STUK-B-YTO 90

Operation of Finnish nuclear power plants

Quarterly report 2nd quarter, 1991

Kirsti Tossavainen (Ed.)
DECEMBER 1991

SÄTEILYTURVAKESKUS
Strålsäkerhetscentralen
Finnish Centre for Radiation and Nuclear Safety

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Index terms PWR type reactors, BWR type reactors, NPP operating experience

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 also includes 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.

The Finnish nuclear power plant units Loviisa 1 and 2 as well as TVO I and II were in operation for almost the whole second quarter of 1991. Longer interruptions in electricity generation were caused by the annual maintenances of the TVO plant units. The load factor average was 87.4 %.

In consequence of a fire, which broke out in the switchgear building, connections to both external grids were lost and TVO II relied on power supplied by four back-up diesels for 7.5 hrs. The event is classified as Level 2 on the International Nuclear Event Scale.

The process of examining the non-leaking fuel bundles removed from the Loviisa nuclear reactors has continued. The examinations have revealed, so far, that the uppermost spacing lattices of the bundles exhibit deformations similar to those detected in the leaking fuel bundles removed from the reactors. This event is classified as Level 1 on the International Nuclear Event Scale. Other events in this quarter which are classified according to the International Nuclear Event Scale are Level Zero (Below Scale) on the Scale.

The Finnish Centre for Radiation and Nuclear Safety has assessed the safety of the Loviisa and Olkiluoto nuclear power plants based on the new regulations issued on 14.2.1991 by the Council of State. The safety regulations are much more stringent than those in force when the Loviisa and Olkiluoto nuclear power plants were built. The assessment indicated that the TVO nuclear power plant meets these safety regulations. The Loviisa nuclear power plant meets the requirements with the exception of certain requirements related to the ensuring of safety functions and provision for accidents. At the Loviisa nuclear power plant there are several projects under consideration to enhance safety.

Occupational radiation doses and releases of radioactivity off-site were below prescribed limits in this quarter. Only small amounts of radioactive materials 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 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 also include regulatory control of physical protection, emergency preparedness and nuclear material safeguards. 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 fourth 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. The events and observations described in the report are classified according to the International Nuclear Event Scale which is currently undergoing a trial period.

Apart from 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 1991

The Finnish nuclear power plants were in operation for the most part of the second quarter of 1991. The TVO plant units were off the national grid for a total of 34 days owing to the annual maintenance outages and a switchgear fire at TVO II. Some brief interruptions in electricity generation also occurred at the plant units.

2.1 Production data

Nuclear electricity accounted for 33.9 % of the total amount of electricity generated in Finland during this quarter. The load factor average of the plant units was 87.4 %. Production and availability figures are presented in more detail in Tables I and II.

Power diagrams describing electricity generation by the plant units and causes of power reductions are presented in Figures 1 - 4.

Table I. Electricity production and availability of the units.

	Electricity production (gross, TWh)		Availability factor (%)		Load factor (%)	
	Second quarter 1991	Beginning of 1991	Second quarter 1991	Beginning of 1991	Second quarter 1991	Beginning of 1991
Loviisa 1	0.97	1.96	98.8	99.4	95.2	96.8
Loviisa 2	1.02	2.03	100.0	100.0	100.3	100.3
TVO I	1.28	2.87	82.6	91.1	79.8	89.9
TVO II	1.19	2.77	76.5	88.3	74.1	86.9

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

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

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

	Second quarter 1991	Beginning of 1991	1990	1989
Production of nuclear electricity (net, TWh)[a]	4.3	9.2	18.1	18.0
Total production of electricity in Finland (net, TWh)[a]	12.7	28.4	51.7	50.8
Share of nuclear electricity of total production	33.9	32.4	35.0	35.4
Load factor average of the Finnish plant units (%)	87.4	93.5	89.1	89.9

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

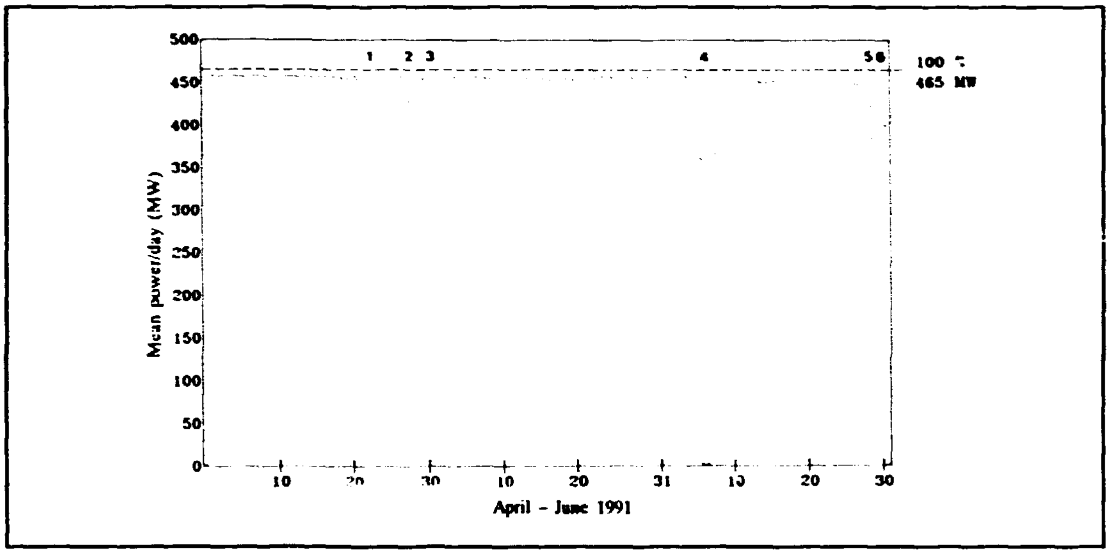

Fig 1. Average daily gross power of Loviisa 1 in April – June 1991.

