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Safety and Radiation Protection at Swedish Nuclear Power Plants 2004

May 2005

Background

Reports on the status of safety and radiation protection have been prepared by the Swedish Nuclear Power Inspectorate (SKI) and the Swedish Radiation Protection Authority (SSI), since 1990. The reports are written jointly by both regulatory authorities on behalf of the Swedish Government. SKI is responsible for co-ordinating the reports and for ensuring that the Government receives them by May 1 every year.

In the reports, the regulatory authorities provide an overall evaluation of safety and radiation protection based on what has emerged from the supervisory and regulatory work, or in other ways, during the year. The evaluations in the reports are based on relevant legislation and on regulations promulgated by the authorities.

SKI consults both its reactor safety advisory committee and its own board about its evaluations. SSI consults its board. The reports are primarily addressed to the Government and Swedish Riksdag (parliament) as well as to relevant licensees. Since the reports have been found to have a considerable information value, the media are also a target group.

To the Government | April 29, 2005

Ministry of the Environment
103 33 STOCKHOLM

SKI 2005/596
SSI 2005/929-250

Safety and Radiation Protection at Swedish Nuclear Power Plants 2004

In the directive for the 2005 budget year, the Government charged SKI with the task of, together with the Swedish Radiation Protection Authority (SSI) and no later than May 1, 2005, reporting to the Government concerning the status of safety and radiation protection at Swedish nuclear power plants. SKI was charged with ensuring that the joint report is submitted to the Government.

The report has been reviewed by SKI's reactor safety committee which has assisted SKI in the safety evaluations reported in the summary. SKI's and SSI's Boards have been consulted on the matter in accordance with § 22 of the Agency Ordinance (SFS 1995:1322). Neither board had any objection, from the point of view the boards are charged to consider, to the evaluations of the safety and radiation protection presented in the report.

The report on safety and radiation protection at the Swedish Nuclear Power Plants 2004 is hereby submitted.

SWEDISH NUCLEAR POWER INSPECTORATE

Judith Melin, Director General

SWEDISH RADIATION PROTECTION AUTHORITY

Lars-Erik Holm, Director General

Signed document, see original report to the Swedish Government.
(SKI Rapport 2005:32, SSI Rapport 2005:05)

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SUMMARY

The safety philosophy upon which the Swedish Nuclear Power Inspectorate's (SKI) supervisory and regulatory activities are based assume that multiple physical barriers will exist and that a plant-specific defence-in-depth approach 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 layers of different technical systems and operational measures as well as administrative routines in order to protect the barriers and maintain their effectiveness during normal operation and during anticipated events and accidents. If this fails, a system for emergency preparedness should be in place in order to limit and mitigate the consequences of a severe accident.

An effective defence-in-depth approach is based upon sound management and control of safety, and an 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 the barriers should be intact. This means, for example, that a containment leak should normally result in the shutdown of a reactor, even if all other barriers are intact and safety is thereby not jeopardized.

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

No Severe Events

In 2004, no severe events occurred which challenged the safety at Swedish nuclear power plants. Two events were classified as Level 1 events on the 7-point International Nuclear Event Scale. The events are described in the chapter, Operating Experience.

Relatively Little Damage – However, Surprises Occur

During the year, relatively little new degradation and deficiencies were detected in the reactor barriers. The number of fuel defects is constantly decreasing. The same applies to the number of defects in the pressure-bearing systems. On the other hand, SKI has observed that damage is beginning to occur in the reactor containment.

During the 1980's and part of the 1990's, a large number of fuel defects induced by stress corrosion were reported. The fuel cladding did not comply with the requirements concerning its resistance to the environment. Since then, the trend has gone towards more resistant cladding material and no damage of this type has been reported recently. The damage that occurs in the cladding nowadays has mainly been caused by small objects in

the coolant which wear holes in the cladding. The problems with fuel bowing that occurred in the pressurized water reactors at Ringhals are followed by SKI through annual reports from Ringhals AB. Previously identified problem areas have been analyzed and followed up for pressure-bearing systems. Altogether, these measures mean that SKI currently sees no serious tendencies to age-related degradation in these systems of the type that could lead to reduced safety at the facilities. Applied control programmes are effective and capture most of the damage at an early stage before safety is affected. However, individual defects have been detected in material where such degradation was not anticipated and which is currently not regularly checked. SKI will follow up these observations thoroughly in order to judge whether there is a need for increased inspections.

During the year, two defects found in the reactor containment were reported. The damage and degradation that occurred indicate that the causes were mainly due to defects during construction, or during subsequent plant modification. Taking into account the difficulty of inspecting the reactor containments and other vital building structures reliably, it is important for the licensees to continue to study possible ageing and degradation mechanisms that can affect the integrity and safety of the components.

SKI continuously follows the progress of the degradation in the mechanical devices and building structures that form the plant barriers and defence-in-depth system. This includes both overall evaluations of the progress of degradation as a whole and the progress of degradation in each facility. Furthermore, the occurrence of different degradation mechanisms is followed. In the chapter on Technology and Ageing, SKI has collected some of the indicators that we consider to be of interest for a wider readership.

The ageing of electrical cables and other equipment in the facilities' I&C systems has been observed by SKI. Supervisory work has so far shown that these issues are largely being handled in a satisfactory manner by the licensees, but that some supplementary investigations must be conducted.

Time of Major Change

The power companies have intensified the rate of investment in nuclear power plants. Modernization work and safety reviews stipulated by the Government are part of the reason and will be a feature of the next ten-year period. Furthermore, in new regulations, SKI has introduced more stringent requirements on facility design and construction, based on the experience that has been accumulated since nuclear power was introduced in Sweden. At the same time, the power companies intend to implement power uprating at several of the reactors, which will require extensive safety reviews. In 2004, SKI submitted statements to the Government concerning the application for power uprating at Ringhals 1 and 3. SKI is currently conducting its review of the application submitted by Oskarshamn nuclear power plant, OKG, concerning power uprating at Oskarshamn 3.

The investments will place considerable demands on the resources and competence of the licensees and their suppliers. SKI's supervisory capabilities will also be put under pressure, in terms of focus, competence and capacity. Priorities have been adjusted by SKI and resources are being channelled into these issues.

Besides focusing on individual issues, supervisory work at SKI will focus on how the licensees, in their organizations, are handling these issues. In particular, SKI will review the self-assessment that licensees must conduct in order to ensure that nuclear safety issues are given the attention required so that safety at the facilities is not reduced in connection with the extensive modification work.

Major power uprates require a large amount of analysis work and refurbishment at the facilities in order to take into account increased capacity requirements on safety systems and other factors. The planning and implementation of this refurbishment has much in common with the refurbishment that is carried out due to ageing, increased requirements on maintenance and testing as well as, in particular, the consequences of the new regulations on the design and construction of nuclear reactors which entered into force on January 1, 2005.

In the light of the above, in SKI's view, the licensees must allocate considerable resources for self-assessment. In particular, this means reinforcing the internal review function to ensure that changes are conducted in a way that corresponds to the high demands on safety required by legislation and regulations. The licensees must also ensure that the same high demands have an impact on the large quantity of work conducted by suppliers of equipment and services. Up to date and documented safety analyses and safety reports must be prepared and actively included in the preventive safety work. A complete risk assessment is essential in order to evaluate the measures that the licensees intend to implement, especially with respect to power uprating and the work on compliance with the new regulations on the design and construction of reactors.

During the year, the work on the new regulations for physical protection intensified and a revised draft of regulations and general recommendations has been subjected to a formal review by licensees concerned. The new regulations are expected to lead to consequences for most of the licensees in terms of increased requirements on site protection, building protection[1] and access control. The transitional regulations will allow the licensees a reasonable amount of time to implement the necessary measures at each facility.

Maintenance Developed

During the year, SKI initiated an investigation into how maintenance strategies have developed at Swedish nuclear power plants since the deregulation of the Swedish electricity market in the mid-nineties. The investigation shows that the rate of change over the past five-year period has been faster than during the previous five to ten-year period. Changes have occurred with respect to strategy and organization. Deregulation has been the most important driving force for internal improvements. One conclusion is that the changes have contributed to the learning and development of both individuals and organization. Furthermore, there is no sign of a negative impact on reactor safety. In SKI's opinion, the maintenance activity is extremely important to safety, and supervision will focus on work loads, responsibilities and roles, work satisfaction and motivation, maintenance procedures as well as the possible impact of the combination of financial pressure and a high rate of change.

[1] Building protection: Protection of buildings or parts of buildings that contain equipment for the safe operation of the facility or in which nuclear substances or nuclear waste is handled, treated, stored or deposited.

Intensified Supervision in Barsebäck and Studsvik

During the year, it was announced that Barsebäck 2 would be closed down at the end of May 2005. SKI will continue to maintain intensified supervision, which means a higher inspector presence than normal and more stringent reporting requirements. In SKI's opinion, Barsebäck Kraft AB (BKAB), with the measures that have been implemented, is maintaining safety at the Barsebäck nuclear power plant. In December, Studsvik Nuclear AB decided to close down the two reactors at Studsvik. Therefore, SKI immediately initiated an intensified supervision of the decommissioning process at the reactors.

Satisfactory Handling of Nuclear Waste

The handling of nuclear waste at nuclear power plants, including the operation of the Repository for Low and Intermediate-level Operational Waste (SFR-1) and the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB) has largely functioned well for the most part.

Satisfactory Safeguards

In 2004, SKI, the IAEA and the European Commission conducted inspections into how safeguards are handled at the facilities. During the inspections, nothing was found to indicate deficiencies in safeguard control at the nuclear power plants.

Good Radiation Protection Situation

In 2004, the total radiation dose to the personnel at nuclear power plants was 6.4 manSv[2], which is lower than in 2003. The average value for the past five years is 9 manSv. The shutdown periods were shorter at a few reactors due to the fact that work progress surpassed expectations. Technical problems and unplanned repair work resulted in a somewhat higher dose than expected at a few reactors. No individual received a radiation dose greater than 20 millisievert[3] (mSv). The fuel defects that occurred in 2004 did not result in any significant impact on radiation protection.

The dose to people living in the vicinity of the nuclear power plants in 2004 was below 1 per cent of the permitted dose[4]. The control measurements that SSI conducts on environmental samples around nuclear power plants and on the radioactive releases to water show a good agreement with the licensees' own measurements.

[2] manSv is the unit used for total radiation dose (collective dose) which is obtained as the total of the individual radiation doses.
[3] The origin of the 20 mSv value is that the total of an individual's radiation doses may not exceed 100 mSv over five consecutive years.
[4] The radiation dose from the exposure of an individual living near to a nuclear power plant to radioactive substances may not exceed 0.1 mSv per year.

PREMISES AND EVALUATION CRITERIA

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

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

Defence-in-depth Principle

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

Defence-in-depth assumes that there are a number of specially-adapted physical barriers between the radioactive material and the plant personnel and environment. In the case of nuclear power reactors operating, 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 approach in order to protect the barriers and maintain their efficiency during normal operation and under anticipated disturbances in operation and accidents. If these fail, measures should be in place in order to limit and mitigate the consequences of a more severe accident.

In order for the safety of a facility as a whole to be adequate, an analysis is performed of which barriers must function and which parts at different levels of the defence-in-depth that must function under different operating conditions. 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. 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 approach are stipulated in SKI's regulations and general recommendations, as well as in the stipulations that the Government and SKI include 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 2004. SKI describes major work conducted during the year and describes the events and defects detected at each reactor. More details concerning operation and availability data can be found on the company's website and in the annual report of each nuclear power plant which, in accordance with SKI's regulations, submitts to SKI.

Two events in 2004 have been classified as 1 on the International Nuclear Events Scale (INES). These events, that occurred at the facilities in Forsmark and Oskarshamn, are described in the text under each facility's heading. Neither of the events was a threat to the safety of people living nearby.

