the analyses show that the filtered containment venting systems installed at all Swedish nuclear power plants after the Three Mile Island (TMI-2) accident in 1979 in many scenarios have a good capacity to mitigate the consequences in the event of a damaged reactor core or loss of coolant accident due to damaged safety systems.

However, SKI does not intend to place special demands on nuclear power plants to further protect the facilities against terrorist attacks in the event of aircraft being used as weapons. In SKI's view, protection against terrorist attacks, which is a threat to all parts of society, must be based on the principle of preventing aircraft from being used as weapons in terrorist actions. Through discussions with the Civil Aviation Authority, SKI has been informed of the measures implemented on aircraft and at airports to prevent such actions.

In connection with the evaluation and review of the licensees' investigations, SKI has co-operated closely with several of its counterparts in Europe. Based on a new set of threat scenarios, SKI is now preparing new regulations with more stringent requirements on the physical protection of nuclear power plants, see Chapter 6.

Further Requirements on Mitigative Measures Under Consideration

The importance of ensuring that basic conditions are maintained in the reactor containment water phase during different accident situations has been discussed for a

[9] The Ability of Swedish Reactors to Withstand External Events. SKI-PM 03:15. Swedish Nuclear Power Inspectorate, November 2003. In Swedish.

long time and has been the subject of different investigations. The general issue of pH control has become more salient during the year in connection with SKI's review of the material used for determining the quantities and types of radioactive substances that can be released in connection with radiological accidents, known as source terms.

The reason for this is that the requirement on a basic water phase, in this case a pH value greater than seven, is directly connected to the assumption regarding the composition of radioactive iodine that is released to the containment. It is well known that iodine accounts for a significant part of the radiological consequences arising in connection with radioactive releases to the environment. Cesium iodide is released as an aerosol (small particles) and is easily soluble in water and can be deposited on surfaces. Both cesium iodide and elemental iodide are largely removed in the filters while organic iodine is only removed to a minor extent in the pressure relief and filtered venting systems installed at Swedish nuclear power plants after the TMI-2 accident, in accordance with special government decisions.

In the light of this and taking into account the basic conditions envisaged by the Government with its decisions in the 1980's concerning release-mitigating measures, SKI has requested all of the nuclear power companies to submit information:

- regarding how the increased knowledge of the risks of forming organic iodine have been evaluated,
- regarding if any and which measures the power companies intend to adopt in order to maintain a basic environment in the containment water phase.

Based on this information, which is now being evaluated, SKI will adopt a position regarding the possible additional requirements that must be made in order to maintain as low a level of releases as possible in the event of a severe accident.

Deficient Reactor Containment Integrity

As discussed in the section above, with the overall evaluation of damage evolution, defects and other degradation of reactor containment leaktightness at the plants are often caused by deficiencies during construction or later plant modification. This observation applies to Swedish as well as foreign plants. During the year, additional such cases have been reported.

In connection with inspections prior to the startup of Barsebäck 2 after its lengthy refuelling and maintenance outage, a water leak was detected between the containment wall and reactor building. After extensive investigations and testing, the leak was found in a weld between a sealing plate and the containment pool bottom plate. The weld was of poor quality and had also been damaged by corrosion attack. The function of the sealing plate was to anchor a ladder that had been installed in 1989. Unlike the rest of the mechanical design of the pool bottom, the plate was not attached to the cast bottom plate with bolt reinforcements. Therefore, the design had not been analyzed for and was not intended to withstand the considerable flow loads which can arise in an accident with blowdown from the reactor pressure vessel to the pool.

In December 2003, a leak was also detected in the liner in the Ringhals 1 condensation pool. In this unit, the condensation pool bottom plate is connected with wall plates via a toroid ring. The ring consists of an inner and outer plate with a leak monitoring device between the plates. The cause of the leak which has now been detected has not yet been identified. However, the data indicate that there is a deficiency in the inner toroid ring. By keeping valves and plugs for leak monitoring between the plates closed, no leaks have currently occurred from the containment. SKI has therefore given permission for Ringhals 1 to be kept in operation until the refuelling and maintenance outage when investigations are to be conducted and measures implemented.

In connection with SKI's evaluation of the events relating to the leakage in Barsebäck 2, the question has been raised concerning how plant modifications are made in the containments and how the principles are applied for the classification of plant components into quality classes which determine design and quality control requirements. In addition, this event – and the as yet uninvestigated leak in Ringhals 1 – are further examples that the periodic reactor containment leak testing must also continue to be conducted at relatively frequent intervals.

Periodic In-Service Inspection and Performance Testing Programmes Reviewed

Periodic inspection and performance testing of mechanical devices and building structures are an important part of the defence-in-depth system which allows damage and other types of degradation to be detected on a timely basis, before safety is jeopardized. The purpose of inspection and testing is also to confirm, on a periodic basis, the state of vital plant components and to ensure that the characteristics and conditions on which the design is based still apply.

According to SKI's regulations (SKIFS 2000:2), the extent and focus of recurrent performance testing shall be determined by the risk for nuclear fuel damage, radioactive releases, inadvertent chain reaction and degradation of the safety level in general as a result of cracking or other types of degradation. Swedish plants have applied a risk model for the practical application of these regulations since the end of the 1980's. This is a risk model with indicators providing qualitative measures of the probability that such cracking or other degradation will arise in the particular component as well as the probability that degradation will cause nuclear fuel damage or any other type of degradation of the safety level.

The risk model for determining the focus of recurrent performance testing has proven to be relatively effective in detecting damage in vital plant components at an early stage before safety is jeopardized. As described in the section on the overall evaluation of damage evolution, most of the damage occurring so far has been detected in time through periodic performance testing and inspections. Only a small part of all damage has led to leakage or other severe conditions as a result of cracking and other types of degradation which have remained undetected.

However, some criticism has been directed towards the possibility that the risk model can, in certain plants, lead to excessively comprehensive inspection and testing. SKI considers that it is possible to further optimize inspection and testing without jeopardizing safety. Optimization can be achieved through inspection and testing programmes based on in-depth analyses with the help of quantitative risk models, where probabilistic fracture mechanics models are combined with probabilistic safety assessment models. The application of more quantitative risk models in these contexts is also taking place internationally and relatively comprehensive development work is in progress.

Ringhals AB has announced that it intends to apply a new inspection and testing programme at Ringhals 2-4 which is based on more quantitative models. In addition, pilot studies are underway at additional plants and, during the year, SKI has adopted a position with regard to proposals for risk models for the testing of certain reactor pressure vessel components. SKI is now conducting additional investigation and evaluation work in order to establish its position with respect to the application of quantitative risk models for inspection and testing purposes.

3. Core and Fuel Issues

Reduced Number of Fuel Failures

The basis for ensuring that radioactive releases inside and from the containment do not occur is leaktight fuel cladding. Therefore, stringent quality requirements with a low level of defect frequencies are placed on fuel cladding fabrication. The quality requirements have resulted in the fact that the number of fabrication defects is on the order of 1 rod per 100,000 rods. Stringent requirements are also placed on ensuring that the cladding, as far as is possible and reasonable, can resist the radiation and other possible conditions in the operating environment of the fuel. Furthermore, the design must be well-tested and suitable programmes must be in place to follow up and control fuel behaviour in the reactor.

In the 1980's and a few years into the 1990's, a large number of defects was reported as a result of stress corrosion and where the fuel cladding did not comply with the operating conditions requirements that were placed. Since then, the trend has been towards more resistant cladding material and no defects of this type have been reported in recent years. The long-term trend is a decrease in the number of fuel defects in Swedish reactors. However, some reactors (Forsmark 1 and 3 and Oskarshamn 3) have higher defect frequencies with about one fuel defect per year in the past ten-year period.

The damage which occurs nowadays has mainly been caused by small objects which have entered into the fuel via the coolant, and which wear holes in the cladding. In order to minimize this type of damage, fuel with debris filters is successively being introduced. There is also a greater awareness of the importance of keeping the coolant free from foreign objects which can wear holes into the cladding. Over the past five-year period, between 2 to 5 instances of damage due to wear have been reported per year. Therefore, it is too early to draw any conclusion about whether the damage frequency can be further reduced.

In 2003, two possible cases of damage caused by wear were reported. The damage occurred at the end of the year. Therefore, it has not yet been possible to investigate the fuel bundles concerned in greater detail in order to establish the root cause. Furthermore, one case of damage was reported which was caused by a fabrication defect.

