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Operation of Finnish nuclear power plants

Quarterly report, 3rd quarter 1996

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ABSTRACT

Quarterly Reports on the operation of Finnish nuclear power plants describe events and observations relating to nuclear and radiation safety which the Finnish Centre for Radiation and Nuclear Safety (STUK) considers safety significant. Safety improvements at the plants are also described. The Report also includes a summary of the radiation safety of plant personnel and of the environment and tabulated data on the plants' production and load factors.

In the third quarter of 1996, the Finnish nuclear power plant units were in power operation except for the annual maintenance outages of Loviisa plant units and a shutdown at Olkiluoto 1 to identify and repair malfunctions of a high pressure turbine control valve. The load factor average of all plant units was 77.2%.

Events in the third quarter of 1996 were classified level 0 on the International Nuclear Event Scale. Occupational doses and radioactive releases off-site were below authorised limits. Radioactive substances were measurable in samples collected around the plants in such quantities only as have no bearing on the radiation exposure of the population.

The names of Teollisuuden Voima Oy's plant units have changed. Olkiluoto 1 and Olkiluoto 2 now replace the names TVO I and TVO II previously used in quarterly reports.

CONTENTS

1 INTRODUCTION

According to the Nuclear Energy Act (990/87), regulatory control of the use of nuclear energy belongs to the Finnish Centre for Radiation and Nuclear Safety (STUK). The Centre's functions also include control of physical protection, emergency preparedness and nuclear material safeguards. The scope of nuclear power plant regulatory control and inspections is given in Appendix 1 and general information about Finnish plants in Appendix 2.

STUK publishes quarterly a report on the operation of Finnish nuclear power plants. In this report, plant events and observations in each quarter are described, tabulated data on the plants' production and availability factors are given and the radiation safety of plant personnel and of the environment is summarised. Safety improvements at the plants are also reported.

The report is based on information submitted to STUK by the utilities and on observations made by the Centre during its regulatory activities. The events described in the report are classified on the International Nuclear Event Scale (INES).

2 OPERATION OF NUCLEAR POWER PLANTS IN JULY–SEPTEMBER 1996

Finnish nuclear power plant units were in power operation in the third quarter of 1996 except for the annual maintenance outages of the Loviisa plant units and a shutdown at Olkiluoto 1 to identify and repair malfunctions of a high pressure turbine control valve.

2.1 Production data

Nuclear's share of total electricity production was 29.7%. The load factor average the plant units was 77.2%.

Detailed production and availability figures are given in Tables I ja II.

Power diagrams describing electricity generation at each plant unit and the causes of power reductions are given in Figs 1–4.

Table I. *Plant electricity production and availability.*

	Electricity production (gross, TWh)		Availability factor (%)		Load factor (%)	
	Third quarter 1996	From beginning of 1996	Third quarter 1996	From beginning of 1996	Third quarter 1996	From beginning of 1996
Loviisa 1	0.30	2.33	31.9	76.3	28.9	77.1
Loviisa 2	0.89	2.93	89.4	96.5	86.0	95.8
Olkiluoto 1	1.66	4.45	99.0	91.6	95.8	90.1
Olkiluoto 2	1.59	4.51	99.5	94.6	98.0	93.2

$$\text{Availability factor} = \frac{\text{generator synchronized (h)}}{\text{calendar time (h)}} \cdot 100\%$$

$$\text{Load factor} = \frac{\text{gross electricity production}}{\text{rated power} \cdot \text{calendar time (h)}} \cdot 100\%$$

Table II. Nuclear energy in Finnish electricity production.

	Third quarter 1996	From beginning of 1996	1995	1994
Nuclear electricity production (net, TWh)*	4.3	13.6	18.1	18.3
Total electricity production in Finland (net, TWh)*	14.5	48.0	60.6	62.1
Nuclear's share of total electricity production (%)	29.7	28.3	29.9	29.5
Load factor averages of Finnish plant units (%)	77.2	88.9	88.8	90.0

* Source: Statistics compiled by the Association of Finnish Electric Utilities.

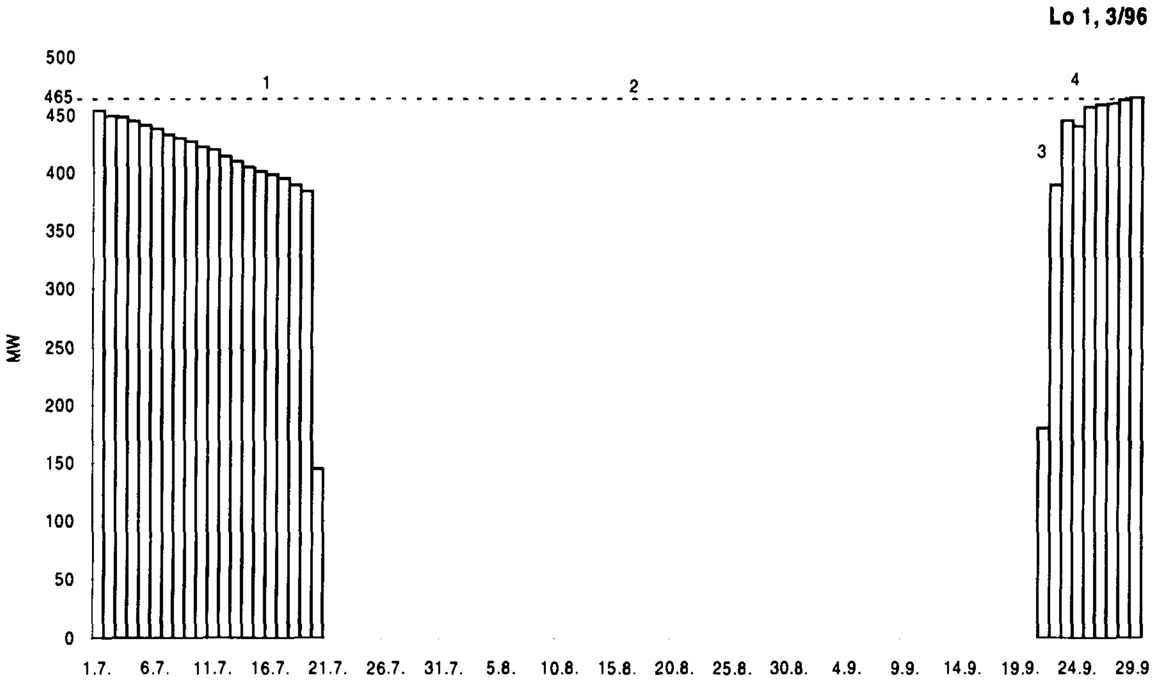
2.2 Annual maintenance outage of Loviisa 1

The 19th refuelling and maintenance outage of Loviisa 1 was from 20 July to 21 September 1996. The plant unit was off the national grid for 62 days.

Apart from Imatran Voima Oy's own staff, the maximum number of contract workers participating in the outage was about 1000. The collective radiation dose incurred in outage work was 1.79 manSv (0.37 manSv in 1995). The increase was due to extensive repairs and modifications. The higest individual dose was 10.0 mSv.

