OPERATING EXPERIENCE FROM SWEDISH NUCLEAR POWER PLANTS
THE NUCLEAR TRAINING AND SAFETY CENTER, KSU AB

KSU AB is the Swedish nuclear utilities’ centre for simulator training of the operators of the Swedish nuclear power plants. The company was founded in 1972 and is jointly owned by Barsebäck Kraft AB, Forsmarks Kraftgrupp AB, OKG AB and Ringhals AB.

KSU’s headquarters are located in Studsvik and there are local branches in Ringhals, Forsmark and Oskarshamn. The company employs about 160 persons, of whom 20 are located at the local branches.

Since the beginning more than 1000 million Swedish crowns have been invested in training simulators and auxiliary equipment. The investment rate has during recent years on the average been about 70 million crowns per year.

A considerable part of the competence of the Swedish nuclear power operators is created and maintained by the KSU training activities. 800 operators are trained each year during about 250 weekly courses using full scope simulators corresponding to the main control room of the power plants. KSU’s training programmes also include general operational training and extended theoretical education at university level.

KSU analyses operational experiences from nuclear power plants all over the world and shares the results with the Swedish nuclear power plants. The company also produces and maintains textbooks and other documentation necessary for the company’s training programmes.

The Analysis Group, supported by KSU, informs society’s decision-makers and creators of public opinion on matters related to nuclear power safety, ionising radiation and comparison of risks/environmental influences of different energy sources.

WANO

WANO (World Association of Nuclear Operators) is an international organisation for increasing the safety and reliability of nuclear power by mutual exchange of operational experience. All utilities having a nuclear power programme are members. KSU holds the WANO membership for the Swedish nuclear utilities. WANO worldwide is organised in four regions with regional offices in Atlanta, Moscow, Paris and Tokyo. In addition there is an administrative office in London. KSU belongs to the WANO Paris region.
From a safety point of view, 2000 was - as were previous years - satisfactory. Total electricity production from the Swedish nuclear power stations amounted to 54.2 TWh, which was over 20% less than the 70.2 TWh produced in 1999. The two main reasons for the reduction were the closure of Barsebäck 1 on 1st December 1999, and the cutback in output from all reactors due to the particularly good availability of hydro power in 2000. Some reactors were even shut down completely as a result of the low power demand, which has not happened previously.

The quantity of unutilised production capacity as a result of these reductions amounted to 11.6 TWh. Coastdown operation prior to the annual overhaul shutdowns, which makes better use of the fuel, represented a further 2.1 TWh of unutilised capacity.

The average energy availability of the three PWRs at Ringhals was 82.0%, while that of the eight BWRs was 84.2%. Forsmark 3, Ringhals 3 and Oskarshamn 3 all had average availabilities of over 90%.

Of five events with safety implications that occurred in the plants during the year, three are described under Special Reporting. One of them relates to the crack indications in welds that were found in an American PWR in the autumn, and which were subsequently also found in Ringhals 4.
ELECTRIC POWER IN SWEDEN 2000

Total electricity production from all the Swedish nuclear power plants in 2000 amounted to 54.2 TWh, i.e. considerably less than the previous year’s 70.2 TWh. The reduction was due to the good availability of hydropower during the year and the closure of Barsebäck 1 on 1st December 1999. The country’s total electrical energy consumption amounted to 144.7 TWh, an increase of 1.6 % over 1999.

The particularly good availability of water for hydropower production resulted in substantial power reductions from the nuclear power plants due to low power demand during the year, equivalent to 11.6 TWh of unused capacity.

Hydropower production amounted to 76.9 TWh, or 20 % more than during a statistically average climatic year, and the highest value of absolute annual production to date. The previously highest production was 73.3 TWh, which occurred in 1993. 8.4 TWh were produced by conventional, mostly bio fuelled combined cycle plants. Wind power production increased by 0.1 TWh to 0.4 TWh.

Total electricity production in Sweden was 139.9 TWh, a reduction of 8.5 % relative to 1999. Exports amounted to 13.4 TWh and imports to 18.2 TWh, i.e. a net import of 4.8 TWh, which can be compared with the previous year’s net export of 7.3 TWh.

The above figures are based on preliminary production statistics. A detailed presentation of Sweden’s production and use of electrical energy is given in the Annual Report from Svensk Energi.
Nuclear Power Plant History

Comparison of Reactor Types - BWR, PWR

Unit Capability Factor, %

WANO comparison data 1997-1999, NPPs worldwide

BWR

- 81,9 % = Mean value
- 85,2 % = Median value

PWR

- 81,4 % = Mean value
- 84,4 % = Median value

Number of Reactor Scrams

WANO comparison data 1999, NPPs worldwide

BWR

- 0,7 = Mean value
- 0,0 = Median value

PWR

- 0,7 = Mean value
- 0,0 = Median value

Collective Radiation Exposure, manSievert

WANO comparison data 1997-1999, NPPs worldwide

BWR

- 1,99 manSv = Mean value
- 1,67 manSv = Median value

PWR

- 1,13 manSv = Mean value
- 1,00 manSv = Median value

Note

The WANO values for 2000 were not available when printing this report.
**Comparison of Reactor Generations**

**Classification** Each curve represents a specific reactor design or "family" which group by group corresponds to a stage in reactor technology development and safety concept. See table on page 4.

<table>
<thead>
<tr>
<th>BWR</th>
<th>PWR</th>
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<td><strong>Generation 1</strong></td>
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<td>Barseback 1*</td>
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* There are no values for Barseback 1 as from year 2000 on the pages 5-8. The reactor was permanently shutdown on the 1st of December in 1999.

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**BWR**

**Unit Capability Factor, %**

WANO comparison data 1997-1999, NPPs worldwide

- 81.9% = Mean value
- 85.2% = Median value

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**PWR**

**Unit Capability Factor, %**

WANO comparison data 1997-1999, NPPs worldwide

- 81.4% = Mean value
- 84.4% = Median value

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**BWR**

Unit capability for Swedish BWRs was once again high compared to the international average for the period 1997-1999. Generation 4 reached 93.1%.

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**PWR**

Unit capability for Swedish PWRs was somewhat higher compared to the international average for the period 1997-1999.

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**Note**

The WANO values for 2000 were not available when printing this report.
The scrams shown in the histograms are unplanned automatic scrams at criticality according to the WANO definition. The WANO values for 2000 were not available when printing this report.

**BWR**

The 2000 average for Swedish BWRs was 0.8 scrams. An international comparison for 1999 shows that the Swedish BWRs - with an average value of 1.2 scrams - exceeded the WANO average of 0.7.

**PWR**

Two scrams occurred during the year at one of the Swedish PWRs. An international comparison for 1999 shows that the Swedish PWRs - with an average value of 0.0 scrams - were below the WANO average of 0.7.
COMPARISON OF REACTOR GENERATIONS

BWR

Collective Radiation Exposure, manSievert

WANO comparison data 1997-1999, NPPs worldwide

The 2000 average for Swedish BWRs was 0.85 manSv. An international comparison for 1999 shows that the Swedish BWRs - with an average value of 1.12 manSv - were below the corresponding international WANO values of 1.99 for 1997-1999.

PWR

Collective Radiation Exposure, manSievert

WANO comparison data 1997-1999, NPPs worldwide

The 2000 average value for Swedish PWRs was 0.43 manSv, i.e., the same low value as for 1999. The WANO value was 1.13 manSv for 1997-1999.

Note

The WANO values for 2000 were not available when printing this report.
In accordance with a political decision, Barsebäck 1 was closed down on 1st December 1999. All the fuel was removed from the reactor core during the start of 2000 and placed in fuel ponds: by 28th February, all the fuel had been transferred.

As it is unlikely that the reactor will be reloaded, the safety requirements for the unit have changed. The technical specifications have therefore been modified to suit the new conditions, and came into force on 22nd June 2000. However, the plant is still regarded as a nuclear facility.