More and more plants are also now implementing a strategy to prevent a cladding defect from leading to secondary damage which will result in uranium leaking into the reactor coolant. The strategy is to, as quickly as possible, shut down the reactor and remove the damaged fuel when signs of damage can be observed. In this way, primary system contamination, which can otherwise cause the radiation conditions to deteriorate and thereby make maintenance work, inspections and testing difficult, can be avoided.

Followup of Bowed Fuel Continues

Since the mid-1990's, the Ringhals 2, 3 and 4 pressurized water reactors have had problems with fuel bowing beyond the permitted 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 analyze 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 RAB describes the status of the bowing. The follow-ups show that fuel bowing is decreasing. 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

On the international front, development work has been underway for several years to improve economic margins through core optimization, improved fuel utilization, new fuel designs and increased operating flexibility. The aim is to modernize 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 optimization work.

In the past in Sweden, there has not been any incentive to increase fuel burnup. However, the licensees have revised their cost optimizations for reactor fuel and consider that the aim should be to achieve a somewhat higher burnup. SKI is following these discussions in detail and is preparing to conduct reviews in the future by participating in research which will provide data to verify the safety limits for fuel with a high burnup. Among the issues that are important to monitor in this context is the possibility that certain damage mechanisms can once again be of interest when a higher burnup is the target.

During the year, Barsebäck Kraft AB and Ringhals AB submitted an application to increase the highest local burnup for the nuclear fuel in Barsebäck 2 and Ringhals 1. As a basis for its decision, SKI considers that there is now sufficient empirical data available and other types of investigations to allow an increase in the maximum permitted burnup to 65 MWd/kg UO_2. However, SKI has established stipulations which must be applied in connection with core design and in-core fuel management in order to ensure that reactivity-initiated fuel damage does not occur.

Preparations for Power Increases

An operating licence stipulates the maximum thermal power at which the reactor can be operated. In order to change the maximum thermal power, a new regulatory safety review must be conducted. In addition to this, the Government must issue a licence for the change. The maximum thermal power of several Swedish boiling water reactors was changed in the 1980's, see *Table 1*. The technical background for raising the power, compared with the rated power, includes increased operating experience, safety margins in the original design, improved analysis methodology and fuel performance optimization.

Smaller increases in generated electrical power can be implemented without increasing the reactor thermal power and this possibility is often utilized if it entails a minor investment and if it can be kept within the scope of the maintenance that has already been decided. Such an increase could involve adjustments to reactor efficiency through modifications on the turbine side, for example, through the replacement of the low-pressure rotors.

Most power increases which have so far been conducted in Sweden can be categorized as an improved utilization of existing safety margins, improved analysis methodology and improved fuel. Major components have not yet been replaced with the aim of increasing power.

Reactor	Rated power (MWth)	Power after increase	Year of increase	Increase (%)	Power density in core (MWth/m^3)
Barsebäck 2	1700	1800	1985	5.9	47
Forsmark 1	2711	2928	1986	8.0	50
Forsmark 2	2711	2928	1986	8.0	50
Forsmark 3	3020	3300	1989	9.3	52
Oskarshamn 1	1375	-	-	-	36
Oskarshamn 2	1700	1800	1982	5.9	47
Oskarshamn 3	3020	3300	1989	9.3	53
Ringhals 1	2270	2500	1989	10.1	45
Ringhals 2	2440	2660	1989	9	100
Ringhals 3	2783	-	-	-	105
Ringhals 4	2783	-	-	-	105

Table 1. Power increases at Swedish nuclear power plants. The higher power density at Ringhals 2 to 4 is due to differences in reactor type

The possibility of implementing larger power increases is now being investigated at several of the Swedish units and applications are expected to be submitted in 2004. In the case of such large power increases, such as those implemented at certain Finnish plants, more extensive plant modifications are required. Furthermore, certain phenomena must be taken into account. The steam flow to the turbines, and thereby the pressure drop in the steam lines, will increase. The following types of problems can occur: problems with the regulation of the turbine governor valves, steam line oscillations and high void moisture content. The heat that has to be removed after the chain reaction has ceased is proportional to the reactor power during operation. This may entail modification of the reactor pressure relief and cooling systems. Furthermore, improved analysis methods are required in order to stay closer to limits through reduced uncertainty while maintaining safety.

SKI is closely following the discussions concerning larger power increases at the plants. The forthcoming regulatory reviews are being prepared through contact and exchange of experience with SKI's counterparts in other countries where such major power increases have been implemented. SKI will review each application separately in order to ensure that adequate safety margins also exist after the power increase.

4. Reactor Safety Improvements

Modernization Project

Safety improvements are largely implemented during each refuelling and maintenance outage as well as following events and detected conditions. After the TMI-2 accident in the USA 1979, the possibility of handling a severe accident was substantially improved. After the “strainer incident” in Barsebäck in 1992, the reactor’s ability to handle events requiring emergency core cooling was reinforced. The power utilities have also identified a need for more comprehensive modernization work, based on design reviews and more detailed safety analyses as well as considerations relating to operating economy. Above all, it is the older plants that need to be backfitted and modernized in order to meet higher requirements on reliability and safety. SKI is currently preparing new regulations for the design and construction of nuclear power reactors and these will entail an extensive need for improvements. The need for improvement varies depending on the reactor concerned.

Underlying the need for backfitting are increased requirements on maintenance and testing. In certain cases, technical equipment may have to be replaced due to ageing and the difficulty of locating spare parts or maintenance technicians with the necessary expertise. Electronic equipment is one such example where old equipment will be replaced by modern equipment, based on digital technology. The new technology places new and different demands on the utilities’ safety work, which has also been noted in previous years.

Several nuclear power units have control room modernizations in progress or planned. Above all, it is in the older plants that the major modifications are being implemented. In these cases, SKI has required that the power utilities integrate aspects relating to man-technology-organization already at the planning stage and then throughout the development process. The utilities must be able to show that the operators will be able to work in a safe manner with the solutions that are identified.

Oskarshamn 1 is the first Swedish reactor which has undergone very extensive modernization. The work, which was completed in 2002, involves a new safety system design, new instrumentation and control equipment as well as a new control room.

Other Swedish reactors have modernization plans and ongoing modernization projects. Several of these involve modernization in stages, lasting for several years into the future. For example, the work at Ringhals 2 has so far been conducted on switchgears and waste systems and, in coming years, will focus on all instrumentation and control (I & C) equipment, including the control room. Ringhals 1 is also preparing to renovate and upgrade its I & C equipment.

As was previously mentioned, the utilities are planning to apply for permission to increase the power of their reactors. This includes Oskarshamn 3, Ringhals 1 and Ringhals 3. Major power increases require extensive analysis work and a number of plant modifications in order to take into account the increased capacity requirements on safety systems. The planning and implementation of these modifications have much in common with the modifications based on ageing, increased requirements on maintenance and testing as well as, in particular, with the consequences of the new nuclear reactor design and construction regulations being prepared by SKI.

SKI is supervising the ongoing modernizations and is planning for extensive regulation and supervision over a period of several years with respect to the future modernizations and the forthcoming applications for permission to increase reactor power.

Probabilistic Safety Assessments

A basic condition for the operation of nuclear facilities is that there should be analyses of all conditions that are of importance for safety. Both deterministic and probabilistic safety assessments (PSA) must be conducted in order to obtain as comprehensive a view as possible of risk and safety. The original plant design and safety reports are essentially based on deterministic analyses while probabilistic safety assessment is a way of verifying the original deterministic requirements. PSA is an essential tool for identifying the possible need for safety improvement measures and should also be used to evaluate other modifications in plant design, operating procedures (Technical Specifications) and emergency operating procedures.

PSA was introduced in Sweden in the mid-1970's and the use of probabilistic assessments increased during the 1980's and 1990's. The results have provided an important basis for the continuous safety improvement work conducted at Swedish nuclear power plants. Throughout this time, intensive development work has been conducted in the area, in Sweden and internationally. Through SKI's regulations on safety in nuclear power plants, SKIFS 1998:1, the requirements on the implementation and use of PSA have been further formalized. A complete PSA must contain all events, incidents and accidents as well as the impact of external events on the systems such as fire and floods. The PSA must also include all operating licences in addition to power operation, power ascension and power descent as well as refuelling and maintenance outages at the plant.

An increased use of PSA for the optimization of plant modifications, maintenance, control and testing places new demands on the extent, coverage, quality and validity of the models and input data. Previously conducted PSA for Swedish plants contain a number of deficiencies in these respects which are gradually being corrected. During the year, SKI has followed and evaluated parts of the utilities' work on the development of PSA and on how identified deficiencies are being corrected.