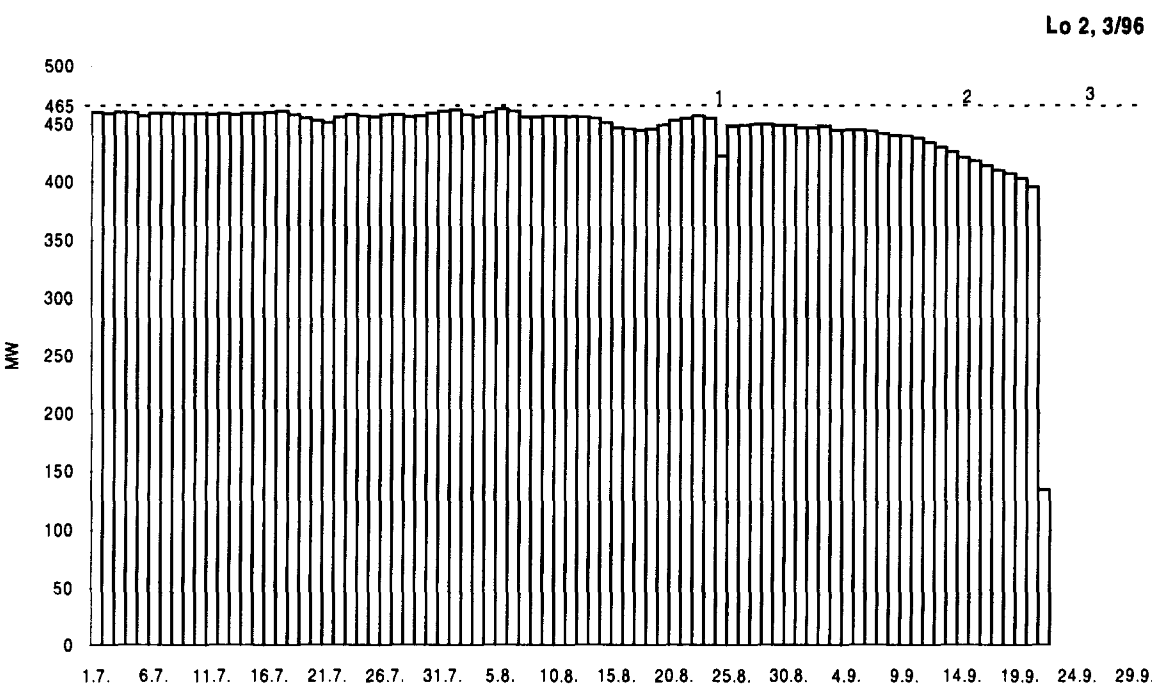
The most important repair during the outage was reactor pressure vessel annealing by which the pressure vessel's fracture toughness was restored as close to the original as possible (see subsection 3.1). Other modifications made during the outage to improve safety are described in chapter 5.

After the annual maintenance outage, the plant unit was brought back on-line on 21 September 1996.



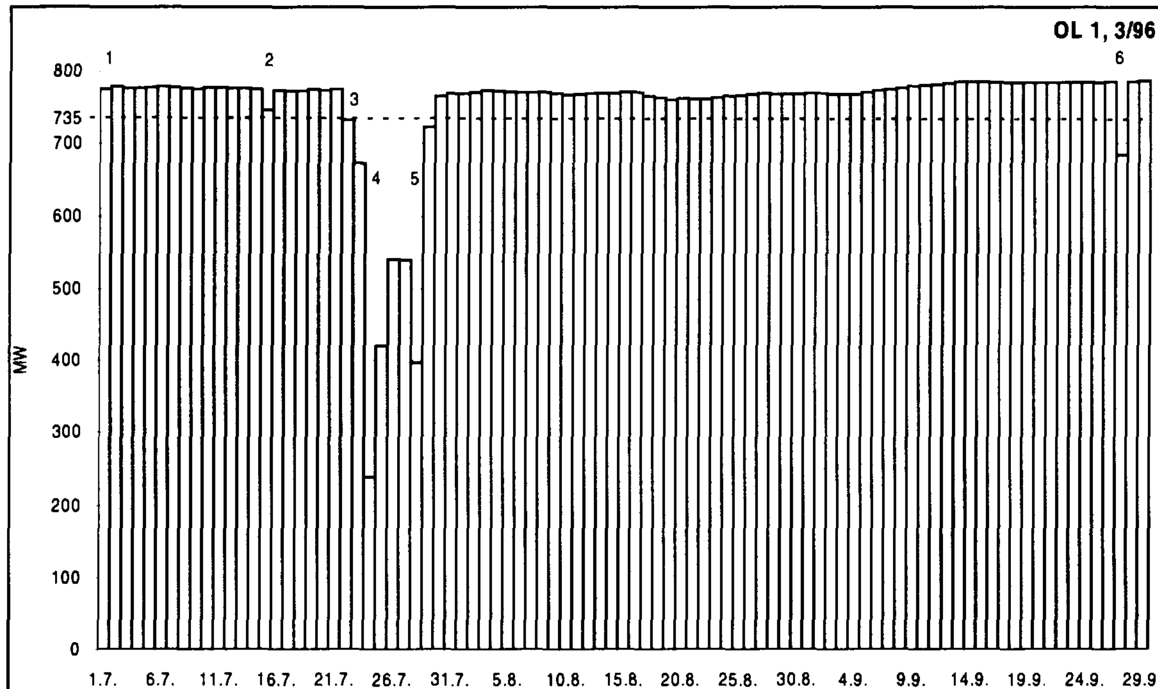
1. Power reduction due to degradation of the steam generator water chemistry, lowest reactor power was 74%.
2. Annual testing of the steam line safety valves, lowest reactor power was 74%.

Fig 1. Daily average gross power of Loviisa 1 in July–September 1996.



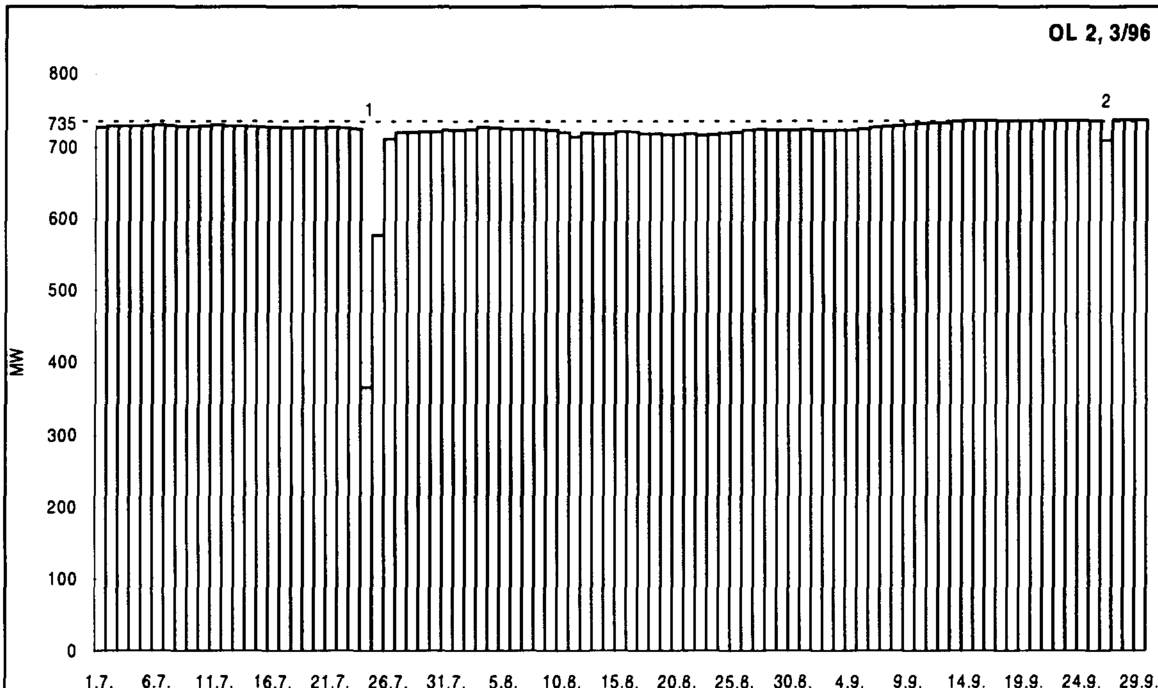
1. One primary circulation pump stopped due to a level measurement malfunction, lowest reactor power was 82%.
2. A pump's bearing was replaced, lowest reactor power was 80%.