Barsebäck

Barsebäck 1

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

Barsebäck 2

On January 4, a fuel defect was detected. The defect became progressively worse. On January 30, BKAB decided to shut down the reactor and to replace the damaged fuel element. The reactor was removed from the grid on February 1. In connection with the shutdown of the reactor, a check was made that the drainage pipes inside the containment were correctly installed. It was found that, in connection with the 2003 refuelling and maintenance outage, one of the drainage pipes had been placed at an incorrect height and was positioned above, instead of below, the condensation pool's water surface. The discovery led to BKAB launching an inspection of mechanical modifications conducted over the past two years in order to ensure that the installation was correct. The inspections showed that the mechanical modifications implemented during the past two years had no shortcomings. The reactor was re-started and synchronized to the grid on February 16.

During the period of May 7 to 25, refuelling and a number of tests were conducted. During the remainder of the year, the unit was operated at full power apart from brief power reductions for routine testing.

Forsmark

Forsmark 1

Forsmark 1's refuelling and maintenance outage was conducted between June 13 and 21. A fuel defect was detected during refuelling. The defect was found to be caused by debris in the reactor systems. An additional fuel defect was discovered in autumn. Otherwise, the unit was operated at full power apart from certain power reductions for routine testing.

Forsmark 2

Forsmark 2's refuelling and maintenance outage was conducted between July 4 and 14. The unit was operated at full power apart from certain power reductions for routine testing.

INES 1 – Containment Isolation Valve Failure in Residual Heat Removal System, Forsmark 2

The main task of the system is to cool the reactor in connection with power reduction to cold shutdown. During normal operation, the system is also a part of the reactor coolant cleanup system. In connection with quarterly testing of isolation valves in the systems, one of the external containment isolation valves failed to close. When the operators gave a new closure signal, the valve closed as intended. The same fault occurred during retesting. The maintenance personnel then blocked the valve in a closed position and repaired the fault. The faulty valve was one of two which isolate the containment when necessary. As a result of the degraded containment function, the event was classified as 1 on the INES-scale.

Forsmark 3
Forsmark 3’s refuelling and maintenance outage was conducted from July 24 to August 30. The long refuelling and maintenance outage was due to the replacement of the low-pressure turbine. The core spray system of Forsmark 3 was rebuilt this year in a similar manner to the earlier modifications to Forsmark 1 and 2. Otherwise, the reactor was operated at full power apart from certain power reductions for routine testing.

Oskarshamn

Oskarshamn 1
Oskarshamn 1 started up in January 2003 after having undergone an extensive modernization which included major safety-enhancing measures. Oskarshamn 1 has since been under SKI’s special supervision. This means that the company must report operating experience, in writing, on a quarterly basis.

At the start of the year, a minor fuel defect was found which was repaired in connection with the refuelling and maintenance outage. At the beginning of the year, the plant was shut down on a couple of occasions to correct vibrations in the turbine plant. The annual refuelling and maintenance outage started on July 3 and ended on August 10. A number of turbine problems as well as isolation valve defects led to certain abnormal operating conditions during the rest of the year. A number of minor faults also occurred in the electrical and electronics equipment.

INES 1 – Faults in Level Measurement in Oskarshamn 1
When Oskarshamn 1 was shut down for refuelling and maintenance in July, an alarm for low water level in the reactor pressure vessel was indicated in the control room. However, inspections conducted by the control room personnel showed unambiguously that false signals had been received. If this had occurred during normal operation, power reduction to cold shutdown would have been started. However, the facility already had this status. The cause of the erroneous alarm was that the wrong material had been used to make the connecting cables to the level indicators. In the hot and damp environment where the cables are, the marking emitted chlorine gas which caused corrosion attack on the level indicators.

OKG inspected all of the level indicators and found similar defects. During the investigation, deficiencies in the installation inspection were discovered. If the procedures had functioned as intended, the faulty material would have been detected. In the light of this, OKG and SKI rated the event as 1 on the INES-scale. Furthermore, SKI decided to report the event to the international systems for experience and event reporting, IRS, (Incident Reporting System).

In 2004, SKI can observe, as a whole, that Oskarshamn 1 is increasingly being operated in accordance with normal procedures following the extensive modernization.

Oskarshamn 2

The annual refuelling and maintenance outage at Oskarshamn 2 started on August 15. Major work conducted included inspection of the welds in the reactor pressure vessel, RPV boron and emergency core cooling systems. The test results did not indicate any defects. Following the outage, the unit was restarted at the end of September. Operation prior to and following the refuelling and maintenance period occurred at full power apart from certain power reductions for routine testing and brief outages due to turbine problems.

Oskarshamn 3

On May 23, the annual refuelling and maintenance outage was started and was concluded on June 12 when the reactor was re-synchronized to the grid. Prior to and after the refuelling and maintenance outage, the unit was operated at full power apart from certain power reductions for routine testing. On November 4, indications of a small fuel defect were found. It is not expected that the damage will have to be corrected before the 2005 refuelling and maintenance outage.

Ringhals

Ringhals 1

At the end of 2003, Ringhals 1 reported a defect in the containment barrier. The report concerned damage to the innermost of two steel plates comprising the containment leaktight lining. Ringhals showed that the defect probably only concerned the inner steel liner. Consequently after an analysis, SKI decided that operation could continue until the refuelling and maintenance outage in August. However, SKI required that the damage should be corrected after this in order for reactor operation to be continued.

Ringhals 1's refuelling and maintenance outage was conducted between August 6 and September 6. During the outage, a drive mechanism actuator line and the leak in the containment liner were repaired. During the outage, certain defects were also found in a level measurement nozzle and in the main recirculation loops. A number of power reductions, for routine testing and other reasons, were conducted during the year.

Ringhals 2

Ringhals 2's refuelling and maintenance outage started on May 31 and electricity generation resumed on June 23. During the outage, changes were made to the pressurizer pressure relief line in addition to normal maintenance and refuelling.

On July 16, SKI was informed that a leak had been found in the innermost of two steel plates comprising the containment leaktight lining. SKI decided that the reactor could be operated until the 2005 refuelling and maintenance outage with certain stipulations but could not be restarted after that time without SKI:s permission. However, the plant was shut down in February 2005 for repairs since subsequent measurements showed a higher flow than assumed in the basis for SKI's earlier decision.

A number of power reductions for routine testing were conducted during the year.

Ringhals 3

Ringhals 3's refuelling and maintenance outage started on May 2. The reactor was re-started on May 16. A number of power reductions for routine testing were conducted during the year.

Ringhals 4

Ringhals 4's refuelling and maintenance outage started on September 2. The outage was extensive with a number of plant modifications, including the replacement of the RPV head and pressurizer pressure relief valves. Synchronization to the grid occurred on September 30. A number of power reductions for routine testing occurred during the year.

2. TECHNOLOGY AND AGEING

Overall Evaluation of Damage Evolution

Swedish nuclear power reactors are between 19 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 degradation mechanisms, must be kept under constant surveillance. The licensees must be good at planning ahead and at implementing preventive measures in order to avoid degradation 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 degradation was conducted at the Swedish facilities. Much of this replacement work was conducted for preventive purposes as a greater understanding was obtained of degradation causes and mechanisms. In other cases, replacement work was conducted when degradation occurred. During the year, relatively few new cases of degradation 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 reduced safety at the plants.

SKI is continuously following the evolution of degradation in the mechanical devices and building structures that form the plant barriers and defence-in-depth system. This includes an overall evaluation of degradation evolution as well as degradation evolution at each plant. In addition, the occurrence of different degradation mechanisms is also followed.

The overall evaluation of all cases of degradation[5] in mechanical devices since the first plant was taken into operation confirms that preventive and corrective measures have had the intended effect[6].

This conclusion applies even when the cases of degradation that occurred up to the end of 2004 are taken into account. As shown in *Diagrams 1* and *2* (pages 18 and 19), 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 degradation that has occurred to date was detected in time through periodic in-service inspection and testing before safety was affected. Only a small portion of all of the degradation 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 that have resulted in the cases of degradation mechanism which have occurred, see *Diagram 4* (page 20). The most common degradation

[5] *Cases of degradation*: 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 degradation.

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

mechanism is intergranular stress corrosion cracking. The second most common degradation mechanism is 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 depends partly on their chemical composition and partly on the thermal treatment and machining that they have been subjected to during manufacturing and installation in the plant. In spite of the fact that considerable knowledge of the factors affecting this degradation mechanism as well as how these factors interact has been developed in recent decades, 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 boundary piping systems (directly connected to the RPV) and in safety systems, erosion corrosion usually occurs in secondary systems, such as the steam and turbine parts. Thermal fatigue, which is the third most common degradation mechanism, has mainly occurred in primary piping systems and in safety systems where large temperature variations occur.

Preventing an increase in degradation as the plant ages requires a continued high level of ambition in terms of preventive maintenance and replacement work. Therefore, SKI will continue to provide the 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 advanced planning, considerable problems can arise when degradation occurs and the significance of the degradation to safety has to be evaluated. The lack of data, suitable analysis and testing methods leads to uncertainty regarding margins and, thereby, regarding the safety importance of the degradation.

The damage and degradation that have occurred in the reactor containment show that these have mainly been caused by the deficiencies in connection with construction or subsequent plant modifications. This type of degradation has been observed in Barsebäck 2, Forsmark 1 and Oskarshamn 1. During the year, additional degradation of this type was reported, which is described below. Taking into account the difficulties of reliably inspecting the reactor containments and other vital structures, SKI considers that it is important for the licensees to continue to study possible ageing and degradation mechanisms that can affect component integrity and safety.

SKI is also continuing its own investigation and research on damage and other degradation which can affect the reactor containments. This also includes research on the inspection programmes and inspection methods that need to be developed in order to deal with possible threats to containment leaktightness and integrity in time.

The ageing of electrical cables and other equipment in the I&C systems has attracted international attention. Observed and possible problems were identified and reported in August 2004 within the framework of an international cooperation project with participants from the nuclear industry and the regulatory authorities. The aim was to collect international experience on, for example, the risk of cable fires due to ageing, as well as to obtain a better basis for relevant risk assessments and to implement appropriate measures.

With respect to the situation in Swedish plants, SKI requested the licensees to submit information on their handling of ageing phenomena and environmental qualification of these components. The licensees responded in autumn 2003. The reports which were submitted have been reviewed and are the basis of SKI's follow up work during the year. The results obtained so far show that these issues are largely being handled in a satisfactory manner by the licensees, but that that some supplementary investigations need to be conducted. The continued reporting by the licensees will be included in the reports that the licensees are to submit in accordance with the amended regulations, SKIFS 2004:1, as well as in connection with the forthcoming recurrent overall evaluations which the licensees must conduct to show that the facilities can continue in operation and maintain safety.

