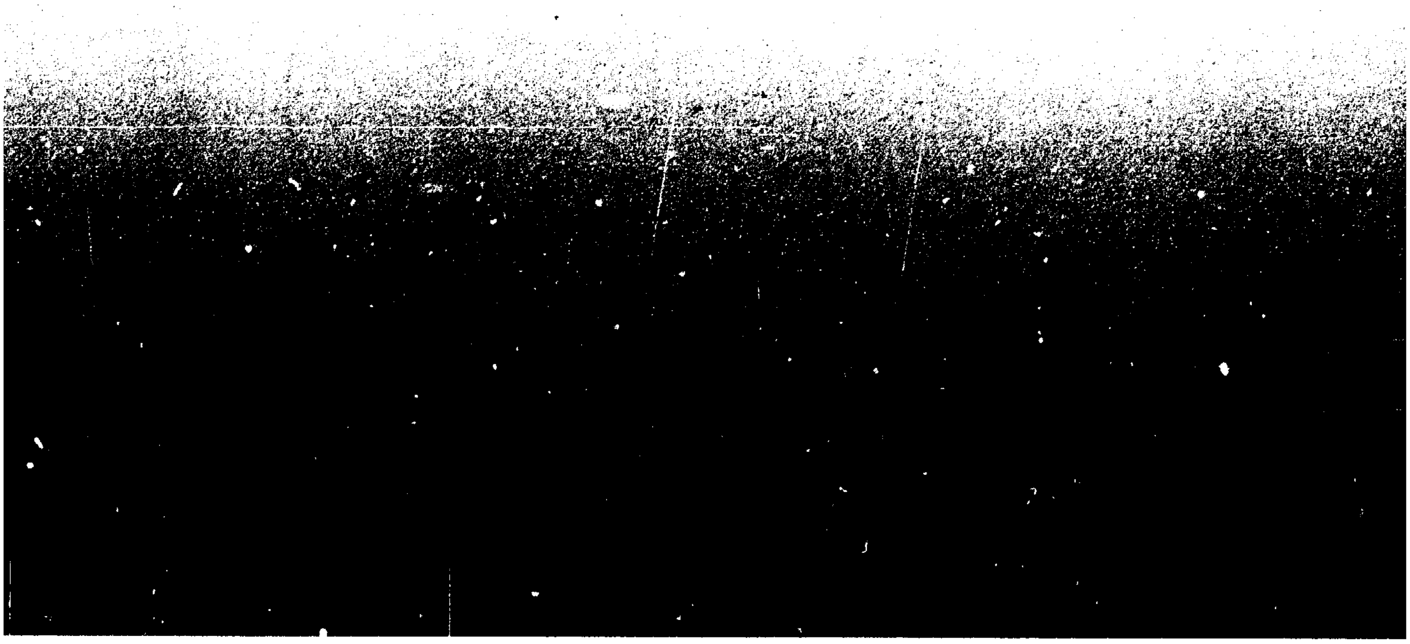
STUK-B-YTO 76

Operation of Finnish nuclear power plants

Quarterly report
2nd quarter, 1990

Kirsti Tossavainen (Ed.)

DECEMBER 1990



SÄTEILYTURVAKESKUS
Strålsäkerhetscentralen
Finnish Centre for Radiation and Nuclear Safety

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Kirsti Tossavainen (Ed.)
Department of Nuclear Safety

FINNISH CENTRE FOR RADIATION
AND NUCLEAR SAFETY
P.O.BOX 268 SF-00101 HELSINKI
Finland
Tel. +358 0 70821

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ABSTRACT

In the Quarterly Reports on the operation of the Finnish nuclear power plants such events and observations are described relating to nuclear and radiation safety which the Finnish Centre for Radiation and Nuclear Safety considers safety significant. Also other events of general interest are reported. The report includes also a summary of the radiation safety of the plants' workers and the environment, as well as tabulated data on the production and load factors of the plants.

During the second quarter of 1990 the Finnish nuclear power plant units Loviisa 1 and 2 and TVO I and II were in commercial operation for most of the time. The feedwater pipe rupture at Loviisa 1 and the resulting inspections and repairs at both Loviisa plant units brought about an outage the overall duration of which was 32 days. The annual maintenance outages of the TVO plant units were arranged during the report period and their combined duration was 31.5 days. Nuclear electricity accounted for 35.3 % of the total Finnish electricity production during this quarter. The load factor average of the nuclear power plant units was 83.0%.

Three events occurred during the report period which are classifed as Level 1 on the International Nuclear Event Scale: feedwater pipe rupture at Loviisa 1, control rod withdrawal at TVO I in a test during an outage when the hydraulic scram system was rendered inoperable and erroneous fuel bundle transfers during control rod drives maintenance at TVO II.

Other events during this quarter are classified as Level Zero (Below Scale) on the International Nuclear Event Scale.

Occupational radiation doses and external releases of radioactivity were considerably below authorised limits. Only small amounts of nuclides originating in nuclear power plants were detected in samples taken in the vicinity of nuclear power plants.

CONTENTS

1 INTRODUCTION

As prescribed by the Nuclear Energy Act (990/87), regulatory control of the safety of the use of nuclear energy rests with the Finnish Centre for Radiation and Nuclear Safety. The functions of the Finnish Centre for Radiation and Nuclear Safety include also regulatory control of physical protection, emergency preparedness and nuclear material safequards. The scope of regulatory control related to nuclear power plants is specified in Appendix 1. General information relating to the Finnish nuclear power plants is presented in Appendix 2.

The Finnish Centre for Radiation and Nuclear Safety publishes a quarterly report on the operation of Finnish nuclear power plants. The report on the last quarter also contains a summary of the information reported during the year in question. The report is based on the information reported to the Finnish Centre for Radiation and Nuclear Safety by the power companies and the observations made by the Finnish Centre for Radiation and Nuclear Safety during regulatory control and inspections. The events and observations described in the report are classified according to the International Nuclear Event Scale which is currently undergoing a trial period.

In addition to event descriptions, the report contains a summary of the radiation safety of nuclear power plant workers and the environment and tabulated data on the production and load factors of nuclear power plants.

2 OPERATION OF NUCLEAR POWER PLANTS IN APRIL–JUNE 1990

Finnish nuclear power plants were in commercial operation for the most part of the 2nd quarter of 1990. Inspections and repairs due to a feedwater pipe rupture at Loviisa 1 brought about an outage at the Loviisa plants which lasted 32 days. The TVO plant units were off the grid for a combined 31.5 days owing to annual outages. Furthermore, TVO I was disconnected from the national grid for three days due to less demand for electricity.

2.1 Production data

Nuclear electricity accounted for 35.3 % of the total amount of electricity generated in Finland during this quarter. The load factor average of the plant units was 83.0 %. Production and availability figures are presented in more detail in Tables I and II.

Power diagrams describing electricity generation at the plant units and summaries of power reductions are presented in Figures I – 4.

Table I. *Electricity production and availability of the units.*

	Electricity production (gross, TWh)		**Availability factor (%)**		**Load factor (%)**	
	Second quarter 1990	**From beginning of 1990**	**Second quarter 1990**	**From beginning of 1990**	**Second quarter 1990**	**From beginning of 1990**
Loviisa 1	0.89	1.89	88.3	94.1	87.2	93.8
Loviisa 2	0.91	1.88	91.4	93.8	89.2	93.1
TVO I	1.28	2.85	82.9	90.7	79.8	89.1
TVO II	1.21	2.79	80.0	89.7	75.7	87.5

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

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

***Table II.** Nuclear energy in the Finnish production of electricity.*

	Second quarter 1990	**From beginning of 1990**	**1989**	**1988**
Production of nuclear electricity (net, TWh)[a]	4.1	9.0	18.0	18.4
Total production of electricity in Finland (net, TWh)[a]	11.6	26.7	50.8	53.5
Percentage of nuclear electricity of total production	35.3	33.7	35.4	34.4
Load factor averages of the Finnish plant units (%)	83.0	90.9	89.9	91.2

[a] Source: Statistics compiled by the Finnish Association of Electricity Supply Undertakings.