Fig 2. Daily average gross power of Loviisa 2 in July–September 1996.



1. Periodic tests requiring power reduction, lowest reactor power was 70%.
2. Annual maintenance (see chapter 2.2).
3. Reactor scram in consequence of a turbine by-pass valve malfunction.
4. Testing and trial operation relating to the power upgrade, i.a. a turbine trip test (see chapter 3.2).
5. Low electricity demand, lowest reactor power was 80%.
6. Load reduction test, whereafter long-term test operation at 105% uprated power was started (see chapter 3.2).

Fig 3. Daily average gross power of Olkiluoto 1 in July–September 1996.



1. Coastdown operation (by the start of annual maintenance, the reactor power had reduced to 96%).
2. Annual maintenance (see chapter 2.3).
3. Hot shutdown due to low electricity demand and turbine generator rotor repairs (see chapter 2.4).

Fig 4. Daily average gross power of Olkiluoto 2 in July–September 1996.

2.3 Annual maintenance outage of Loviisa 2

The 16th refuelling and maintenance outage of Loviisa 2 began towards the end of the third annual quarter, on 21 September 1996. The outage will be more closely reported in the next quarterly report.

2.4 Repair shutdown at Olkiluto 1 to identify and repair malfunctions of a high pressure turbine control valve

Steam generated in the reactor pressure vessel is directed to high pressure turbines via four separate pipelines. The rate of inflow of steam to the turbine and, simultaneously, the reactor pressure is controlled by a control valve in every pipeline.

One of four high pressure control valves closed for about a second on two successive days, 22 and 23 of July 1996, while the reactor was operating at 105% power. In consequence of the inadvertent closure, the reactor protection system reduced reactor power to about 62%. Valve adjustment and the control circuits were checked but no reason was found for the valve closure of 22 July. However, after the event of 23 July, the reason was found to be a defective sealing of the control cable from the controller to the valve actuator. The defect caused a shortcut in the control circuit's switching connector which resulted in the valve's closure. Teollisuuden Voima Oy fixed the wiring of the switch case and checked the corresponding control cables and their connectors of three other control valves. These were found to be acceptable.

On 25 July 1996, at 85% reactor power, the same control valve abruptly closed again. Operation of the plant unit was continued and steam was directed to a high pressure turbine via three lines at 76% reactor power. The plant unit was shut down on 28 July 1996 to identify and repair the fault and to open the valve actuator. In the inspection, the cable of the position sensor of the control valve inside the actuator was found defective. The cable and its connectors were replaced and the valve operated acceptably in tests. The plant unit was connected to the national grid the same day.

The cables of the valve actuators are due for inspection by the utility at some appropriate time, not later than during the 1997 annual maintenance, however.

3 EVENTS AND OBSERVATIONS

Loviisa 1

In the third quarter of 1996, annual maintenance of Loviisa 1 was held during which the reactor pressure vessel was annealed to restore the ductility of its steel. During the outage, the cold pressurisation protection of the primary circuit was found insufficient. During the outage, the external grid connection was lost and when the plant unit was started up after the annual maintenance power was raised too quickly. The events are level 0 on the INES scale.

3.1 Reactor pressure vessel annealing

Neutron irradiation causes changes in the micro structure of steel and the changes raise the transition temperature indicating the brittle fracture behaviour of steel. At low temperatures the ability of steel for plastic deformation deteriorates and it becomes brittle. If, at such a temperature, the structure is subjected to high stresses and if there is a sufficiently large crack at the point concerned, the crack will grow fast and the structure will break. High stresses at a low temperature can arise for example during emergency cooling. Reactor pressure vessels are regularly inspected to observe potential flaws.

Steel's impurities increase the susceptibility to change of the transition temperature which is induced by neutron irradiation. Impurities exist particularly in the welded seam in the core region of the Loviisa 1 reactor pressure vessel.

The materials specimen which were irradiated inside the Loviisa 1 reactor pressure vessel in 1980 showed that embrittlement took place considerably faster than the design values presented by the plant supplier suggest. Several modifications have been made at both plant units to slow down the rate of embrittlement of steel and to limit potential overcooling transients.

The ductile properties of steel can be restored close to the original by annealing for several days at a temperature of 475° C. This method has already been applied to over ten foreign reactor pressure vessels of the VVER-440 type. Imatran Voima Oy has carried out annealing-related studies for many years.

The Finnish Centre for Radiation and Nuclear Safety in 1993 decided to allow the extended operation of the Loviisa 1 reactor pressure vessel until the 1996 refuelling outage. The decision required measures to reduce the brittle fracture risk of the pressure vessel. Imatran Voima Oy made a decision to anneal the reactor pressure vessel and started to draw up the reports required for the annealing and for a new operating licence.

In older foreign reactor pressure vessels of the VVER-440 type, samples have been taken before and after annealing thus ensuring the restoration of fracture toughness. The inner surface of the Loviisa 1 pressure vessel is covered by a 9 mm thick welded stainless steel cladding which prevents sample taking from the weld. Therefore, the restoration of fracture toughness must be shown in some other way. That is why a sufficient number of systematic studies were required to indicate the restoration of material properties, the rate of re-embrittlement and also the reliable measurement of the temperature of the welded seam during annealing to keep the temperature within the range determined by materials studies. It was also required that annealing does not harm the reactor pressure vessel or its surrounding structures. The Finnish Centre for Radiation and

Nuclear Safety reviewed and approved the annealing plans.

In the 1996 refuelling outage, an embrittled welded seam closest to the reactor core was annealed to 475...500°C for one hundred hours. The annealing was carried out by a joint enterprise formed by Skoda and Bohunice nuclear power plant and the annealing went according to the approved programme and without deviations. The Finnish Centre for Radiation and Nuclear Safety witnessed the execution of the annealing.