1 Repairs of leaks in HP bleeding points
2 Repair of a HP turbine drain pipe, reactor operating at 52 % power
3 Superheater leaks repaired, reactor operating at 52 % power
4 Hot shutdown to repair drainage pumps in the special sewerage system (see Chapter 2.2)
5 Superheater leak repaired, reactor operating at 52 % power
6 Less demand for electricity during weekend and repair of a control valve of the HP pre-heater

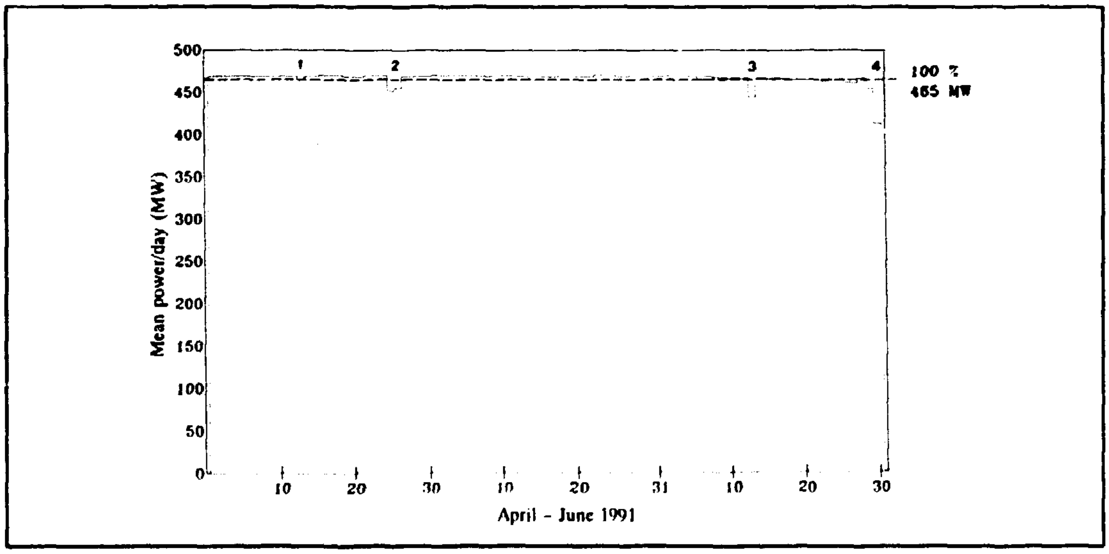

Fig 2. Average daily gross power of Loviisa 2 in April – June 1991.

1 Sea water pump tripped in connection with relay replacement, reactor power level to 85 %
2 One main circulation pump tripped due to a relay fault, reactor power level to 76 %
3 One main circulation pump tripped due to an erroneous temperature measurement, reactor power level to 77 %
4 Less demand for electricity during weekend

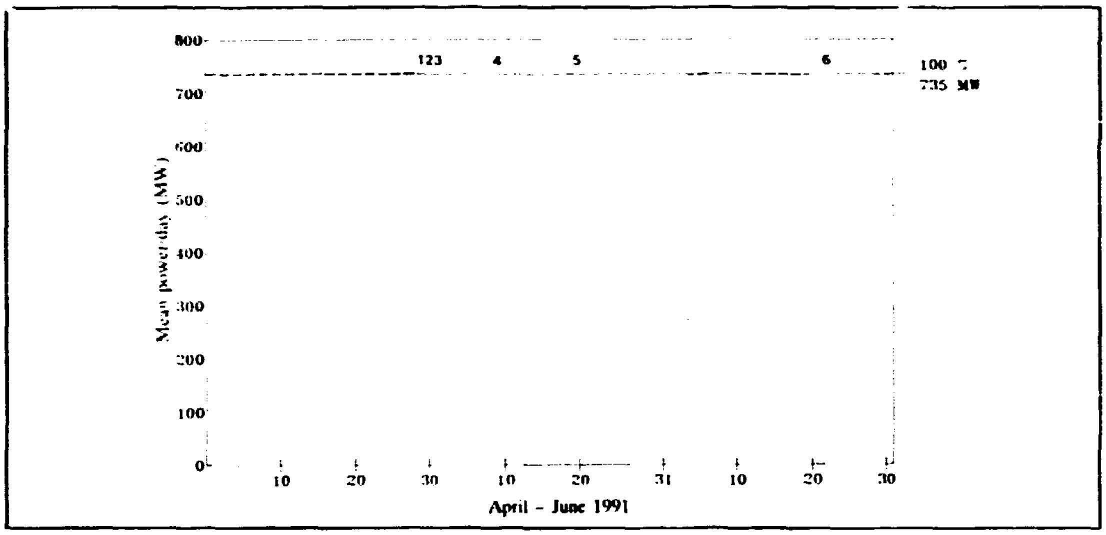

Fig 3. Average daily gross power of TVO I in April - June 1991.

1. Reactor trip caused by a phase short-circuit of the 400 kV line (see Chapter 2.3)
2. Localization of a small fuel leak observed on 11.4.1991, reactor operating at 50 % power (power reduction was also necessary due to less demand for electricity)
3. Periodic tests, reactor operating at 70 % power (power reduction was also necessary due to less demand for electricity)
4. Nuclear fuel had burnt to such an extent that the power has started to decrease gradually (coast-down)
5. Annual maintenance outage (see Chapter 2.4)
6. Cold shutdown to repair an inner isolation valve and power reduction (reactor operating at 55 % power) due to less demand for electricity (see Chapter 2.5)