The time plan for the removal of nuclear fuel from the station foresees the fuel ponds being emptied by the end of 2001. It is planned to use new fuel and fuel with a low burnup fraction in Barsebäck 2. Other fuel will be transported to the intermediate storage facility for highly active fuel, CLAB, at Oskarshamn, where it will be kept while awaiting a decision on final storage.

In the short term, the work which is at present in progress at Barsebäck 1 is aimed at maintaining the nuclear safety requirements as long as the fuel remains in the plant. In addition, other work is in progress on conservation of systems and system parts, so that they can later be used as full integrity spare parts. Parts of the plant are being decontaminated in order to reduce radiation levels.

In the longer term, preparations are being made for sometime future demolition of the plant. Investigations are also being made into how systems and system parts - mainly from the electrical equipment in Barsebäck 1 - can be used further to improve safety at Barsebäck 2.

Events

On 17th October, it was found that the periodic testing of the activity monitoring equipment in the main chimney stack had been incorrectly performed both on unit 1 and 2. The equipment had been replaced and complemented during the 1999 annual refuelling outage. This event has been preliminarily rated as a Level 1 event on the INES scale.

Barsebäck 1 started commercial operation in 1975. It is a boiling water reactor (BWR) manufactured by ABB Atom and of the same generation as Barsebäck 2 and Oskarshamn 2. The thermal power output was 1800 MW and the electrical output 600 MW net.

The Reactor Containment is designed for a pressure up to 0.7 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consisted of 444 fuel elements. The total fuel cycle was five years on average. 109 control rods and the water flow from four external recirculation pumps were used to control the reactor power.

The Turbine Plant consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. Both the stator and the rotor of the generator are water-cooled.

The Electric Power System consists of two separate trains. The unit is connected to the national high voltage grid through separate 400 and 130 kV lines. Emergency power is supplied by two diesel generators and two gas turbines (shared with Barsebäck 2).
Events of Importance to Unit Capability and Safety

4th January: Power reduction to 55% for quarterly testing and location of a damaged fuel bundle.

25th March: Power reduction due to low power demand. Such reductions continued for much of the year.

8th April: Reduction to cold shutdown reactor for repair of a valve in the feed water system.

12th May: The unit was shut down due to good availability of hydro power. The opportunity was taken to check crack indications in the core spray mounts. The results were successful. At the same time, the fuel was examined after damage had previously been found, and various items of maintenance work and some of the planned plant changes were carried out. The unit remained shut down until 1st August, when ownership of Barsebäck Kraft AB was transferred to Ringhals AB. From that date, and until the planned annual refuelling outage, the plant was operated at full power.

Annual refuelling outage, 24th August – 20th September

The annual refuelling outage was planned to take 24 days, but actually took 27 days. Maintenance, various work in the plant and scheduled inspection during the shutdown were all carefully planned. In addition to the annual refuelling, 38 plant modifications were made, including:

- Installation of equipment for temperature measurement in the reactor core.
- Improved fire separation.
- Improved discharge venting in the reactor and turbine building.
- Work on the boron injection system.

Inspection found foreign objects on nine of the fuel bundle bottom plates. Fuel bundles that were to be re-used were successfully cleaned.

Instrumentation for all systems has been checked. This work has included adjustment of the pressure switches that isolate the reactor pressure vessel in the event of a leak.

The collective dose during the outage was 0.62 mSv, which was 0.17 mSv lower than budgeted. In combination with the lower measured levels of activity in the plant, this shows that the zinc dosing of the feed water that was introduced in 1998 has given the expected results.

During the Year

- There have been extensive output reductions during the year, as the availability of hydro power has been very high. This has meant that 1663.8 GWh of production capacity, equivalent to about 113 days at full power, have not been utilised.

- There was no coastdown operation during the year.

SCRAMS

18th September: The reactor temperature was being raised prior to hot control rod drive tests. When working on the hydraulic system for the control rod drives, a valve in the shutdown reactor cooling system was closed. When the valve was re-opened, cold water entered the reactor, causing a rapid rise in power which resulted in an automatic scram.
Events

- When, on 21st February, revising the maintenance procedures for pressure switches that are intended to isolate the reactor pressure vessel, an error was found in the calibration procedure. This was rated as a Level 1 event on the INES scale.

- On 8th April, while reducing output to the cold shutdown reactor state, a manual change-over from the station transformer to the starting transformer was carried out prior to opening the generator circuit-breaker. A 6 kV breaker malfunctioned, causing the closing coil on the breaker to burn out. The reason for failure of the breaker to close was found to be dried grease, preventing the coil from operating properly.

- On 17th October, it was found that the periodic testing of the activity monitoring equipment in the main chimney stack had not been correctly performed on units 1 and 2. See the description under unit 1 on page 9.

Barsebäck 2 started commercial operation in 1977. It is a boiling water reactor (BWR) manufactured by ABB Atom and of the same generation as Barsebäck 1 and Oskarshamn 2. The thermal power output is 1800 MW and the electrical output is 600 MW net.

The Reactor Containment is designed for a pressure up to 0.7 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consists of 444 fuel elements. The total fuel cycle is five years on an average. 109 control rods and the water flow from four external recirculation pumps are used to control the reactor power.

The Turbine Plant consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. Both the stator and the rotor of the generator are water-cooled.

The Electric Power System consists of two separate trains. The unit is connected to the national high voltage grid through separate 400 and 130 kV lines. Emergency power is supplied by two diesel generators and two gas turbines (shared with Barsebäck 1).
The operational year is characterized by the most extensive load-following operations since the unit was commissioned.

29th January: Power stability measurements.

3rd–30th March: Power reduction.

20th April–19 July: Power reduction.

23rd May: Start of coastdown operation.

19th July–6th August: Reduction to shutdown reactor due to low power demand.

Annual refuelling outage: 6th August–22nd September

The refuelling outage was planned to take 49 days. Most of the work was identical with that for Forsmark 2 that had been carried out in May and June. Replacement of the core grid and the core shroud meant that all the fuel in the core had to be removed. Cracks were found in one turbine rotor, and a spare rotor was installed, which extended the outage time for the turbines. Nevertheless, the total outage time was held to just under 47 days.

The following work has been carried out, in addition to the regular annual work of refuelling, preventive maintenance and tests:

The reactor part

- The fuel assemblies in the reactor pressure vessel are enclosed in an inner encasement known as the core shroud, within which the fuel assemblies are kept in position by a grid, the core grid. The core grid and the core shroud are made of stainless steel. Neutron irradiation means that these components become brittle when aging. This year, both the core shroud and the core grid were replaced, as they were nearing the ends of their lives. They have been replaced by fully forged designs, with a minimum number of welds, which reduces the risk of stress corrosion and the need for regular testing.

- The original stainless steel pipes in the residual heat removal system were made of a material with a high carbon content. Pipes and valves have been replaced by components made of a material less susceptible to stress corrosion.

- About 40 control rods have been replaced.

- A new inverter drive system for the main circulation pumps has been installed. It provides a means of energy storage.

- Crack indications were found in two pipe joints in the low-pressure core cooling system. The sections of pipes and a joint in the reactor water treatment system were changed.

- A number of neutron flux detectors in the reactor core were replaced.

The turbine part

- Both high pressure turbines were dismantled for overhaul. A leaking joint flange in the steam inlet pipe was found.

- The low pressure turbines were showing erosion damage to the blade carriers and sealing ring mounts, and a number of damaged blades were replaced. Ultrasonic inspection of the blades revealed several indications of cracks. It was decided to replace all the rotors in this turbine plant: rotor replacements in the other turbine are planned for next year’s outage.

- The stator and the exciter rotor of one of the generators were replaced as planned. After these replacements, both generators are now set up for many further years of operation.