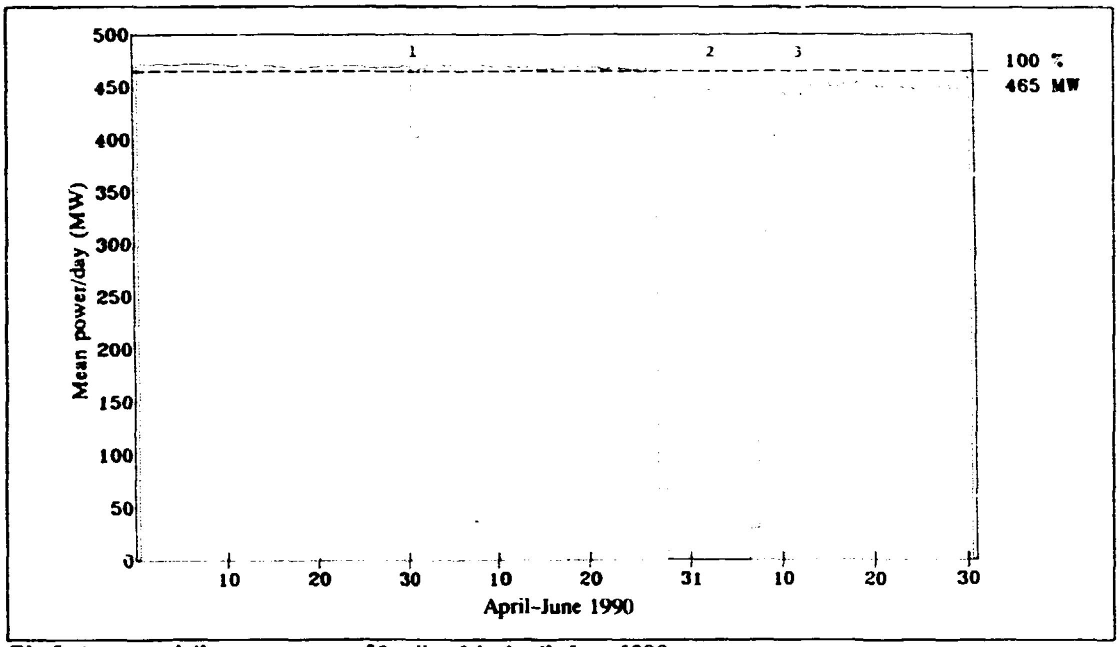

Fig 1. Average daily gross power of Loviisa 1 in April–June 1990

1 Less demand for electricity, reactor operating at 79 % power
2 Shutdown due to feedwater pipe rupture and cold shutdown for inspection and repair of feedwater piping
3 Primary circulating pump trip, reactor to 76 % power

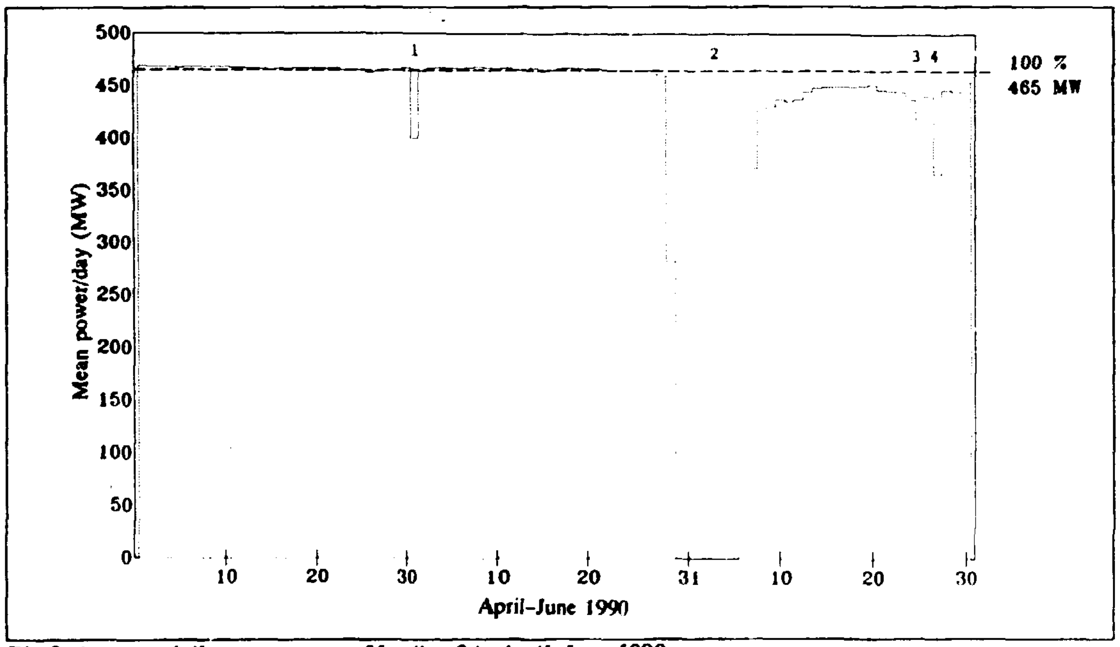

Fig 2. Average daily gross power of Loviisa 2 in April–June 1990.

1 Less demand for electricity, reactor operating at 79 % power
2 Cold shutdown for inspection and repair of feedwater piping
3 Repair of the circulating filter of the condenser purification system, reactor operating at 73 % power
4 Turbine trip in consequence of the tripping of the generator differential protection, reactor to 52 % power

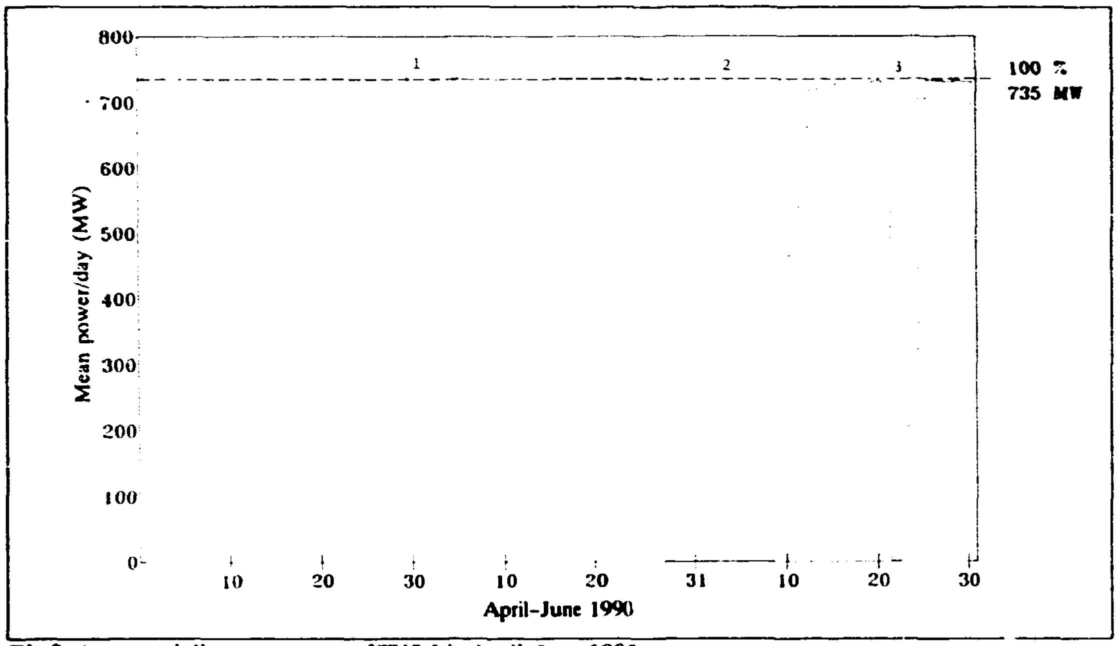

Fig 3. Average daily gross power of TVO I in April–June 1990.