The Finnish Centre for Radiation and Nuclear Safety approved, according to the application of Imatran Voima Oy, the operation of the Loviisa reactor pressure vessel until the 2004 refuelling outage. In support of the application, Imatran Voima Oy submitted the pressure vessel's safety analysis which has been reviewed by the Centre. The transition temperature for the year 2004 has been very conservatively calculated and Imatran Voima Oy will re-assess it before the year 2004 utilising i.a. the results obtained from the irradiation samples manufactured of the tailored weld material and placed inside the pressure vessel in 1996. After three years the samples will be annealed and placed again in the core for re-irradiation.

3.2 Insufficient cold pressurisation protection of the primary circuit during the annual maintenance outage

Cold pressurisation protection is intended to prevent pressurisation of the reactor pressure vessel within pressure and temperature ranges where brittle fracturing can occur. If required, the protection system stops pumps which raise primary circuit pressure and switches off the heating resistors of the primary circuit pressuriser. The protection signal is accomplished only if, simultaneously, two out of three primary circuit pressure measurements exceed and two out of three temperature measurements are below set protection limits.

During the annual maintenance outage of Loviisa 1 from 17 to 19 August 1996, a primary circuit pressurisation test was conducted after the annealing of the reactor pressure vessel. A detailed plan had been drawn up for the test arrangements and the inspections during it. The operating personnel had also been issued instructions by an operational order pertaining to the test. The plan and the operational order required that the cold pressurisation protection function be in operation when primary circuit temperature is below 100°C. The protection function's operation was ensured on 17 August by tests prior to the heating of the primary circuit. When primary circuit pressure was raised during the pressure test the cold pressurisation protection stopped the pumps at 40 bar. The faulty operation of the protection function was attributed to the fact that some temperature measurement detectors were not in their right place, i.e. in their measuring pockets. They hung in the air, measuring room air temperature. The detectors had been taken out of the measuring pockets earlier to perform periodic inspections of piping. As the inspections were postponed to a later point of time in the outage the detectors were not returned to their measurement pockets. After having ascertained by other reliable measurements that primary circuit temperature was above 100° C as required, the cold pressurisation protection was switched off and the pressure test was accomplished in compliance with the programme. After the test, the primary circuit was cooled down but cold pressurisation protection was not switched on until on 19 August. The protection function thus was not in operation as designed when temperature went below 100°C.

Due to the annual maintenance there was no nuclear fuel in the reactor pressure vessel during the event and it thus had no bearing on nuclear safety. However, when the event was analysed, some deficiencies were detected in the Loviisa plant's system of procedures and in work supervision at administrative level. Imatran Voima Oy has taken the necessary corrective measures to prevent recurrence.

3.3 External grid loss at Loviisa 1 during the annual maintenance outage

The Loviisa plant units are supplied the electrical power they require during the annual maintenance outages by either the 400 kV or the 110 kV external grid. In case the external grid connection is lost, back-up diesels automatically start to supply the electrical power required by the units.

A transient occurred on 12 September 1996, during the Loviisa 1 annual maintenance outage, which resulted in the unit losing its external grid connection for a few minutes. At the time of the event, electrical power required by the unit was supplied by the 110 kV external grid since the 400 kV grid connection had been separated due to maintenance work The operation of one back-up diesel was being tested and the other three were ready for operation. In addition to the above, operational tests of the protection systems and switches of the 110 kV switchgear were also being performed relating to preventive maintenance of electrical systems. Due to a human error in connection with the tests, the 110 kV supply switch inadvertently opened, causing the loss of off-site power supply. The three back-up diesels in stand-by started as designed and supplied electrical power. The diesel generator undergoing testing had been in operation already before the event and it continued to operate as designed. Within a few minutes after the event, power supply from the 110 kV external grid was restored and the back-up diesels were stopped.

Since the whole plant unit was in cold shutdown state the event did not significantly affect its operation. The auxiliary power supply systems designed for loss of power events operated as designed and the event was thus of minor safety significance.

As a corrective measure, Imatran Voima Oy decided to minimise the possibility of malfunctions by making uniform control circuits installed when the connections for Loviisa's 110 kV switches are replaced. Imatran Voima Oy is also looking into administrative measures to prevent the loss of external grid connections due to corresponding operational tests.

3.4 Power was raised too quickly during Loviisa 1 start-up after the annual maintenance

A nuclear power plant's power ascension is performed slowly to avoid quick, stress-related changes in fuel which could weaken its mechanical endurance. In the Technical Specifications the highest allowable power ascension rates for various situations are given. During the start-up of Loviisa 1 after the annual maintenance, power was raised at a rate of about 39 MW/h and within a power range of 40–53% of full power. The highest allowable power ascension rate is 20 MW/h. The erroneous power ascension rate was not noticed during the start-up but it was only detected in an inspection conducted later.

Before the power ascension rate was exceeded, a change of shift had just taken place during which power had constantly been kept at about 40% for a long time. The new shift misinterpreted the meaning of the power ascension rate 20 MW/h which is allowable within the 35–53% power range. They assumed that low power ascension rate during the shift change allowed a higher power ascension rate later on, as long as the average power ascension rate within the power range in question did not exceed the allowable limit. It was due to this erroneous interpretation that the new shift used a power ascension rate too high when it continued power ascension within the 40-53% power range.

The power ascension which was too quick may have weakened the fuel's endurance to some extent, adding to the probability of a small fuel leak later on. Fuel leaks are monitored by following the acitivity concentration of primary circuit water. Sporadic fuel cladding failures have been taken into account in the design of Loviisa power plant.

Loviisa 2

No reportable events occurred at Loviisa 2 in the second quarter of 1996.

Olkiluoto 1

In the third quarter of 1996, an operational transient due to a high level in the drainage tank of the steam reheater occurred at Olkiluoto 1. A disturbance in the 400 kV external grid caused a reactor scram at both plant units. The events are level 0 on the INES scale.

3.5 Operational transient at Olkiluoto 1 due to high steam reheater drainage tank level

The steam reheater system of the turbine plant transfers steam from high to low pressure turbine. The system dehumidifies and heats the steam. The steam reheater system has tanks for collecting humidity. The level of the drainage tanks is monitored by means of level transmitters and the data transmitted by them is used to control the reheater control valves and, further, the emergency drainage valves.

Olkiluoto 1 was being operated at 105% reactor power on 15 July 1996 when one reheater drainage tank level switch for the first time sent an alarm signal for high level for about four seconds at 00.06 hours The control room personnel checked the drainage tank level and noted the alarm to have been erroneous. The alarm was repeated after 30 minutes, however, and was valid for about 40 seconds.

Because the alarm signal lasted for more than 20 minutes the live steam valves of the steam reheater closed and the bypass control valves opened to control turbine and reactor pressure. Following the reduction of pressure, there was turbulence in the drainage tank and, due to the raised level of the tank, the primary circulation pumps began to operate at reduced speed. In consequence of the event, reactor power decreased as designed to a power level of about 62%.

The erroneously tripped level switch was examined. The event was assumed to have been caused by a contact deteriorated due to oxidation or other impurities. The closing of the live steam valves of the steam reheater for its part was due to a design failure in the acknowledgement of the alarm signal. A corresponding event had occurred on 30 June 1996 and an unacknowledged trip condition pertaining to it was already in force.