Updating of Safety Reports and Technical Specifications

In the mid-1990's, the utilities started to review the original design basis and safety reports for the reactors. The reviews were initiated after the "strainer incident" which had occurred at Barsebäck in 1992 which highlighted deficiencies in the design basis. Significant work has been conducted, especially with respect to the oldest reactor types. The reviews have identified a number of weak points in the original designs and these have been corrected or will be corrected.

As a result, up-to-date safety reports are now available for Barsebäck 2, Oskarshamn 2 and Ringhals 1. Following its modernization, Oskarshamn 1 has also submitted a revised safety report.

In the case of Forsmark 1 and 2, the updated safety reports are expected to be ready in 2004. According to the utilities, there is a risk of delay in the case of Forsmark 3 and Oskarshamn 3 since it is difficult to locate external/internal resources for the work.

Corresponding reviews are in progress for the pressurized water reactors at Ringhals. The work is expected to be completed by mid-2004.

SKI has continuously followed the utilities' design basis review work. Through random sampling, SKI has also evaluated the modernized safety reviews for Oskarshamn 2 and Barsebäck 2. In SKI's opinion, the reports that have so far been submitted are an essential improvement of the documentation and a better verification of the design basis. Identified deficiencies in the plants and in the basis for the analysis have either been corrected or corrections have been planned.

However, the updating of the evaluation of the plants in the light of new knowledge has so far been achieved to a varying extent. Therefore, SKI intends to continue regulatory in-depth reviews and evaluations of important parts of the safety reports the underlying data. This will be conducted in connection with the entry into force of new regulations for the design and construction of nuclear reactors as well as the updating of the general regulations concerning safety in nuclear facilities where SKI has specified its expectations.

For some time, Ringhals AB has been conducting a project to modernize and simplify the Technical Specifications of pressurized water reactors, based on a principle called MERITS. The principle was developed in the USA and is based on probabilistic criteria. SKI will review the Technical Specifications and decide whether RAB can implement them. RAB has presented a new project schedule where it is planned to implement the new Technical Specifications around year-end 2004.

In the light of the above, SKI considers that the licensees are currently conducting acceptable safety development work. However, it is essential that the ongoing programmes should not be further delayed. Experience shows that SKI's supervision and its role as a driving force is important for progress.

New Regulations for the Design and Construction of Nuclear Reactors

In connection with the decision made regarding SKIFS 1998:1, SKI conducted a consequence investigation. SKI noted that the more explicit requirements, namely that the basic plant design should contain barriers and a defence-in-depth system, did not have any immediate technical consequences for the facilities concerned. However, it was not excluded that more detailed requirements would be made at a later stage.

In recent years, SKI has worked on specifying the requirements for the design and construction of nuclear reactors. An extensive dialogue has also been held with the licensees on the subject. The principle for the backfitting of Swedish reactors in order to enhance safety has been to successively improve the facilities through plant modifications and special work in connection with identified problems. Examples of such problems include the "strainer incident" in Barsebäck which occurred in 1992 where it was found that the emergency core cooling systems in boiling water reactors with external reactor recirculation pumps did not function as assumed in the safety reports. The “strainer incident” and the subsequent modification of the emergency core cooling systems in all Swedish reactors marked the start of a number of projects in the nuclear power industry, in co-operation with reactor vendors, to review and update the safety reports. The aim was to ensure that no further hidden safety problems existed. The licensees also started a joint project, known as the “Värnamo project”, to define a design standard for Swedish nuclear reactors in operation in the 2000’s. In parallel, SKI started the “R 2000 project” to follow and evaluate the industry project. When, after a couple of years, it was found that the final report of the “Värnamo project” would be delayed, SKI decided to take the initiative and issue general recommendations for the design and construction of nuclear reactors. The decision was not prompted by any acute safety-related problems, but was viewed as a way of providing guidance prior to modernization and backfitting in order to enhance the safety of Swedish reactors to prepare them for their remaining operating lifetimes.

In the case of the oldest reactor, Oskarshamn 1, an extensive modernization was implemented in 1995. SKI had placed demands on the design of this reactor as a condition for continued operation. Major modernization projects have subsequently also been planned for several of the other nuclear reactors and, consequently, SKI had to also formulate requirements for these reactors. In the light of this, SKI has decided, instead of issuing guidelines, to promulgate regulations containing general safety requirements on the design and construction of nuclear reactors which will apply in the foreseeable future.

The premises for the new regulations and general recommendations are Swedish and include foreign operating experience, the safety reports of the last decade and the results from research and development projects as well as the development of the IAEA’s[10] safety standards and the industry standards that were applied in connection with the construction of the facilities. The requirements cover design principles, robustness with respect to certain defects and events, environmental robustness, the possibility for monitoring and maneuvering from control rooms, emergency control rooms, safety classification, event classification and regulations concerning the reactor core design and operation.

The eleven nuclear reactors have different conditions for complying with the general design and construction regulations. For this reason, a reactor-specific consequence assessment is conducted. The preliminary assessments show that plant modifications need to be done to a varying degree depending on the basic reactor design and the backfitting that has already been conducted.

On condition that Board approval is obtained, the new regulations are expected to enter into force on January 1, 2005. Interim regulations will give the licensees the necessary time to implement the measures that are needed at each reactor.

[10] International Atomic Energy Agency in Vienna.

5. Organization, Competence Assurance and Safety Culture

This section deals with how nuclear power plants, in SKI's view, has worked with questions relating to organization, competence assurance and safety culture in 2003. Safety issues in the industry include both the handling of ageing phenomena and technical development, organizational development, competence development, economic efficiency and environmental development. The ability to handle a complex interaction between technology, people, organization and economy is necessary in order to maintain and to continue to improve safety.

Organizational Changes and How Control and Safety Review of Activities Is Conducted

Procedures for handling changes in the organization and activities exist at all of the nuclear power plants. SKI has found that the nuclear power plants have procedures that allow the safety aspects of modification work to be identified at an early stage and handled throughout the process. This means that the personnel is also involved in the development work and that the changes are reviewed from the standpoint of safety before they are implemented. In connection with major or new changes or changes which relate to principle, SKI makes the decision regarding the review and follows up how these changes are being applied.

The organizational changes at OKG Aktiebolag which were implemented in 2002 are an example of an untried nuclear organization in Sweden. The organization changed over to a matrix organization. In connection with this organizational change, SKI required OKG Aktiebolag to conduct and report analyses of competence and staffing for the jobs concerned, a safety evaluation of the impact of the reduction in the number of managers and other personnel as well as a clarification in its quality system concerning how the competence followup is to be conducted in the different activities, bearing in mind that several managers are concerned. SKI also requested a report on how OKG's work is progressing on revising its quality management system as well as a report on the results and lessons learnt from evaluations that had already been conducted. The intention was also to review the reports from the standpoint of safety in accordance with the requirements of SKIFS 1998:1. OKG has implemented measures and reported these measures to SKI. In SKI's view, OKG has corrected the deficiencies identified by SKI in connection with the organizational change, except for the fact that OKG needs to describe in its quality system how the competence followup work will be conducted. In addition, SKI has found that OKG is following up and evaluating its organizational change on a continuous basis. SKI is following OKG's work on developing the organization and activities in its regular supervision of the licensee.

In 2001, Forsmarks Kraftgrupp AB implemented an organizational change. A new production organization was formed with a maintenance unit alongside the three production units with their operations and ordering units. Furthermore, the maintenance unit was changed to a matrix organization. The company identified and gave a thorough account of the safety issues that the change highlighted. As a condition for the implementation, SKI required further reports. Since this, SKI has both reviewed FKA's organizational change and followed this up on several occasions in its regular supervisory work. In 2003, SKI observed that FKA had continued with its work on evaluating and further developing the activity by, for example, clarifying roles in the maintenance teams, improving resource planning and the management of maintenance plans. At the end of 2003, after notifying SKI, FKA implemented an additional organizational change based on the lessons it had learnt. FKA noted that the maintenance unit's matrix organization did not function satisfactorily due to difficulties with joint planning and prioritization within the maintenance units. FKA also detected deficiencies in the joint function between operations and maintenance and has had difficulty in following up the need for training in the matrix organization. The organizational change in 2003 entailed the reorganization of the maintenance unit into a line unit, thereby reducing the complexity of the unit. The planning was given a stronger and more central role in the activity, e.g. the supervisors were given a clearer role in conjunction with the production units. In SKI's view, FKA implemented the change well and in a controlled manner, in accordance with its routines.