1 Less demand for electricity, reactor in hot shutdown with closed isolation valves
2 Annual maintenance and refuelling outage
3 Less demand for electricity, reactor in hot shutdown with closed isolation valves

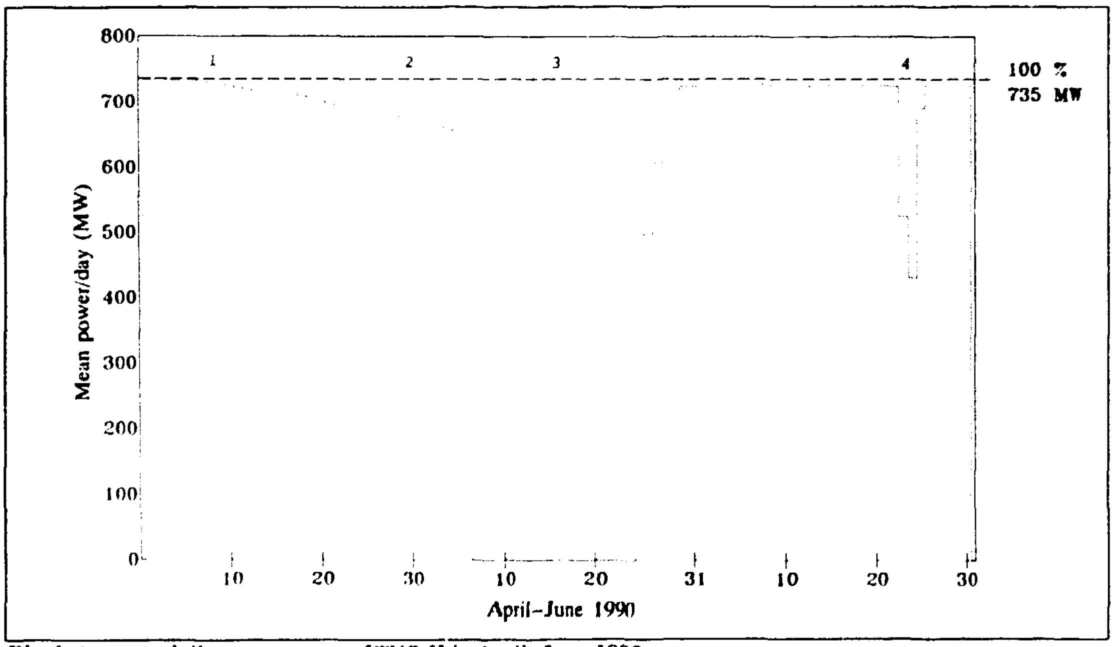

Fig 4. Average daily gross power of TVO II in April–June 1990.

1 Nuclear fuel has burned to such an extent that power has started to sink gradually (coast-down)
2 Less demand for electricity, reactor operating at 91 % power
3 Annual maintenance and refuelling outage
4 Less demand for electricity, reactor operating at 61 % power

2.2 Loviisa 1

2.2.1 Outage due to a feedwater pipe rupture

A feedwater pipe rupture occurred at Loviisa 1 on 28.5. Repairs and inspections caused a 16.5-day shutdown. The event is dealt with in chapter 3.1.2 of this report.

2.3 Loviisa 2

2.3.1 Cold shutdown for inspecting feedwater system piping

Loviisa 2 was placed in cold shutdown on 29.5. for inspecting and strengthening feedwater piping due to the feedwater pipe rupture at Loviisa 1. The inspections and repairs done are accounted for in chapter 3.2.1.The shutdown lasted 15.5 days.

2.4 TVO I

2.4.1 Hot shutdown on May Day due to less demand for electricity

TVO I was detached from the national grid on 30.4. due to less demand for electricity. The plant unit was in hot shutdown with the reactor at normal operating temperature and pressure but no steam was generated. During the shutdown minor repairs were conducted, e.g. a steam extraction valve leak was repaired. The plant unit was connected to the national grid on 1.5.

2.4.2 Annual maintenance

Eleventh refuelling and maintenance outage at TVO I was held on 27.5. - 9.6. The plant unit was detached from the national grid for about 13 days.

During a refuelling and maintenance outage, numerous inspections, repairs and maintenance jobs are performed according to the maintenance programme and also separately.

Last autumn metal powder was detected in the primary circuit. Owing to this the cleanliness of the primary circulating pump level and the guide tubes of four control rods were chosen for re-inspection inside the reactor pressure vessel. At pump level minor amouts of metal powder and other impurities were detected. These were removed by vacuum extraction. In post-outage tests the control rods were noted to function faultlessly. During plant unit start-up some control rods got stuck during withdrawal. All control rods could be manipulated, however.

In the outage only one of a total of 121 control rods was inspected since, owing to the metal powder detected in the primary circuit, all control rods had been inspected last autumn. No control rod replacements were made. Of the control rod drives 20 had been chosen for maintenance on the basis of operating experience. 0 - 5 g, mostly less than 1 g, of metal powder was found in the crud pockets of the drives picked up for maintenance.

During the outage, a new control valve was installed in parallel with the old one in the feedwater system. Also, a new controller was installed in parallel with the old one in the feedwater control system. By these modifications feedwater control was made more accurate than before during operation at low power levels. In connection with plant unit start-up, controller performance test and final adjustment were conducted.

The size of the filter of the condensate purification system was increased and flow distribution inside the filter was altered for improved efficiency.

In addition to Teollisuuden Voima Oy's own staff 800 non-utility persons took part in the annual maintenance outage. The collective radiation dose arising from work performed during the outage was 0.44 manSv which is 49 % less than last year. The highest individual radiation dose was 9.5 mSv. The limit authorised for a quarter of a year is 25 mSv.

A reactor scram occurred during plant unit start-up. While the core was being made critical a control rod was withdrawn too much which increased the neutron flux. At the same time, a measuring element for a small neutron flux (source area) was erroneously left in the core and the measuring value reached the trip limit. At the same time the scale of the neutron flux measuring range was increased which, for its part, resulted in the measuring value falling below the measuring range lower limit. These together caused a scram.

2.4.3 Hot shutdown at Midsummer due to less demand for electricity

TVO I was detached from the national grid on 22.6. due to less demand for electricity. The plant unit was placed in hot shutdown. At the same time i.a. leaking drainage valves of steam lines were repaired. The valves' moment switches caused the leaks as they had erroneously prevented the valves from closing tightly. Also leaking seals of other systems were repaired during the outage.

The plant unit was brought back on the national grid on 23.6. Owing to less demand for electricity power was raised to 100 % on the afternoon of 24.6.

2.5 TVO II

2.5.1 Annual maintenance

At TVO II the ninth refuelling and annual maintenance outage was held on 6.5. - 25.5. The plant unit was detached from the national grid for 18.5 days.

During a refuelling and maintenance outage, numerous inspections, repairs and modifications according to the maintenance programme and also individually are conducted.