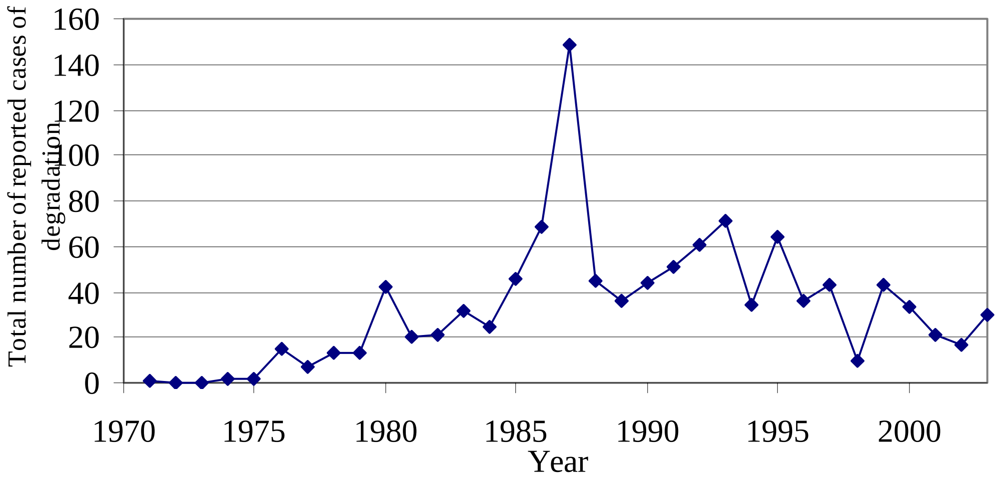
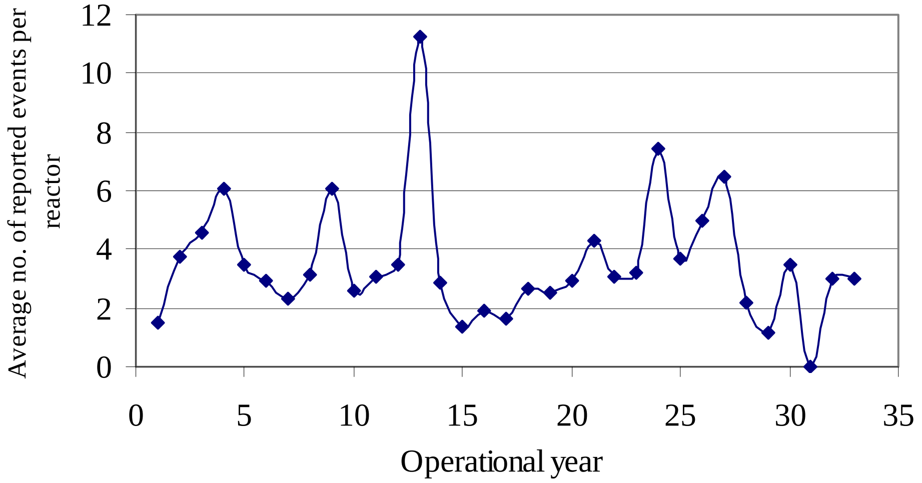


Diagram 1.
Total number of reported cases of degradation per year at Swedish nuclear power plants. Degradation in steam generator tubes is not included.



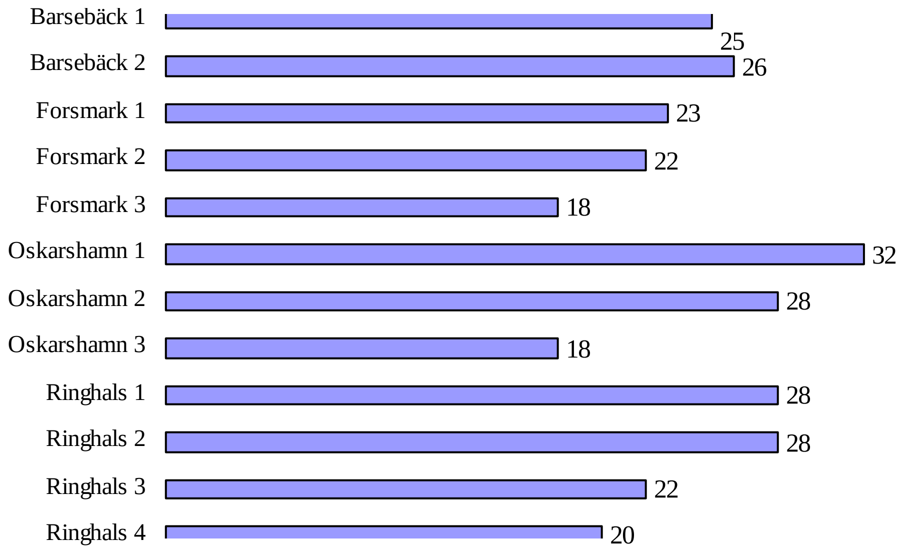


Diagram 2. *The uppermost of the two diagrams shows the average number of reported cases of degradation per unit and operating year for all Swedish nuclear power plants. The diagram comprises degradation to pressure vessels, pipelines and other mechanical devices apart from steam generator tubes. The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

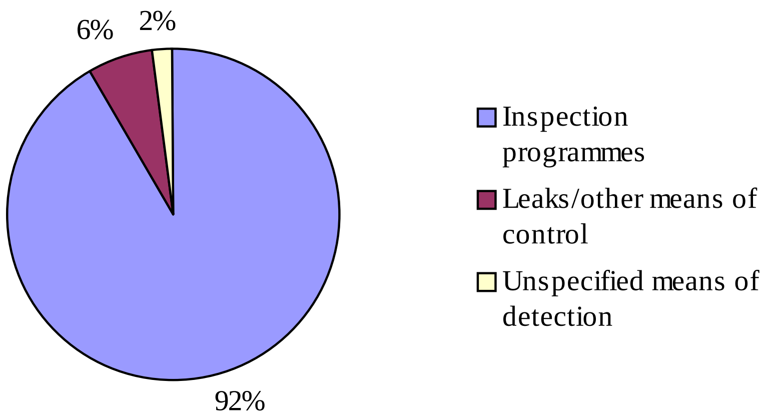


Diagram 3. *The number of cases of degradation detected through periodic in-service inspection and testing and the number of instances of degradation that have resulted in leakage or that have been detected in some other way.*

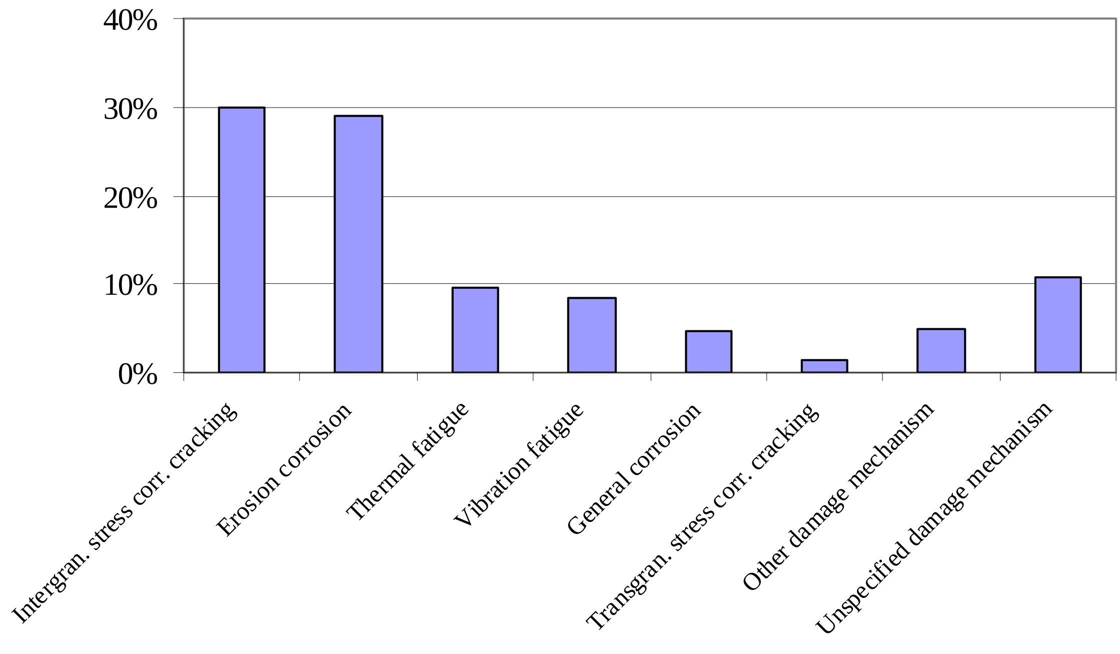


Diagram 4. *Cases of degradation sorted according to degradation mechanism. ("Other degradation mechanisms" includes cases of damage caused by grain boundary attack, corrosion fatigue and mechanical damage).*

New Problems with Damage in Components Manufactured of Nickel-based Alloys

Nickel-based alloys are a relatively common construction material in nuclear power plants. This particularly applies to Alloy 600 and the weld variety of the material, called Alloy 182. The material is used because it is a highly durable material with good corrosion resistance. The material has been used to manufacture nozzles (pipe connections), tubes and safe-ends the latter are 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 degradation 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. These increased inspections have over the last few years resulted in the discovery of degradation in nozzles and safe-ends in several Swedish reactors.

The sensitivity of the material and degradation found have also resulted in the replacement of large components such as the steam generators in Ringhals 2 and 3, as well as new RPV heads in Ringhals 2 and 4. In addition, Alloy 182 weld material in the safe-ends of several facilities, including Forsmark 1 and 2, Ringhals 3 and 4, has been replaced by a less stress corrosion-sensitive material of the type Alloy 52 or 82. However, during the year, degradation was also detected in material that has been welded with Alloy 82. The degradation was detected in Ringhals 2 steam generators. The cracks were removed in boat-shaped pieces which make it possible to conduct materials investigations in order to determine the cause of the degradation. The results of the analyses show that the probable cause is a type of stress corrosion cracking. SKI will follow up these observations thoroughly in order to evaluate whether additional requirements of increased inspections should be made.

During the refuelling and maintenance outage, previously detected defects and cracks in a number of level measurement, core and boron spray nozzles in Oskarshamn 2 have once again been followed up. 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 in connection with manufacture and was overlooked during the manufacturing inspections. The follow up inspections did not show any signs of crack growth.

Long-term Increase of Degradation Steam Generators

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 plants. The degradation is therefore being closely followed through comprehensive annual testing and other investigations in accordance with SKI's requirements. An additional 50 tubes with indications of stress corrosion cracking have been detected as well as minor growth of previously detected cracks.

Tubes with such limited degradation that sufficient margins to rupture remained have been kept in operation. Tubes degraded to the extent that insufficient margins to rupture remained were taken out of service by plugging their ends, and thereby preventing further crack growth. During the year, a total of 44 tubes were plugged. 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 2.71 per cent of the tubes.

As mentioned above, Ringhals 2 and 3 have replaced their steam generators by generators of a new and partially different design and with tubes manufactured from a less crack-sensitive material. In connection with the periodic in-service inspections and testing conducted, no signs of environmental degradation have been noted. The operating experience so far obtained with 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.

Additional Core Spray Systems Removed

The core spray systems at Barsebäck 2, Oskarshamn 2 and Ringhals 1 are also plant components which have been affected by stress corrosion cracking 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 cracking.

The core spray systems in Oskarshamn 2 and Ringhals 1 have been replaced by new ones, partially of a different design. This was carried out in 2002 and 2003. The new core spray systems have been manufactured by less degradation-sensitive material.

In 2003, the core spray systems in Forsmark 1 and 2 were removed. In 2004, the core spray system in Forsmark 3 was also removed. Forsmarks Kraftgrupp AB (FKA) implemented these measures to avoid future crack-related problems in stays and in nozzle piping systems. The stipulation for the modification was that FKA had to show that the core can be cooled under all conditions, and that the generated heat can be led to adequately sized heat sinks. Before the modifications were 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 certain critical cases in addition to these postulated accidents. The modifications that have now been implemented in the Forsmark reactors mean that all the water from the emergency core cooling system and from the auxiliary feedwater system is fed into the RPV downcomer, a method that was found to be an adequate replacement for the core spray system.

Follow up of Excessive Temperature Loads

In connection with the loss of offsite power on September 23, 2003, the reactor pressure vessel in Oskarshamn 3 was subjected to large temperature loads. 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 lower region. This resulted in severe temperature loads and caused the Maximum Permitted Limit Value (MPLV) for Oskarshamn 3 to be exceeded. In SKI's decision to allow re-start of the plant, requirements were made on follow up inspections of some internal parts in the RPV which had been subjected to large temperature loads. These inspections were conducted during the annual refuelling and maintenance outage, and no signs of damage were found. The inspections thereby confirmed the assumptions upon which SKI's decision to re-start the plant in 2003 had been based.