To conclude, SKI has found that the licensees for the nuclear facilities have prepared procedures which are to provide support in the organizational change work. Instructions also exist which provide support in the safety review of such changes.

Major organizational changes implemented within the nuclear industry in recent years have provided positive lessons with respect to the licensees' work procedures. For example, they have improved the application of the experience that they have gained from each other and, in their processes for the handling of organizational changes, they have implemented several of the steps that SKI considers to be necessary in order to achieve good internal control over the implementation of organizational changes. SKI has also seen, in its role of regulatory and supervisory authority, that the safety review of organizational changes has functioned well.

Other experience indicates that the procedures implemented by the licensees may have to be further developed. For example, the extent of all of the work required in connection with a major re-organization can sometimes be underestimated. This particularly applies to the work on assessing the impact of the change on the quality management system and procedures and to the work on revising the necessary parts. However, one positive aspect is that there are examples of the licensees conducting a safety review and prioritization of the parts that must be revised first. The work on conducting and documenting competence analyses as a result of changes in the allocation of responsibilities and tasks in jobs requires a considerable amount of work and tends to take a long time.

Other experience also shows that the introduction of a matrix organization or aspects of a matrix organization in a major organization requires considerable preparation in the form of clarifying responsibilities, roles and interactions for all involved and requires following up the change so that role uncertainty does not occur with negative consequences for safety.

BKAB's decision to give RAB the task of implementing certain measures which, in accordance with the Act on Nuclear Activities, are to be conducted by the licensee raised questions concerning what these measures are, their extent and how they will be managed and controlled. This has resulted in several discussions with the licensees regarding actions where sub-contractors have been hired for certain tasks. SKI has prepared a memorandum on the possibility of the licensees handing over nuclear activities to a sub-contractor. In 2003, SKI and the licensees discussed the content of the memorandum and SKI clarified its position.

In 2003, SKI conducted an inspection at Forsmarks Kraftgrupp AB with the aim of inspecting whether and how FKA was complying with the requirements of the Act on Nuclear Activities and of SKI's regulations in connection with the handing over of a nuclear activity to a sub-contractor. SKI's memorandum provides a basis for the preparation of evaluation criteria and for overall evaluation. The inspection showed that established routines for management and control exist, based on the requirements in FKA's formal systems and that responsibilities and roles are clear, both within FKA's internal organization and between FKA and the sub-contractor.

Continued Development of Quality Systems and Audits

Changes in the organization and in activities also entail changes in the quality systems.

The Ringhals group continued to develop the activity management and control systems for Barsebäck and Ringhals. Part of the continued work is the process development that is in progress. Work on preparing a process chart as well as roles and responsibilities for the Ringhals group has been conducted. The purpose of the process chart is to allow the Ringhals group to control and measure its most important measures, to develop its activities efficiently, to show how work is conducted and to allow employees to see the context of the work that they are involved in. In addition, a number of processes have been developed and are at different stages of implementation. SKI is following the process development work through information meetings.

Process development work is also underway at OKG. SKI is keeping itself informed of progress but has not yet reviewed the quality management system after the organizational change.

SKI finds that the licensees at the nuclear power plants are continuing to develop their activities by conducting internal audits. Furthermore, SKI finds that all of the nuclear power plant control and work on internal audits is of a high quality. Every year, SKI meets the licensees in order to form an opinion of the internal audits that have been conducted, the quality of the audits, nonconformancies found and the areas for improvement that have been identified as well as the overall evaluation of the activity.

Uncertainty About Barsebäck Remains

In 2003, the political debate concerning the closure of Barsebäck 2 once again accelerated. SKI has continued, and will continue, to conduct special supervision of BKAB as long as the uncertainty surrounding the closure of the unit remains since, in SKI's view, it cannot be excluded that the situation as it is now, which is characterized by uncertainty, will have a negative impact on safety at the facility. However, SKI's opinion is that BKAB has continued to handle the situation in a satisfactory manner.

Improved Competence and Resource Assurance

SKI has observed that all of the plants now have documented, systematic methods to ensure that there is adequate personnel and competence now and several years into the future. During the year, this has been followed up through plant monitoring activities to ensure that a living system is being implemented and that the benefits of the competence assurance process are also clear to the licensees. Some work still remains to be done on competence assurance with respect to inter-unit functions.

In view of the responsibility and importance of the operating personnel for the operating safety at a reactor unit, such personnel must comply with special requirements. The regulations concerning the competence of operating personnel at reactors have been in force since January 2001. In the case of operating personnel, the work on achieving compliance with SKIFS 2000:1 has been underway for a long time. At the nuclear power plants that SKI has inspected, full compliance with the requirements has not been achieved. SKI has requested that a programme of measures be implemented in order to correct the deficiencies that have been found and SKI has also conducted plant monitoring in order to follow the progress of work. Two nuclear power plants have not yet been inspected by SKI in relation to SKIFS 2000:1.

On the whole, it can be said that the competence assurance work has been given a high priority by the nuclear power plants and that the plants are adopting a systematic approach to ensuring that they have adequate competence and staffing.

Annual Evaluation of Safety Culture

2003 has clearly shown that safety culture is an essential area of work. The licensees have understood this and are allocating more and more resources to conducting more active work on developing and reinforcing safety management in order to create the necessary conditions for the improvement of the safety culture.

SKI's supervision is based on knowledge of the necessary conditions for an organization to achieve a good safety culture. These conditions are to be created through active safety management. Important conditions for a good safety culture include the commitment of the corporate management, visible leadership, high priority to safety, a proactive approach and a long-term perspective, openness and communication, order, organizational learning, motivation and job satisfaction, good change management, good resource allocation, the commitment of all employees, good working conditions with respect to time, work load and stress, unambiguous roles and clear responsibilities, followup of safety work, a systems approach to safety, quality of documentation and procedures etc. A good safety culture is important. If a licensee's organization has a good safety culture, SKI assumes that the possibility of the organization identifying threats to safety or direct safety deficiencies will be greater.

Through its supervision, SKI can observe whether any of these conditions are lacking or obviously deficient. Such an observation results in SKI implementing additional supervisory measures of some sort in relation to SKI's requirements. Such deficiencies could be that the procedures are not revised, that incidents are not analyzed in adequate depth and that lessons are not learnt, that there is an increase in the number of deviations, that operability and maintenance are deficient, that the quality and safety departments have a low status, that a systematic approach to safety is lacking, that resources are not adequate and that the implementation and identification of necessary safety measures are deficient.

In connection with certain events during the year, SKI has also indicated deficiencies in safety work. These include deficiencies in safety evaluation and in a comprehensive investigation of conditions detected, deficiencies in experience feedback, in the role of the safety department, the lowering of project priorities, role uncertainty in decision-making when unforeseen events occur or unclear conditions. A strong focus has been discerned with respect to costs and efficiency, which can also have a negative impact on the safety culture in the sense that resources are not adequate, necessary safety measures are not implemented or are postponed and that conflicts in prioritization arise. At the same time, SKI considers that the licensees have, in different ways, focused on the importance of a good safety culture at the facilities. SKI will continue to follow these issues.

The nuclear power plants conduct a survey each year of how the personnel perceives the safety culture at the plant. These surveys were also conducted at the end of 2003. In SKI's view it is important that the licensees continue to conduct these surveys and to quantify the safety culture as well as that the licensees provide feedback on the results to the personnel and discuss the results with them in order to achieve improvements. Always putting safety first, continuous improvement and obtaining the active commitment of the management in order to achieve this are important factors in work on safety and safety culture.

Events during the Year

In 2003, as was previously mentioned, two major events occurred at nuclear power plants which resulted in SKI initiating regulatory reviews where deficiencies in the safety culture and organization were identified. One event was the exceeding of the Maximum Permitted Limit Value (MPLV) for temperature changes in the reactor pressure vessel at Oskarshamn 3 and the other was the thermal mixer incident at Barsebäck. The aim of the reviews was to, on the basis of reported investigations and analyses, evaluate the safety-related consequences and the compliance of the licensees with the stipulated requirements.

In short, it can be stated that OKG, in an acceptable manner, investigated the consequences for safety of the event and also identified the cause of the event. OKG also provided a detailed account and evaluation of the entire event sequence. The measures decided and proposed improvements are expected to create the necessary conditions to prevent a recurrence of the event. In addition, SKI found that OKG adequately handled the identified deficiencies that required immediate action.