During inspections, a crack was detected in one of the 121 control rods. The control rod was replaced. A slot-headed screw which was detected in a control rod drive which got stuck during the previous operating cycle was removed. The screw originated in a primary circulating pump slip ring. The fixing screws of the slip ring were locked now. During start-up one control rod drive got stuck but later on the control rod could be manipulated. In inspections of reactor pressure vessel piping and components no faults were detected which would have exceeded the acceptance limit.

During plant unit start-up a leaking gasket of the stem of a steam line drainage valve was observed and the plant unit was placed in cold shutdown for repairing the valve. During the second start-up it was noted that the turbine needed balancing and adjustment. The plant unit was placed in hot stand-by and the necessary repairs were made. The turbine had to be balanced for a second time. During the shut-down conducted for this purpose, a reactor scram occurred due to an operator error. Reactor water sank to a level at which the reactor protection system triggered the scram function.

Apart from Teollisuuden Voima Oy's own personnel 900 non-utility persons participated in the annual maintenance outage. The collective radiation dose arising from work done during the outage was about 0.93 manSv which is about 8 % less than the previous year. The highest personal dose was 9.7 mSv. The limit authorised for a quarter of a year is 25 mSv. During the outage a minor internal dose uptake, less than 0.7 mSv (see chapter 3.4.2) occurred to two individuals in connection with assignments related to valves.

3 EVENTS AND OBSERVATIONS AT EACH PLANT UNIT

3.1 Loviisa 1

In the second quarter of 1990 a feedwater pipe ruptured at Loviisa 1. The reactor was stopped without delay by a scram and the event was brought under control quickly. In inspections the pipe rupture was traced to erosion corrosion. Thinning caused by erosion corrosion which required reparation was detected also elsewhere in the feedwater circuit. Owing to the event, investigations to limit the occurrence of erosion corrosion in pipings and to complement inservice inspection programmes for piping were stepped up. The event is classified as Level 1 on the International Nuclear Event Scale.

Other events at Loviisa 1 during this quarter were the jamming open of two check valves of the service water system and the closing of the emergency feedwater lines when a steam generator control valve failed. These events as such did not disturb plant unit operation but under some failure conditions they would have hampered management of event. The events are classified as Level Zero (Below Scale) on the International Nuclear Event Scale.

3.1.1 Jamming open of two service water system check valves

At the Loviisa plant a subsystem (VF24) of the service water system (VF) cools down the heat exchangers of the ventilation system of the control and office buildings as well as the air coolers of the emergency feedwater pump rooms. The subsystem consists of two circuits which cool down one emergency feedwater pump room each. Both circuits supply water to the heat exchangers of the ventilation system.

In connection with an inspection relating to a periodic test on 24.4. two subsystem check valves were noted to have jammed open. Both circuits were thus interconnected so that as a result of a potential leak (pipe rupture) sufficient flow to both circuits could have been lost. If emergency feedwater pumps had been needed at the same time, insufficient cooling would have endangered operation of pumps. Had the pipe failure occurred on a hot summer day functional failures of some electrical, instrumentation and control equipment in the control building might have occurred. In both cases two unusual events would have coincided. Even during these events safety of plant unit could have been ensured by systems independent of the components in question.

The jamming open of the check valves was traced to layers of rust and algae which had accumulated inside the valves hindering valve diaphragm function. Valve housings were in a good condition considering their service age.

As a temporary corrective measure the check valves were replaced with new identical check valves. In the 1991 annual maintenance outage the valves are intended to be replaced with check valves the basic state of which will be adjusted so that the functioning of both circuits will not be lost in case of a potential leak.

In the Technical Specifications the maximum length of valve unavailability is defined. This did not suffice, however, since no replacement valves were available. The defined maximum time was exceeded by virtue of exemption granted by the Finnish Centre for Radiation and Nuclear Safety.

3.1.2 Feedwater pipe rupture

At the Loviisa plant units the reactor core is continuously cooled by means of water circulating in the primary circuit. From the primary circuit heat is transferred to water fed to the steam generators' secondary side. Water is first fed to the feedwater collector and henceforth to the steam generators. Five feedwater pumps supply water to the feedwater collector. Four of these pumps are in operation and one on stand-by during operation at full power. Water supply to the steam generators is ensured by i.a. two auxiliary feedwater pumps. Feedwater pumps are located in the turbine hall. The outside diameter of feedwater line piping is 325 mm and nominal wall thickness 18 mm.

At the Loviisa 1 assembly of switchgear a human error occurred on 28.5. in connection with preventive maintenance. The measuring wires of a voltmeter had been erroneously left in a wrong position. The resulting shortcut triggered two protective switches and transmitted a signal to automation of the loss of a 6 kV electricity supply busbar. Automation, for its part, tripped, according to its design function, one of the operating feedwater pumps and two primary circulating pumps. As a consequence of the tripping of the primary circulating pumps, a power limiting controller decreased reactor power to 60 % of nominal power.

The stand-by feedwater pump started immediately after the tripping of the operating feedwater pump. From the feedwater system's operational point of view the event had so far been similar to the regular replacement of a pump with a stand-by pump in connection with i.a. the repair of feedwater pumps.

The starting of the stand-by feedwater pump brought about a pressure shock in the feedwater lines. This resulted in a pipe rupture in one feedwater line during which about 70 m^3 of water from the secondary circuit was discharged into the turbine hall. Pressure decrease in the feedwater collector and in the feedwater lines tripped all operating feedwater pumps. Reactor operator in the control room brought about a scram manually as presupposed in the procedures concerning loss of feedwater. A scram would have occurred automatically after some time upon the decreasing of steam generator water levels below the safety limit. Auxiliary feedwater pumps started operation when steam generator water level decreased.

On the pressure side of the feedwater pump the isolation of the rupture from the process took place automatically when a shut-off valve closed. The rupture was localised visually and was isolated from the pump's suction side by closing a manually operated valve.

Nobody was injured in connection with the event and no radioactive discharges occurred on-site.

The feedwater pipe rupture was downstream of a feedwater pump in the flange of an orifice plate used for flow measurement close to a welded seam. The rupture was attributed to heavy erosion corrosion which had reduced pipe wall thickness to 1 - 2 mm circumferentially in the rupture point. A schematic presentation of the rupture is given in Fig 5.

After the event four other corresponding locations in feedwater lines were inspected. The rupture and the other four locations in the other lines were repaired temporarily. In feedwater lines also the flanges of orifice plates of each steam generator used for power measurement were inspected. One of them was repaired temporarily. Permanent repairs will be conducted in the annual maintenance outage.

The pipe rupture and the water discharged through the rupture damaged cable trays and cables near the pipe. Cables and adjacent measurement devices were inspected and damages repaired. Water damaged also fire suppression systems located in the same room. The damage was repaired temporarily without delay. Repairs on a more permanent basis will be carried out during the annual maintenance outage.

The plant unit was started on 13.6.