After the event in Oskarshamn 3, SKI requested information from all of the licensees concerning which equipment is installed to detect excessive temperature loads, as well as which administrative measures apply. In 2004, SKI reviewed the reports that had been submitted. The results of these reviews show that, to a varying degree, there is a need for additional measures, both for monitoring and alarm in connection with large temperature loads as well as administrative control via procedures and decision-making in connection with this type of event.

Additional Deficiencies in Reactor Containment Integrity

As discussed in the section above, with the overall evaluation of degradation evolution, defects and other degradation of reactor containment leaktightness of 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.

During the 2004 refuelling and maintenance outage at Ringhals 1, the cause of a previously observed leak from the innermost steel plate in the reactor containment toroid ring was determined. At that part of the containment, the condensation pool bottom plate is connected with the wall plates via a toroid ring. The ring consists of an inner and outer plate with a leak monitoring device between them. The leak was detected in December 2003 and Ringhals AB was granted permission by SKI to operate the plant until the time of the next planned refuelling and maintenance outage. This decision was mainly based on the fact that the outer plate was leaktight and, after analyses were conducted, was considered to be able to assume the leaktight function of the inner plate. No leakage out of the containment occurred since valves and leak monitoring plugs between the plates were kept closed.

The investigations that were conducted in connection with the repair of the toroid plate in Ringhals 1 showed that the leak was the incorrect cleaning of the condensation pool during the 2003 refuelling and maintenance outage that led to two small holes - a couple of mm^2 - in the plate. However, the leakrate testing conducted after the repair work showed that only a very small amount of leakage remains. This is now being monitored by regular measurements.

After the refuelling and maintenance outage at Ringhals 2 at the end of June, a water leak was detected from the lower part of the reactor containment. In this facility, the cast plate is also connected with the bottom plate via a toroid ring. Ever since the plant was taken into operation, Ringhals 2 has had minor leak from the inner toroid plate. During the most recent leakrate test conducted in 2000, the outer plate was assessed as being leaktight although investigations conducted in 2004 also showed minor leakage from the outer plate. The deficiency that caused the leak through the outer plate arose afterwards. No unambiguous explanation has yet been found for the cause of the leak. In September 2004, after reviewing the reported data and analyses, SKI gave permission for Ringhals 2 to remain in operation until the 2005 refuelling and maintenance outage on condition that the leak rate was regularly measured, and that it did not markedly increase in size. In addition, requirements on certain additional analyses and investigations were imposed. In November 2004, follow up leak measurements and chemical analyses of the leak water were performed. Certain problems relating to the measurement method were noted. In February, a considerably higher flow rate was measured than had been the bases for SKI's decision to permit continued operation of the plant until the planned outage. In SKI's view, this increase could not be accounted for by uncertainties in the measurements. In February 2005, the plant was shut down for additional investigations. These showed corrosion attack which was partly due to the fact that installation and construction drawings had not been followed. Ringhals AB has therefore decided to replace the entire toroid.

Development and Optimization of Periodic In-Service Inspection and Performance Testing Programmes

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 reduction 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 reduction of the safety level.

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

In recent years, both Swedish and foreign plants have shown an increasing interest in optimizing periodic in-service inspection and performance testing programmes using quantitative risk-oriented models. These methods combine probabilistic fracture mechanics models with probabilistic safety assessment models.

The main driving force for the application of these models is the reduction of inspection and testing costs. Therefore, SKI must ensure that the changes are made without any risk for increased core damage and radioactive releases. Like its sister authorities in the other countries which have started to apply the models, SKI has placed stringent quality requirements on input data to the models, as well as requirements on the validation of such models.

SKI has recently completed its review of a proposal from Ringhals AB to use a periodic in-service inspection and performance testing programmes for piping systems in Ringhals 2, based on a quantitative risk-informed test selection in accordance with a procedure developed by Westinghouse Owners Group (WOG).

Even if SKI has had viewpoints on the proposal, the authority has found that the work on applying this procedure has provided a good understanding of the risks that the various passive mechanical devices of the facility represent.

The optimization of inspections and the reduction of the cost for such work can also be achieved through the application of licence-based inspection and testing principles. To an increasing extent, the licensees have started to apply such principles to safety and isolation valves in the nuclear power facilities. During the year, SKI reviewed applications from Ringhals AB and Barsebäck Kraft AB to change over from fixed scheduled surveillance testing of safety valves to tests conducted at time intervals that depend on the condition of the valves in connection with previous testing. SKI has approved these changes at the same as it has placed demands on more realistic testing conditions, and more thorough follow up of results with trend analyses. This also applies to an application from Barsebäck Kraft AB for permission to apply licence-based inspection and testing principles to isolation valves.

Review and Amendment of Regulations concerning Mechanical Devices

SKIFS 2000:2 (Regulations concerning mechanical devices in certain nuclear facilities) entered into force on April 1, 2001. These regulations apply to design and construction as well as periodic in-service inspection/performance testing of such mechanical devices that are included in primary systems, containment barriers, safety, service and auxiliary systems in nuclear facilities. However, events and experience in recent years have shown that there is a need for some changes. SKI has therefore prepared a proposal for amendments to the regulations and has distributed the proposal to external bodies for a formal review. The amended regulations are expected to enter into force in the autumn of 2005.

The proposal is to expand the area of application of the regulations to include thermal liners, internal mixers and similar devices which perform the function of protecting pressure and load-bearing components against harmful loads. The reason for expanding the area of application is the “mixer incident” that occurred at Barsebäck 2 in 2003. In this case, pipe system internals become detached from their attaching device as a result of deficiencies during the construction phase in which the loads etc. had been underestimated.

The detached parts of the piping internals then damaged pressure-bearing components and partially blocked the feedwater flow which affected the safety level at the plant. This event clearly showed the importance of paying considerable attention to analysis, design and inspection of pipe internals.

It is difficult to get an overall view of the current requirements for inspections and testing of reactor containments. The inspections and testing carried out also vary from plant to plant. Certain requirements result from current stipulations in SKIFS 2000:2 and certain requirements are made in the Technical Specifications (STF) for each plant. Furthermore, there are other plant-internal requirements. A number of defects that have occurred in recent years have, as explained above, also indicated the need to increase general inspection requirements, both for metallic and concrete parts. SKI’s intention is therefore to collect in general regulations all of the requirements on analysis and inspection and testing that are necessary to ensure that containment leaktightness and pressure suppression are maintained over time, and in the accident situations when the containment function is needed. However, some requirements must be studied further before they can be introduced into general regulations. Such investigations are in progress at SKI.

However, the first stage is now a number of supplements and clarifications of SKIFS 2000:2. These mean that the basic safety regulations, the regulations on periodic in-service inspection and performance testing shall continue to be applied to the reactor containment metallic parts. In SKI’s opinion, the impact of these supplements and clarifications provide a better overview of the inspection requirements for metallic parts and lead to improved periodic inspection and performance testing of the condition in some plants.

Furthermore, in SKI’s view, these clarifications in the regulations improve predictability with respect to what should be done when degradation of metallic containment parts occurs. Requirements on measures in connection with plant modifications or amendments to operating conditions are being clarified. These clarifications are being made in light of the plans that the nuclear industry has announced to increase the thermal power of some reactors.

General recommendations for the regulations on the scope and focus of periodic in-service inspections and performance testing are being expanded. One reason that this is being done is the fact that licensees have started to apply quantitative risk models for determining inspection and testing needs.

In addition to these proposed changes, certain amendments are being made to SKIFS 2000:2 to harmonise in with other SKI regulations in order to ensure that consistent terminology and way of expressing certain types of requirements in SKI’s regulatory code.

3. CORE AND FUEL ISSUES

Fuel Failures Continue to Decrease

The basis for ensuring that radioactive releases inside and from the containment do not occur is leaktight fuel cladding. Therefore, stringent quality requirements are placed on fuel cladding fabrication for a low level of defect frequencies. The quality requirements have resulted in the fact that the number of fabrication defects is of 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 requirements concerning the operating condition. 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, see Diagram 5. However, some reactors (Forsmark 1 and 3 and Oskarshamn 3) have higher defect frequencies, with about one fuel defect per year over the past ten-year period.

The damage with 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 in 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 as to whether the damage frequency can be further reduced.

In 2004, four fuel defects were reported. Three of these occurred at the end of the year and the damaged fuel is still in the core. SKI will obtain information about the cause of damage in 2005 when the fuel bundles have been removed from the core and investigated.

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 can be avoided, which can otherwise cause the radiation conditions to deteriorate and thereby make maintenance work, inspections and testing more difficult.

Follow up 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 follow up methods used and is continuing to monitor progress via annual reports where Ringhals AB describes the status 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 which have been taken are having an impact.

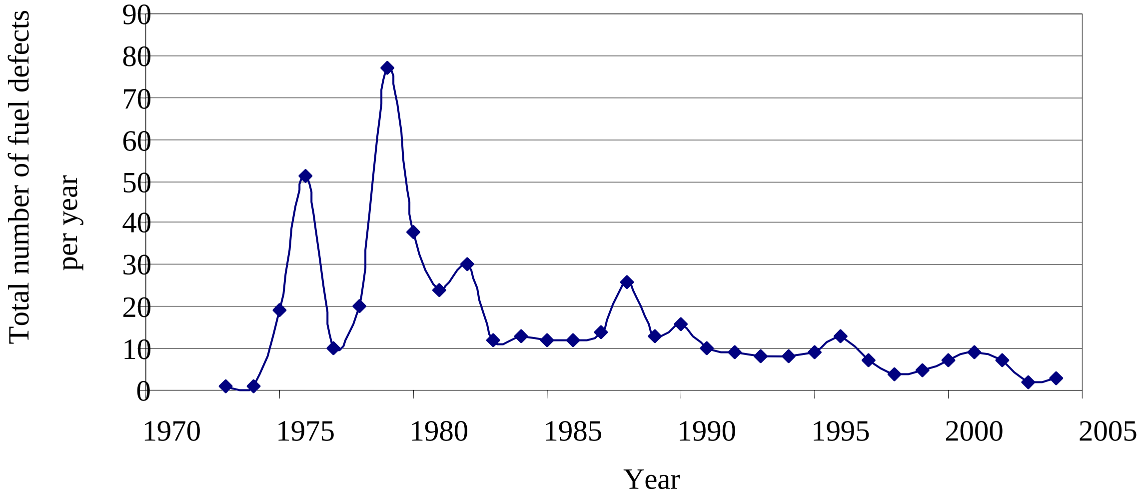


Diagram 5.
Total number of reported fuel defects per year at the Swedish nuclear power plants.

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.

SKI has granted Barsebäck Kraft AB and Ringhals AB permission to increase the local pellet burnup in the Barsebäck 2 and Ringhals 1 reactors from 60 MWd/kgUO_2 to 65 MWd/kgUO_2. As a stipulation for these decisions, SKI has required that certain limits should be applied in connection with core configuration and core calculations to avoid reactivity-initiating nuclear fuel defects as well as that the core configuration and burnup should be locally monitored in the core.

Changed Safety Margins for Demonstration Fuel

New fuel designs must be verified through demonstration operation in a reactor before they can be used as replacement fuel. This is still also in agreement with accepted international practice. Demonstration operation must show agreement (compatibility) with the rest of the core, coolant, core instrumentation, core monitoring systems, control and protection systems, reactivity control systems, handling equipment and procedures and routines. In order to verify the mechanical, nuclear and thermohydraulic properties of new fuel designs, experience of about 2 years of irradiation in a nuclear power reactor is the aim. However, the evaluation of fuel properties in a reactor environment assumes that the fuel has been tested for as long as possible before the final verification in a reactor environment.

SKI has previously required that extra safety margins should be applied for demonstration fuel, in addition to those which apply to other fuel bundles in the core. The reason has primarily been that the underlying safety report was incomplete, and only limited tests were conducted for this reason. These deficiencies have been corrected and, nowadays, the safety report for demonstration fuel is of the same quality as the corresponding report for replacement fuel. Experience in recent years also shown that fuel designs that have been trial operated at low power loads, namely lower than those for which the replacement fuel has been licensed, have later experienced unexpected problems.