- Modern digital control and supervisory systems have been installed for the turbines and condensate cleaning plant. This has affected the turbine operators’ methods of working: they now use display screens and large-screen projectors in the control room.

- Extensive changes have been made to the process and control equipment used in the power and governing oil systems.
The collective dose during the outage was 0.94 manSv, which was 0.29 manSv less than forecast.

**DURING THE YEAR**
- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 1467.3 GWh of production capacity, equivalent to almost 63 days at full power, have not been utilised.
- Coastdown operation at the end of the operating period meant that a potential 82.7 GWh (almost 4 days at full power) of production capacity was not utilised, in the interests of good fuel husbandry.

**SCRAMS**
There were no scrams with a critical reactor during the year.

**EVENTS**
No events of importance to safety occurred during the year.

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**Forsmark I** started commercial operation in 1980. It is a boiling water reactor (BWR) manufactured by ABB Atom and of the same generation as Forsmark 2. The thermal power output is 2928 MW and the electrical output is 968 MW net.

**The Reactor Containment** is designed for a pressure up to 0.46 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

**The Reactor Core** consists of 676 fuel elements. The total fuel cycle is five years on average. 161 control rods and the water flow from eight internal recirculation pumps are used to control the reactor power.

**The Turbine Plant** consists of two separate trains. Each train consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. Both the stator and the rotor of the generator are water-cooled.

**The Electric Power System** consists of four separate trains. The unit is connected to the national high voltage grid through separate 400 and 70 kV lines. Emergency power is supplied by four diesel generators.
24th January: Output power was reduced because a malfunctioning control rod decreased the reactor core’s load margins.

7th February: Coastdown operation started.

4th–26th March: Power reduction.

19th–28th April: Power reduction due to low power demand: operation with only one turbine from 19th April. Further power reduction from 28th April when the other turbine and the reactor were shut down.

Annual refuelling outage, 2nd May–28th June

The annual refuelling outage started on 2nd May, and was planned to take 52 days. It in fact took 57 days, including a two-day break in the work for the mid-summer weekend. Most of the additional time was due to problems with fitting four control rod guide tubes in the reactor pressure vessel and with testing the turbine governor and process control after modification.

The following larger items of work have been carried out, in addition to the regular annual work of refuelling, preventive maintenance and tests:

The reactor part

- The fuel assemblies in the reactor pressure vessel are enclosed in an inner encasement known as the core shroud, within which the fuel assemblies are kept in position by a grid, the core grid. The core grid and the core shroud are made of stainless steel. Neutron irradiation means that these components become brittle when aging. This year, both the core shroud and the core grid were replaced, as they were nearing the ends of their lives. They have been replaced by fully forged designs, with a minimum number of welds, which reduces the risk of stress corrosion and the need for regular testing.

- The original stainless steel pipes in the residual heat removal system were made of a material with a high carbon content. Pipes and valves have been replaced by components made of a material less susceptible to stress corrosion.

- A new inverter drive system for four of the main recirculation pumps has been installed. It provides means of energy storage.

- The software in the existing control equipment has been updated.

- A computerised surveillance system monitoring systems important to safety has been installed.

The turbine part

- Modern digital control and supervisory systems have been installed for the turbines and condensate cleaning plant. This has affected the turbine operators’ methods of working: they now use display screens and large-screen projectors in the control room.

- Extensive changes have been made to the process and control equipment used in the power and governing oil systems.

The collective dose during the outage was 1.31 manSv, which was 0.07 manSv more than forecast.

7th July – 30th August: Power was reduced to 50% due to low power demand. One of the turbines was vibrating, and was therefore taken out of operation for rebalancing. When it was returned to service, the other turbine was shut down for repair of leakage in the generator stator cooling system.

1st–30th September: Power reduction.

26th September – 3rd November: Reactor output was limited to 98% while waiting for new limiting values for fuel dry-out.

7th – 8th December: The plant was shut down for discharge of a damaged fuel element.

27th December: When testing the mobility of the control rods a rod was separated from the drive. The control rod and its symmetry rod were inserted.
DURING THE YEAR

- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 1052.1 GWh of production capacity, equivalent to about 45 days at full power, have not been utilised.

- Coastdown operation at the end of the operating period meant that a potential 210.3 GWh (about 9 days at full power) of production volume was not utilised, in the interests of good fuel husbandry.

SCRAMS

There were no scrams during the year.

EVENTS

No events of importance to safety occurred during the year.

Forsmark 2 started commercial operation in 1981. It is a boiling water reactor (BWR) manufactured by ABB Atom and of the same generation as Forsmark 1. The thermal power output is 2928 MW and the electrical output is 964 MW net.

The Reactor Containment is designed for a pressure up to 0.46 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consists of 676 fuel elements. The total fuel cycle is five years on average. 161 control rods and the water flow from eight internal recirculation pumps are used to control the reactor power.

The Turbine Plant consists of two separate trains. Each train consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. Both the stator and the rotor of the generator are water-cooled.

The Electric Power System consists of four separate trains. The unit is connected to the national high voltage grid through separate 400 and 70 kV lines. Emergency power is supplied by four diesel generators.
24th March: Coastdown operation started.


1st–30th April: Power reduction due to low power demand. Minor fuel damage was found. Vibration on three of the eight main recirculation pumps resulted in power reduction.

23rd–27th June: A power inverter for one of the main recirculation pumps failed due to a cable failure.

30th June: The plant was stopped due to low power demand over a week before the date of the planned annual shutdown. Opportunity was taken during shutting down to test transfer to nuclear island operation: a turbine throttle valve opened when it should not have done during the test, and caused a reactor scram.

Annual refuelling outage, 8th–24th July

The annual refuelling outage was planned to take 13 days, but in fact took 16 days. This was the shortest shutdown for Forsmark 3 to date. A piece of stainless steel bar was found in one of the control rod guide tubes: it had come away from one of the three cages protecting thermocouples in the lower part of the reactor pressure vessel. A similar event occurred in 1987, and the discovery again this year meant that the remaining cages were removed, which extended the shutdown by about three days. After synchronising the plant with the grid and performing tests, it was shut down and placed on 24-hour starting notice due to low power demand.

In addition to the regular annual work of refuelling, preventive maintenance and tests, the following larger items of work were carried out:

The reactor part:

- A leaking fuel bundle was replaced in the reactor core.
- Three measurement probes and drive motors in the neutron flux measuring systems' starting channels were replaced.
- Ten control rods were replaced.
- New modified control valves have been fitted to four of the steam isolation valves.
- Fire detectors of the ion chamber type in areas not accessible during operation were replaced by optical detectors.

The turbine part:

- Two particle separators were fitted in the feed water system between the feed water pumps and the high pressure preheaters in order to prevent foreign objects entering the reactor and damaging the fuel.
- One of the three feed water pumps has been modernised: it is now controlled electro-hydraulically, in the same way as for the turbine throttle valves.
- One of the feed pump drive motors failed at the end of the outage.

The collective dose during the refuelling outage was 0.40 mSv, which was 0.06 mSv less than forecast.

24th July–30th August: The unit was shut down, on 24 hours' notice to start, due to the country's power situation. Output was increased to 65% on 7th August, and to 90% on 30th August.

12th–13th September: Vibration on four of the eight main circulation pumps resulted in an output power reduction.

10th–17th October: A low pressure drain pump was shut down for repair.
DURING THE YEAR

- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 1090.8 GWh of production capacity, equivalent to about 39 days at full power, have not been utilised.

- Coastdown operation at the end of the operating period meant that a potential 512.2 GWh (almost 19 days at full power) of production capacity were not utilised, in the interests of good fuel husbandry.

SCRAMS

▼ 30th June: Transfer to nuclear island operation was tested when reducing output prior to the annual refuelling outage. This involves disconnection from the 400 kV grid, so that the generator supplies the station's power requirements. During the changeover, a turbine throttle valve started to open spuriously, which caused such a pressure fluctuation that the reactor scammed.