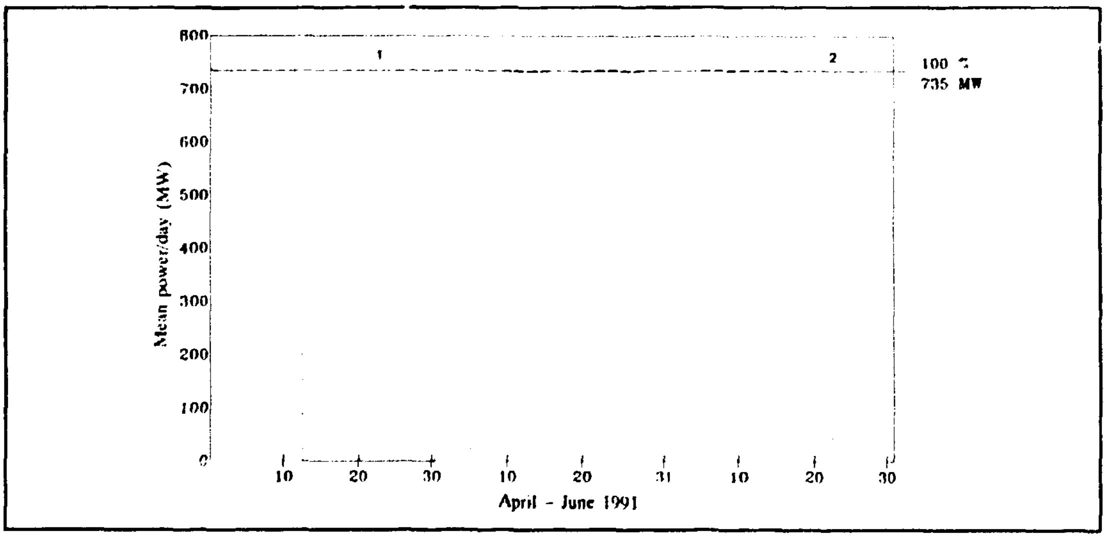

Fig 4. Average daily gross power of TVO II in April - June 1991.

1. Outage caused by a switchgear fire and the annual maintenance outage (see Chapters 2.6 and 3.4)
2. Power reduction (reactor operating at 60 % power) and hot shutdown due to less demand for electricity (see Chapter 2.7)

2.2 Hot shutdown at Loviisa 1

Loviisa 1 was placed in hot shutdown on 6.6. for repairing two drainage pumps of the containment special sewerage system. The pumps serve as each other's back-ups and they are used to pump leak water into a special clean-up system. One pump had failed earlier and now that the other one failed, too, they had to be repaired to prevent the containment sump from gradually filling up. The pumps are located in a space which cannot be entered during operation. Electricity generation was resumed on 7.6.

2.3 Scram at TVO I

A scram occurred at TVO I on 29.4. in consequence of a phase short circuit of the 400 kV national grid. The short circuit was caused by a reed fire below the power lines seven kilometers from Olkiluoto. The short circuit caused disturbances in turbine control. The disturbances further lead to a turbine trip and a reactor scram. Power generation was resumed on 30.4.

2.4 Annual maintenance outage at TVO I

The twelfth refuelling and maintenance outage at TVO I was held from 12.5. to 27.5. The plant unit was off the national grid for 14.5 days.

During the outage, part of the spent fuel was replaced with fresh fuel and modifications were made which enhance plant safety and operational features. Also numerous check-ups, repairs and maintenance operations were performed.

Among the most important modifications was the adding of two new signals to the reactor protection system. One of the signals shuts the steam line isolation valves on low reactor pressure and high power. It serves to prevent fuel failures potentially arising from deteriorated core cooling as well as the creation of a hydraulically unstable core. The other signal trips the hydraulic scram system when the reactor screw shutdown function is actuated when the reactor power exceeds 30 %. Thus, concentration of power generation in the upper region of the reactor during screw shutdown, and the potentially resulting fuel failures, are avoided.

Apart from Teollisuuden Voima Oy's own staff, a maximum of 1019 non-utility staff participated in the annual maintenance outage. The collective radiation dose arising from the work done during the outage was 0.54 manSv.

2.5 Cold shutdown at TVO I at Midsummer

TVO I was placed in cold shutdown on 21.6. due to less demand for electricity at Midsummer. The repair of the position indicator of the other isolation valve of a line of the core spray system was timed to occur during the outage. The plant unit should have been placed in cold shutdown in the near future anyway to repair this fault. The spray system serves to cool down the core in the event of a possible accident. Also conventional inspections and maintenance operations were carried out during the outage. The plant unit resumed power generation at Midsummer 22.6. It was first operating at 55 % power owing to less demand for electricity and was back on full power on the evening of Monday 24.6.

2.6 Outage caused by switchgear fire and annual maintenance outage at TVO II

The tenth refuelling and maintenance outage of TVO II was held from 12.4. to 1.5. The plant unit was off the national grid for 19.5 days. Owing to a switchgear fire on 12.4. (see Chapter 3.4), annual maintenance was brought ahead of schedule ca three weeks as Teollisuuden Voima Oy wanted to minimize plant unit downtime.

During the outage, the electrical components damaged by fire were repaired, part of the spent nuclear fuel was replaced with fresh fuel and modifications to enhance plant safety and operational features were made. Also numerous repairs, check-ups and maintenance operations were performed.

A new control valve was installed in the feed-water system to function abreast with the old one. Feedwater control was thus made more precise than before when operating at low power levels. Modifications identical to those made at TVO I (see Chapter 2.4) were carried out in the reactor protection system.

Apart from Teollisuuden Voima Oy's own staff, a maximum of 961 non-utility workers participated in the annual maintenance. The collective radiation dose arising from work carried out during the outage was 0.73 manSv.

2.7 Hot shutdown of TVO II at Midsummer

Owing to less demand for electricity at Midsummer power reduction at TVO II was initiated on Midsummer's Eve 21.6. and the plant unit was placed in hot shutdown on 22.6. At that time TVO I had already been connected to the national grid after cold shutdown. During shutdown, minor repairs, check-ups and maintenance operations were performed. The plant unit resumed power generation on Monday 24.6.

3 EVENTS AND OBSERVATIONS AT EACH PLANT UNIT

Loviisa 1 and 2

Failures detected in the uppermost spacing lattices of leaking nuclear fuel bundles removed from the Loviisa nuclear reactors have given cause to examine also non-leaking bundles removed from the reactor. The results so far indicate that the non-leaking fuel bundles removed from the reactor exhibit damage identical to that found in the leaking bundles. Spacing lattice failures do not significantly increase the risk of damage to the fuel rods during normal operation. However, under certain exceptional accident or transient conditions the number of fuel leaks may increase. The event is classified as Level 1 on the International Nuclear Event Scale.