SKI has therefore changed its opinion and considers that demonstration fuel should to be operated at the power load to which future replacement fuel will be exposed. The purpose is thus to verify that the fuel can manage the power load and to detect deviations in expected behaviour at an early stage, for example, excersive oxide growth. Since demonstration fuel, before it is introduced into a reactor core, nowadays has usually undergone extensive testing based on tried and tested methods and long experience, SKI considers that no extra margins are warranted.

Power Uprating

The operating licence issued by the Government stipulates, as a condition for granting the license, the maximum thermal power at which the reactor can be operated. Thus, the licence only applies for that specific thermal power. In order to change the maximum thermal power, a new licence is required in accordance with the Act on Nuclear Activities for the desired increase in thermal power.

The thermal power of a reactor can be increased through core optimization or through increasing the quantity of fissile material in the fuel. Core optimization can be achieved so that the power in low power load fuel bundles is increased while the power in the fuel bundle with the highest load is not affected. The quantity of fissile material can be increased by increasing the enrichment.

In a boiling water reactor (BWR), the higher power in the core is removed through increased feedwater flow and steam flow. The recirculation flow can either be maintained, which leads to a higher void in the core, or increased, maintaining the void. A combination of these two options can also be used.

In a pressurized water reactor (PWR), the higher power in the core is removed either through an increased coolant flow in the core or through a higher temperature increase over the core. A combination of these options can also be used. The higher thermal energy generated on the primary side then leads to an increased steam production on the reactor secondary side.

The higher steam flow is transported to the turbine plant where opening additional power control valves which results in the generator being able to produce more electric power.

A power uprate can affect the facility in a number of different ways and to a varying degree, depending on the size of the increase. The conditions and parameters that can affect safety must therefore be identified and analyzed in order to establish whether the safety requirements are fulfilled with the necessary safety margins. The following main conditions and parameters are affected by a major power uprate:

- The average power density in the core increases with a power uprate. Depending on how the uprate is achieved, this may mean a reduction in the margin to DNB[7]/dryout[8]. Through suitable core optimization, the power load in fuel bundles with a low load can be increased while the bundle with the highest load is not affected. This allows the margin to DNB/dryout to be maintained. Furthermore, modern fuel with intermediate mixing grids normally has a larger margin to DNB/dryout than older fuel.

- During normal operation, the steam flow from the BWR reactor pressure vessels and the PWR steam generators will normally increase with a power uprate. This results in a higher pressure drop in the steam lines which leads to a higher load on certain systems and components. Improved monitoring and follow up as well as new analyses may therefore be warranted, for example with respect to vibrations in piping systems as well as in the RPV and steam generator internals.

- Certain abnormal event sequences will occur more rapidly. For example, loss of power, certain pressure increases in the BWR RPV and PWR steam generators will be faster and probably larger. In connection with steam line block in BWRs, the pressure

[7] Departure from Nucleate Boiling (DNB) is a phenomenon which arises in PWRs and which means that the surface of the fuel is covered by a steam film which leads to an increase in cladding temperature. This can cause fuel cladding damage.
[8] Dryout is a phenomenon which arises in boiling water reactors and which occurs when the fluid film on the surface of the fuel disappears. This causes a temperature increase in the cladding which can cause fuel cladding damage.

increase is more pronounced because of an increase in reactor power. The reactor protection system age will be affected. This means that new analyses must be performed and other measures taken in order to show that the requirements are met.

- Certain accident sequences will be affected by a power uprate. This means that the facility's incident response and emergency preparedness must be reviewed.

- Residual heat will increase when there is a power uprate, resulting in an increased load on the safety systems. In certain situations, the time for operator action will be reduced. New safety analyses must therefore be performed to show that the safety requirements are met with the necessary margins. The Technical Specifications (STF) and procedures must also be updated. Training programmes for operating personnel must also be reviewed.

- Mass and energy release in the reactor containment in the event of a steam pipe break or primary system break can be affected by a power uprate. Pressure increases in the containment in connection with these events are largely due to thermal power and the primary system operating temperature. In a short-term sequence, the mass release is the determining factor whereas the long-term sequence is affected by the residual heat and, thereby, by the power uprate. New mechanical strength and safety analyses must therefore be carried out to show that the safety requirements are met with the necessary margins.

- A power uprate will change the temperature conditions in PWR coolant loops. This can affect loads and corrosion susceptibility in some parts. New analyses must therefore be carried out to show that the necessary mechanical strength margins are maintained. Periodic inspection programmes may also have to be reviewed.

- The shutdown margin may be reduced in the event of a power uprate. This has to be taken into account through the strategies used for core re-loading.

- The load on certain electrical systems and components may increase in connection with a power uprate. This means that requirements must be reviewed how the capacity of the electricity supply (diesel generators, batteries, converters etc.) in emergency and accident situations is ensured in connection with the higher power level.

- Furthermore, the plant environment is affected through the fact that more heat is emitted to the sea, that the waste contains more radioactive substances, that radioactive releases increase and that more uranium and chemical products are used. The consumption of fissile material (U-235) increases at the most in proportion to the power uprate. The consumption of chemicals can be expected to increase to a corresponding degree. However, the operation of the plant and the loading of the core have a greater impact than the power level on fuel consumption. Through changes in the way of loading the core and operating the plant, the increase in fuel consumption can probably be limited compared to what would otherwise result from the power uprate.

On March 23, 2004, Ringhals AB submitted an application for permission to increase the maximum permitted thermal power of Ringhals 3 from the current 2,783 MW to 3,160

MW. The same day, Ringhals AB also submitted an application for permission to increase the maximum permitted thermal power of Ringhals 1 from the current 2,500 MW to 2,540 MW.

In its review of the applications for Ringhals 1 and 3, SKI has found that Ringhals AB has identified the parts of the plants and activities that can be affected by the power uprates. For the most part Ringhals AB has also identified and reported the analyses, technical plant modifications and other measures that must be implemented in order for safety requirements to be met after the uprates. However, in SKI's opinion, additional analyses and measures are required in order to ensure that the safety requirements are met.

If these analyses and measures are implemented, SKI considers that the premises will exist for the thermal power of Ringhals 1 and 3 to be raised, and for the plants to be operated at the higher power levels in a way that meets the safety requirements with the necessary safety margins. Therefore, SKI has, in its review statement, proposed that the Government grant Ringhals AB permission, in accordance with the Act on Nuclear Activities, to operate Ringhals 1 and Ringhals 3 at the higher power levels. SKI has also proposed to the Government that the licenses should carry stipulations that the reactors may not be taken into trial operation or routine operation at the new maximum permitted thermal power without SKI's approval.

If the Government grants permission to increase the thermal power, SKI will then successively review the in-depth analyses, technical plant modifications and other measures that have to be conducted before the plants are taken into trial operation and subsequent routine operation at the higher power lever.

On October 6, 2004, OKG Aktiebolag submitted an application to SKI for permission to increase the maximum permitted thermal power for the Oskarshamn 3 reactor from the current 3,300 MW to 3,900 MW. SKI has started the reviews and has sent information and the related environmental impact statement to the necessery authorities and organizations.

Forsmarks Kraftgrupp AB has announced that they will be submitting applications at the end of September 2005 for permission to raise the thermal power at Forsmark 1, Forsmark 2 and Forsmark 3.

4. REACTOR SAFETY IMPROVEMENTS

New Regulations for the Design and Construction of Nuclear Reactors

The principle for upgrading the safety of Swedish reactors has been to successively improve the plants through modifications and implementing extra measures in connection with identified problems. Examples of such problems include the “strainer incident” in Barsebäck which occurred in 1992 when it was found that the emergency core cooling systems in BWRs 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 purpose was to ensure that no further hidden safety problems existed.

In the case of the oldest reactor, Oskarshamn 1, an extensive modernization was started in 1995. SKI had imposed conditions 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 also had to formulate requirements for these reactors. An extensive dialogue has also been conducted with the licensees about this.

SKI’s regulations (SKIFS 2004:2) concerning the design and construction of nuclear reactors were completed and approved in 2004. Through these regulations, SKI has developed and clarified the safety requirements for nuclear reactors. The requirements entail significant economic consequences, especially for the older reactors, although they will lead to their improvement of the safety. These safety improvements comprise design principles, the ability to withstand certain malfunctions and events, environmental qualification, monitoring and manoeuvring from the control room and emergency control posts, safety classification, event classification and regulations concerning reactor core design and operation.

The regulations have been in force since January 1, 2005 with transitional regulations which mean that the licensees concerned will be given the necessary time to plan and implement the measures in the plants that are required to comply with the regulations.

These new regulations will provide support for safety and regulatory work. They also provide increased clarity and predictability for the licensees concerning SKI’s expectations on the advancement of safety.

Modernization Project

The nuclear power plants have previously identified the need for major and thorough plant modernization. Oskarshamn 1 was the first Swedish reactor to undergo very extensive modernization work. 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.

Future plant modernization work is required in part as a result of the new regulations on design and construction of nuclear reactors which contain new and more stringent requirements. Other reasons for plant modernization include operating economy, increased demands on maintenance and testing, the need to replace technical equipment due to ageing, and the fact that there are difficulties in locating spare parts or competence for maintenance. The electronics and equipment in the control room are examples of the latter, where older equipment will be replaced by more modern equipment, based on digital technology.

The Swedish nuclear power plants have modernization plans and ongoing modernization projects. Several of these involve modernization in stages, lasting many years in to the future. For example, Oskarshamn 2 has presented modernization plans up to 2012 and FKA has presented plans up to 2013 for its three reactors. The plans for Ringhals 2 have so far concerned switchyards and waste systems and, in future years, will comprise all I&C equipment, including the control room. Ringhals 1 is preparing to rebuild and supplement I&C equipment.

The power companies have applied for permission for uprating the Oskarshamn 3, Ringhals 1 and Ringhals 3 reactors. In addition, there are plans to apply for permission for uprating other reactors. These major uprates require extensive analysis work and rebuilding of the plants in a number of cases in order to accommodate increased capacity requirements on the safety systems. The planning and implementation of the rebuilding has much in common with rebuilding due to ageing, increased requirements on maintenance and testing and, especially, with the consequences of the new regulations on design and construction of nuclear reactors which entered into force in January 2005.

SKI is supervising the ongoing modernizations and is planning for supervision of the future modernizations and the notified applications for power uprating. The supervision will last several years and will be very extensive.

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 the more modern reactors, Forsmark 1, Forsmark 2, Forsmark 3 and Oskarshamn 3, the consequences of the design reviews were less significant and no major review of the safety reports is expected.

Corresponding reviews are in progress for Ringhals 2, 3 and 4. The work is expected to be completed by mid-2005.

For some time, Ringhals AB has been conducting a project to modernize and simplify the Technical Specifications (STF) of PWR, based on a principle called MERITS. The principle was developed in the USA and is based on probabilistic criteria. SKI reviewed and approved, with certain reservations, the new Technical Specifications in 2005.

Probabilistic Safety Assessments

A basic condition for the operation of nuclear plants is that there should be analyses of all conditions 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 1990’s. Throughout this time, intensive development work has been conducted in the area, in Sweden and internationally. 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 flood. The PSA must also include all operating conditions, namely in addition to power operation, start up and shut down, as well as refuelling and maintenance outages at the plant.

SKI has observed an increased use of PSA. From previously being primarily used to identify improvement needs, it is now used to balance and optimize construction, operation and maintenance. Examples include test interval changes for active safety components, permitted repair times during operation of safety equipment, non-destructive testing of piping systems, and alternative solutions for safety modernization. These applications place new and greater demands on the scope, coverage, quality and validity of the models, as well as input data and parameters used.