However, the event at OKG has highlighted some deficiencies relating to experience feedback, the role of the safety department, the lowering of project priorities and role uncertainty in decision-making in connection with unforeseen events. These factors have confirmed indications previously observed by OKG that the safety culture was not developing satisfactorily.

On the other hand, SKI considers that OKG, to an adequate extent and with an adequate level of quality, has conducted the primary and independent safety review of the event. SKI also observed that it has not deviated from the working methods and procedures of the quality system in connection with the shift team's handling of the abnormal event.

The event at Barsebäck 2 shows major deficiencies in the control and management of activities and, thereby, major deficiencies in the views and attitudes that characterize a good safety culture. This was a question of an inadequately systematic, controlled and formal approach with unclear decision-making processes and responsibilities where safety issues were not highlighted in an adequately timely and clear manner for decision-making and where these were not documented. Even if formal procedures existed, they were not always followed and even if a forum for the handling of safety issues existed it was not convened. Furthermore, at several levels in the organization, attitudes were not sufficiently critical. Unless these deficiencies are corrected, they can jeopardize the organization’s ability to effectively handle unclear and difficult situations and to maintain safety.

SKI decided to give BKAB the task of implementing a number of measures within the following areas: to bring the plant to a safe condition, design and design control, safety review and safety culture. These measures were to be implemented and reviewed by SKI before Barsebäck 2 could be taken into operation after the refuelling and maintenance outage. Furthermore, SKI decided that BKAB should implement a number of measures within the areas of supplier evaluation and function procurement, the quality management system, including the handling of nonconformancies and personnel training. These measures had to be implemented before February 1, 2004.

In 2003, SKI conducted a number of inspections, reviews and plant monitoring at Barsebäck in order to establish whether the implemented measures were sufficient. SKI reached the conclusion that BKAB had implemented measures to improve the safety work and to correct the deficiencies identified by SKI. In SKI’s view, the measures were sufficient to give permission for the startup of Barsebäck 2. Furthermore, SKI decided that BKAB should be kept under special supervision.

In SKI’s view, both of the above events show the importance of an active safety management in avoiding events of this type which in different ways challenge the safety systems and safety margins at the reactor units concerned. In retrospect, SKI considers that it is very important for the licensees to maintain proactive safety work and an efficient internal control which includes a high quality of safety work in the line organization and in the primary and independent safety review. It is also of considerable importance that adequate human resources should be allocated to the independent safety review and that it has adequate influence over decision-making. In its review of the events, SKI has placed more stringent requirements on the licensees to improve their management and control of safety and to ensure that relevant measures are adopted. SKI will follow this work thoroughly in its supervision as well as through the forthcoming periodic regulatory safety reviews.

6. Nuclear Safeguards and Physical Protection

Satisfactory Nuclear Safeguards at Plants

In 2003, SKI, the IAEA and the European Commission all conducted inspections of how safeguards were being implemented at the nuclear power plants. 61 inspections have been conducted at the plants. The criteria applied by the IAEA and the European Commission mean that the time interval between two inspections at a plant which has irradiated nuclear fuel should not exceed three months. Furthermore, each plant should conduct a physical inventory of its radioactive material once a year. At the nuclear power plants, this inventory is taken in connection with the refuelling and maintenance outage. The result of the inventory-taking is then verified by SKI, the IAEA and the European Commission. The inspections conducted in 2003 do not indicate any deficiencies in safeguards at the nuclear power plants.

In 2003, the plant descriptions submitted to SKI for the supplementary protocol to the safeguards agreement with the IAEA was updated for certain plants. The supplementary protocol is expected to enter into force in spring 2004. This means that the state must provide the IAEA with more information than before concerning nuclear activities and activities relating to the nuclear fuel cycle. The supplementary protocol also expands the IAEA’s inspection rights. Safeguards within the EU are regulated by an ordinance from 1976. A proposal for a new ordinance was discussed in 2002 and 2003 and the Swedish plants were given the opportunity to comment on the proposal. The new ordinance will enter into force in spring 2004. The ordinance gives the European Commission the right to require that information be submitted that the Commission needs to comply with the requirements of the supplementary protocol. Since the ordinance has been decided, SKI can prepare regulations for national safeguards.

Requirements on Measures for Physical Protection

One of the conditions for the operation of nuclear facilities is that measures for physical protection should be implemented. At the nuclear power plants, the main aim is to protect the plant against unauthorized intrusion, sabotage or a similar action that can result in a radiological accident. Physical protection is therefore an integral part of safety at the plant.

Regulatory and Supervisory Activities

In SKI’s view, all of the nuclear power plants have a functional physical protection based on the requirements that apply. This evaluation is based on regulatory and supervisory activities such as plant monitoring, event reporting as well as the review of annual reports concerning the physical protection at each plant.

New Regulations concerning the Physical Protection of Nuclear Facilities

The current physical protection of nuclear facilities is based on design basis threat scenarios and a concept established at the end of the 1970’s. Both regulations and requirements on measures and the design basis threat scenarios have been evaluated as suitable in connection with periodic reviews and, in SKI’s view, protection has been suitable. However, SKI has identified a need to prepare new, general regulations concerning the physical protection of nuclear plants and to modernize the regulations in view of the development of international terrorism. The aim of the new regulations and general recommendations is to raise the physical protection at Swedish nuclear facilities to a new and higher level in response to more threatening design basis scenarios.

During the year, the work on promulgating new regulations for the physical protection of nuclear facilities has been identified. SKI has established a new set of design basis threat scenarios. The design basis threat scenarios are the assumed events and other conditions upon which SKI's new regulations concerning the physical protection of nuclear facilities are based. Furthermore, the scenarios, in parallel with SKI's regulations, are a basic point of departure for the licensees in their design of the physical protection at each facility. The scenarios provide answers to the following question: What must the facilities be protected against? The scenarios are also formulated so that changes in the individual scenarios can occur without the facilities having to change their protection in order to respond to these changes. Therefore, the scenarios give the licensees a long-term basis for formulating suitable protective action. The content of the design basis scenarios are, for understandable reasons, confidential. However, it can be said that, compared with the previous scenarios, a more violent attacker whose sole purpose may be to damage a facility is assumed.

During the year, the proposed regulations have been distributed to the licensees and police authorities concerned. The aim has been to obtain, at an early stage, comments and preliminary assessments of the consequences that the regulations could have to the parties concerned. Based on the comments received, SKI will prepare an edition of the regulations for distribution to reviewing bodies as part of a formal review process and a consequence analysis which will be attached. The formal review is expected to be conducted during the third quarter of 2004. Interim regulations will give the licensees the necessary time to implement the necessary measures at each plant.

Co-operation with the Police

The concept for physical protection which is established and which is also assumed to apply in the future is based on the licensees implementing the necessary measures to prevent sabotage, attacks and other similar deliberate actions from resulting in a radiological accident. In the event of a criminal attack, the police is also expected to act rapidly, together with the licensee, to protect the plant and avert the attack.

In parallel with the work on the new regulations, SKI is therefore conducting a dialogue with the National Criminal Investigation Department and the police authorities in the municipalities hosting nuclear facilities. The background is the central role of the police in the event of a criminal attack on a nuclear facility, such as a nuclear power plant. The police is the weapon-bearing incident response force charged with the responsibility of primarily providing the licensee with assistance in maintaining reactor safety and, in the event of an occupation, of regaining control of the facility and regaining control of necessary operator areas.

In the light of the new design basis scenarios and the conditions that they entail, SKI considers that it is necessary to, as far as possible, ensure that the police authorities concerned maintain an adequate operational incident response in the event of an attack or severe threat situation at a nuclear facility.

7. Radiation Protection

Radiation Protection in 2003

In 2003, the collective dose to the personnel at Swedish nuclear power plants was 11 manSv[11] which is less than in 2002. The result is on a par with the average value for the past five years, which is 10 manSv. Additional and extended outage periods, caused by technical problems and unplanned repair work, nevertheless resulted in a higher dose than planned at a few reactor units. Eight people received radiation doses that exceeded 20 millisievert (mSv) and the highest individual dose was 27 mSv.

In general, the radiation levels are low, but are now increasing at some reactors as a result of specific operating conditions and the re-oxidation of previously replaced or cleaned surfaces. A few fuel defects that occurred during the year have not resulted in severe radiation protection effects.