The event had no bearing on plant safety. According to preliminary investigations, the event was caused both by aged level transmitters and a design error in the alarm acknowledgement procedure of the sub-system in question. Teollisuuden Voima Oy will replace all contacts of the level transmitters in question in the turbine automation system and other systems during the next two years. The defective level transmitters have been sent for checks to find out the cause of the contact failure. The design error in the alarm signal's acknowledgement will be fixed in the forthcoming 1997 annual maintenance outage.

3.6 Reactor scram at the Olkiluoto plant units due to a disturbance in the 400 kV external grid

Olkiluoto nuclear power plant normally supplies electricity to the 400 kV external grid. If this connection is lost the reactor switches to low power level, i.e. house load operation, to supply electricity for the plant's own systems. Should this fail, power is supplied by the 110 kV off-site grid. Power supply to safety-significant functions has also been ensured by on-site diesel generators, four at each plant unit. Such redundancy in power supply also during shutdown state is necessary because a nuclear reactor generates heat even when in shutdown state. This decay heat must be removed from the reactor to avoid damage.

A ground contact occurred in the 400 kV national grid on 24 July 1996, causing the automatic disconnection from the grid of both Olkiluoto plant units. The Olkiluoto 1 reactor was operating at 95% power and the Olkiluoto 2 reactor at 100% power when the disturbance occurred.

Early in the disturbance Olkiluoto 1 switched to house load operation and reactor power settled at about 60% in consequence of the reduction in the operating speed of the primary circulation pumps. Steam was directed past the turbine to the condenser, and pressure control was switched over to by-pass valves. At this stage, the unit's automation and the systems it controls operated as designed. In about one minute from the start of the disturbance, however, the condenser level measurement indicated increased level due to which a reactor scram was initiated by the protection system. According to the estimates made, however, the scram may have been caused by increased condenser pressure which caused water level to rise in the level measurement equipment tubing. Corresponding excessive sensitivity of the level measurement equipment has been observed earlier during certain operational transients. Since the condenser was no more available for use as a heat sink, an automatic device simultaneously initiated steam discharge to the containment building condenser pool. Blow-down into the condenser pool resulted in a turbulent reactor surface which actuated a protection function closing the steam line isolation valves. At this stage of the transient, power was supplied by the main generator whose operating speed was decreasing.

At the time of the grid disturbance, one diesel generator at Olkiluoto 1 was undergoing a load test according to the periodic test programme. A brief increase in the turbine's operating speed at the early stages of the disturbance caused an overfrequency in the supply voltage of the desel generator and the diesel generator in question was tripped by the protection system. The reactor protection system switched the plant unit's other three diesel generators to no-load operation.

The reduced operating speed of the main generator caused the opening of the generator switch. The resulting undervoltage of the house load operation grid actuated an automatic switching device which ensures power supply from the external grid. The device switched the power supply of the 6 kV power supply system for house load operation to take place from the 110 kV external grid. Due to an undervoltage in the diesel-backed 690 kV busbars, three diesel generators were connected to their own busbars by automatic devices as designed and began to supply power. Voltage was manually connected to the fourth 690 kV busbar whose diesel generator had tripped from overvoltage.

The situation then stabilised and power supply for even the 690 kV diesel-backed busbars supplied power by diesel generators were switched to take place from the 110 kV external grid, and the diesel generators were stopped.

At Olkiluoto 2, reactor pressure control failed in connection with the grid disturbance and a reactor scram was initiated by the brief pressure increase. The plant unit's power supply was automatically switched to take place from the 110 kV external grid. The diesel generators of three sub-systems went on no-load operation as designed and, due to a periodic test, the fourth diesel generator had been in operation even before the disturbance.

According to investigations, the event was initiated by a ground contact caused by a tree growing beneath the 400 kV transmission line.

Based on the analyses made and the reports received from Teollisuuden Voima Oy, both plant units mostly operated according to design during the disturbance. In addition to the above malfunctions, automated start-up of the auxiliary feedwater pump according to design failed at both units. To find out what caused this operational deviation, Teollisuuden Voima Oy has launched investigations to identify a potential design error in startup automation and to carry out the modifications required in the control logic. Teollisuuden Voima Oy will also investigate on a wider scale the possibility of making more reliable the plant's switching to house-load operation and keeping it that way. Modification of the protection system and improvement of the condenser level measurement will be analysed among other things.

Olkiluoto 2 was connected to the national grid at 20.26 hours the same evening and Olkiluoto 1 at 03.07 hours the next morning.

This event did not significantly affect nuclear safety.

Olkiluoto 2

In the third quarter of 1996, three reactor pressure vessel safety valves unnecessarily opened in a periodic test at Olkiluoto 2. During preventive maintenance of the back-up diesel generators of Olkiluoto 2, a fuel transfer pump motor was replaced at the wrong plant unit by mistake. These events are level 0 on the INES scale.

3.7 Unnecessary opening of three reactor pressure vessel safety valves during a periodic test at Olkiluoto 2

The overpressurisation protection of the reactor pressure vessel of the Olkiluoto plant units is taken care of by the relief system. The opening signal for the relief valves comes from i.a. the function initiated by the reactor protection system condition "high reactor pressure". The protection system comprises four individual control channels. When two of them are actuated, the necessary protection function is initiated.

A periodic test of the reactor pressure vessel instrumentation system was being carried out at Olkiluoto 2 on 8 August 1996. The condition "high reactor pressure" was being checked for proper functioning. In the test, it was intended to test the operation of limit value detectors indicating pressure and which belong to each of the four control channels. During the test, one sub-condition is tripped at a time and the sending of a protection signal is ensured.

The test was performed according to the procedures by first tripping the limit value detector of channel A. The sub-condition of B was already erroneously on trip mode and thus the simultaneous activation of two sub-systems caused the opening of three discharge valves. Two safety valves were open for about three seconds and the manually closed quick-opening valve for about 30 seconds. The opening of the valves caused a pressure reduction of about 2.2 bar and a 115% power peak in the reactor. The control room personnel reduced reactor pressure to 95% according to the procedures.

Investigations after the event showed that the tripping of sub-condition B was due to a clearly higher transfer resistance in the relay's pair of contacts. Teollisuuden Voima Oy has submitted the relay to further examination. Potential further measures will be decided on the basis of the results.

The valve's opening had no immediate bearing on nuclear safety. However, the event could have caused an operational transient and actuated the reactor protection system.

3.8 The motor of a back-up diesel generator fuel transfer pump was replaced at wrong plant unit

Both Olkiluoto plant units have four back-up diesel generators subject to preventive maintenance according to a pre-determined programme. At Olkiluoto 2, preventive maintenance of one diesel generator and its related components was begun on 2 September 1996. In connection with the maintenance, the entire diesel generator was replaced with a diesel generator which had undergone overhaul. The work took about four days.

The replacement of the motor of the diesel generator's fuel transfer pump was among the work to be done during preventive maintenance. The preventive maintenance assignment on 2 September 1996 was erroneously carried out for a component at the wrong plant unit. The decoupling of the electricity supply cables of the transfer pump's motor and the replacement of the pump itself was made at Olkiluoto 1 although it was due at Olkiluoto 2. The error was not noticed in connection with the incoupling of the cables and the motor because the motor did not start and the cables were not energized during the maintenance. The error was detected in the pump's performance test on 6 September 1996.