The event did not endanger safety of plant unit. In plant unit design loss of feedwater e.g. as a result of feedwater pump trip is considered an operational disturbance which occurs at few years' intervals at most. The plant unit is equipped with systems required in such events. It is possible to supply feedwater from

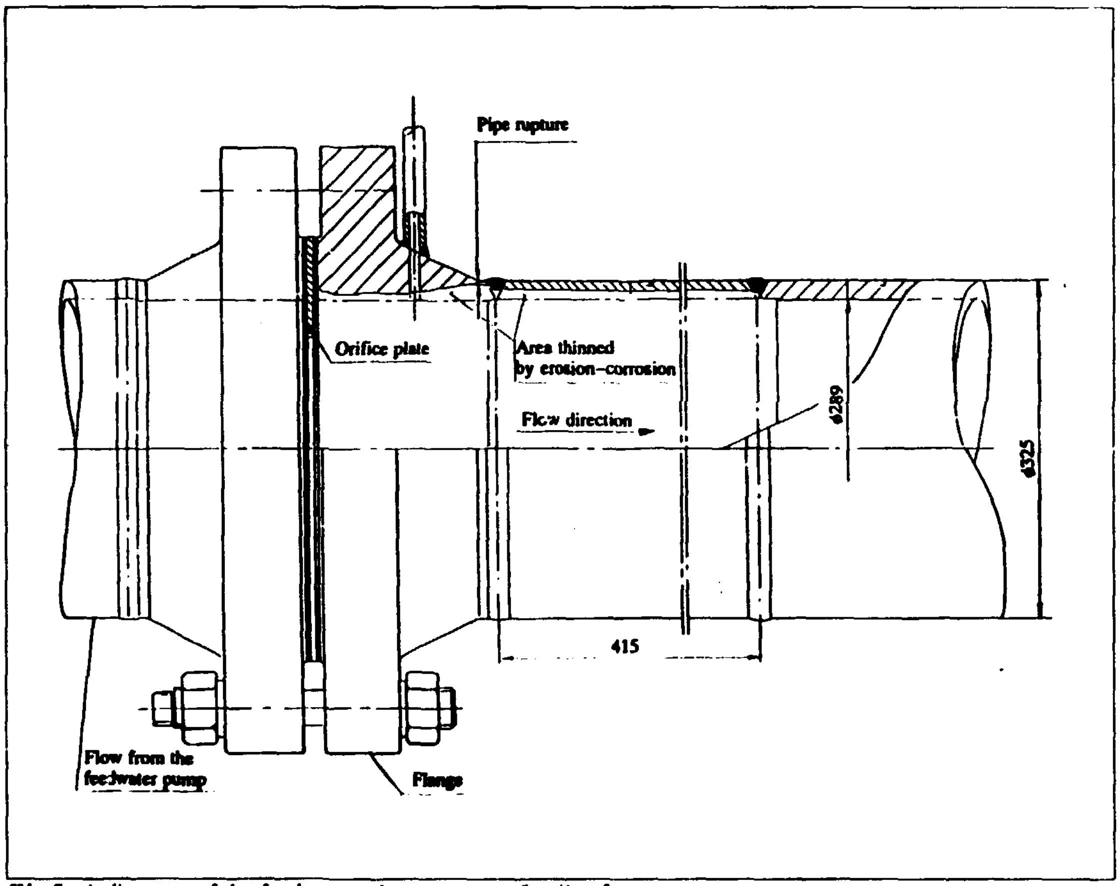

Fig.5. A diagram of the feedwater pipe rupture at Loviisa 1.

the auxiliary feedwater pumps to the steam generators to cool down the primary circuit. Furthermore, a supplemental auxiliary feedwater system independent of other systems was installed at the plant in the current year which is intended for use under particularly difficult conditions. In addition to these systems water could be supplied to the steam generators by the primary circuit make-up water pumps. The auxiliary feedwater pumps operated acccording to plans and it was not necessary to undertake the two last mentioned options during this event.

The plant unit's primary systems operated normally during the event and the auxiliary feedwater pumps started immediately after loss of main feedwater. Control room personnel complied with operating procedures during the whole event.

Erosion corrosion of pipings as well as other phenomena due to wear are monitored by means of inservice inspection programmes. Programmes have been drawn up based on experience. They are not so comprehensive, however, that the thinning of the flanges of the orifice plates used for flow measurement could have been detected in the inspections conducted on their basis.

The event was an indication of the importace of paying even more attention to operating experience. A corresponding feedwater pipe rupture had occurred in the USA in 1986. Due to the rupture also the scope of the inspection programme for piping at the Loviisa plant units had been extended significantly e.g. concerning pipe bends and flow reduction points. Additional inspections of the flanges of orifice plates were not conducted however. After the event inservice inspection programmes were complemented. The flanges of orifice plates and certain other items were added to the programme. Furthermore, Imatran Voima Oy set up a working group the function of which is to find out the rate of occurrence of erosion corrosion, the adequacy in the long run of inservice inspection programmes and the possibilities of eliminating existing problems.

The Finnish Centre for Radiation and Nuclear Safety assesses coverage of the inservice inspection programmes for piping and suitability of materials used for piping on the basis of reports by Imatran Voima Oy and inspections conducted during annual maintenance.

3.1.3 Closing of emergency feedwater lines when steam generator control valve fails

At the Loviisa plant units steam generator water levels are controlled by means of automatic level controllers which control feedwater system control valves. There is a control valve in every feedwater line which leads to each of the six steam generators.

The Finnish Centre for Radiation and Nuclear Safety has noted that in the event of a steam generator control valve failure at Loviisa 1, an other emergency feedwater pump has been used to control steam generator level. The shut-off valves of the feedwater lines leading to the other five steam generators have been closed temporarily. These valves do not open automatically in the event of an accident situation. By means of the emergency feedwater pumps, primary circuit cooling is ensured during events which include loss of feedwater. Should this kind of event occur when the emergency feedwater lines are closed, water supplied by the other emergency feedwater pump would be available to one steam generator only.

Shut-off valves will be modified to open automatically during accidents. The modification will be implemented in the annual maintenance outage of 1991. Before this, valve opening during accidents was ensured by a requirement added to the instructions concerning steam generator level control. At Loviisa 2 the shut-off valves in question will open automatically during potential accidents.

3.2 Loviisa 2

In the second quarter of 1990 feedwater piping was inspected at Loviisa 2 owing to the feedwater pipe rupture which occurred at Loviisa 1. Heavy wear induced by erosion corrosion was observed in the inspections. The event is classified as Level Zero (Below Scale) on the International Nuclear Event Scale.

3.2.1 Inspection of feedwater system piping

Owing to the feedwater pipe rupture at Loviisa 1 on 28.5.1990 Loviisa 2 was placed in cold shutdown for the period 29.5. – 13.6. for inspections. At the plant unit all the five flanges of orifice plates used for flow measurement located after the feedwater pumps, all the six steam generator specific flanges of orifice plates used for power measurement as well as other feedwater system flanges of orifice plates used for flow measurement were inspected. Erosion-corrosion induced wear was detected in four flanges of orifice plates used for flow measurement which were repaired temporarily. Wear was observed also in two flanges of orifice plates used for power measurement which were strengthened. Final repairs will be done in the annual maintenance outage.

3.3 TVO I

At the TVO I a trip test of the so called V-circuit which is part of the reactor protection system was carried out with the hydraulic scram system rendered inoperable in the second quarter of 1990. The plant unit underwent annual maintenance at the time with the reactor shut down. Owing to the event, the Technical Specifications will be made more specific since the hydraulic scram system is required to be operable during the event in question to ensure nuclear criticality safety. The event is classified as Level 1 on the International Nuclear Event Scale.

Based on activity measurements a fuel cladding leak was noted in this quarter. The fuel bundle containing the leaking fuel rod was localised and removed during the annual maintenance outage. The leak is classified as Level Zero (Below Scale) on the International Nuclear Event Scale.

3.3.1 Fuel cladding leak

Nuclear fuel, uranium oxide, is placed inside fuel rods of which there are about 40 000 pcs at both TVO plant units. Fuel rod walls form a gas-tight cladding around the fuel which prevents transfer of fission products from the uranium dioxide fuel to the water circulating in the primary circuit (reactor water). If a through-wall crack appears in the cladding fission products will escape from fuel to reactor water. The concentration of radioactive substances in reactor water is under continuous monitoring. Reactor water clean-up systems are so designed that 1 % of the fuel rods, i.e. ca 400 rods, may leak.