New PSA which are conducted, of for example, external events, have also resulted in plans for updating SARs.

Previously prepared PSAs for the Swedish plants have some deficiencies in these respects which are successively being dealt with. During the year, SKI has followed and reviewed some of the work conducted by the power companies on the further development of the PSAs and how the deficiencies identified are being corrected.

In the light of the above, SKI considers that the licensees are largely developing, safety in an acceptable manner, but that it is essential that ongoing programmes for conducting safety analyses are not further delayed. A complete risk picture is essential in order to assess whether the measures that the licensees are to report at the end of 2005 are sufficient to meet the new regulations on the design and construction of nuclear reactors, SKIFS 2004:2.

5. ORGANIZATION, COMPETENCE ASSURANCE AND SAFETY CULTURE

Safety issues in the nuclear industry include both the handling of ageing phenomena and technical development, organizational development, organizational development, competence development, economic efficiency and environmental development. The ability to handle a complex interaction between technology, people, organizations and economy is necessary in order to maintain and to continue to improve safety. This section deals with how nuclear power plants, in SKI's view, have worked with questions relating to organization, competence assurance and safety culture in 2004.

Organizational Changes and How Control and Safety Reviews of Activities Are Conducted

The plants did not make any major organizational changes in 2004 and SKI has noted that procedures for handling changes in organization and activities exist at all of the nuclear power plants. The safety aspects of changes are identified early and addressed throughout the process.

During the year, SKI started an investigation into how the maintenance strategies have developed at the nuclear power plants since the deregulation of the Swedish electricity market in the mid-1990's. This investigation shows that the rate of change over the past five years has been faster than during the previous five to ten-year period. Changes have been made in strategy as well as organization. The deregulation has been the most important driving force for accelerating internal improvements. The study also shows that the maintenance organizations at all of the nuclear power plants have gone from decentralization to centralized shared maintenance organizations, with different degrees of matrix organization.

Work satisfaction and motivation have been affected negatively, in some cases, by the new organizational forms. Furthermore, it was difficult to clarify responsibilities and roles in the matrix organization. A positive factor is that the possibilities for experience feedback have improved with a shared maintenance organization. Other results show that staffing has been reduced or remained unchanged, and that requirements concerning the work have increased. Certain activities have been outsourced. Furthermore, maintenance competence has been redistributed so that requirements for analytical skills are increasing.

New maintenance strategies have been developed. Computer-based maintenance systems exist at all of the plants. However, there is a general need to develop maintenance procedures. One conclusion is that the changes have been favourable to learning and the development of individuals and the organization as a whole, combined with the fact that no signs of a negative impact on reactor safety have been identified. SKI's supervision will focus on work load, lack of clarity regarding responsibilities and roles, lack of work satisfaction and motivation, deficiencies in maintenance procedures as well as a combination of financial pressure and a high rate of change.

A review of the documented requirements regarding the professional competence has been conducted for personnel performing independent safety evaluation at the four nuclear power plants. SKI's review resulted in a decision that the documented competence requirements at Barsebäck Kraft AB, Ringhals AB and OKG Aktiebolag should be supplemented. The supplements have been submitted to SKI and SKI is currently reviewing the measures that have been implemented. At first glance, SKI has found that the content of the documented competence requirements in the industry has improved considerably.

During the year, SKI conducted an inspection at Ringhals AB with the overall aim of evaluating whether Ringhals AB has a system for ensuring that identified situations are evaluated from the standpoint of safety without undue delay. SKI intended to determine how detected deficiencies are handled, how information channels and how the decision-making process work in connection with detected deficiencies are dealt with. Furthermore, SKI intended to determine whether procedures exist that ensure that detected deficiencies are handled in a suitable manner in harmony with requirements. SKI found that, in 2004, Ringhals AB had a system for handling unclear conditions that are detected. Ringhals AB has procedures for ensuring that these are handled in accordance with requirements, through different meeting forms, information channels, decision-making processes and documented procedures.

During the year, SKI inspected the safety department's (BQ) position within Barsebäck Kraft AB. SKI found that the position and status for BQ have improved. BQ's contacts with the organization have also been formalized through more controlled meeting fora. Earlier deficiencies in resources in the form of job vacancies have improved through new recruitment, which provides greater possibilities to deal better with long-term issues. However, SKI considers that it is important for BQ to evaluate whether there is sufficient competence in the area of human factors (MTO).

Continued Development of Quality Systems and Audits

The review that SKI performed in 2004 of OKG's management system showed that OKG has a management system that is established, documented and that covers all activities. However, SKI found a number of measures that need to be implemented in order for the management system to provide adequate support for management, control, evaluation and development of the company's activities. In November, OKG submitted a programme of measures that describe the way in which OKG intends to implement improvements. Within the framework of the development of the management system, OKG will also develop the processes in the activity. SKI is following OKG's work and considers that the overall approach and updated programme of measures that OKG has presented has good premises for ensuring that the management system will be the support for the activity that is intended.

Within the Ringhals group, work is continuing on developing the activity control system as well as the process development that was started a few years ago. Among other things, the overall process map has been developed and improved in the management handbook of the Ringhals group. SKI considers that this is positive and favourable to the control of activities.

SKI finds that the licensees of the nuclear power plants are continuing to develop their activities by conducting internal audits. Furthermore, SKI finds that all have a process for documenting internal audits in the management system as well as that there is an established practice for working with internal audits. In SKI's view, all of the nuclear power plants are maintaining a good level of quality with respect to the control of work and internal audits.

Decommissioning Situation at Barsebäck and Studsvik

The reinforced supervision of BKAB, prior to decommissioning, has continued during the year. This work is being conducted to ensure that BKAB will continue to adopt adequate measures for safe operation. During the end of the year, it was announced that Barsebäck 2 would be closed in 2005 and the reinforced supervision is therefore continuing. In SKI's view, BKAB has handled the situation satisfactorily, for example, with the measures that it has implemented, such as the employment guarantee and the extra focus on safety-related tasks.

In December, Studsvik Nuclear AB decided to close down the reactors at Studsvik and, thus, SKI initiated a reinforced supervision of Studsvik's decommissioning process. The reinforced supervision involves increased presence at Studsvik, including meetings with the management and personnel. In SKI's view, Studsvik has started work on the decommissioning in a satisfactory manner.

Competence and Resource Assurance Focussing on Operating Personnel

In previous years, SKI has followed up the plants' competence assurance systems and found that all of them had documented systematic methods to ensure that there are enough personnel and adequate competence for the present and several years hence. In 2003, SKI found that some work remained concerning competence assurance with respect to the interdisciplinary functions in several units at Ringhals, Barsebäck and Forsmark. During the year, SKI followed up this work at Ringhals where the licensees identified three interdisciplinary functions which have been analyzed, and for which specifications have been prepared.

Special requirements are made with respect to the responsibility and importance of the operating personnel for the operational safety at a reactor. The regulations on the competence of operating personnel at nuclear power plants have been in force since January 2001. In the case of operating personnel, the work of adjusting to SKIFS 2000:1 has been underway for a long time. In the nuclear power plants that SKI inspected earlier, namely Oskarshamn and Ringhals, SKI identified a need for some measures. During the year, these measures were followed up and SKI has evaluated that the measures previously identified at Ringhals and Oskarshamn were largely realized. A few remaining points are to be followed up in spring 2005.

In 2004, a similar inspection was conducted at Barseback. Two main areas in need of measures were identified. A need for measures was identified regarding parts of the competence assurance process with respect to operations management, and a need for measures was also identified with respect to procedures for keeping the quality assurance system up-to-date with regard to competence and training. During the year, both Ringhals and Barsebäck applied for exemptions from the requirement concerning allocation of authorization (5 § SKIFS 2000:1) with respect to operations management levels 2 and 3, as well as operations management level 1. SKI granted permission for exceptions for a limited period of time, in the light of the fact that the people holding these posts had long operating experience as well as experience in these positions at each nuclear power plant.

Forsmarks Kraftgrupp AB still remains to be inspected by SKI with respect to SKIFS 2000:1. This will be done in 2005.

SKI has found that the inspections provide impetus since the nuclear power plants which have had time to implement their measurement programmes have reported their improvements concerning all operations management levels. The work on competence assurance has been given high priority by the nuclear power plants and there is a systematic approach to how the facilities ensure that they have adequate competence and staffing.

Continued Development of Safety Culture

For some years, the licensees have conducted a survey of the safety culture at each plant. The safety culture surveys were also conducted this year and the response rate was better than before. SKI is positive to the licensees working on their safety culture and has found that various efforts are underway in this area such as seminars and interorganizational discussions.

In an ongoing research project, *Approaches to Safety Culture Enhancement*, SKI has tried to obtain more knowledge of methods and possibilities of reinforcing the safety culture at the licensees' plants. The focus of the project is on management's attitude and understanding of safety and safety culture. The research project is based on a model for enhancing the awareness of different perceptions of the organization's safety and safety work. During the year, Oskarshamn and Ringhals have participated in the project and SKI also intends to conduct the study at Westinghouse Electric Sweden in 2005. The purpose of the entire project is also for SKI to have an overall and balanced view of the status of safety culture in the Swedish nuclear industry.

Follow up of the "Mixer Incident" at Barsebäck

The "mixer incident", which occurred at Barsebäck 2, in 2003, indicated major deficiencies in the control and management of the activity and, thus also deficiencies in the conditions and attitudes that characterize a good safety culture. In 2004, Barsebäck reported its experience of the organizational and administrative measures that were conducted in the areas of bringing the reactor to a safe state, design control and safety review. Furthermore, Barsebäck reported the measures that were conducted within the framework of the safety culture programme which was developed at a result. In 2004, SKI followed Barsebäck's work on improving activities in the above areas in a series of meetings with the plant. In SKI's view, Barsebäck has handled and developed activities in a satisfactory manner.

6. NUCLEAR SAFEGUARDS AND PHYSICAL PROTECTION

Satisfactory Nuclear Safetguards at Plants

In 2004, SKI, the IAEA and the European Commission all conducted inspections of how safeguards were being implemented at the nuclear power plants. 64 inspections were 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 this inventory-taking is then verified by SKI, the IAEA and the European Commission. The inspections conducted in 2004 do not indicate any deficiencies in safeguards at the nuclear power plants.

In 2004, the plant descriptions submitted to SKI for the supplementary protocol to the safeguards agreement with the IAEA were sent to the IAEA within the stipulated 180 days after the entry into force on April 30. The protocol 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. The proposal for a new ordinance, which has been discussed since 2002, was approved in April. The new ordinance will enter into force in winter 2005 after first having been translated into all the EU languages. The ordinance gives the European Commission the right to require that information be submitted necessary for the Commission to comply with the requirements of the supplementary protocol. Since the ordinance has come in to force, SKI can prepare regulations for national safeguards. This will be done in 2005.

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 the safety at the plant. This condition has been clarified further in SKI’s regulations concerning safety in nuclear facilities, SKIFS 2004:1, which were approved on June 15, 2004.

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.

During the year, the work on new regulations for physical protection was intensified and a revised draft of the regulations and general recommendations was sent for formal review by the licensees concerned. The proposed regulations and consequence analysis were distributed for formal review in March 2005. The new regulations are expected to have consequences for most of the licensees, including more stringent requirements on site protection, building protection and access control. Transitional regulations will give the licensees the necessary time to implement the measures necessary at each facility.

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 are 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, as far as possible, to 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 2004

In 2004, the collective dose to the personnel at Swedish nuclear power plants was 6.4 manSv[9] which is less than in 2003. The result is on a par with the average value for the past five years, which is 9 manSv. The refuelling and maintenance outages were shorter at a few reactors due to the fact that the work progressed beyond expectations. Technical problems and unplanned repair work resulted in a somewhat higher dose than expected at a few reactors. No individual received a dose higher than 20 millisievert[10] (mSv).