The fuel transfer pump injects fuel from an outside storage tank common for the back-up diesels to motor-specific day tanks beside each diesel motor. Both plant units have their own storage tanks and, beside them, four fuel transfer pumps each of which, if necessary, pump fuel to the day tanks of each of the four diesels. The pumps automatically start from decreased day tank level.

Auxiliary components essential for the operation of the diesel generator, such as the fuel transfer pump, must be operational. In this case, the fuel transfer pump of one diesel was inoperable at Olkiluoto 1 during the replacement. Other fuel transfer pumps were available however, reducing the event's actual bearing on safety.

The situation endangered personal safety in the sense that safety measures concerning the motor's replacement were intended for the device in Olkiluoto 2 but the work was done in Olkiluoto 1. If the motor had received a signal to start, its supply cables would have been energized.

The on-site identification system which is based on room and component identification symbols is not working very well in areas outside the plant building. Teollisuuden Voima Oy has initiated a root cause analysis into the causes of the event and the related deficiencies.

Olkiluoto 1 and 2

Analyses relating to the modernisation of the Olkiluoto plant units have shown that the cubical content of the containment buildings of the units is larger than assumed. The error is assessed to be of minor safety significance.

3.9 The cubical content of the containment buildings of the Olkiluoto plant units is larger than assumed

In connection with analyses relating to the modernisation of Olkiluoto plant units it was discovered that the cubical content of the containment building dry space exceeds by about 200 m^3 the value 4350 m^3 used in accident analyses. In accident analyses including a large coolant circuit leak, 3.69 bar is the maximum pressure obtained using the incorrect containment cubical content. The use of the correct cubical content increases the pressure to 3.89 bar. The containment is designed to withstand pressure up to 4.7 bar. This design pressure is not exceeded even though the corrected value is used for the cubical content of dry space. Margin to design pressure is reduced, however.

Due to the error, containment leaktightness tests have been conducted at too low pressure due to which the leaks measured during the tests are probably smaller than the actual values. The results of the tests have been below the acceptance limits set for them, however, and the error is thus assessed to be of minor safety significance for containment leaktightness

Due to the event, Teollisuuden Voima Oy will examine the event and analyse the effect of the detected error on the results of the containment leaktightness test. On the basis of the results of this examination, the requirements for a containment building leaktightness test and isolation valves in the Technical Specifications are changed to correspond to the new testing pressure and the new total cubical content of the containment building. Furthermore, the instructions for leaktightness tests will be correspondingly revised.

4 RADIATION SAFETY

Individual doses to nuclear power plant personnel were below the annual dose limit. Also environmental releases were well below the release limits. In samples collected around the Finnish nuclear power plants, radioactive substances originating from the plants were measurable in such quantities only as have no bearing on the radiation exposure of the population.

4.1 Occupational exposure

The highest individual dose received at a Finnish nuclear power plant in the third annual quarter was 18.7 mSv and it was received at Loviisa nuclear power plant. The Radiation Decree stipulates that the effective dose caused by radiation work to a worker shall not exceed 50 mSv in any single year. The dose may not exceed 20 mSv per year as an average over five years. This monitoring of the annual average was started at the beginning of 1992. Radiation doses at Loviisa and Olkiluoto nuclear power plants have been below authorised limits.

Occupational dose is mainly incurred in work performed during annual maintenance outages. The annual maintenance outage of Loviisa 1 and part of Loviisa 2's annual maintenance were in this annual quarter.

The individual dose distribution of nuclear power plant personnel is given in Table III which specifies the number of exposed individuals by dose range and plant site. This information is from STUK's central dose register.

Collective occupational dose at the Loviisa plant units was 1.97 manSv and 0.03 manSv at the Olkiluoto units in this quarter. According to a STUK Guide, the collective dose limit for one plant unit is 2.5 manSv per one gigawatt of net electrical power averaged over two successive years; this means a total annual collective dose of 2.22 manSv/year and of 3.56 manSv/year for the Loviisa and Olkiluoto units respectively.

4.2 Radioactive releases into the environment

In Table IV, the releases of radioactive substances measured at each plant site and the annual release limits are given. During this report period, releases into the environment were well below authorised limits.

4.3 Environmental monitoring

Radiation safety in the vicinity of Finnish nuclear power plants is ensured by regular sampling and analysis programmes. The environmental distribution of radioactive releases and their transfer to food chains is monitored and it is thus ensured that the releases remain below authorised limits. In this quarter, a total of 173 samples was analysed according to the programmes.

Radioactive substances originating from Loviisa nuclear power plant were measured in nine samples of air, three samples of deposition, four samples of seaweed, three samples of sedimenting matter and two samples of sea water. The most common nuclides originating from the nuclear power plants were cobalt-58 and -60, manganese-54 and silver-110m. In addition, some samples contained antimony-124, zirkonium-95 or niobium-95. The samples of sea water had tritium concentrations slightly above normal.

In samples collected around Olkiluoto nuclear power plant, radioactive substances originating

Table III. Occupational dose distribution in the third quarter of 1996 and from beginning of 1996.

Dose range (mSv)	Number of persons by dose range					
	Third quarter 1996			From beginning of 1996		
	Loviisa	Olkiluoto	Total*	Loviisa	Olkiluoto	Total*
< 0.5	223	86	314	238	532	705
0.5–1	101	9	121	106	273	353
1–2	114	9	151	117	217	319
2–3	74	–	93	79	91	160
3–4	45	–	58	51	52	99
4–5	35	–	48	36	36	79
5–6	31	–	47	28	12	45
6–7	26	–	31	27	12	50
7–8	21	–	31	21	7	45
8–9	15	–	21	13	4	37
9–10	14	–	26	13	6	31
10–11	8	–	15	9	5	28
11–12	6	–	7	9	7	21
12–13	6	–	8	5	–	10
13–14	4	–	7	5	2	11
14–15	–	–	1	1	1	7
15–16	4	–	4	3	–	5
16–17	3	–	3	4	–	8
17–18	1	–	1	2	–	5
18–19	1	–	1	1	–	3
19–20	–	–	–	–	–	2
20–25	–	–	1	–	–	4
> 25	–	–	–	–	–	–

* The data in these columns also include Finnish workers who have received doses at Swedish nuclear power plants. The same person may have worked at both Finnish nuclear power plants and in Sweden. The highest dose to a Finnish nuclear power plant worker this quarter, 21.1 mSv, was received at a nuclear power plant in Sweden.

from the power plant were detected only in indicator samples of the marine environment (seaweeds and sinking matter). The nuclides detected were manganese-54, cobalt-58 and -60. All these concentrations were low and require no measures.

Radioactive strontium and caesium isotopes (strontium-90, caesium-134 and -137) and plutonium isotopes (plutonium-238, 239+240) and tritium originating from the Chernobyl accident and the fallout from nuclear weapons tests are still measurable in environmental samples. Natural radioactive substances (i.a. beryllium-7, potassium-40, decay series of uranium and throrium) are also detected whose concentrations in the samples in question are usually much higher than the concentrations of nuclides originating from the power plants or fallout.

Table IV. Radioactive releases by plant site, third quarter 1996.