It was noted at TVO I on 13.4. on the basis of continuous activity measurements that activity of gases extracted from reactor water by the gas treatment system had increased. The observed increase in activity was an indication of a leak in a fuel rod cladding.

In reviewing laboratory samples which are taken regularly of reactor water it was noted that iodine 131 concentration had about three-folded in comparison with pre-fuel leak level. After this, iodine 131 concentration decreased and stabilized at 200 Bq/l by the end of May.

Activity of reactor water had been all the time clearly below the limits prescribed in the Technical Specifications. The event had no significance as regards environmental releases. In this quarter radioactive releases into the environment were significantly below authorised limits.

The detected changes in activity were due to one leaking fuel rod. The fuel bundle containing the leaking fuel rod was localised and removed from the reactor during the annual maintenance outage.

3.3.2 Trip test of the screw shut-down circuit with the hydraulic scram system rendered inoperable

At the TVO plant units the reactor protection system triggers protection functions when certain parameters (e.g. power) measured in the reactor deviate from the allowable range. The start-up interlock circuit (the S-circuit) of the protection system, when triggered, prevents control rod withdrawal. The screw shutdown circuit (the V-circuit)active in the next phase brings about control rod insertion by means of motors. Motor-assisted full insertion of control rods from the fully withdrawn position takes about four minutes. The reactor scram circuit (the SS-circuit) for its part triggers the hydraulic scram system as the result of which control rods are inserted in about four seconds by means of nitrogen pressure from the fully withdrawn position.

In the screw shutdown circuit trip test the correct mode of transfer of the screw shutdown circuit signals to the process sytems is checked. At the beginning of the test all control rods are fully inserted. For conducting the test 20 control rods are withdrawn about 0.5 %.

Control rod withdrawal in excess of 1 % is prevented by a computer. After withdrawal the screw shutdown circuit is tripped and it is checked that the motors have fully inserted the control rods. Control rod withdrawal takes place by means of a computer.

The screw shutdown circuit trip test is always performed towards end of the annual maintenance outage. Earlier it was done with the reactor pressure vessel head closed and the hydraulic scram system operable. This year the test was conducted earlier than usual (6.6.) with the reactor pressure vessel head open. The hydraulic scram system had been rendered inoperable for reasons of occupational safety. Prior to the test the preconditions of the Technical Specifications and the test procedures for conducting the tests were checked. Conducting of tests under the circumstances in question was not directly prohibited in the Technical Specifications. It is the view of the Finnish Centre for Radiation and Nuclear Safety that the Technical Specifications are deficient in this respect.

The carrying out of the screw shutdown circuit trip test under the circumstances described above has a bearing on nuclear criticality safety. Local criticality would be created in the core if two rods next to each other would be withdrawn in excess of 10 % and there would be sufficiently reactive fuel bundles adjacent to them. Rod control has been arranged in such a manner, however, that rods situated next to each other cannot be withdrawn simultaneously. Excessive withdrawal could happen if relays would fail simultaneously in the control units of two control rods situated next to each other which failures would prevent tripping of motors which move the rods. Furthermore, it would be presupposed that the operator does not notice the erroneous moving of the rod which is first withdrawn but nevertheless starts witdrawal of a second rod. In this situation the hydraulic scram system would be the only automatically functioning system to stop rod movement. Probability of criticality was low despite the absence of the hydraulic scram system because no control rod control unit relay has ever failed at either TVO plant unit. In addition to this the operators were particularly careful and ascertained control rods to have stopped at design position prior to withdrawal of the rods next in line.

On account of the event Teollisuuden Voima Oy reviews the Technical Specifications and testing procedures. The Finnish Centre for Radiation and Nuclear Safety requires an unambiguous provision in the Technical Specifications according to which control rods may not be manipulated unless the scram system is operable with the exception of potential separately defined exceptions. The Finnish Centre for Radiation and Nuclear Safety also considers it important that outage-related plans are adhered to as strictly as possible and that the Finnish Centre for Radiation and Nuclear Safety will be notified of any deviations without delay. Furthermore, the Finnish Centre for Radiation and Nuclear Safety has required Teollisuuden Voima Oy to submit a Probabilistic Safety Assessment of the rate of increase in the probability of a criticality accident due to the rendering inoperable of the hydraulic scram function.

3.4 TVO II

At TVO II fuel bundle transfers were made simultaneously with control rod drives servicing during annual maintenance in the second quarter of 1990. At that time two fuel bundles next to each other were erroneously removed from such a space reserved for a control rod and four fuel bundles, a so called supercell, from which a control rod had been withdrawn. When the error was noticed one fuel bundle was transferred from the fuel pool back to the supercell although this should not have been done. The event is classified as Level 1 on the International Nuclear Event Scale.

During the annual maintenance outage internal radiation doses to three workers were observed in measurements made during exit from work areas. In further investigations the doses were noted to be very low. These cases of occupational contamination are classified as Level Zero (Below Scale) on the International Nuclear Event Scale.

3.4.1 Erroneous fuel transfers during servicing of control rod drives

At the TVO plant units control rods are inserted into the core through the bottom so that a control rod moves along a cruciform space between four fuel bundles. The area in the core comprising four fuel bundles is called the supercell. When servicing control rod drives the rods must be withdrawn in order to open and service the drives below them. After servicing control rods are fully inserted again. The drives are serviced one by one to ensure maintenance of reactor subcriticality.

During control rod drives servicing the reactor must be cold and devoid of pressure. Usually such a situation prevails during refuelling outages. To save time drives servicing is scheduled to take place during fuel bundle transfers which are accomplished much later than drives servicing. To ensure nuclear criticality safety and fuel and control rod integrity the Technical Specifications place restrictions on the carrying out of fuel transfers during control rod drives servicing. Fuel bundle transfers may not be made in the very supercell from which a control rod has been withdrawn. Also, to ensure trouble-free rod movement the requirement was valid at that time that the supercell's diagonally positioned fuel bundles shall be in their places during control rod insertion.

During the annual maintenance of TVO II on 8.5. fuel bundles were being removed from the core and, at the same time, control rod drives were being serviced. During the first phase two fuel bundles next to each other were removed from such a supercell from which the control rod had been withdrawn due to servicing. The mistake was attributed to human error and, to some extent, to an insufficient procedure in registering drives servicing. The fuel bundle was placed in the fuel pool. When the error was noticed one of the removed fuel bundles was returned to the same supercell from which the control rod was still withdrawn. This was done in order to have two diagonally positioned bundles in their places in the supercell. The transfer did not comply with the list of transfers or the Technical Specifications. In connection with the transfer it was ensured carefully, however, that the right bundle was transferred to the reactor. If a wrong (too reactive) bundle would be placed in the reactor the reactor might become locally critical under certain circumstances. According to calculations made by Teollisuuden Voima Oy afterwards there was no danger of criticality although the transferred bundle would have been as reactive as possible.

Due to the event Teollisuuden Voima Oy improves loading routines, clarifies the text of the Technical Specifications and steps up the training of loading supervisors. The Finnish Centre foi Radiation and Nuclear Safety has also urged investigations into the possibility of coordinating fuel bundle removals from the core and drives servicing better than at present to avoid recurrence of corresponding errors.

3.4.2 Cases of mild occupational contamination

During the annual maintenance of TVO II a valve (V5) was being installed in the shutdown cooling system. In connection with a pipe cutting job on 9.5. a plant maintenance man cleaning a work area received a minor amount of radioactive materials in his body. The event was detected in a routine radiation measurement during exit from the plant unit. The plant maintenance man did not use respiratory protection in his work since it was not required in the instructions displayed in the work area.