EVENTS

No events of importance to safety occurred during the year.

Forsmark 3 started commercial operation in 1985. It is a boiling water reactor (BWR) manufactured by ABB Atom and of the same generation as Oskarshamn 3. The thermal power output is 3300 MW and the electrical output is 1155 MW net.

The Reactor Containment is designed for a pressure up to 0.6 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consists of 700 fuel elements. The total fuel cycle is five years on average. 169 control rods and the water flow from eight internal recirculation pumps are used to control the reactor power.

The Turbine Plant consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. The stator of the generator is water-cooled and the rotor is hydrogen-cooled.

The Electric Power System consists of four separate trains. The unit is connected to the national high voltage grid through separate 400 and 70 kV lines. Emergency power is supplied by four diesel generators.
12th January: Reduction to hot shutdown reactor in order to seal an oil leak in the condenser.

21st January: Reduction to hot shutdown reactor for repair of a toothed ring used by the turbine's speed sensor.

14th February: Power reduction due to faulty operation of a manual control device, resulting in closure of a valve dealing with drainage from the turbine reheater.

16th April: Power reduction due to air leakage from a connection, causing a valve dealing with drainage from the turbine reheater to close.

25th March: Power reduction due to low power demand. Load-following operations then occurred at intervals during the rest of the year.

15th-18th May: Planned shutdown for replacement of brushes on the generator and tightening a cover on the reheater. During restart on 17th May a reactor scram occurred (see below).

3rd June: Start of coastdown operation.

25th June: Reduction to hot shutdown reactor for repair of a crack in an oil pipe in the turbine governor system.

Annual refuelling outage, 19th August–16th September

The good availability of electricity meant that power reduction prior to the annual refuelling outage could be brought forward by about seven days. The outage was planned to take 22 days, but was extended by six days, mainly due to work on a leak in the reactor vessel level measurement pipes. In addition to the regular annual work of refuelling, preventive maintenance and tests, the following larger items of work have been carried out:

The reactor part
- Replacement of control rod drives.
- Replacement of a main recirculation pump.
- Installation of separate power supply to the main steam valves' control valves.

The turbine part
- Repair of the high pressure feed water preheaters.
- Reconditioning of the condenser vacuum-breaker.
- Replacement of a hydrogen seal in one of the generators.

The collective dose during the refuelling outage was 0.46 manSv, which was just less than budgeted.

DURING THE YEAR

- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 280.3 GWh of production capacity, equivalent to about 25 days at full power, have not been utilised.

- Coastdown operation meant that a potential 129.9 GWh (about 12 days at full power) of production capacity was not utilised, in the interests of good fuel husbandry.

SCRAMS

▼ 17th May: A fault in the reducer station throttle valves caused the reactor power to rise so rapidly that it initiated a scram.

▼ 12th September: The neutron flux is normally monitored by three separate channels. Control mode is 2 out of 3, i.e. if any two channels detect a higher neutron flux than is permitted, a scram will be initiated. On this occasion, one neutron flux monitoring channel was disengaged whilst performing local criticality measurements. This meant that a scram would be initiated if only one channel detected excessive neutron flux. Unfortunately, this occurred when a control rod was inserted into the core during the criticality measurements, and the reactor was scrammed.
EVENTS

- Oskarshamn 1 and 2 share two gas turbine backup power units. On 4th July, when Oskarshamn 2 was testing the starting sequence of one of the units, a protection circuit on the gas turbine generator transformer tripped when the large pumps powered from the transformer were started. This was rated as a Level 1 event on the INES scale. Further details can be found in the section on Special reporting.

Oskarshamn 1 started commercial operation in 1972. It is a boiling water reactor (BWR) manufactured by ABB Atom. The thermal power output is 1375 MW and the electrical output is 445 MW net.

The Reactor Containment is designed for a pressure up to 0.45 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consists of 448 fuel elements. The total fuel cycle is five years on average. 112 control rods and water flow from four external recirculation pumps are used to control the reactor power.

The Turbine Plant consists of one radial flow high-pressure turbine with two counter rotating shafts. On each shaft there are one single and two dual axial flow low-pressure turbines. The unit has two generators, one on each shaft. The stators of the generators are water-cooled and the rotors are hydrogen-cooled.

The Electric Power System consists of two separate trains. The unit is connected to the national high-voltage grid through separate 130 kV lines. Emergency power is supplied by two diesel generators and two gas turbines (shared with Oskarshamn 2).
Oskarshamn 2

**Events of Importance to Unit Capability and Safety**

17th March: Power reduction due to low power demand. Load-following operations then occurred at intervals during the rest of the year.

**Annual refuelling outage, 26th May–17th July**

The good availability of electricity meant that the unit could be shut down for annual refuelling outage on 26th May, one day earlier than originally planned. The shutdown was planned to take 33 days, but was extended to 52 days as a result of inspection and repair of damage to the supports for the reactor core spray system in the reactor pressure vessel.

In addition to the regular annual work of refuelling, preventive maintenance, inspection and testing, the following larger items of work were carried out:

**The reactor part**
- Shortcomings discovered in the boron system were rectified.
- Extensive testing of two of the main cooling water pumps.
- Major pressure testing of the reactor containment.
- Alteration of the power supply system to the auxiliary feed water pumps.

**The turbine part**
- Fitting of new endshell seals in the reheaters.
- Alteration of the turbine cooling system.

The collective dose during the outage was about 0.87 manSv, which was about 0.17 manSv less than forecast.

**During the Year**

- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 546.6 GWh of production capacity, equivalent to about 36 days at full power, have not been utilised.
- There was no coastdown operation during the year.

**SCRAMS**

▼ 26th May: The generator circuit-breaker was tripped when shutting down the unit for the annual refuelling outage. Dried-out grease in the circuit-breaker auxiliary contacts resulted in delay in indication that the breaker had changed state. The control system interpreted this as a disturbance, and initiated a turbine trip and a reactor scram.
Events

- When the starting sequence of one of the gas turbines was being tested on 4th July, the gas turbine transformer circuit-breaker was tripped by protective circuitry responding to the starting current of large pumps. The protective equipment was found to be incorrectly connected, interpreting the pumps' starting current as a fault current. The protective equipment for the two gas turbine transformers was connected in the same way, which meant that two independent power supplies were not ready for operation. The event was rated as a Level 1 event on the INES scale. For further information, see section Special reporting.

**Oskarshamn 2** started commercial operation in 1975. It is a boiling water reactor (BWR) manufactured by ABB Atom and of the same generation as Barseback 1 and 2. The thermal power output is 1800 MW and the electrical output is 605 MW net.

The Reactor Containment is designed for a pressure up to 0.5 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consists of 444 fuel elements. The total fuel cycle is five years on average. 109 control rods and the water flow from four external recirculation pumps are used to control the reactor power.

The Turbine Plant consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. The stator of the generator is water-cooled and the rotor is hydrogen-cooled.

The Electric Power System consists of two separate trains. The unit is connected to the national high voltage grid through separate 400 and 130 kV lines. Emergency power is supplied by two diesel generators and two gas turbines (shared with Oskarshamn 1).
**Oskarshamn 3**

**Events of Importance to Unit Capability and Safety**

![Graph showing daily average power, unit capability, and utilization]

27th January: The reactor was scrammed manually after a battery-backed alternating current distribution system was mistakenly de-energised when restoring operation after maintenance work. The loss of power resulted in a confused display of both reactor and turbine information in the control room.

25th February: Power reduction due to low power demand. Load-following operations then occurred at intervals during the rest of the year.

4th July: Coastdown operation was started.

18th July: Power reduction to zero output due to low power demand. The generator was disconnected from the grid, enabling preparations for the annual refuelling outage to be started about five days earlier than planned.