Gaseous effluents (Bq) a)

Plant site	Noble gases (Krypton-87 equivalents)	Iodines (Iodine-131 equivalents)	Aerosols	Tritium	Carbon-14
Loviisa					
Report period	$8.4 \cdot 10^{9}$ b)	$6.1\ 10^{5}$	$1.5 \cdot 10^{8}$	$4.9 \cdot 10^{10}$	$1.1 \cdot 10^{10}$
Early 1996	$2.3 \cdot 10^{10}$ b)	$6.2 \cdot 10^{5}$	$1.5 \cdot 10^{8}$	$1.6 \cdot 10^{11}$	$8.1 \cdot 10^{10}$
Olkiluoto					
Report period	$1.4 \cdot 10^{11}$	$9.9 \cdot 10^{5}$	$4.7 \cdot 10^{5}$	$6.1 \cdot 10^{10}$	c)
Early 1996	$8.7 \cdot 10^{12}$	$2.4 \cdot 10^{7}$	$1.3 \cdot 10^{7}$	$1.6 \cdot 10^{11}$	c)
Annual release limits					
Loviisa	$2.2 \cdot 10^{16}$	$2.2 \cdot 10^{11}$			
Olkiluoto	$1.8 \cdot 10^{16}$	$1.1 \cdot 10^{11}$			

Liquid effluents (Bq) a)

Plant site	Tritium	Other nuclides
Loviisa		
Report period	$2.2 \cdot 10^{12}$	$6.6 \cdot 10^{6}$
Early 1996	$7.6 \cdot 10^{12}$	$5.4 \cdot 10^{7}$
Olkiluoto		
Report period	$2.7 \cdot 10^{11}$	$3.0 \cdot 10^{9}$
Early 1996	$1.9 \cdot 10^{12}$	$1.4 \cdot 10^{10}$
Annual release limits		
Loviisa	$1.5 \cdot 10^{14}$	$8.9 \cdot 10^{11}$ e)
Olkiluoto	$1.8 \cdot 10^{13}$	$3.0 \cdot 10^{10}$

a) The unit of radioactivity is Becquerel (Bq); 1 Bq = one nuclear transformation per second.
b) In addition, the calculated release of argon-41 from Loviisa 1 and 2 in krypton-87 equivalents was $2.5 \cdot 10^{11}$ Bq in the report period and $8.6 \cdot 10^{12}$ Bq from beginning of 1996.
c) The carbon-14 release-estimate based on experimental data was $1.7 \cdot 10^{11}$ Bq in Olkiluoto in the report period and $4.7 \cdot 10^{11}$ Bq from beginning of 1996.
d) The figure shows the release limit for the Loviisa plant site, assuming that the sum of various types of release limit shares shall be smaller than or equal to 1.

5 SAFETY IMPROVEMENTS AT NUCLEAR POWER PLANTS

In the third quarter of 1996 was the annual maintenance outage of Loviisa 1 and part of Loviisa 2's annual maintenance outage during which several plant modifications important to safety were implemented. The Olkiluoto plant units were mostly in power operation and no significant plant modifications were made.

Pressuriser emergency spraying by the emergency make-up pumps was made possible by the installation of two connecting pipelines (fig. 5). This modification enhances primary circuit pressure reduction to minimise a potential leak and speeds up reactor cooling. The installation was made during the Loviisa 1 annual maintenance. At Loviisa 2, the installation was made already in the 1994 annual maintenance.

A new auxiliary emergency make-up tank shared by the units and piping (fig. 5) were installed at the Loviisa plant units. This ensures supply of cooling water long enough to cool down the primary circuit to cold unpressurised state even if water is lost to outside the containment building in consequence of a primary to secondary leak in the steam generator and a stuck-open secondary circuit saftey valve.

In order to protect the electrical and instrumentation rooms and the control room located below the feedwater tank level, modifications were made in the feedwater piping above the level in question because loads caused by high pressure jets from a feedwater pipe leak might break the floor of the feedwater tank level. In the modification, the piping above the floor level in question at Loviisa 1 was replaced with stainless piping which withstands well erosion-corrosion. A corresponding modification is due at Loviisa 2 in the 1998 annual maintenance outage. In addition, collars made of steel pipe were anchored around the welded seams of the pipes. The collars break up and make less hazardous any high pressure jets from pipe leaks, thus ensuring the integrity of the feedwater tank level.

Measures were taken to reduce the risk of clogged band screens at the sea water intake to prevent loss of the service water circuit. Pumps will be automatically stopped one at a time when pressure difference across the band screen grows reaching the limit value. The display indicating pressure differences is in the main control room. The modification was made in the annual maintenances of both Loviisa plant units.

On the pressure side of the emergency cooling pumps are minimun flow circuits which protect the pumps from damage during startup. These circuits return a small amount of water back to the emergency make-up tank. If a minimun flow circuit erroneously remains open in an accident situation after the pump has started, part of the water is recirculated via the minimun flow circuit to the make-up water tank. When the tank is empty water circulation is via the containment building sinks. Water recirculated to the tank via the minimum flow circuit therefore soon reaches a level at which the pumps automatically switch to draw water again from an almost empty tank. The pumps' suction source is thus being switched between sink and tank which, before long, leads to pump and valve failure. The old minimum flow circuits of the emergency cooling pumps were removed to reduce the risk and the new