At Barsebäck 2, repair work was conducted in January to February as a result of damage in the feedwater system. The refuelling outage at Barsebäck 2 started in July and startup only occurred early in December as a result of testing, repair work and a leak in the condensation pool. At Oskarshamn 2, extensive modernization work was conducted within the PRIM project. During the refuelling and maintenance outage at Ringhals 3, crack-sensitive material in the reactor pressure vessel outlet nozzles, known as safe-ends, was replaced. At Forsmark nuclear power plants, the core spray nozzles were removed from the Forsmark 1 and Forsmark 2 reactors. The work to check and repair systems for measuring the water level in the reactor (reactor pressure vessel pipes and pipe connections) at Barsebäck 2, Oskarshamn 2 and Ringhals 2 was dose-intensive.

In 2003, the collective dose to people living in the vicinity of nuclear power plants was lower than one per cent of the dose constraint[12]. The control measurements conducted by SSI on samples taken from the environment around nuclear power plants and from releases to water show a good agreement with the licensees' own measurements.

SSI's Evaluation and Supervision

SSI's overall evaluation is that radiation protection at Swedish nuclear power plants is good. So far, SSI has not seen any sign of a lack of necessary resources or competence to maintain a satisfactory radiation protection. Competence and an interest in radiation protection issues on the part of the operations management of the nuclear power plants is of vital importance for a continued positive development.

In the near future, SSI is focusing its supervisory efforts on the radiation protection work in connection with plant modifications, the followup of radiation levels in the plants and internal dosimetry-related issues.

[11] manSv is the unit used for the collective dose which is the sum of the individual doses.
[12] Radiation dose from radioactive releases to a person living near a nuclear power plant may not exceed 0.1 mSv per year.

SSI is following these developments after the recent years' organizational changes and the aim of SSI's inspections is to identify any impact on the quality of the radiation protection work at an early stage. SSI is also focusing on resource and competence-related issues relating to personnel terminating employment and the nuclear power plants' utilization of external resources.

SSI anticipates that technical modifications, caused by work to maintain and improve safety at Swedish nuclear power plants are being planned and implemented. The licensees are conducting studies into the possibility of increasing the power of certain reactors. This will result in planning and implementation of modifications at certain reactor units which, in turn, can result in higher radiation doses for certain individual years.

The radiation doses received by the public from Swedish nuclear power plants continue to be low. SSI continues to place requirements on continuous work at the nuclear power plants to further reduce radioactive releases by applying Best Available Technique (BAT)[13]. The measures that the nuclear power plants report in order to achieve the target values[14] indicate, in most cases, a satisfactory level of ambition.

Radiation Protection at the Nuclear Power Plants

Barsebäck Nuclear Power Plant
The radiation protection activity at Barsebäck nuclear power plant has, during the year, been managed in a satisfactory manner. The collective dose was 1.2 manSv. No abnormal radiation doses were reported. At Barsebäck 1, the radiation doses in connection with service operation during shutdown were small.

In January, the operation of Barsebäck 2 was interrupted due to damage in a feedwater system thermal mixer. After measures were implemented, Barsebäck was taken into operation again seven weeks later. The dose received from the repair work was 0.3 manSv.

The annual refuelling and maintenance outage was planned for five weeks. In addition to refuelling and normal maintenance, reactor pressure vessel testing and inspections were conducted. Due to recurrent measures and increased testing, the outage was extended by 17 weeks. The unplanned measures comprised extra controls as a result of the previous damage in the feedwater system as well as locating and repairing a condensation pool leak. The total radiation dose to the personnel during the outage was 0.9 manSv.

Forsmark Nuclear Power Plant
At Forsmark nuclear power plant, the collective dose was 2.4 manSv. From the radiation protection standpoint, the activities were satisfactory. During the operating year, no fuel failures occurred at Forsmark Nuclear Power Plant. On a couple of occasions, electricity production was interrupted at Forsmark 1 and Forsmark 2 in order to repair minor leaks.

[13] "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.
[14] The target value must be seen as a measure of the release level that can be achieved during a certain period.

The refuelling and maintenance outages resulted in a somewhat higher radiation dose than planned, as a result of extra repair work and as a result of an increase in radiation levels. The core spray nozzles were removed from the Forsmark 1 and 2 reactors at Forsmark nuclear power plant.

The refuelling and maintenance outage at Forsmark 1 lasted for almost four weeks and the total radiation dose was 0.8 manSv. A somewhat higher radiation level and extra unplanned work stages contributed to a higher dose than planned.

The refuelling and maintenance outage at Forsmark 2 lasted for five weeks and the total dose was 1.0 manSv. New work stages and technical difficulties in removing the core spray meant that the outage had to be extended by nine days. Together with the increased radiation levels in the plant, this contributed to a higher dose than planned.

The refuelling and maintenance outage at Forsmark 3 lasted for one and a half weeks. The radiation dose to maintenance and service personnel was 0.15 manSv. The radiation levels at the reactor unit continue to be low.

Oskarshamn Nuclear Power Plant
The collective dose at Oskarshamn nuclear power plant in 2003 was 3.1 manSv. No abnormally high radiation doses were registered during the year.

A minor fuel defect was detected at Oskarshamn 2 in autumn 2002. Radioactive releases from damaged fuel decreased in spring 2003 and, during the refuelling and maintenance outage in summer, the fuel was removed. After the outage at Oskarshamn 1, a minor fuel defect was detected. However, no corrective action was necessary in 2003.

An incident with a potential risk for high radiation doses occurred in connection with startup after the refuelling outage at Oskarshamn 2. An unlocked door and a radiation shield that was not in place were found leading to a room that contained a strong radiation source (activated measurement equipment). The installed warning alarm was out of service at the time. OKG Aktiebolag has investigated the event and implemented measures to prevent a recurrence. The incident and the measures decided and implemented by OKG have been reported to SSI.

The refuelling and maintenance outage at Oskarshamn 1 lasted for six weeks and the collective dose to the personnel was 0.7 manSv. The outage was extended for three weeks which was mainly due to the increased servicing of drive mechanisms and reactor pressure vessel cleaning.

The refuelling and maintenance outage at Oskarshamn 2 lasted for 20 weeks and the collective dose was 2.2 manSv. The PRIM project, a project to replace primary system pipes and valves, was the largest planned task of the outage. A chemical cleaning of several of the reactor pipe systems was conducted to reduce the radiation doses to the outage personnel. The outage was extended by 12 weeks to repair reactor pressure vessel pipe connections as well as core grid damage. During the refuelling and maintenance outage, a zinc dosing system to change the water chemistry and counteract the dispersion of radioactive substances in the reactor systems was installed.

The refuelling and maintenance outage at Oskarshamn 3 lasted for just over three weeks and comprised normal maintenance and refuelling. The collective dose was 0.3 manSv[15].

Ringhals Nuclear Power Plant
The collective dose at Ringhals nuclear power plant was 4.2 manSv. The dose at all of Ringhals's reactors has been favourable in recent years. No abnormal radiation doses or incidents occurred during the year. Ringhals 3 and Ringhals 4 were operated with minor fuel damage for part of the operating cycle. At Ringhals 1, an extra outage was conducted as a result of leakage in a weld joint inside the "biological shield".

The outage at Ringhals 1 lasted for just over seven weeks. The collective dose was 2.0 manSv. The outage was extensive and extra work stages, such as repairing a leak in a pipe beneath the reactor, delayed startup and led to extra doses. The individual task which was most dose-intensive was the replacement of a feedwater pipe inside the reactor containment.

The refuelling and maintenance outage at Ringhals 2 lasted for three weeks and the collective dose was 0.4 manSv. The radiation levels at Ringhals 2 are still low, although a slight increase has been measured since 2002.

The outage at Ringhals 3 lasted for seven weeks and most of the time was devoted to a planned repair of the reactor pressure vessel outlet nozzles. The collective dose was 0.6 manSv.

The outage at Ringhals 4 lasted for five weeks. The total radiation dose was 0.5 manSv. The radiation levels at Ringhals 4 are still low, although a slight increase has been observed since 2002.

Collective Dose

In 2003, the collective dose to the personnel, including sub-contractors, at Swedish nuclear power plants was 11 manSv. The collective dose was somewhat lower in 2002 (2002: 13 manSv; 2001: 6.7 manSv) and on a par with the average value of 10 manSv for the past five years. During the year, 4,074 people received a registered effective dose.

Diagram 5 shows the collective dose at nuclear power plants in Sweden during the period 1993-2003.

[15] The collective dose per reactor unit and refuelling and maintenance outage is based on OKG's internal occupational dosimetry system.