The radiation levels in the facilities are generally low. They are decreasing at a few reactors, depending on specific operating conditions and zinc dosing, and are increasing at a few reactors as a result of re-oxidation of previously replaced or cleaned surfaces. The fuel defects that occurred in 2004 have not resulted in any severe radiation protection effects.

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[11]. 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. Furthermore, SSI cannot see any sign that the resources and the competence required to maintain a good radiation protection will decrease. However, it is of vital importance, for a continued positive development, that the radiation protection issues should be given a high priority by the nuclear power plants' operations managements.

A relevant supervisory and regulatory issue for SSI in the future is the decommissioning of nuclear facilities that has arisen through the decision to also close the last reactor at Barsebäck nuclear power plant. Another important supervisory issue concerns planned power increases. The plant owners have conducted studies into the possibility of uprating the power at certain reactors and SSI has conducted reviews of the power uprates at Ringhals 3 and Ringhals 1 during the year. Several studies are also expected to be submitted for review by SSI in the next year.

SSI also assumes that the modernization work with the aim of maintaining and improving safety at Swedish nuclear power plants will continue. Extensive modernization projects, including the rebuilding work at individual reactors to increase the reactor power, could

[9] manSv is the unit used for the collective dose which is the sum of individual doses.
[10] The limit of 20 mSv originates in the fact that the sum of an individual's radiation doses may not exceed 100 mSv in five consecutive years.
[11] Radiation dose from radioactive releases to a person living near a nuclear power plant may not exceed 0.1 mSv per year.

lead to higher collective doses in individual years at the reactors concerned. This means that SSI will have to prioritize supervisory work at such times.

Furthermore, SSI is following developments after the past years' organizational changes and an important aim of the inspections is to identify, at an early stage, any impact on the quality of the radiation protection work. This also includes resource and competence-related issues connected to employee redundancies and the nuclear power plants' use of external resources. The radiation dose received by the public from the Swedish nuclear power plants continues to be low. SSI continues to place requirements on continuous work at the nuclear power plants to further reduce radioactive releases by applying the Best Available Technique[12] (BAT). The measures that the nuclear power plants report in order to achieve the target values[13] indicate, in most cases, a satisfactory level of ambition.

Radiation Protection at the Nuclear Power Plants

Barsebäck Nuclear Power Plant
From the standpoint of radiation protection, work at Barsebäck nuclear power plant went well during 2004. The collective dose was about 0.4 manSv and no abnormal radiation doses were reported. The largest individual dose was 8.6 mSv and no-one with an committed effective dose was registered. The dose from service operation during shutdown at Barsebäck 1 was insignificant. The 2004 outage at Barsebäck 2 was not a normal refuelling and maintenance outage but only a refuelling outage including a number of minor inspection and service measures. The outage lasted 14 days, which is the shortest regular outage in the history of the plant. This explains the comparably low radiation dose for the year, which was 0.17 manSv.

At the beginning of 2004, indications were received that a minor fuel defect occurred at Barsebäck 2. The defect progressed in such a way that a decision was made to close down the reactor in February in order to replace the fuel element. The refuelling resulted in a radiation dose of 0.05 manSv.

Forsmark Nuclear Power Plant
In 2004, the collective dose at Forsmark nuclear power plant amounted to only 1.3 manSv which is related to the largest amount of electricity generated in the history of the plant, almost 25 TWh. The largest individual dose was 11 mSv. No-one with an committed effective dose was registered. During the year, the radiation protection was adequate and no incidents were reported. During the operating year, two minor fuel defects were detected at Forsmark nuclear power plant.

The annual refuelling and maintenance outages were short at Forsmark 1 and 2, but long and work-intensive at Forsmark 3. In terms of radiation protection, the outages went well without any serious deviation from scheduled plans. The outage at Forsmark 1 lasted for eight days and the collective dose was 0.16 manSv, which was well within the planned budget. The radiation levels in the reactor containment and in the turbine plants have increased by 20 to 35 per cent since 2003.

[12] "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.
[13] The target value must be seen as a measure of the release level that can be achieved during a certain period.

The outage at Forsmark 2 lasted for almost ten days and the collective dose was 0.22 manSv, which is insignificantly higher than the planned dose. The additional stage of work extended the outage by about two days. Generally seen, the radiation levels in the facility were only somewhat higher than the previous year.

The refuelling and maintenance outage at Forsmark 3 lasted for 38 days. During the outage, a large quantity of complex plant modifications was conducted including the installation of new low-pressure turbines. Furthermore, extensive testing of pipe connections to the reactor pressure vessel was conducted. The collective dose to the maintenance and service personnel was 0.6 manSv, which can be considered to be a very good result. The radiation levels at the reactor continue to be low following the chemical cleaning of reactor systems, which was conducted in 2001.

Oskarshamn Nuclear Power Plant
In 2004, the collective dose at Oskarshamn nuclear power plant was 1.6 manSv. During the year, the radiation protection operations were performed well. No abnormal radiation doses or severe incidents occurred during the past year. Two minor incidents involving internal contamination occurred in 2004. The committed effective dose was 0.5 mSv and 0.6 mSv, respectively. In 2004, at Oskarshamn 1 and Oskarshamn 3, two minor fuel defects occurred which did not need to be corrected.

The refuelling and maintenance outage at Oskarshamn 1 lasted for 38 days instead of the planned 31 days and the cause included the malfunction of a loading machine and repair work on a valve stem in the residual heat removal system. The collective dose was 0.8 manSv.

The refuelling and maintenance outage at Oskarshamn 2 lasted for 33 days and the collective dose was 0.3 manSv. The forecasted dose was 0.6 manSv, and the reason that it was lower than calculated was that the re-contamination after the previous year's outage, with decontamination and introduction of zinc dosing, led to better results than expected. The outage at Oskarshamn 3 lasted for 21 days and comprised normal maintenance and refuelling. The collective dose was 0.2 manSv.

Ringhals Nuclear Power Plant
The collective dose at the Ringhals nuclear power plant was 3.1 manSv. In recent years, the collective dose at all of Ringhals reactors has been satisfactory. No abnormal radiation doses or incidents occurred during the activity year. Ringhals 2 and Ringhals 3 were each operated with a fuel defect during parts of the year.

The refuelling and maintenance outage at Ringhals 1 was conducted for just over four weeks. The collective dose was 1.0 manSv. Examples of work conducted during the outage period included repair of a containment leak, replacement of a reactor recirculation pump and replacement of a pipe in the scram system. The work on enlarging two manholes in the reactor containment was the work that resulted in the largest dose.

At Ringhals 2, the refuelling and maintenance outage lasted for 26 days. The collective dose was 0.7 manSv. The radiation levels at Ringhals 2 are still low and a slight decrease has been measured since the previous year. During the outage, work was conducted on drawing cables in the containment and the reinforcement of pipelines from the pressurizer.

The refuelling and maintenance outage at Ringhals 3 lasted for two weeks. The collective dose was 0.1 manSv. In addition to the normal refuelling and testing, insulation around the reactor pressure vessel inlet nozzles was replaced. The radiation environment was satisfactory.

The refuelling and maintenance outage at Ringhals 4 lasted for just over three weeks. The collective dose was 0.7 manSv. In addition to refuelling and testing, the reactor pressure vessel was replaced during the outage. The radiation levels at Ringhals 4 are still low, although an increase has been observed since 2003.

Collective Dose

In 2004, the collective dose, including sub-contractors, at Swedish nuclear power plants was 6.4 manSv. The collective dose was lower than in 2003 (2003: 11 manSv; 2002: 13 manSv) and lower than the average, 9 manSv, for the past five years. During the year, 3,664 people received a registered effective dose. Diagram 6 shows the collective dose at the nuclear power plants for the period of 1994 to 2004.

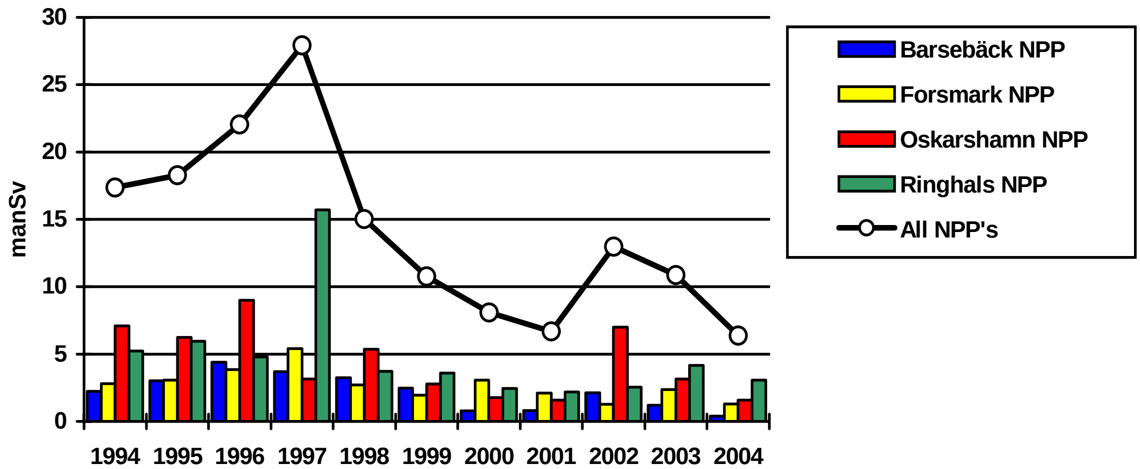


Diagram 6: *Annual collective dose (manSv) at Swedish nuclear power plants..*

The average dose to the personnel was 1.7 mSv in 2004 which was less than the previous year (2003: 2.7 mansv; 2002: 2.9 manSv). No individual received a radiation dose which exceeded the limits[14]. The highest registered dose in 2004 was 19.5 mSv. Two individuals were registered with an internal radiation dose as a result of the intake of radioactive substances. The committed effective dose was 0.5 mSv and 0.6 mSv, respectively. The reporting limit is 0.25 mSv. Table 1 presents the dose data from Swedish nuclear power plants for 2004.

[14] 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.

	Collective dose (manSv)			
Barsebäck	0.4	8.6	0.7	583
Forsmark	1.3	10.7	1.3	1037
Oskarshamn	1.6	18.1	1.7	935
Ringhals	3.1	19.5	1.9	1617

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

Table 1: *Individual doses at nuclear power plants in 2004.*

Environmental Qualification

Environmental qualifications of the Swedish nuclear power plants are in full progress. Ringhals AB was the first nuclear power plant to submit an application for permission under the Environmental Code for existing and expanded activities. The application covers the entire activity at the plant. Planned, expanded activities, such as power uprating at the nuclear power plant units are covered in the application.

The use of the Best Available Technique (BAT) is central to the Environmental Code. The use of BAT is also a requirement in SSI’s regulations concerning releases from nuclear facilities. The decisive question for SSI’s review of the application from Ringhals AB was whether the release-mitigating systems at Ringhals met the BAT requirements. According to the application, the planned power uprates will lead to increased radioactive releases. Increased releases are not compatible with the international obligations that Sweden has undertaken to reduce radioactive releases, primarily under the OSPAR convention for protection of the marine environment in the Northeast Atlantic. Furthermore, SSI considered that investments to increase reactor power should include costs for an improved environmental protection. In SSI’s opinion, Ringhals did not show that BAT will be applied to release-mitigating systems after a power uprate.

During the main negotiation, SSI presented what the authority considered to be BAT, which was based on the report where Ringhals had presented its view on BAT. Ringhals accepted SSI’s proposal for release-mitigating measures that successively need to be implemented over a five-year period.

With release reductions such as these, SSI came to the conclusion that BAT will be met. During 2005 and 2006, similar processes will be in question for OKG AB and Forsmarks Kraftgrupp AB. For Barsebäck AB, the environmental qualification process will focus on the decommissioning of the facility.