Annual refuelling outage, 21st July–11th August

The refuelling outage period took 19 days and 5 hours, i.e. about 2.5 days longer than planned. Work in the reactor hall on fuel and control rods dominated the year's work: modifications and maintenance were very limited.

In addition to the regular annual work of tests and refuelling, the following larger items of work were carried out:

**The reactor part**
- One of the main recirculation pumps was reconditioned.
- The pressure relief system and the outboard steam isolation valves have been fitted with new control valves.
- The position sensors for the feed water valves have been modified.
- Work on preventing the build-up of non-condensable gases in the reactor vessel level monitoring system has been concluded.

**The turbine part**
- The tube bundles in the reheater were tightness tested without adverse results. 21 tubes were plugged as a preventive measure.
- A pump in the main cooling water system was replaced by a spare unit.

The collective dose during the outage was 0.23 manSv, which was 0.16 manSv less than forecast.

7th–14th October: Shutdown to cold shutdown reactor state for repair of control valves for the main steam isolation valves.

28th October: Power reduction for connection of equipment to protect the generator and generator transformer against geomagnetic currents.

**During the year**

- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 1946.0 GWh of production capacity, equivalent to about 68 days at full power, have not been utilised.
- Coastdown operation meant that a potential 29.4 GWh (about 1 day at full power) of production capacity was not utilised, in the interests of good fuel husbandry.
SCRAMS

8th August: A reactor scram occurred whilst restarting and testing the pressure relief valves in the reactor pressure relief system. One of the valves failed to close correctly and triggered a rapid increase in the reactor power.

EVENTS

A spurious partial scram occurred on 28th September, and the same thing occurred the next day. It was caused by a fault in the power supply unit for a temperature measurement point. The power supply was replaced, and full power was restored on 30th September.

Oskarshamn 3 started commercial operation in 1985. It is a boiling water reactor (BWR) manufactured by ABB Atom and of the same generation as Forsmark 3. The thermal power output is 3300 MW and the electrical output is 1.160 MW net.

The Reactor Containment is designed for a pressure up to 0.6 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consists of 700 fuel elements. The total fuel cycle is five years on average. 169 control rods and the water flow from eight internal recirculation pumps are used to control the reactor power.

The Turbine Plant consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. The stator of the generator is water-cooled and the rotor is hydrogen-cooled.

The Electric Power System consists of four separate trains. The unit is connected to the national high voltage grid through separate 400 and 130 kV lines. Emergency power is supplied by four diesel generators.
25th March: Coastdown operation started.

20th April: Power reduction due to low power demand. Load-following operations occurred through the rest of April and until shutdown for the annual refuelling outage.

13th July: Power reduction to zero due to good availability of hydro power.

Annual refuelling outage 29th July – 6th January

The good availability of hydro power meant that the annual refuelling outage could be started on the turbine side about two weeks earlier than planned, which also meant that the work could be carried out at a less hectic rate than usual. One of the results of this was that the collective dose during the outage was the lowest to date.

The reactor part

Inspecting the supports of the core spray, which were repaired during the 1999 annual shutdown, took a lot of time. This year’s inspection used improved test equipment, which found about a further 20 indications in the core spray supports. Most of them were repaired by replacing the damaged support by a new one. However, some of the supports were not replaced, as calculations have shown that the loads on them are not such that the crack indications can propagate any more. The Nuclear Power Inspectorate questioned this. Nevertheless, after exhaustive analysis, the Inspectorate decided on 21st December to grant Ringhals 1 a limited operating concession until the end of 2002.

A new core shroud lid, with a new core spray, has been ordered, and will be installed during the 2002 annual shutdown, in good time before the limited concession expires.

Preparing for restarting took a number of days, as the unit had been shut down for more than six months. It came on line again on 6th January 2001.

The turbine part

The high pressure turbine of one of the turbine sets was inspected during the shutdown. The generator rotor on this turbine was also replaced. Damaged tubes were found in the reheater, and were repaired.

The collective dose during the outage was 0.98 mSv, which was about 0.23 mSv less than forecast.

DURING THE YEAR

- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 603.8 GWh of production capacity, equivalent to 30 days at full power, have not been utilised.

- Coastdown operation at the end of the operating period meant that a potential 293.1 GWh (almost 15 days at full power) of production capacity was not utilised, in the interests of good fuel husbandry.

SCRAMS

No scrams occurred during the year.

EVENTS

Parts of the fire protection system for Ringhals 1 and 2 were rebuilt in 1997. The previously used halon gas was replaced by the less environmentally damaging gas Inergen. Incorrectly installed fire dampers were found in Ringhals 1 during the spring of 2000. Investigation of how this affected the fire protection system discovered that the walls in the relay room areas in Ringhals 1 and Ringhals 2 were not designed to withstand the pressure generated when the Inergen system operates. For further information, see Special reporting.
Ringhals I started commercial operation in 1976. It is a boiling water reactor (BWR) manufactured by ABB Atom. The thermal power output is 2500 MW and the electrical output is 835 MW net.

The Reactor Containment is designed for a pressure up to 0.5 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consists of 648 fuel elements. The total fuel cycle is five years on average. 157 control rods and the water flow from six external recirculation pumps are used to control the reactor power.

The Turbine Plant consists of two separate trains. Each train consists of one single axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. The stators of the generator are water-cooled and the rotors are hydrogen-cooled.

The Electric Power System consists of four separate trains. The unit is connected to the national high voltage grid through separate 400 and 130 kV lines. Emergency power is supplied by four diesel generators.
Ringhals 2

EVENTS OF IMPORTANCE TO UNIT CAPABILITY AND SAFETY

4th March: Reactor scram from full load due to a fault in the 400 kV switchyard.

15th March: Coastdown operation started.

29th April: Power reduction and change to operation of one turbine only due to low power demand.

3rd May: Shutdown of the remaining turbine due to good availability of hydro power.

Annual refuelling outage, 5th May–17th June

The unit was shut down for refuelling outage as planned on 5th May. Most of the work during the shutdown was devoted to the continued major modernisation of the unit's electrical power system that was started in 1998. Work this year involved replacement of equipment in two of the main sections of the electrical system.

In addition to regular routine inspections and refuelling, the reactor containment has been leak-tested and the safety valves of the pressurizer have been modified. The boron injection tank valves were modified, and standby cooling for the charging pumps was installed.

Inspection of the fuel did not find any leaks, but it was found that some of the fuel rods were more bent than expected. This resulted in modification of the core design, and restrictions on core power similar to those applied in Ringhals 3 and Ringhals 4 were introduced.

The collective dose during the outage was about 0.42 mSv, which was about 0.15 mSv less than forecast.

18th June: Restoration of full power output after the outage.

23 June: Power reduction and change to single turbine operation. Load-following operations continued at varying levels until 3rd September.

11th–21 August: The unit was shut down due to low power demand.

3rd September: Full power was restored.

13th November: The reactor was shut down for repair of a leaking seal weld in a pressure pipe connected to the reactor vessel head, containing the stepping mechanism for the control rods.

20th November: Restoration of full power operation.

8th December: One of the turbines was shut down to replace the generator rotor after a water leak.

15th December: The turbine was restarted. Full power on 17th December, after reduced power operation on 15th and 16th December due to low power demand.

DURING THE YEAR

- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 973.5 GWh of production capacity, equivalent to about 46 days at full power, have not been utilised.

- Coastdown operation at the end of the operating period meant that a potential 212.3 GWh (10 days at full power) of production volume was not utilised, in the interests of good fuel husbandry.

SCRAMS

4th March: Severe weather had resulted in the outdoor 400 kV switchyard being hosed down in order to prevent salt build-up. Unfortunately, this resulted in a flashover on one phase, tripping power to parts of the electrical system and stopping the reactor cooling water pumps. As all the reactor cooling water pumps are required for operation at full output, this automatically generated a reactor scram, with the core being cooled by natural circulation. This was followed
by a pressure difference between the steam generators, initiating safety injection into the reactor. All safety systems operated as expected.