3.1 Nuclear fuel bundle spacing lattice failures

Examination of the deformations detected in the uppermost spacing lattices of the fuel bundles removed from the Loviisa nuclear reactors has been continued (see the report STUK-B-YTO 88).

The Loviisa fuel bundles are encased in hexagonal shroud tubes of zirconium alloy which are attached to the structures of the bundles. One fuel bundle comprises 126 rods inside which is the nuclear fuel proper in the form of ceramic uranium dioxide pellets (UO_2). The rods are kept in place by 11 spacing lattices ten of which are attached to a central water rod. The uppermost spacing lattice is attached to the top piece of the hexagonal shroud tube. All the new fuel bundles loaded into both Loviisa plant units since 1987 have the same structure. The structure was changed that year, as the 8 mm growth margin reserved for rod axial growth in the previous structure proved insufficient. In the current structure, the corresponding growth margin is 25 mm. Rod axial growth is attributable to the effects of temperature elevation, neutron irradiation as well as PCI (pellet-cladding interaction).

Examination of spent nuclear fuel bundles is very difficult owing to their high radiation level. It can only be done deep under water or in hot cells of a special construction which do not exist in Finland. Imatran Voima Oy has developed so called fuel surveillance equipment for the examination of spent fuel bundles at the Loviisa nuclear power plant. By the means of it, the hexagonal shroud tube of the fuel bundle can be removed and the structure of the bundle examined. Examination takes place under water by a video camera and periscope. Afterwards, the bundle is re-assembled and it can be handled and stored by existing equipment.

Deformations detected in the spacing lattices of the fuel bundles removed from the reactor due to leaks indicate that even the spacing lattices of the non-leaking bundles removed from the reactor may be deformed and relocated. In the early spring of 1991 the possibility of measuring lattice deformation and relocation in the non-leaking bundles removed from the reactor was looked into. Imatran Voima Oy developed a method by which the position of the uppermost spacing lattice can be measured from the top of the bundle. The results of these measurements so far justify the conclusion that also the uppermost spacing lattices of the removed non-leaking bundles exhibit deformation and relocation similar to that found in the leaking bundles which were disassembled.

Deformation and relocation of the uppermost spacing lattices is probably due to the fact that the uppermost spacing lattice of the fuel bundle presently in use is permanently attached from three corners to the top piece by means of a jointing sleeve. It appears that the rods cannot glide smoothly enough through the spacing lattice when growing and thus the spacing lattice moves along with the rods, ending up deformed and relocated.

A slight increase in the number of fuel leaks after the introduction of the uppermost spacing lattice structure now in use is obvious. Leak rates are still internationally comparable, however.

Clarifications related to the extent and significance of failure problems related to uppermost spacing lattices are still under review and Imatran Voima Oy will carry out further measurements in connection with the 1991 refuelling outages. Current estimates have it that the phenomenon does not significantly increase the risk of fuel rod failures during normal plant operation. Under certain exceptional transient or accident conditions the number of fuel leaks could grow, however.

The fuel manufacturer has initiated measures to modify the structure of the topmost part of the bundle. The introduction into use in Loviisa of the new structure is under review.

TVO I

In the second half of 1991, doors, which should have been closed and locked, of rooms containing components important to safety, were kept open. Also, nonconformances to instructions were detected in spent fuel transports. Both events are Level Zero (Below Scale) on the International Nuclear Event Scale.

3.2 Doors of rooms containing auxiliary feedwater and emergency cooling systems were open

In the fire protection inspection at TVO I on 30.4. performed by the Finnish Centre for Radiation and Nuclear Safety it was found out that the doors of two rooms containing components of the auxiliary feedwater and emergency cooling systems were open and the doors of two other rooms unlocked. The doors shall be kept closed and locked to ensure operational and fire safety.

On the day of the event, periodic tests of the auxiliary feedwater system were conducted with associated vibration measurements by maintenance personnel in one room. On accomplishment of the measurements, the worker who did the maintenance job left the room, leaving the door open for a final inspection by the field operator who participated in periodic testing. Two other doors were left unlocked and one was open, since periodic testing was still unaccomplished. On completion of periodic testing, the field operator shut and locked the doors. The plant unit was operating at 70 % power at the time of the event.

It is the function of the auxiliary feedwater and emergency cooling systems to secure reactor cooling under transient and accident conditions. There are four redundant sub-systems in the systems two of which suffice to ensure measures important to and necessary for safety. The pumps, heat exchangers and piping of the systems are located in four separate rooms, in so called H-spaces. The doors to the rooms are to be kept closed and locked. The doors, for their part, form a boundary between fire compartments and prevent unauthorized access into the rooms in question. Closed, leak-tight doors also keep the water of the containment condensation pool in the rooms in question in the event of leaks and pipe breaks. Maintaining a sufficient volume of water in the condensation pool is essential to condense the steam possibly blown there in the event of a transient.

The safety connotation of open doors was insignificant in this case as the doors were simultaneously unlocked only for a short time.

The cause of the event can be attributed to the performing of periodic tests without understanding the safety significance of the closing and locking of the doors.

All routines involving the use of keys will be reviewed to prevent recurrence. The doors of the so called H-spaces will be fitted with alarms and the importance of closing the doors will be explained to the maintenance personnel.

A corresponding event which occurred in 1989 is addressed in the report STUK-B-YTO 72.

3.3 Errors in handling of spent nuclear fuel transport cask

Procedural deviations from approved instructions occurred in the handling of spent nuclear fuel. No damage or releases of radioactive material resulted.

Since the autumn of 1987, spent nuclear fuel from the TVO nuclear power plant has been transferred from the plant units to the spent fuel store on the site. A massive transport cask is used for the transfers. Fuel is transferred underwater into a cask in the plant unit's loading pool. The cask is closed and lifted to the surface for the final closure of the lid. Then it is lifted further to the service area in preparation for the transfer and lowered along a lifting shaft onto a carriage at ground level. At the spent fuel store the cask is lifted from the carriage to the store's pool room and from there further to the loading pool for opening and unloading.

The transport cask weighs ca 93 tonnes. The transfer area is carefully designed to limit the consequences of a potential accident including a drop. When lifting the cask in the approved transfer area, certain specified lifting heights shall be complied with to ensure the stability of the structures beneath in case the lifting equipment failed.