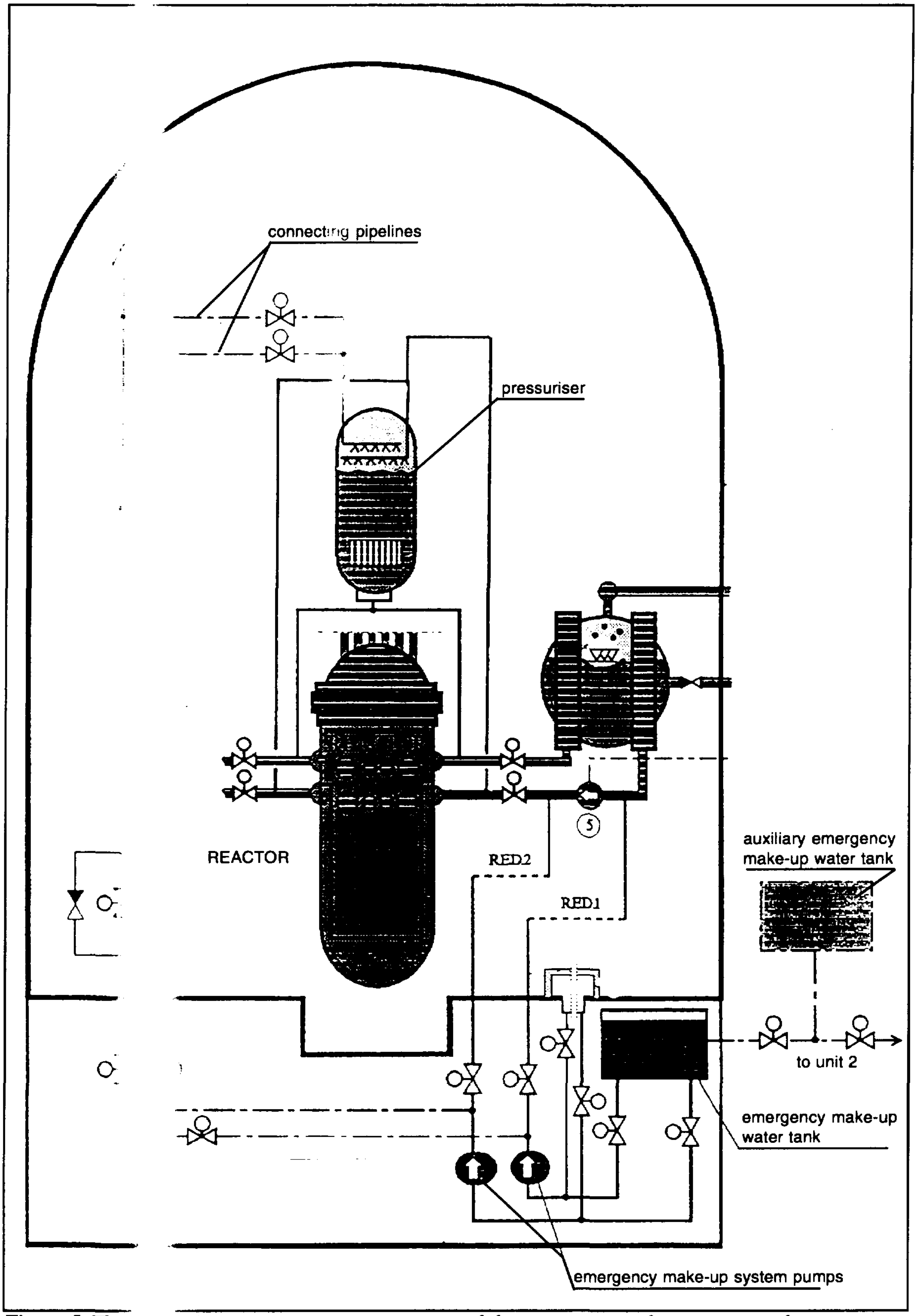


Figure 5. The ...uriser emergency spray system and the emergency make-up water tanks.

flow circuits equipped with heat exchangers were installed from emergency make-up pump pressure side direct to suction side. Redundance 1 was modified in this way in the Loviisa 1 annual maintenance. Redundance 2 of Loviisa 1 will be correspondingly modified and Loviisa 2 will be entirely modified in the 1997 annual maintenance.

The primary circuit overpressurisation protection and pressure reduction system was renewed. During annual maintenance, the pressuriser main safety valves were replaced with valves which function also during a water blowing situation. The pressuriser was also fitted with new discharge lines for primary circuit pressure relief during accidents. A safety valve was installed near one of the two discharge lines. The valve will be used for primary circuit overpressurisation protection in shutdown state. Primary circuit pressure reduction is an important measure to help maintain primary circuit and containment building integrity in servere addicents and in transients in which the reactor scram function fails. The modifications were made in the annual maintenances of both Loviisa plant units.

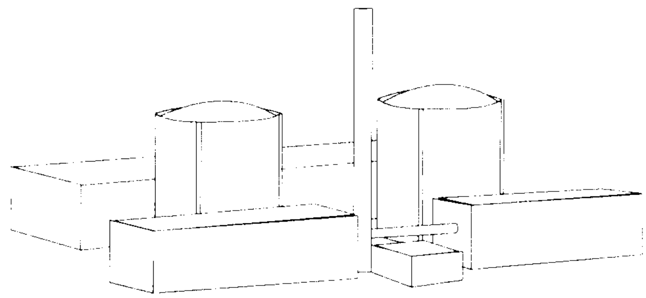
The accuracy and reliability of the pressuriser level measurement was improved by installing a new type of condensate chamber for level measurements via which no non-condensable gases are dissolved into the measurement reference piping. The modification was made at both plant units in connection with annual maintenance.

The reactor pressure vessel of Loviisa 1 was subjected to heat treatment by annealing it for 100 hours at a temperature of 475...500°C. A more detailed description of the annealing can be found in sub-section 3.1.

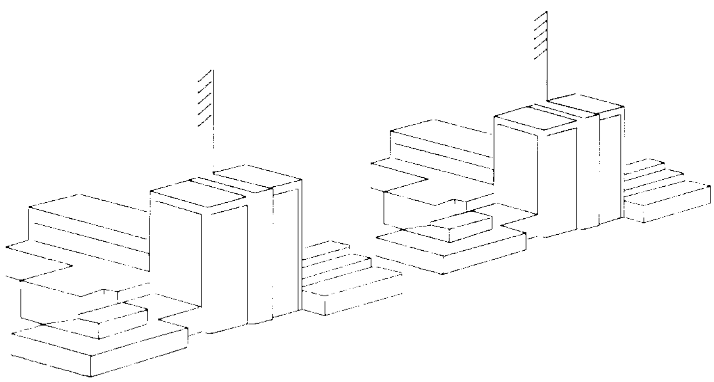
APPENDIX 1

Council of State Decisions	Regulatory control and inspections by the Finnish Centre for Radiation and Nuclear Safety
	Preparation of a nuclear power plant project • Preliminary plans for the plant and safety principles • Location and environmental impact of the plant • Arrangements for nucler fuel and nuclear waste management
Decision in Principle	
	Plant design • Preliminary safety analysis report on the planned structure and operation of the plant plus the preliminary safety analysis • Safety classification of components and structures • Quality assurance plan • Plans for nuclear fuel and nuclear waste management • Physical protection and emergency preparedness
Construction Permit	
	Construction of plant • Construction plans, manufacturers, final construction and installation of components and structures • Performance tests of systems • Final safety analysis report on the structure and operation of the plant and the final safety analyses • Probabilistic safety analysis • Composotion and competence of the operating organisation • Technical Specifications • Nuclear fuel management and safeguards • Methods of nuclear waste management • Physical protection and emergency preparedness
Operating Licence	
	Plant operation • Start-up testing at various power levels • Maintenance, inspections and testing of components and structures • Operation of systems and the whole plant • The operating organisation and management • Training of personnel • Qualifications of individuals • Operational incidents • Repairs and modifications • Refuelling • Nuclear fuel management and safeguards • Nuclear waste management • Radiation protection and safety of the environment • Physical protection and emergency preparedness • Fire protection

APPENDIX 2



Plant unit	Start-up	Commercial operation	Rated power (gross/net, MW)	Type, supplier
Loviisa 1	8 Feb.1977	9 May 1977	465/445	Pressurized water reactor (PWR), Atomenergoexport
Loviisa 2	4 Nov. 1980	5 Jan. 1981	465/445	Pressurized water reactor (PWR), Atomenergoexport



Plant unit	Start-up	Commercial operation	Rated power (gross/net, MW)	Type, supplier
Olkiluoto 1	2 Sept. 1978	10 Oct. 1979	735/710	Boiling water reactor (BWR), Asea Atom
Olkiluoto 2	18 Feb. 1980	1 July 1982	735/710	Boiling water reactor (BWR), Asea Atom

Imatran Voima Oy owns the Loviisa 1 and 2 plant units in Loviisa and Teollisuuden Voima Oy the Olkiluoto 1 and 2 plant units in Olkiluoto, Eurajoki.

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