**25th August:** An incorrectly adjusted regulator and a defective solenoid valve caused a drain tank in the turbine plant to overfill in connection with a system change in the alignment. At the time, the plant was running at 38% power, with only one turbine in operation. The operating turbine was tripped by its safety systems which automatically generated a reactor scram. All safety systems operated as expected.

**Events**

It was found, during the annual shutdown, that the walls in the relay equipment building were not designed to withstand the pressure generated when the fire protection system operates. The fire protection system was shut down, and temporarily replaced by patrolling watchmen. The walls were strengthened, and the gas extinguishing system was modified. For further information, see Special reporting.

### Energy Capability and Utilization

The figure shows the energy capability and utilization from 1993 to 2000. The data indicates a steady increase in capability and utilization over the years.

### Production Loss

The figure illustrates the production loss percentage from 1993 to 2000. The data shows fluctuations in production loss with a noticeable increase in 1996.

### Scrams

The figure depicts scram occurrences broken down by plant section and cause of fault from 1993 to 2000. The data reveals a gradual increase in scrams over the years.

### Collective Radiation Exposure

The figure presents collective radiation exposure in manSv/yr from 1993 to 2000. The data indicates a steady increase in exposure over the years.

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**Ringhals 2** started commercial operation in 1975. It is a pressurized water reactor (PWR) manufactured by Westinghouse. The thermal power output is 2652 MW and the electrical output is 872 MW net.

**The Reactor Containment** is designed for a pressure up to 0.5 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

**The Reactor Core** consists of 157 fuel elements. The total fuel cycle is five years on average. The reactor power is regulated by 48 control rods and by adjusting the boron content in the primary system coolant.

**The Turbine Plant** consists of two separate trains. Each train consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines, and a generator; all mounted on one shaft. The stators and the rotors of the generators are water-cooled.

**The Electric Power System** consists of four separate trains. The unit is connected to the national high voltage grid through separate 400 and 130 kV lines. Emergency power is supplied by four diesel generators.
**Ringhals 3**

**Events of Importance to Unit Capability and Safety**

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<tr>
<th>% Daily Average Power</th>
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<td>100</td>
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<td>80</td>
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Coastdown

**Unit Capability 92.3 %**

**Utilization 77.1 %**

Jan ' Feb ' Mar ' Apr ' May ' Jun ' Jul ' Aug ' Sep ' Oct ' Nov ' Dec

**24th March:** Coastdown operation started.

**13th April:** One of the two turbine units was stopped due to spurious operation of a vacuum pressure monitor switch. The turbine was back in operation after four hours. Substantial power reduction due to low power demand.

**17th April:** One turbine was stopped, due to low power demand and no need of standby capacity.

**8th May:** Power increased. Maximum possible power during coastdown operation occurred on 11th May.

**9th June:** Reduction to shutdown reactor due to low power demand, one week before the starting date of 16th June for the annual refuelling outage.

**Annual refuelling outage, 16th June–13th July**

The annual refuelling outage went as planned, being completed in 28 days. Several of the internal components of the reactor pressure vessel were inspected. The inspections showed that Ringhals 3 is in excellent condition after 20 years' operation.

New rectifiers were installed, further to improve the operational reliability of the uninterruptible power supply system. Backup cooling of the charging pumps has been installed, and the remaining work on the fuel handling system was completed.

**The reactor part**

The time determinant for this outage was set by two inspections that required the reactor pressure vessel to be empty. The fuel in the pressure vessel is surrounded by a cylindrical core barrel. On the inside of this barrel there is a metal structure, known as the core baffle, in order to accommodate the angular shape of the core to the shape of the barrel. The baffle is secured to the barrel by a large number of bolts. Over 1000 of these bolts were inspected by ultrasonic inspection, and found to be defect-free.

The other inspection involved inspection of the welds between the carbon steel of the reactor pressure vessel nozzles and the stainless steel of the pipes in the reactor cooling loops. The investigations were carried out with advanced methods, employing eddy current and ultrasonic examination. Two defect indications were found, but their effect on the integrity of the cooling circuit was found to be so slight that it did not prevent continued operation of the plant. Similar, but larger, defects were subsequently found in Ringhals 4. However, based on experience from Ringhals 4, consideration is being given to shutting Ringhals 3 down in the spring of 2001 in order further to inspect the weld defect indications that were found.

The penetrations through the reactor vessel head were also tested during the shutdown, and a number of smaller, negligible indications were found.

**The turbine part**

The low pressure turbine of one of the two turbine plants was extensively overhauled.

The collective dose during the outage was the lowest ever achieved in the history of the unit: 0.19 mSv, as against a forecast 0.26 mSv.

**13th July:** The unit was restarted on reduced power after the refuelling outage, with only one turbine in operation. Reduced power continued during the remainder of the month and in August, varying between 50 % and 90 % power.

**28th August:** Power was increased to 100 %, and remained at this level for the rest of the year.
DURING THE YEAR

- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 850.2 GWh of production capacity, equivalent to 38 days at full power, have not been utilised.

- Coastdown operation meant that a potential 351.1 GWh (about 16 days at full power) of production capacity was not utilised, in the interests of good fuel husbandry.

SCRAMS

No scrams occurred during the year.

EVENTS

No events with safety implications occurred during the year.

Ringhals 3 started commercial operation in 1981. It is a pressurised water reactor (PWR) manufactured by Westinghouse and of the same generation as Ringhals 4. The thermal power output is 2783 MW and the electrical output is 920 MW net.

The Reactor Containment is designed for a pressure up to 0.4 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consists of 157 fuel elements. The total fuel cycle is five years on average. The reactor power is regulated by 48 control rods and by adjusting the boron content in the primary system coolant.

The Turbine Plant consists of two separate trains. Each train consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. The stators and the rotors of the generators are water-cooled.

The Electric Power System consists of four separate trains. The unit is connected to the national high voltage grid through separate 400 and 130 kV lines. Emergency power is supplied by four diesel generators.
EVENTS OF IMPORTANCE TO UNIT CAPABILITY AND SAFETY

14th January: Power reduction to 50% for repair of a fault in the outdoor switchyard.

17th February: A fault on a circuit board in the turbine governing system reduced power for a few hours.

17th April: Power reduction due to low power demand.

18th May: Coastdown operation was started. Continued power reduction, with single-turbine operation from 20th July.

16th August: Reduction to shutdown reactor, one week before the start of the annual shutdown, due to good availability of hydro power.

Annual refuelling outage, 24th August–14th December

The refuelling outage was originally planned to continue until 25th September, but was extended until 14th December, on which date one of the turbines was re-synchronised to the grid.

Work carried out during the outage included the usual examination of safety valves and isolation valves.

The reactor part

Ringhals 4 is the only Ringhals PWR plant in which the steam generators have not been replaced. However, the number of tubes that have been plugged due to leaks has increased over the years, to the extent that they have recently started to constitute a limitation on power output. In order to improve this situation, a number of the plugs were removed during the outage, and replaced by sleeves inserted into the tubes.

Backup cooling for the charging pumps has been installed.

The welded joints between the reactor pressure vessel nozzles and the pipes in the three reactor cooling water loops were also inspected, using ultrasonic testing equipment. Four crack indications were found in one of the circuits in the weld between the reactor pressure vessel nozzle and the outgoing pipe in the cooling circuit. The defective material has been removed, in order to prevent the cracks from propagating. After extensive investigations, it was decided that the remaining material was sufficiently strong to allow operation to be continued for a limited time: the Nuclear Power Inspectorate therefore granted a three-month operating concession on 8th December, and the unit was brought up to normal power operation on 14th December. See also further information under the heading Special reporting.

The turbine part

The turbine plants were given their normal overhaul. In addition, the rotor of one of the generators was replaced.