In a check carried out at TVO I on 15–21.3. to assess the cask's route of transfer, it was found out that the permissible lifting heights had been exceeded. It was also found out that the electrical limit positions set in the crane did not correspond to the limits of the approved transfer areas and that the keys for the electrical limit positions were continuously kept at their places of use, which is against instructions.

The deviations were attributed to several causes. The highest allowable lifting height for the transport cask in the floor area is so low that it is easily exceeded. Also ascertaining the right lifting height has been based on estimates. The service area originally appointed for the cask has been altered but the crane's electrical limit positions have remained unchanged. The transport operation is a sequence of events which lasts for several days. The main instruction and other instructions for such a sequence of events are an entity not easily mastered. Also human factors and attitudes have lead to errors in the handling of the transport cask.

The event has no direct bearing on safety. Unplanned handling of the transport cask may lead to accident conditions, however, the consequences of which have not been assessed.

The deficiencies detected in transfers are prevented by modifications in the equipment as well as by training before spent fuel transfers are continued. Plans concerning the transfer area and equipment are being discussed in Teollisuuden Voima Oy to further enhance the overall safety of transfers.

TVO II

In the second half of 1991 a fire broke out in the switchgear building of TVO II as the consequence of which the plant unit lost connections to both external grids and operated 7.5 hrs on power generated by four back-up diesels. The event was an indication of deficiencies in the reliability of external power supply. A fire in one general busbar lead to a prolonged loss of all external grids since the busbars were not adequately separated from each other. Adequate separation of the damaged point was not possible, either. Therefore, restoration of external power supply took a long time. No personal injuries or radioactive releases occurred. The event is classified as Level 2 on the International Nuclear Event Scale.

In this quarter also administrative errors occurred at TVO II during the annual maintenance outage. These are classified as Level Zero (Below Scale) on the International Nuclear Event Scale.

3.4 Loss of external grids due to switchgear fire

A fire broke out in the 6.6 kV switchgear building of TVO II on 12.4. As a consequence, the plant unit lost connections to both external grids for 7.5 hrs and relied on back-up diesels for power supply.

At the TVO nuclear power plant the power required by the plant units is supplied by the general 6.6 kV system (system 642, Fig. 5). The system contains four sub-systems, busbars (642 A101, B201, C301 and D401), physically separated from each other. During normal and house turbine operation the generator supplies the power required by the plant unit via two plant transformers.

During startup and outages, when the plant unit itself does not generate electricity, power is supplied by the 400 kV external grid via the main transformer and plant transformers. When the 400 kV external grid or the unit's generator is unavailable, the power required by the plant unit is supplied by the 110 kV external grid via the startup transformer. Back-up diesels auto-start on loss of both external grids. One defective diesel generator can be replaced by a diesel generator of the other plant unit.

Event description

It had been found out at TVO II on 8.4. that the power measurement of one busbar (642 C301) of the general 6.6 kV system indicated a value considerably too low. Investigations into the fault were initiated in the late morning of 12.4. Damaged terminal blocks were found in the secondary circuit of the current transformer which measures the power of the incoming cable from the plant transformer to the busbar. The terminal blocks are located in the unit's cubicle HXA 301. To make the terminal blocks currentless, the busbar's power supply was switched from the 110 kV external grid via the startup transformer to the unit's second cubicle (HXA 303). The damaged terminal blocks sparked when touched and the cubicle started to emit smoke. The fire brigade was alerted at 13.38.

In consequence of the fire, a short circuit by arching occurred in the busbar owing to which relay protection opened both the 400 kV and the generator breakers. Loss of the 400 kV grid connection resulted in a turbine trip, partial scram and the tripping of the recirculation pumps. Somewhat later, when the fire had reached the cubicle (HXA 303) containing the incoming cable from the start-up transformer, another short circuit by arching occurred. Due to the short

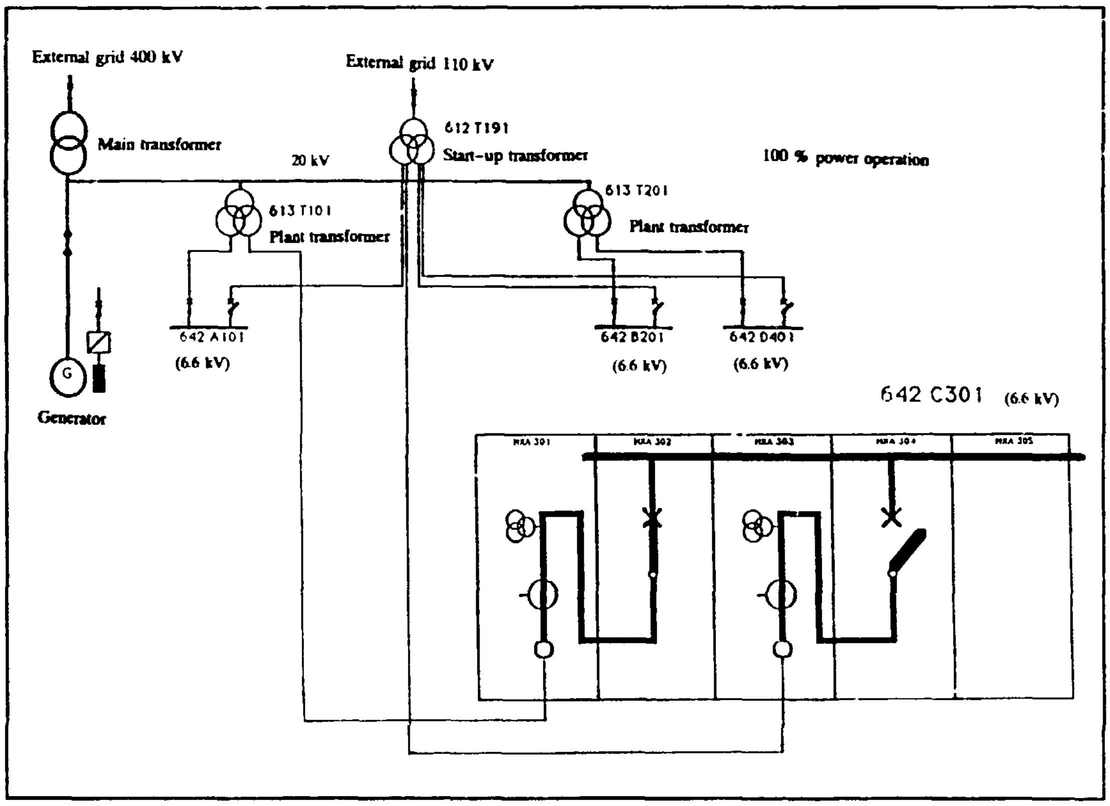

Fig 5. Diagram of the general 6.6 kV system of TVO II.