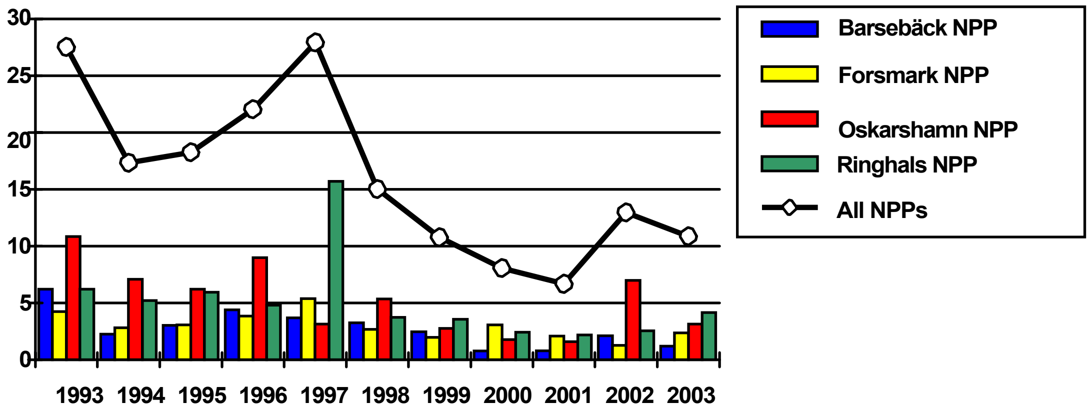


Diagram 5. Annual collective dose (manSv) at Swedish nuclear power plants

The average dose to the personnel was 2.7 mSv in 2003 which is somewhat less than the previous year (2002: 2.9 mSv, 2001: 1.8 mSv). No-one received a radiation dose above the established dose limits[16]. The highest registered individual dose in 2003 was 26.7 mSv. Eight individuals received radiation doses that exceeded 20 mSv. One individual was registered with an internal radiation dose (0.7 mSv) which exceeded the reporting limit, 0.25 mSv, as a result of the intake (via the mouth or through respiration) of radioactive substances. *Table 2* presents the dose data from Swedish nuclear power plants for 2003.

	Total radiation dose (manSv)	Largest individual dose (mSv)	Average dose (mSv)	Number of individuals[1] with registered dose > 0.1 mSv
Barsebäck	1.2	12.7	1.4	871
Forsmark	2.4	17.9	2.1	1143
Oskarshamn	3.1	19.6	2.4	1306
Ringhals	4.2	23.0	2.7	1528

1) Since a person in a single year can work at several plants the numbers in the columns can't be added in order to get the total amount of persons having received a registered dose.

Table 2. Individual doses at nuclear power plants in 2003.

Radioactive Releases to the Environment

Nuclear power plants release, under controlled forms, small quantities of radioactive substances to both air and water. These releases are continuously measured. The radiation dose is calculated using models which are plant-specific, which take into account meteorological conditions and the local soil and water environment. The

[16] For an individual year, the dose constraint is 50 mSv. For five subsequent years, the dose received by an individual may not exceed 100 mSv.

measurement and reporting of releases are to be conducted in accordance with the regulations established by SSI, the *Swedish Radiation Protection Agency's Regulations concerning the Protection of Human Health and Environment in connection with the Release of Radioactive Substances from Certain Nuclear Facilities* (SSI FS 2000:12). The regulations contain requirements that the licensees must report the reference values for releases of individual or groups of radionuclides. The aim is for these values 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 2003, the reference value was exceeded in certain cases. This does not mean that the public has been exposed to significant dose increases, but that the plant's release-mitigating system did not perform optimally for one reason or another. 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 values are 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 report their aims and strategies with respect to mitigating releases in the short and long term. 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. The first target values that are reported by the licensees are to be achieved by 2006. Examples of measures are:

Oskarshamn Nuclear Power Plant

- Reduced activity on system surfaces through zinc dosing
- Low core contamination and avoidance of fuel failure
- Locating sources and creating routines to promote clean systems
- Low offgas flows
- Modernization of the waste facility for Oskarshamn 1 and 2
- Administrative measures to reduce radioactive releases to water

Ringhals Nuclear Power Plant

- Damage-free cores
- New cleaning stages for releases from the laundry
- New technology to reduce water consumption

Barsebäck Nuclear Power Plant

- Measures to reduce airborne activity in connection with pool cleaning

Forsmark Nuclear Power Plant

- Reduced releases to water
- Preventing objects from entering the primary system and causing fuel damage

Diagram 6 shows the radiation doses that resulted from radioactive releases in 2003. 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.

The plants conduct environmental monitoring in accordance with SSI's instructions. A limited selection of the samples taken were 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.

SSI conducts inspections to follow up compliance with the regulations. In 2003, inspections focused on quality control of laboratory activities at the nuclear power plants.

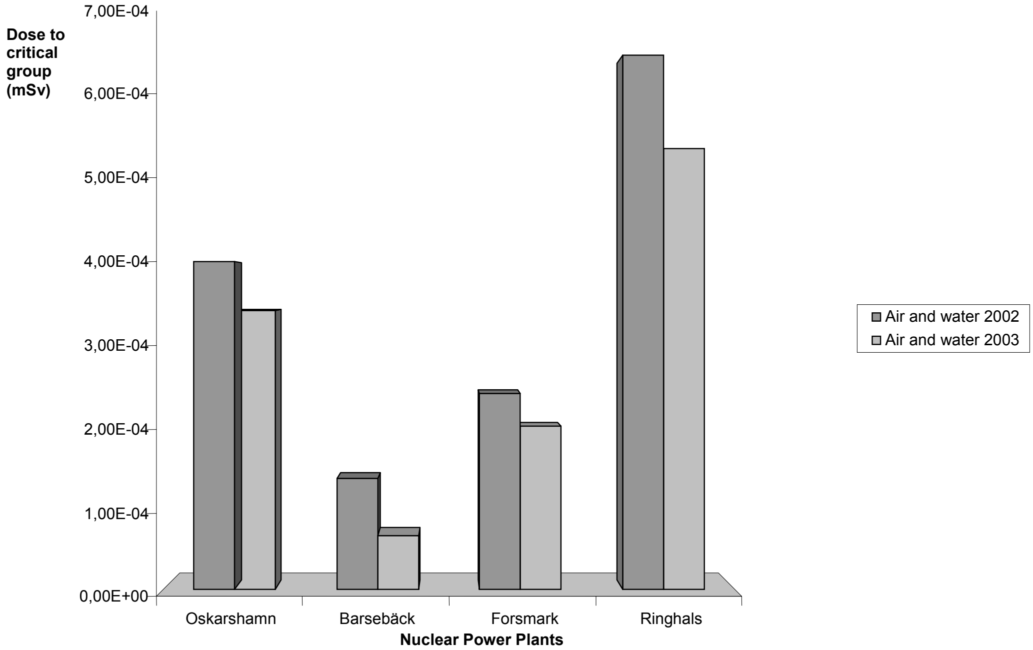


Diagram 6. Radioactive releases to air and water from nuclear power plants in 2002 and 2003, shown as the dose to the critical group.

8. Waste Management

Treatment, Interim Storage and Disposal of Nuclear Waste

At the nuclear power plants, radioactive operational waste is treated and disposed of in local landfills at Forsmark, Oskarshamn and Ringhals, providing that the level of radioactivity is sufficiently low. If the waste contains higher levels of radioactivity, it is deposited in the repository for radioactive operational waste, SFR-1, which is located at Forsmark nuclear power plant. Waste is also treated at Studsvik, where waste incineration and scrap metal melting are conducted. Waste with a very low concentration of radioactive substances can be exempted from the regulations of the Radiation Protection Act and the Act on Nuclear Activities (free-released) and then re-used without restriction, incinerated or deposited in municipal waste dumps.

In 2001, SKB submitted to SKI and SSI an overall report of safety at SFR-1 during operation and post-closure. SKI's and SSI's overall evaluation of safety at SFR-1 is provided in a review report (SSI 2003:21, SKI 2003:37). SSI and SKI find that there are certain deficiencies in SKB's reporting. Therefore, both authorities have decided to issue further stipulations for the operation of SFR-1.

SKB is to report its operating experience since the facility was taken into operation at the end of the 1980's. The report is to provide an account of operating safety, waste package handling, evaluation and assessment of package types and experience from the analysis of long-term safety and how the results have been applied in waste disposal plans. SFR-1's inventory of radioactive substances, which are to provide the design basis for the disposal, must be updated and reported. Furthermore, SKB is to present a disposal plan which ensure that waste packages are distributed between different repository parts so that the different barrier functions of the repository are used in an optimal manner.