The collective dose during the outage was about 0.37 manSv, which was about 0.09 manSv less than forecast.

14th December: Return to full power after the extended refuelling outage.

DURING THE YEAR

- There have been extensive load-following operations during the year, as the availability of hydro power has been very high. This has meant that 1089.6 GWh of production capacity, equivalent to about 50 days at full power, have not been utilised.

- Coastdown operation at the end of the operating period meant that a potential 300.0 GWh (about 14 days at full power) of production capacity was not utilised.

SCRAMS

No scrams occurred during the year.

EVENTS

Apart from the welding defects, described in Special reporting, no events with safety implications have occurred during the year.
Ringhals 4 started commercial operation in 1983. It is a pressurized water reactor (PWR) manufactured by Westinghouse and of the same generation as Ringhals 3. The thermal power output is 2775 MW and the electrical output is 915 MW net.

The Reactor Containment is designed for a pressure up to 0.4 MPa and during operation it is filled with nitrogen gas. A system for filtered venting is automatically connected to the containment via a rupture disc in order to prevent the release of radioactivity in the event of a loss of coolant accident.

The Reactor Core consists of 157 fuel elements. The total fuel cycle is five years on average. The reactor power is regulated by 48 control rods and by adjusting the boron content in the primary system coolant.

The Turbine Plant consists of two separate trains. Each train consists of one dual axial flow high-pressure turbine, three dual axial flow low-pressure turbines and a generator, all mounted on one shaft. The stators and the rotors of the generators are water-cooled.

The Electric Power System consists of four separate trains. The unit is connected to the national high voltage grid through separate 400 and 130 kV lines. Emergency power is supplied by four diesel generators.
Special Reports

Unavailability of Standby Power from Gas Turbine Transformers, Oskarshamn 2

Summary
When the starting sequence of one of the gas turbines was tested on 4th July, a protective circuit tripped the gas turbine transformer when the transformer was loaded with the heavy starting current load of large pumps. The protective circuit was incorrectly connected, with the result that the pump starting currents were interpreted as a fault current. The protective circuits for the two gas turbine transformers were connected in the same way, which meant that two independent power supplies were not available. The event was given an INES Level 1 rating.

Background
New switchgear was installed in the spring, so that the gas turbine generator units could be used for backup power supply to the auxiliary feed water system. This system previously received its backup supply from the diesel generators, which also provided backup power to the core spray system. However, as the capacity of the diesel generators was limited, it was wished to have an alternative means of powering the auxiliary feed water pumps from the gas turbines. Oskarshamn 2 has two gas turbine generator units. The necessary switchgear installation for one unit was completed in April, and that for the second unit in May.

The gas turbine transformer has several protective circuits. One of these, the differential protection, is intended to protect the transformer against the high currents associated with a short circuit. In addition, there are gas-operated relays which are actuated as fast as the differential protection when a fault occurs.

Description of the Event
When the starting sequence of one of the gas turbines was tested on 4th July, the differential protection tripped the gas turbine transformer when the transformer was loaded with the heavy starting current load of large pumps. The differential protection circuit was found to be incorrectly connected, with the result that the starting currents were interpreted as a fault. The differential protection circuits for both transformers were connected in the same way, which meant that two independent power supplies were not available.

Modification and testing of the differential protection were carried out following a plan that had been prepared and checked in accordance with the procedures set out in the power station's quality manual. As the modification had been made while the plant was in operation, it was not possible to test the new arrangement by loading the backup power system as, during normal operation, there were no power-demanding components connected to the gas turbine transformers. The electrical connections were carefully checked against the existing documentation, and the various sub-functions were tested and verified. The inspections and tests that were performed were based on, and relied upon, the existing documentation of the earlier arrangement.

Corrective Actions
The differential protection for the two gas turbine transformers was disconnected for the time needed to complete testing of the modified switchgear arrangement. It was decided that the transformer's other protective devices provided sufficient protection during this period.

When testing was completed, the differential protection was correctly connected and checked.

The event was carefully analysed, and it was found that the root cause was that the old documentation for the differential protection did not agree with the actual previous arrangement. It seems likely that the discrepancies between the documentation and the actual arrangement dated from the original installation of the gas turbine generators. Presumably, during an early phase of commissioning, the incorrect operation of the differential protection was found, and corrected, but the documentation was not altered to match. As the equipment had operated without problems prior to the modification of the switchgear, there had been no reason to question the correctness of the documentation.

Risk of Excessive Positive Pressure in Relay Rooms in the Event of Operation of Fire-Fighting Systems, Ringhals 1 and 2

Summary
Parts of the fire-fighting systems in Ringhals 1 and Ringhals 2 were modified in 1997. The previously used extinguishant, halon, was replaced by the less environmentally harmful gas, Inergen. When planning for a new gas extinguishing system to use Inergen in the spring of 2000, it was discovered that fire dampers in Ringhals 1 had been incorrectly installed. Further investigation of how this fault affected fire protection found that the walls in the relay rooms of both Ringhals 1 and Ringhals 2 were not designed to withstand the pressure transient arising when the Inergen
system is activated. The walls have now been reinforced, and the extinguishing systems have been modified in both plants. The event was rated as a Level 1 event according to INES.

**Description of the Event**
The electrical building in Ringhals 1 contains two relay rooms, A and B. It was found, when testing the fire ventilation in relay room A, that the fire ventilation dampers were not working as intended. Each damper consists of two separate damper halves, which should open and close together. However, they had been installed such that when one half opened, the other closed, and vice versa. The two halves changed positions when the dampers were operated, but the net effect was that one half was always open. The dampers are required to be open 30 seconds after starting the Inergen system so that the air in the room can be expelled. They must then shut, so that the fire is extinguished through lack of oxygen.

It was found that the dampers in the other relay room were also incorrectly installed, with the result that the gas extinguishing system in the two relay rooms did not work correctly. Investigation revealed that fire extinguishing performance in the two relay rooms would be sufficient, despite the incorrectly installed dampers, and nor would the incorrect installation affect the fire separation in the electrical building. The dampers had been incorrectly connected since the halon system was installed in 1987.

There are corresponding relay rooms in the electrical building in Ringhals 2. The dampers in these rooms were inspected and found to be correctly installed. Further investigation of how the incorrectly installed dampers could have affected fire protection revealed shortcomings in the design parameters that had been employed when the new Inergen system was being designed. The pressure generated when the Inergen system is activated could mean that certain walls would be subjected to greater loads than those for which they were designed. These somewhat under-strength walls were present in both Ringhals 1 and Ringhals 2. When this was discovered, operation of the Inergen system was disabled in both plants in order to prevent the walls from being damaged in the event of system actuation. While modifications were being made, the fire extinguishing system was replaced by a patrolling fire watchman.

**Safety Significance**
The calculations showed that the pressure arising from activation of the Inergen system could crack the lightweight concrete walls, particularly around cable and similar penetrations. Pressure differences between adjacent rooms would then be equalised through these cracks.

In the event of a crack in the wall between a relay room and adjacent areas belonging to the same fire cell, extinguishing performance would operate as expected. If damage occurred to the wall between the two relay rooms, which belong to different fire cells, the resulting penetration of extinguishing gas would probably initiate the fire-fighting system in the second room. Full-scale tests that were carried out in another area at Ringhals 1 caused the fire detectors to trigger. However, a crack in the wall between the two relay rooms would mean that the fire separation performance had been compromised, which would necessitate shutdown of the reactor to a cold shutdown state in accordance with the safety regulations. This effect caused the event to be rated as a Level 1 event according to INES.

**Corrective Actions**
The design conditions for the new design have been carefully checked, and the automatic fire-fighting system has been improved. It is now back in service after extensive testing and performance checking.