circuit, the relay protection of the 110 kV grid breaker of the startup transformer opened the breaker. A total loss of external power supply thus resulted. Due to the loss of power supply, the turbine's condenser system was not available anymore and a scram resulted.

The plant unit's four back-up diesels started as planned and began to supply the power it required. The fire had been put out at 14.15. Also in another busbar (642 A101), located in the same switchgear room, soot and molten metal were scattered around during the fire.

The situation was under control after the fire. The plant unit was maintained in hot shutdown by means of back-up diesels and restoration of connections to the external grid were awaited to shut down the plant.

After the fire had been put out, restoration of the external power supply from the 110 kV grid to the two functional busbars (642 B201 and D401) of the general 6.6 kV system was started. To do this, the damaged busbar had to be disconnected from the general 6.6 kV system. At 21.28 hrs the efforts to restore power supply from the 110 kV external grid to these busbars via the startup transformer were successful. The bringing of the plant unit into a cold shutdown state was started on 13.4. at 2.21 hrs.

Event causes and corrective action

The event was probably caused by a break in the test plug of the current transformer's secondary circuit. The break obviously occurred in relay testing during the 1990 annual maintenance. During plant unit startup after the annual maintenance outage, such high voltage was established in the defective secondary circuit that the insulation of the terminal blocks of the circuit and of the adjoining voltage transformers overheated. When inspecting and touching the overheated terminal blocks a galvanic contact was established between the secondary circuits of the current and voltage transformers via the over-heated terminal blocks. This short-circuited the voltage transformer.

The busbar (642 A101) in which soot and molten metal were scattered around during the fire was cleaned, tested and connected to the grid on 16.4. Four cubicles (HXA 301-304) of the busbar (642 C301), which sustained damage in the fire, were replaced and the sooty, damaged cubicles were cleaned and repaired. Incoming cables from the plant transformer and the start-up transformer to the busbar were replaced. The whole unit was tested and energized on 21.4.

During the annual maintenance, the physical separation of the current and voltage transformers was enhanced by means of terminal block rows. A measure was included in the instructions for relay tests to post-test check the integrity of the secondary circuits of the current transformers. Tightness of the terminal blocks was checked and old terminal blocks were replaced with new ones. Thermography of the terminal blocks and test plugs of the general 6.6 kV system was carried out. Monitoring of the internal consumption measurements carried out by the control room was made more efficient.

The event indicated deficiencies in the reliability of external power supply. A fire in one busbar resulted in a prolonged loss of all external grid connections as the busbars are interconnected via both the start-up and plant transformers. The restoration of external power supply took a long time as the options of separating the defective point were insufficient.

The adequacy of both the servicing and preventive maintenance operations related to busbars as well as the need for larger structural modifications of the busbars are being assessed. Further measures deal with the prevention of the recurrence of similar faults, limitation of the consequences of corresponding events, improvement of the options of separating any failure points on the general 6.6 kV system as well as increasing the options of external power supply. Management of electrical fires is developed based on experiences gained of the event.

The event's safety significance

The event did not directly endanger plant unit safety but lead to a re-evaluation of safety provisions. The plant unit's electrical and automation equipment (e.g. back-up diesels, relay protection and reactor protection systems) functioned as designed. No personal injuries occurred. No occupational radiation doses or releases of radioactive material resulted from the event.

No similar event involving the simultaneous loss of both external grids has occurred earlier at the TVO nuclear power plant.

A corresponding total loss of the external power supply in consequence of a fire in one busbar is impossible at the Loviisa nuclear power plant. There are two turbine generator sets at both Loviisa plant units. Both sets are supplied power separately from the 400 kV switchyard.

3.5 Errors during annual maintenance outage

During the annual maintenance outage of TVO II the Finnish Centre for Radiation and Nuclear Safety paid attention to the number of events involving human error in the work done. As single events the errors did not have plant safety implications. The matter is under review at the Finnish Centre for Radiation and Nuclear Safety and in Teollisuuden Voima Oy.

The most important observation was that the work permit routines did not always meet Teollisuuden Voima Oy's own administrative requirements. Work permits had been issued by individuals not authorised to do so. Furthermore, the procedure of acknowledging safety measures to ensure safety at work was found insufficient. Strict adherence to the work permit procedure is vital to ensure implementation of work according to plans and thus plant safety during operation.

Examples of events are given below.

Water was spilled on mechanic during dismantling of valve

A mechanic was opening the lid of a valve of the scram system to repair the valve. During opening, the lid flew off and water from the valve was spilled on the mechanic. Leak tightness tests had been performed on the system valve and the shift manager had issued the necessary permits. In the leak test the valve was found leaky and was to be repaired. The safety measures required by the work permit related to the leak test were restored in compliance with the leak test instruction. The work permit for the valve repair was issued by the work permit office without preparing the required safety precautions and the aforementioned consequences resulted.

Pressure vessel repairs fell short of plan

In the work order the reheater parts due for repair were duly defined. In an inspection carried out by the Finnish Centre for Radiation and Nuclear Safety it was found out that the majority of the items to be repaired still remained undone although the work permit had been returned and the necessary documents had been prepared and signed as acknowledgement of accomplished work. Those responsible for supervision of work had altered the repair plan without applying for the necessary authorisation.

Welder used non-utility individual's identification on his welds although fully licensed himself

A licensed welder borrowed a non-licensed welder's stamping tool to mark his welds. When this was found out, the welder was removed from onsite work.