With respect to SFR-1's performance after closure, SKB is to present an integrated safety concept for the facility which clearly shows the prioritizing of different analyses that have been conducted and how the requirements with respect to barriers are met at different times. The safety report is to be supplemented by systematic work for the formulation of scenarios for the development of the facility. A central scenario is to be included, which takes into account the most probable development of the repository. SKB must also expand its consequence and risk calculations with sensitivity and uncertainty analyses.

Furthermore, one stipulation is that the deposition of nuclear waste from pressurized water reactors (Ringhals 2, 3 and 4) may not continue until SKI has approved an updated radionuclide inventory, especially an improved estimate of the quantity of Carbon-14. The ion-exchange resins used in reactor primary system cleaning systems belong to this type of waste.

SKB has commissioned an evaluation of the process for the approval of new waste types which are to be deposited in SFR-1. As a consequence of the evaluation, SKI and SSI have required SKB to prepare a control document for the preparation of new types of waste at the nuclear facilities. The authorities will then evaluate the routines. During the year, three new types of waste were approved for disposal in SFR-1.

During the year, at SFR-1, 698 m^3 of waste was deposited and, since startup, a total of 30,059 m^3 were deposited which contained $5.9 \cdot 10^{14}$ Bq.

During the year, a category two event occurred at SFR-1. In connection with annual testing of the fire alarm system, logic and signals, a number of events occurred. However, these were not of any importance for safety.

In 2003, SSI conducted theme inspections at all nuclear power plants with the aim of following up the application of SSI's regulations concerning the management of radioactive waste and nuclear waste at the nuclear facilities (SSI FS 2001:1). In SSI's view, the parts of the facilities reviewed largely comply with the regulations. Minor deviations have been pointed out for corrective action, for example, Barsebäck Kraft AB has been required to prepare waste plans for certain types of waste.

During the year, no waste was deposited in any of the landfills. Forsmarks Kraftgrupp AB applied to expand the existing repository. 87.5 tonnes of scrap metal from Barsebäck and 198.2 tonnes from OKG have been treated and recovered at Studsvik Radwaste AB.

In summary, the handling of nuclear waste at the nuclear facilities has been conducted in a satisfactory manner during the year.

Spent Nuclear Fuel

Spent nuclear fuel and the remains from reactor internals which are classified as long-lived waste, are placed in interim storage at CLAB which is located next to Oskarshamn nuclear power plant. OKG Aktiebolag conducts the day-to-day operation at the facility on behalf of SKB which is the licensee.

During the year, twelve category two events (SKI FS 1998:1) occurred. The cause of the relatively large number of deviations is the ongoing building work with the expansion of CLAB stage two and the extensive power outage which also affected CLAB.

The expansion of CLAB is at an intensive stage, where the connecting up of different systems has been initiated during the year. These systems were subjected to several safety evaluations prior to being introduced into the existing operating facility. The safety department at OKG is also following the expansion activities at CLAB and considers that the organization of the facility is handling safety-related issues well. The commissioning will continue into 2004 and SKB expects that the commissioning of CLAB stage two will occur in autumn 2004, assuming that SKI's permission is obtained.

During the year, 61 shipments with 179 tonnes of uranium in the form of spent nuclear fuel have been received at CLAB. Furthermore, four transport containers for core components containing spent control rods have been received.

In total, 19921 fuel elements are stored at CLAB. These elements are distributed as follows:

BWR	17503
PWR	1979
MOX	217
Ågesta	222

CLAB's pools contain a total of 121 cassettes containing scrap metal which is to be deposited in future facilities for long-lived nuclear waste. In addition, there are 18 transport boxes containing spent fuel from Studsvik.

Safeguards have been well implemented at CLAB. Four inspections from the IAEA/Euratom were conducted without comment.

9. Emergency Preparedness

During the year, the authorities have followed the development of emergency preparedness at the nuclear power plants. The issues that have received special attention are the analysis of competence and staffing for the plants' emergency preparedness organization and improved reporting from the plants to SKI in the event of abnormal events. This is an area where SKI has previously identified deficiencies at all of the plants. Furthermore, in connection with SSI's work on the promulgation of regulations, with respect to emergency preparedness at nuclear facilities, the criteria for and requirements of plant preparedness have been investigated.

Issues relating to competence and staffing have been followed up through inspections and plant monitoring. SKI has observed that deficiencies in the area have been corrected at all facilities and that a competence assurance system is now in place which can monitor and follow the competence and staffing in the area.

The access to timely and reliable information is important in order for SKI to fulfill its task in emergency preparedness as well as for the decision-makers who are responsible for early protection measures in threat and accident situations. During the year, a series of inspections comprising all nuclear power plants have been started through the inspection of Oskarshamn nuclear power plant. The inspection focused on the transfer of the first information to SKI after the event had occurred, including the plant's conditions to make contact with SKI without delay. Procedures for the transfer of information to SKI in connection with events which deviate from normal operation have been further developed and tested in connection with several exercises where the plants and SKI have participated. Experience from the exercises show clear improvement and that the development of routines must continue. In spite of the continued need for improvement, SKI considers that preparedness at nuclear power plants is being maintained at an acceptable level.

SKI and SSI have, in co-operation with other actors in the preparedness area, continued work to make preparedness more efficient in the event of a nuclear accident. Several exercises and training sessions where SSI and SKI have participated have been conducted during the year. SSI's web-based tool for information exchange between actors in the event of a nuclear accident, called Kärnporten, has developed into a general system for the handling of crisis information. The system is called Generalen and has been used in connection with these exercises. Municipalities hosting nuclear power plants have been connected to the system for use also in other types of accidents. SSI is responsible for the operation and maintenance of the application and server, which have been placed in a protected location with the support of the Swedish Emergency Management Authority. SSI has also adopted measures with the aim of allowing the system to be used within the framework of the county administrative board's protected LstNet network.

Since the beginning of the 1990's, SSI has conducted theme inspections into the emergency preparedness at the nuclear power plants. SSI's views have been based on good practices, although no formal criteria have existed for the evaluation of emergency preparedness. SSI's views have been taken into account by the licensees, although recent years' efforts to reduce costs in the nuclear industry have resulted in SSI's view that requirements must be clarified and formalized.

With the aim of ensuring an adequate handling of preparedness issues also in the future, SSI has started work on preparing regulations within preparedness. The basis for the work is the IAEA's new recommendations which, where applicable, are taken into account in the work on promulgating regulations. In spring 2003, SSI conducted a feasibility study, followed by a main project, which was started in August of the same year. A reference group with representatives from SKI, the Rescue Services and from the plants have followed the work and have been given the possibility of submitting viewpoints. A first informal external review was held with plants as reviewing bodies in the middle of March 2004. This will be followed up by a formal review in August. The regulations are expected to enter into force in the middle of 2005.

For some time, the nuclear power plants have been using a dispersion and dose calculation code developed by SSI to estimate the consequences in the event of a radioactive release to the atmosphere. During the year, the application has undergone a final upgrade based on user needs.

In order to maintain and develop the analysis capability in connection with nuclear and radiological events, SSI has become part of a consortium comprising the member states of Denmark, Norway, Poland, Ireland and Canada as well as the Baltic States. The consortium has developed the analysis and decision-support system, ARGOS. SSI's aim is to evaluate the system and, on condition that SSI's performance requirements are fulfilled, has adapted the system to Swedish conditions. Adaptation and evaluation is being conducted in close co-operation with the Swedish Meteorological and Hydrological Institute.

During the year, SSI, together with the Swedish Rescue Services, has participated in an investigation concerning alarms at the Swedish nuclear power plants. The investigation, which focuses on the need for and design of systems for indoor alarms, was submitted to the Government at the beginning of 2004.

During the year, work on the areas of co-operation, *Proliferation of hazardous substances*, *Protection, rescue and care* and *Technical infrastructure* has continued. The authorities have individually and together worked on risk and vulnerability analyses, where the threat scenarios have been broadened to include a wide spectrum of events in the nuclear and radiological area. Work on reinforcing the preparedness-related measurement and analysis activity in the national radiation protection preparedness has started.

Finally, SKI and SSI have, with the support of funding from the expenditure area, Civil Preparedness, established a joint preparedness centre which is designed to serve, in the long term, as a management centre in peacetime as well as in the event of an emergency.

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