The whole body dose of the plant maintenance man was measured at the Finnish Centre for Radiation and Nuclear Safety the next day. On the basis the measurement, the internal radiation dose to the individual during the event was below 0.7 mSv. The external radiation dose uptake by the individual during the 1990 annual maintenances of the TVO plant units was otherwise 2.3 mSv (quarterly limit 25 mSv).

In connection with the event a spreading of radioactive substances even outside the work area was noticed at TVO II which was due to work method and insufficient protection. The area was decontaminated without delay.

Also a second case of mild occupational contamination occurred during the annual maintenance of TVO II. A sub-contractor to Teollisuuden Voima Oy employed a subcontractor to install the parts of a valve (V15) of the shutdown cooling system in their place. On 15.5. the two-member team did not present a radiation work permit to the radiation protection technician which is a routine requirement when entering the work area. Teollisuuden Voima Oy's sub-contractor had not handed over a work permit to the workers. On the basis of training given by Teollisuuden Voima Oy they should have been aware of the correct procedure. The workers did not wear respiratory protection although instructions in the work area indicated this should have been done. There were radioactive substances in the work area which had ended up there as a result of the above mentioned pipe cutting job.

In a routine radiation measurement during exit from the plant one worker was noted to have received radioactive substances in his body. A whole body measurement was conducted for him also in the Finnish Centre for Radiation and Nuclear Safety. On the basis of the measurement the individual's internal radiation dose arising from the event was noted to be less than 0.7 mSv. The individual's external radiation dose otherwise incurred at the TVO plant units during the annual maintenances of 1990 was 4.6 mSv (quarterly dose limit 25 mSv).

The events have a bearing on occupational safety since the general objective is to maintain radiation exposure as low as practicable. The radiation dose arising from radioactive materials which end up in the body is normally much lower than the external radiation dose arising from work.

Owing to the event, Teollisuuden Voima Oy clarified i.a. the use of instructions displayed by radiation protection personnel in the work areas. Also, in worker training, special attention is paid to the correct use of protective equipment and work permits.

3.4.3 Radioactive metal particle gets in the eye of a worker

During the annual maintenance of TVO II on 18.5. work was being done at the bottom of the reactor service pool and the surface of the RPV head's seal was being cleaned. As protective equipment at work plastic clothing, rubber boots, rubber gloves and respiratory protection equipment (so called half masks) were worn.

A worker on a cleaning assignment went for a break in the plant's restrooms for the employees. In a routine radioactive contamination measurement during exit control a radiation level in excess of the reference level was observed in the region of the worker's left eye. The eye region was flushed from the outside. As new measurement indicated radioactive substances in the eye region, the worker was escorted by the plant radiation protection technician to the eye clinic of a hospital in the town of Pori. In a flushing of the eye region and the eye which was carried out at the clinic, a small active metal particle came off in the flushing bowl. A physician examined the eye and its surface with a microscope. No perceivable changes were noticed. According to the physician the particle may have been on the conjunctiva of the lower lid.

The metal particle was examined at the TVO nuclear power plant. Its diameter was assessed at ca. 0.15 mm and its activity was laboratory-measured. Laboratory analysis suggests that the material originates in a metal alloy used in the reactor's fuel channels.

The worker visited the Finnish Centre for Radiation and Nuclear Safety on 21.5. for a whole body measurement the results of which confirmed that contamination had left the eye region. Also the metal particle was check measured.

The information obtained of the activity of the metal particle shows that the radiation depth dose to the worker arising from it is low. Assuming that the exposure had lasted for about four hours, the radiation dose to the eye has certainly been less than 10 mSv. The dose is very unevenly distributed, though.

The estimated radiation dose to the worker was within statutory limits.

An investigation was carried out at the TVO nuclear power plant whether activity in the form of loose particles can be found in work areas. The results indicate that this can happen in reactor-related assignments such as control rod drives servicing. In such cases it is necessary to clean work areas carefully and to give thorough training to workers concerning work in contaminated areas.

4 RADIATION SAFETY

Individual occupational radiation doses during the second quarter of 1990 were clearly below the dose limit. Also the collective occupational rediation dose from the beginning of the year at both plant sites was clearly below the limit recommendation given in the guides of the Finnish Centre for Radiation and Nuclear Safety. External releases of radioactivity were considerably below the release limits. Only small amounts of nuclides originating in nuclear power plants were detected in samples taken in the vicinity of nuclear power plants.

4.1 Criteria of occupational radiation protection

Occupational radiation protection is based on legislation and the recommendations of the International Commission on Radiological Protection (ICRP). Radiation doses are aimed to be kept as low as practicable.

In addition, dose limits for individual occupational radiation doses have been set by the authorities. The dose limits are set so that the health risk to workers from radiation is low and comparable to occupational risks in professions which are considered safe.

Total exposure arising from radiation is assessed by the sum of the individual occupational radiation doses, the collective radiation dose.

4.2 Individual occupational radiation doses

Individual occupational radiation doses in the report period remain below the dose limit for three months, 25 mSv. The highest individual radiation dose during the report period was 13.4 mSv and it was received at the TVO plant. It is also the highest individual radiation dose from the beginning of 1990 until the end of the report period.

The distribution of individual occupational doses in the report period is given in Table III which specifies the number of individuals in each dose range and at each plant site. The Table also shows a distribution which is the total number of workers in each dose range. The distributions comprise the doses of persons who have been recorded as nuclear power plant workers in the central dose file of the Finnish Centre for Radiation and Nuclear Safety.

4.3 Collective occupational radiation exposure

In the report period, the collective occupational radiation dose at the Loviisa plant totalled 0.03 manSv and at the TVO plant 1.38 manSv.

The collective occupational radiation exposure from the beginning of 1990 until the end of the report period was 0.08 manSv at the Loviisa plant and 1.48 manSv at the Olkiluoto plant.

The collective radiation dose mainly accumulates *during the annual maintenances of the plant units*. The annual maintenances of the TVO plant units took place during this report period. The dose limit recommended in the guides of the Finnish Centre for Radiation and Nuclear Safety is 5 manSv/GW_e per installed electrical power in one year which is in total 4.45 manSv/year for the Loviisa units and 7.1 manSv/year for the TVO units.

***Table III.** Occupational dose distribution in the report period and from beginning of 1990 until end of report period.*

Dose range (mSv)	Number of persons in the dose range					
	Second quarter 1990			From beginning of 1990		
	Loviisa	TVO	Total[a]	Loviisa	TVO	Total[a]
< 0,5	62	339	405	74	347	423
0,5 – 1	14	220	251	17	226	260
1 – 2	6	204	229	10	206	234
2 – 3	–	92	98	10	99	114
3 – 4	–	57	65	3	65	76
4 – 5	–	27	38	–	30	41
5 – 6	–	18	19	–	19	21
6 – 7	–	8	9	–	9	10
7 – 8	–	8	8	–	9	9
8 – 9	–	3	4	–	5	6
9 – 10	–	4	5	–	4	5
10 – 11	–	–	2	–	–	2
11 – 12	–	2	2	–	2	2
12 – 13	–	2	2	–	2	2
13 – 14	–	1	1	–	1	1
14 – 15	–	–	–	–	–	–
15 – 16	–	–	–	–	–	–
16 – 17	–	–	–	–	–	–
17 – 18	–	–	–	–	–	–
18 – 19	–	–	–	–	–	–
19 – 20	–	–	–	–	–	–
20 – 25	–	–	–	–	–	–
> 25	–	–	–	–	–	–

[a] These columns also include the data of those Finnish workers who have received doses at the Swedish nuclear power plants. The same person may have worked at both Finnish plant sites as well as in Sweden.

4.4 Releases and radiation doses in the environment

External releases of radioactivity in the report period were considerably below the authorised standard release limits (Table IV).