Safety valve retest after failed test was forgotten

Two valves had to be forcibly closed when testing relief system safety valves. One was immediately retested but the other was not tested until the following day, when an inspector of the Finnish Centre for Radiation and Nuclear Safety made a remark about it. There was no mention of the failed test in the test documents but retesting had been left to memory.

Wrong item opened for inspection

When defining the rubber linings chosen for inspection in the service water system an item belonging to another system was erroneously picked up. The system in question was not covered by the work permit and the item had not been isolated for inspection. The definition of items for inspection was,in this case, by memory.

Fuel channel sustained damage in storage pool during refuelling

The fuel channel of a fuel assembly placed in the fuel pool's storage rack sustained damage when hit by another bundle which was being lowered next to it in the rack. No damage was detected in the fuel bundle to be lowered, only scratches in the lower part of its fuel channel. The lifting ear of the fuel channel below was deformed to such an extent that attempts to remove the bundle from its fuel channel have, so far, failed. The event occurred after midnight and was not noticed until after a few days later, when an out-of-the-ordinary looking upper end of a fuel channel was examined closer.

According to the explanation submitted by Teollisuuden Voima Oy, the collision of the lowered bundle with the one below it was attributable to the bundle having been in swinging motion when lowered by the refuelling machine. Swinging, for its part, was due to the refuelling machine having been driven in a jerky manner.

4 RADIATION SAFETY

Individual occupational radiation doses during the second quarter of 1991 were below the dose limit. Releases of radioactive materials off-site were considerably below the release limits. Only small amounts of radioactive materials originating in nuclear power plants were detected in samples taken in the vicinity of nuclear power plants.

4.1. Limitation of radiation exposure

Radiation exposure arising from the operation of nuclear power plants shall be kept as low as reasonably achievable. To accomplish this objective, the sum doses i.e. the collective radiation doses of individuals working in a nuclear power plant and the local population in the vicinity of nuclear power plants shall be monitored. The health effects arising from the radiation doses received are compared with the measures taken to limit the radiation exposure of workers and the population. Furthermore, the limitation of individual radiation doses below the confirmed dose limits shall be implemented.

4.2 Occupational radiation exposure

The radiation safety of nuclear power plant workers is, on one hand, dependent on the plant layout and condition and, on the other, on the radiation protection measures applied at work. The major part of the radiation dose is received in work performed during annual maintenance outages.

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 15.9 mSv and it was received at the TVO nuclear power plant.

The limits for individual occupational radiation doses have been so set that the health risk to workers from radiation is small and comparable to occupational risks in professions considered safe.

The distribution of individual occupational doses in the report period and from the beginning of 1990 until the end of 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.

In the report period, the collective radiation dose at the Loviisa plant was 0.03 manSv and at the TVO plant 1.31 manSv. The annual maintenance outages of both TVO plant units took place in the report period. The dose limit given in the guides of the Finnish Centre for Radiation and Nuclear Safety is 5 manSv/GWe per installed electrical power in a year which means a collective radiation dose of 4.45 manSv/year for the Loviisa plant and 7.1 manSv/year for the TVO plant.

Table III. Occupational dose distribution in the report period and from beginning of 1991 until end of the report period.

Dose range (mSv)	Number of persons in the dose range					
	Second quarter 1991			From beginning of 1991		
	Loviisa	TVO	Total*	Loviisa	TVO	Total*
< 0.5	48	418	466	50	123	473
0.5 - 1	10	266	277	12	264	276
1 - 2	9	190	206	10	194	210
2 - 3	1	72	69	2	77	76
3 - 4	-	25	29	3	25	32
4 - 5	-	25	25	-	22	24
5 - 6	-	21	23	-	11	11
6 - 7	-	11	11	-	3	3
7 - 8	-	3	3	-	2	2
8 - 9	-	2	2	-	1	1
9 - 10	-	1	1	-	2	2
10 - 11	-	2	2	-	4	4
11 - 12	-	4	4	-	2	2
12 - 13	-	2	2	-	2	2
13 - 14	-	2	2	-	1	1
14 - 15	-	1	1	-	1	1
15 - 16	-	1	1	-	-	-
16 - 17	-	-	-	-	-	-
17 - 18	-	-	-	-	-	-
18 - 19	-	-	-	-	-	-
19 - 20	-	-	-	-	-	-
20 - 21	-	-	-	-	-	-
20 - 25	-	-	-	-	-	-
> 25	-	-	-	-	-	-

* 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.

4.3 Releases of radioactive materials off-site and radiation exposure of the population

The radiation exposure of the population in the vicinity of a nuclear power plant is caused by releases of radioactive materials into air and water during operation. Releases are restricted by technical means. Furthermore, the operational condition of the plant and its releases are continuously monitored and compared with predetermined limitations.

In the report period, releases of radioactive materials off-site were considerably below prescribed release limits (Table IV).

The release limits have been so determined that for the individuals with the highest exposure, the annual effective radiation dose will not exceed 0.1 mSv. This is about a fiftieth part of the dose annually received in Finland from natural background radiation, radon in dwellings included. The release limits have been established for such nuclides and release pathways as have significance from the viewpoint of the possibility of exceeding the individual dose limit.

The radiation doses of individuals living in the vicinity of nuclear power plants calculated on the basis of release reports are low and at most less than about a thousandth part of their annual radiation exposure.

The release from nuclear power plants of the long-lived carbon-14 nuclide causes a global collective dose approximately as high as the dose limit for a period of 500 years (5 manSv/GWe per installed electrical power) given in a guide issued by the Finnish Centre for Radiation and Nuclear Safety. This collective radiation dose limit is based on the definite limitation of annual dose arising from the widespread use of nuclear power below 0.1 mSv even for individuals living in the future. When defining the collective dose limit it has been assumed 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. At present, the use of nuclear energy in Finland is about a twentieth part of this value.

Table IV. Releases of radioactive materials at each plant site, second quarter of 1991.