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 that are plant-specific, which take into account meteorological conditions and the local land and water environment. The measurement and reporting of releases are to be conducted in accordance with the regulations established by SSI, the *Swedish Radiation Protection Authority's Regulations on the Protection of Human Health and Environment from the Releases of Radioactive Substances from Certain Nuclear Facilities* (SSI FS 2000:12).

The regulations contain requirements that the licensees must report the reference values for the 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 referenced value is the operating experience and knowledge of the size of the release in a historical perspective.

In 2004, the reference values were exceeded in some 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 value is the level to which the radioactive substances released from a reactor can be reduced during a certain given time, under normal operating conditions. The release mitigating work is therefore controlled by the targets that have been established. According to the regulations, the licensees must report their aims and strategies with respect to mitigating releases in the short and in the long-term work.

The difference between the reference value and the target value is that a reference value shows the situation at the current time while a target value indicates what can be achieved in the future. In the annual reporting to SSI, the measures implemented or planned with respect to achieving the target value are specified. 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 defects
- Locating sources and creating routines to promote clean systems
- Low offgas flows, including with the help of oxygen dosing
- Modernization of the waste facility
- Administrative measures to reduce radioactive releases to water
- Reduction of the water flow load to the waste facilities by redirecting the water and repairing leaks
- Decision taken to introduce recombiners in Oskarshamn 1 (2007) and Oskarshamn 2 (2006)
- Reduction of releases of I-131 through control of operating filters without I-131 dosing

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

- Preventive sludge suction
- Frequent replacement of pre-filters for process water cleaning
- Partial sorting of water for cleaning and direct releases as well as re-direction of water from PWRs to the waste station at R1

Barsebäck Nuclear Power Plant
- Measures to reduce airborne activity in connection with pool cleaning
- Reduction of activity levels in release water
- Reduction of the quantity of released water

Forsmark Nuclear Power Plant
- Reduced releases of water from Forsmark 1 and 2, which means reduced total consumption of water, released water as well as released amount of radioactive substances
- Renovation of evaporators, separators and centrifuges to increase capacity to deal with the water
- Preventing foreign objects from entering the primary system and causing fuel damage

Diagram 7 shows the radiation doses that resulted from radioactive releases in 2004. 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 is also measured by SSI. Cesium-137 from the Chernobyl accident, which occurred in 1986, still dominates the samples taken in the control programme. A number of other radioactive substances can also be detected in the samples taken from the water environment in the vicinity of the nuclear power plants, including samples of algae and bottom sediment.

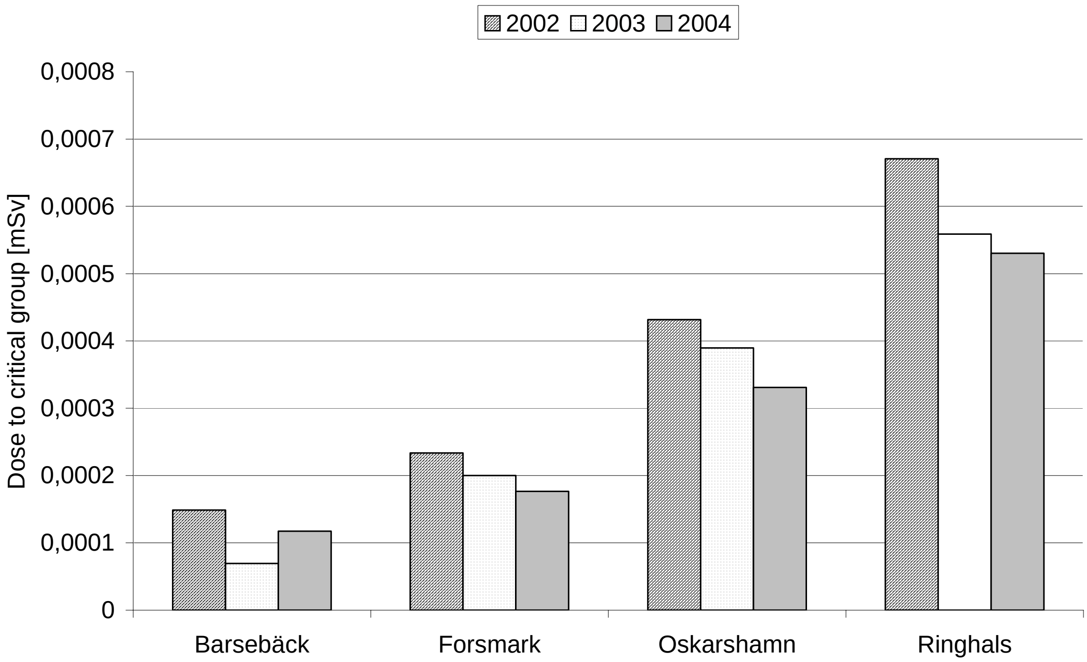


Diagram 7: *Radioactive releases to air and water from nuclear power plants in 2002-2004, shown as the dose to the critical group.*

8. WASTE MANAGEMENT

Treatment, Interim Storage and Disposal of Nuclear Waste

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

In addition to the treatment of normal operational waste, the following can be noted for 2004.

At Barsebäck, trial operation of a new facility for immobilizing ion-exchange resins in cement was started. The facility replaces the previous process with immobilizing in bitumen. SKI has intensified its supervision of Barsebäck’s facilities because of the Government’s decision also to close down the Barsebäck 2 reactor. The Ringhals group is supporting Barsebäck with competence and manpower.

At Forsmark, the low-pressure turbine in Forsmark 3 was replaced. A waste plan was prepared for handling the replaced turbine which has a total weight of about 1,000 tonnes.

At Oskarshamn, the facility for immobilizing of ion-exchange resins in cement has been modernized, and trial operation started during 2005. Internals from Oskarshamn 1 and 2 reactors have been treated for interim storage at CLAB or disposal in SFR. SKI has carried out an inspection to check how deviations in connection with the manufacturing of waste packages are handled. An initial disposal campaign was conducted at the new landfill at the site (see below).

At Ringhals, the reactor pressure vessel head from Ringhals 4 was replaced and the old head was placed in the interim waste facility. A project has been started for waste treatment in Studsvik of the steam generators which have been in interim storage for a long time at Ringhals.

During the year, the procedures for free-release (release of material for unrestricted re-use) were inspected by SSI. The inspections have shown that the nuclear power plants have an acceptable control of the waste that is being free-released.

During the year, waste was disposed of at the landfill at the site. The operating licence for the landfill at Ringhals has been renewed and now also covers the disposal of waste from Barsebäck. Forsmarks Kraftgrupp AB has previously submitted an application to expand their existing landfill. However, several technical issues on the design of the repository need to be clarified by Forsmarks Kraftgrupp for SSI to grant permission.

In 2004, SKB submitted a report concerning long-term safety at SFR:

- An updated nuclide inventory and a disposal plan
- An updated safeguards programme for SFR-1
- A needs analysis of research and development work for the analysis of safety or closure of SFR-1 and an account of how these are taken into account in the further work
- A preliminary plan for the closure of SFR-1 as a basis for supplementing the safety report
- A project plan for the development of models that can describe the impact complex formation on the repository's barrier performance.

In 2004, waste packages corresponding to a volume of 388 m^3 were deposited in SFR-1. Since startup, a total of 30,447 m^3 have been deposited. The total activity content in the waste is about $5.7 \cdot 10^{14}$ Bq.

During the year, two category two events occurred at SFR-1. In connection with the first event, a waste package was deposited which was based on incorrect information which had been introduced into SKB's waste database. In connection with the second event, overpressure occurred in the operating tunnel allowing air to leak out of the facility in an unplanned manner. None of these events is expected to have had any significant impact on safety.

SKB has conducted a project to develop a handbook for developing a type description for low and intermediate-level waste. The handbook will provide a new control document for the preparation and review of type descriptions and will replace the use of the "MAAS document", dated 1991, which was issued by SKI and SSI.

About 600 tonnes of scrap metal from the nuclear power plants were treated at the melting facility at Studsvik in 2004. No waste from the nuclear power plants was treated at the incineration facility at Studsvik.

In conclusion, the treatment, interim storage and disposal of nuclear waste at the nuclear facilities were conducted in a satisfactory way 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. In 2004, SKB's board made a strategic decision that SKB should investigate the conditions for possibly taking over the operation of CLAB under its own auspices. A consequence investigation is being prepared prior to a board decision on the issue in May 2005.

In 2004, four category two events, in accordance with SKIFS 1998:1 occurred. Two events concerned faults in directed ventilation in the reception and storage buildings, the other events concerned faulty testing valves in connection with performance testing of fire extinguishing pumps and a pipe in the cold water system which was not made leaktight after painting. All of the events were analyzed and the safety importance of the events was considered to be negligible.

During the year, 36 transport containers with a total of 112 tonnes of uranium in the form of spent fuel, and two transport containers with core components were received at CLAB.

There are a total of 20,424 fuel elements at CLAB. These are distributed as follows:

BWR	17 894
PWR	2 091
MOX	217
Ågesta	222

CLAB's pools contain a total of 123 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.

The new storage building (CLAB stage 2) has, in principle, been completed during the year and only minor adjustments remain. The work on preparing the new storage compartment for operation has been intensive, as has SKB's work on completing remaining items before an application for permission to start up the new storage compartment is submitted. SKI has closely followed this work.

In December, SKB submitted an application for an expanded operating licence for CLAB which includes CLAB stage 2. SKI has requested that SKB should supplement the application, including a new and updated version of the final safety report.

Safeguard controls at CLAB have not identified any deficiencies. During the year, Euratom and the IAEA conducted four safeguards inspections and a physical inventory.

9. EMERGENCY PREPAREDNESS

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

From November 2003 to May 2004, SKI conducted inspections at all nuclear power plants to determine whether the licensees meet the requirements in the Swedish Nuclear Power Inspectorate’s regulations concerning safety in nuclear facilities with respect to information transfer to SKI during the first hour after a process event has occurred. In SKI’s view, all nuclear power plants that were inspected fulfilled the requirements. However, possibilities for improvement were found for all of the licensees. During the inspections, SKI also found a number of examples of good-practice and these were spread to all of the nuclear power plants. During subsequent visits, SKI found that the licensees had conducted the improvements that SKI indicated, and that they also developed their emergency preparedness in other ways.

During the last year, the work on SKI’s safety regulations, SKIFS 2004:1, has been completed. These regulations include requirements on emergency preparedness. SKI has provided impetus for the safety work by holding a meeting with the licensees to draw their attention to the clarifications that have been introduced and to explain the way in which SKI intends to follow up the requirements in 2005.

Work on promulgating SSI’s regulations for emergency preparedness at certain nuclear facilities to progress as planned during the year. The regulations were approved in April 2005 and will enter into force in January 2006.

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

During the autumn, the national nuclear exercise, HAVSÖRN, was conducted with the county administrative board in Uppsala as the central actor. The emphasis of the exercise was learning and the focus was communication and co-operation between the actors. The exercise lasted two days and was divided into an acute phase during the first simulation day, and a post-release phase on the second day. SSI participated on both days. SKI participated on the first day with all its functions, and on the second day only with the information function. The objective regarding the authority’s participation was met.

SKI and SSI also participated in minor exercises at the nuclear power plants, as well as in training measures. SKI took the initiative and conducted training for the police and the nuclear power plants, to improve co-operation in an event of an antagonistic action.

"The Generalen" information system for documentation and exchange of operational crisis information has been further developed and can now also supply an organization's public website with crisis information. In addition to the authorities that were previously connected to the system, agreements have been reached with three of the nuclear power plants to join the system.

During the year, work between the authorities in the co-operation area of the Proliferation of Hazardous Substances, Protection, Rescue and Care and Technical Infrastructure has continued. In the area of the Proliferation of Hazardous Substances, a report has been prepared as a basis for risk and vulnerability analyses, and the prioritization of further work was clarified. The authorities have also each prepared risk and vulnerability analyses.

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