The lightweight concrete walls have been reinforced so that they now can withstand a pressure of at least 500 Pa, and a new pressure relief system has been installed, which limits the pressure in the room to less than 500 Pa when the fire-fighting system is actuated. Full-scale tests show that there is adequate margin to this pressure limit. Finally, the flow of extinguishing gas has been reduced, so that it takes 60 seconds for the necessary quantity of gas to be supplied, as against 40 seconds as previously. In addition, the quantity of gas delivered will be increased during the 2001 refuelling outages in order to meet requirements stated in the insurance companies' regulations RUS 500:1. These improvements have been carried out in both Ringhals 1 and Ringhals 2.
Defects in Welds between the Reactor Pressure Vessel and the Reactor Cooling Circuit, Ringhals 4

Summary
It is common in nuclear power plants to use nickel-based alloys such as Inconel 600 and Inconel 182 as a filler material when making welds between different metals. It is known that, in the conditions encountered in a BWR plant, these Inconel materials have a tendency to crack as a result of intergranular stress corrosion. Over the years, several such cases of cracking have occurred, and have been reported, internationally.

During the autumn of 2000, axial crack indications were found in welds between the reactor pressure vessel nozzles and the hot leg of one of the reactor cooling systems in two different PWR plants, V.C. Summer and Ringhals 4. In both cases, the indications were found in the welds between the reactor pressure vessel nozzle and the stainless steel of the pipes in the reactor cooling circuits. The results of material analysis indicate that the cracks were caused by stress corrosion. This had caused concern, as the environment in a PWR plant is such that stress corrosion ought not to occur.

Description of the Event
As part of the work of the annual refuelling outage, the welds between the reactor pressure vessel nozzle and the pipes in the three reactor cooling circuits were examined using eddy current and ultrasonic methods on September 1st. This revealed crack indications in one of the original welds between the reactor pressure vessel nozzle and the intermediate section connected to the pipe in the hot leg of the cooling circuit, known as a safe end. The crack indications were orientated perpendicular to the weld. One of the indications was of a 28 mm long and 13 mm deep surface crack on the inside of the pipe, while the other was of an internal crack, 2 mm beneath the internal surface of the pipe and also 28 mm long, but 14 mm deep. Two further indications were found, but it was decided after strength calculations that they could be left without further action. The other connections between the reactor pressure vessel and the cooling circuits were inspected, but no defects were found.

A sample was taken of the material around the surface penetrating crack in order to be able to determine the cause of the crack by metallographic investigations. It was found that the actual depth of the indication was greater than had been indicated by the ultrasonic examinations. A further sample was therefore taken from this area, and also from the three other crack indications.

The particular vessel nozzle concerned in Ringhals 4 has a weld-deposited buttering of Inconel 182. The welded joint between the buttering and the safe end tube is also made of Inconel 182. The safe end section is made of stainless material. The particular weld in Ringhals 4, and the corresponding one in V.C. Summer, have both been made in similar ways, and Inconel 182 has been used in both.

It was suspected that the crack indications were caused by intergranular stress corrosion, as it is known that the Inconel material is sensitive to such corrosion. The results of the metallographic investigations at the Studsvik laboratories confirmed these suspicions. It has not been possible to determine just how the cracks arose,

Corrective Actions
The defective material has been removed in order to prevent the cracks from propagating. After long and extensive investigations, it has been decided that the remaining material is sufficiently strong to permit continued operation for a limited period of time. The Nuclear Power Inspectorate therefore granted permission for three months' operation on December 8th, and the unit was back in operation on 14th December.

Corrective Actions
During the limited time for this operation, a long-term solution how the defects can be repaired is being considered. The alternatives available are to weld the pits left by taking the samples or to cut out the damaged section of pipe and weld in a new section.

The reactor pressure vessel nozzles and the stainless material in the pipes of the reactor cooling circuits in Ringhals 3 were also investigated during the annual refuelling outage and indications of two small defects were found. Their effect on the integrity of the primary circuit was found to be small. However, after the experience of Ringhals 4, consideration is being given to shutting Ringhals 3 down in the spring of 2001 for further investigations.

![Diagram of reactor vessel nozzle and welds](image-url)
Electric power production - Definitions

Corresponding to the UNIPEDEs classification
"Statistical Terminology Employed in the Electrical Supply Industry"

- Etg/En: Unit capability factor (UNIPEDEs definition No. 4.6.03.f)
- Ed/En: Energy utilization factor (UNIPEDEs definition No. 4.5.01)
- En: Maximal producable energy with maximal capacity during total time in a specific period.
- Ed: Actual produced energy within a certain period.
- Etg: Maximal producable energy with available capacity within a certain period.

International nuclear event scale - INES

The International Nuclear Event Scale has been developed by IAEA as a format on assessment and information of nuclear events. Events in Swedish nuclear power plants are reported via the Swedish Nuclear Power Inspectorate to IAEA and foreign events are reported in the other direction. The levels 1 to 3 are events and level 4 to 7 are emergencies with environmental impact. Example: The Chernobyl accident 1986 was rated as 7. Harrisburg 1979 was rated as 5.

<table>
<thead>
<tr>
<th>Level</th>
<th>Off-Site Impact</th>
<th>On-Site Impact</th>
<th>Degraded Defence</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 - Major Accident</td>
<td>Major Release. Widespread health and environmental effects</td>
<td>Severe damage to reactor core and radiological barriers</td>
<td>Near accident. No safety layers remaining</td>
</tr>
<tr>
<td>6 - Serious Accident</td>
<td>Significant Release. Countermeasures fully implemented</td>
<td>Severe damage to reactor core and radiological barriers</td>
<td>Near accident. No safety layers remaining</td>
</tr>
<tr>
<td>5 - Accident with Off-Site Risk</td>
<td>Limited Release. Countermeasures partially implemented</td>
<td>Significant damage to reactor core/barriers/fatal exposure of workers</td>
<td>Near accident. No safety layers remaining</td>
</tr>
<tr>
<td>4 - Accident without significant off-site risk</td>
<td>Minor Release. Public exposure up to prescribed limits</td>
<td>Significant damage to reactor core/barriers/fatal exposure of workers</td>
<td>Near accident. No safety layers remaining</td>
</tr>
<tr>
<td>3 - Serious Incident</td>
<td>Very Small Release. Public exposure at fraction of prescribed limits</td>
<td>Severe spread of contamination/acute health effects to workers</td>
<td>Near accident. No safety layers remaining</td>
</tr>
<tr>
<td>2 - Incident</td>
<td>Significant spread of contamination/over-exposure of workers</td>
<td>Incident with significant failures in safety provisions</td>
<td>Near accident. No safety layers remaining</td>
</tr>
<tr>
<td>1 - Anomaly</td>
<td></td>
<td></td>
<td>Near accident. No safety layers remaining</td>
</tr>
<tr>
<td>0 - Deviation</td>
<td></td>
<td></td>
<td>Near accident. No safety layers remaining</td>
</tr>
</tbody>
</table>

No safety significance

Characteristics

Reactor Containment

Type of containment, condensation pool and atmosphere. Pressure relief systems for the reactor and the containment

Reactor Cooling Systems

Operation: FWP = Feedwater pumps
AFWP = Aux feedwater pumps
RCP = Reactor coolant pump (PWR)
HPCTR = High pressure core spray pumps
LPCSP = Low pressure core spray pumps
HPCCP = High pressure core coolant pumps
LPCCP = Low pressure core coolant pumps
HPJP = High pressure injection pumps
LPJP = Low pressure injection pumps
RHRP = Residual heat removal pumps
ACC = Accumulator tank (PWR)

Turbine Systems

HPRT = High pressure turbine, single- or double radial
HP = High pressure turbine, single- or double axial
LP = Low pressure turbine, single- or double axial

Electric Supply

400kV GAS
130kV

External power supply: Ext. power grid 130-400kV
Ext. aut power grid 70-130kV
Internal backup supply: Diesel backup 6-40kV

2- or 4-subdivisions