The release limits have been determined so that for the individuals with the highest exposure, the annual whole-body radiation dose will not exceed 0.1 manSv. This is about 1/50 of the dose received annually from natural background radiation, radon included, and 1/50 of the statutory dose limit for the population. The release limits have been established for such nuclides and release channels as have significance from the viewpoint of the possibility of exceeding the individual dose limit.

The radiation doses calculated on the basis of the release reports for those who live in the vicinity of nuclear power plants are low and are about a thousandth part of their annual radiation exposure.

Release of carbon 14 causes a global collective dose which is approximately as high as the reference dose limit (5 manSv/GW$_e$ per installed electrical power) in the guide of the Finnish Centre for Radiation and Nuclear Safety. This collective reference dose limit is based on the limitation of the annual dose arising from the widespread use of nuclear power below 0.1 mSv per individual living in the future. When defining the

Table IV. External releases of radioactivity at each plant site, 2nd quarter 1990.

Releases into the air (Bq)[a]

Plant site	Noble gases (Krypton 87 equivalents)	Iodines (Iodine 131 equivalents)	Aerosols	Tritium	Carbon 14
Loviisa					
Report period	b c	$3.1 \cdot 10^{6}$	$2.2 \cdot 10^{7}$	$1.4 \cdot 10^{11}$	d
Early 1990	b c	$3.9 \cdot 10^{6}$	$2.3 \cdot 10^{7}$	$3.4 \cdot 10^{11}$	d
Olkiluoto					
Report period	$8.7 \cdot 10^{11}$	$2.9 \cdot 10^{7}$	$8.0 \cdot 10^{7}$	$2.8 \cdot 10^{10}$	d
Early 1990	$8.7 \cdot 10^{11}$	$2.9 \cdot 10^{7}$	$8.2 \cdot 10^{7}$	$4.6 \cdot 10^{10}$	d
Annual release limits					
Loviisa	$2.2 \cdot 10^{16}$ e	$2.2 \cdot 10^{11}$ e			
Olkiluoto	$1.8 \cdot 10^{16}$	$1.1 \cdot 10^{11}$			

Releases into water (Bq)[a]

Plant site	Tritium	Other nuclides
Loviisa		
Report period	$4.9 \cdot 10^{12}$	$1.4 \cdot 10^{7}$
Early 1990	$9.3 \cdot 10^{12}$	$2.6 \cdot 10^{7}$
Olkiluoto		
Report period	$4.2 \cdot 10^{11}$	$1.5 \cdot 10^{10}$
Early 1990	$7.5 \cdot 10^{11}$	$1.9 \cdot 10^{10}$
Annual release limits		
Loviisa	$1.5 \cdot 10^{14}$	$8.9 \cdot 10^{11}$ e
Olkiluoto	$1.8 \cdot 10^{13}$	$3.0 \cdot 10^{11}$

[a] The unit of radioactivity is Becquerel (Bq); 1 Bq = one nuclear transformation per second.
[b] Below the detection limit.
[c] The calculatory release of argon 41 from Loviisa 1 and 2 expressed as krypton 87 equivalents was $3.9 \cdot 10^{11}$ Bq in the report period and 8.3x1011 Bq from beginning of 1990.
[d] The carbon 14 release estimate based on experimental data was $8.0 \cdot 10^{10}$ Bq in Loviisa and $1.3 \cdot 10^{11}$ Bq in Olkiluoto in the report period. From beginning of 1990 the estimates were $1.7 \cdot 10^{11}$ Bq and $3.0 \cdot 10^{11}$ Bq, correspondingly.
[e] The numerical value shows the release limit for the plant site on the presumption that there will be no releases of other release types. The release limit is set so that the sum of the various types of release limit shares is equal to or smaller than 1.

collective dose limit it has been presupposed that an average of 10 kW of electric power per person will be generated by nuclear power in the whole world truncated at 500 years. The use of nuclear energy in Finland at present is about 1/20 of the mentioned value.

4.5 Radioactivity of environmental samples

Radiation safety in the vicinity of nuclear power plants is monitored by means of regular sampling and analysis programmes. The objective of this monitoring is to follow the dispersion of external releases of radioactivity and their transfer to food chains and to ensure that discharges remain below set limits.

During this quarter about 200 samples were examined. Nuclides originating in a nuclear power plant (manganese 54, cobalt 60, silver 110m) were detected in most indicator samples taken in the marine environment in Loviisa. Indicator samples are samples in which the elements to be examined accumulate. Such samples of the marine environment are e.g. crustaceans and certain species of bivalves and algae. Also, one rain water sample taken in the vicinity of Loviisa contained cobalt 60. Three sea water samples from Olkiluoto contained manganese 54 and cobalt 60 and one sample contained also cobalt 58. Most samples of bladder wrack and sedimenting matter contained manganese 54, cobalt 58 and cobalt 60. In addition, chromium 51 was detected in three and zinc 65 in two samples of bladder wrack. Part of the silver 110m present in some samples still originates in the Chernobyl fallout. Part of the tritium in sea water samples originates in power plant emissions and part in fallout. All the detected concentrations were low and do not give rise to any action.

In environmental samples, the nuclide contents of the measurement results of radioactive substances originating in power plants correlate with power company release reports for the quarter under review and the preceding quarter taking the different behaviour of nuclides in nature and their detection limits in measurements into account.

Apart from artificial radionuclides, environmental samples also usually contain natural radionuclides (uranium and thorium series, beryllium 7 and potassium 40).

5 OTHER MATTERS RELATING TO THE USE OF NUCLEAR ENERGY

Nothing reportable.

APPENDIX 1

REGULATORY CONTROL OF NUCLEAR FACILITIES

The regulatory control perforemd by the Finnish Centre for Radiation and Nuclear Safety encompasses the following areas (the granting of the licenses mentioned in parentheses is recommended when the control activities have been completed and no reason for withholding the license has arisen):

Construction Phase

- Preliminary plans of the nuclear facility
- Location and environmental effects of the plant
- Arrangements for nuclear fuel and nuclear waste management
  (Decision in principle)

- Preliminary safety analysis report on the planned structure and operation of the plant as well as the preliminary safety analyses
- Safety classification of components and structures
- Quality assurance plan
- Plans concerning nuclear fuel and nuclear waste management
- Physical protection and emergency preparedness
  (Construction permit)

- 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
- Composition 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)

Operating Phase

- Start-up testing at various power levels
- Maintenance, inspections and testing of components and structures
- Operation of systems and the whole plant
- Operation and competence of the operating organisation
- Exceptional events
- Repairs and modifications
- Refuelling
- Nuclear fuel management and safeguards
- Nuclear waste management
- Radiation protection and safety of the environment
- Physical protection and emergency preparedness
- Observance of quality assurance programme

APPENDIX 2

PLANT DATA

Plant unit	Start-up	Commercial operation	Rated power (gross/net,MW)	Type, supplier
Loviisa 1	8.2.1977	9.5.1977	465/445	Pressurized water reactor (PWR), Atomenergoexport
Loviisa 2	4.11.1980	5.1.1981	465/445	Pressurized water reactor (PWR), Atomenergoexport
TVO I	2.9.1978	10.10.1979	735/710	Boiling water reactor (BWR),Asea Atom
TVO II	18.2.1980	1.7.1982	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 TVO I and II plant units in Olkiluoto, Eurajoki.

Experts

The following individuals have participated in the drawing up of this report:

Harri Aho
Juhani Hinttala
Riitta Hänninen
Seppo Klemola
Marja Leena Kuutti
Olli Nevander
Mervi Olkkonen (translation)
Pentti Rannila
Jorma Rantakivi
Veli Riihiluoma
Heikki Saari
Kirsti-Liisa Sjöblom
Heimo Takala
Olli Vilkamo

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