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]	$8.7 \cdot 10^{6}$	$2.8 \cdot 10^{6}$	$1.4 \cdot 10^{11}$	[d]
Early 1991	[b,c]	$8.8 \cdot 10^{6}$	$1.3 \cdot 10^{7}$	$3.5 \cdot 10^{11}$	[d]
Olkiluoto					
Report period	$4.3 \cdot 10^{12}$	$1.7 \cdot 10^{8}$	$2.5 \cdot 10^{8}$	$2.2 \cdot 10^{10}$	[d]
Early 1991	$6.3 \cdot 10^{12}$	$2.2 \cdot 10^{8}$	$4.1 \cdot 10^{8}$	$6.3 \cdot 10^{10}$	[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	$6.7 \cdot 10^{12}$	$7.0 \cdot 10^{2}$
Early 1991	$8.6 \cdot 10^{12}$	$7.0 \cdot 10^{2}$
Olkiluoto		
Report period	$8.4 \cdot 10^{11}$	$1.3 \cdot 10^{10}$
Early 1991	$1.3 \cdot 10^{12}$	$1.5 \cdot 10^{10}$
Annual release limits		
Loviisa	$1.5 \cdot 10^{14}$	$8.9 \cdot 10^{11}$
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 $4.2 \cdot 10^{11}$ Bq during the report period. As of beginning of 1991, the release was $8.5 \cdot 10^{11}$ Bq.
[d] The carbon-14 release estimate based on experimental data was $8.7 \cdot 10^{10}$ Bq in Loviisa and $1.3 \cdot 10^{11}$ Bq in Olkiluoto during the report period. The estimates as of beginning of 1991 were $1.8 \cdot 10^{11}$ Bq and $3.0 \cdot 10^{11}$ Bq, respectively.
[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 so set that the sum of the various types of release limit shares is equal to or smaller than 1.

4.4 Radiological monitoring of the environment

Radiation safety in the vicinity of nuclear power plants is controlled by means of regular sampling and analysis programmes. The aim of monitoring is to follow dispersion into the environment of radioactive discharges and to ensure that doses to the local population remain below set limits.

Annually, about 500 samples taken in the vicinity of both the Loviisa and Olkiluoto nuclear power plants are examined. Samples of i.a. air, rain and sea water as well as foodstuffs such as milk, meat, grain, vegetables and fish are collected and analysed. By their help the amounts of radioactive materials possibly accumulating in man can be assessed. Also terrestrial and marine indicator organisms are analysed which effectively enrich radioactive materials from their environment. By their help even very low amounts of radioactive materials can be detected and their dispersion monitored. Nuclides most important from the viewpoint of human exposure are determined from the samples.

Caesium-137, originating in the Chernobyl accident, was still the dominant radionuclide in the samples collected in this report period. In addition to it, other long-lived nuclides such as strontium-90, antimony-125 and caesium-134 were detected in the samples.

Radioactive materials originating in the Finnish nuclear power plant were detected in samples of the aquatic environment only. Small amounts of manganese-54 and cobalt-60 were detected in samples of sea water collected near the water outlet of the Olkiluoto power plant. Correspondingly, the amount of tritium (^3H) detected in sea water samples at Loviisa was somewhat higher than in sea water samples in general at present.

Tables V and VI give the amounts of radioactive materials originating in nuclear power plants detected in the indicator samples of the marine environment. The tables indicate that i.a. manganese and cobalt are present in the environmental samples of both power plants, whereas silver-110m is characteristic of Loviisa and zinc-65 of Olkiluoto. It should be noted that the tables represent concentrations in indicator samples specifically collected to monitor the dispersion of nuclide releases. The samples of fish, for instance, contained no radionuclides originating in power plants. All the concentrations detected were low.

Table V. Radioactive substances originating in the Loviisa nuclear power plant detected in bladder wrack, crustaceans and sinking matter (Bq/kg, dry weight).

Sampling point	Sampling time	^{54}Mn	^{60}Co	^{110m}Ag
Bladder wrack				
Loviisa A	16.5.91	4.0	23	6.9
Loviisa B	16.5.91	1.9	15	4.7
Loviisa C	16.5.91	0.36	0.92	0.76
Crustacean				
Hästholmsfjärden	15.5.91 - 30.5.91	0	5.9	15
Sinking matter				
Klobbfjärden	6.11.91 - 3.5.91	2.5	35	45
Klobbfjärden	3.5.91 - 13.6.91	0	10	0
Hästholmsfjärden	6.11.90 - 3.5.91	11	110	130
Hästholmsfjärden	3.5.91 - 13.6.91	0	13	7.1
Böleviken	6.11.90 - 3.5.91	19	120	130
Böleviken	3.5.91 - 13.6.91	0	11	8.8
Pernajanlahti	6.11.90 - 3.5.91	0	0	0
Pernajanlahti	3.5.91 - 13.6.91	0	0	0

***Table VI.** Radioactive substances originating in the Olkiluoto nuclear power plant detected in bladder wrack, green algae and sinking matter (Bq/kg, dry weight).*

Sampling point	Sampling time	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn
Bladder wrack					
Olkiluoto A	9.5.91	93	10	130	3.9
Olkiluoto A	24.6.91	65	4.7	130	3.8
Olkiluoto B	9.5.91	2[illegible]	2.3	33	0
Olkiluoto B	27.6.91	21	2.3	40	0
Olkiluoto C	8.5.91	1.2	0	3.6	0
Olkiluoto C	24.6.91	1.4	0	3.6	0
Green algae					
Olkiluoto A	24.6.91	20	0	12	0
Sinking matter					
Lippo	28.4.91 - 13.6.91	27	3.5	71	0
Susikari	22.11.90 - 25.3.91	27	0	42	0
Susikari	28.4.91 - 14.6.91	23	0	48	0
Tankokarit	22.11.90 - 28.4.91	31	0	60	0
Tankokarit	28.4.91 - 13.6.91	27	7.8	66	0

5 OTHER MATTERS RELATING TO THE USE OF NUCLEAR ENERGY

The Finnish Centre for Radiation and Nuclear Safety has assessed the safety of the Loviisa and Olkiluoto nuclear power plants based on the new regulations issued by the Council of State.

5.1 Safety assessments of the Loviisa and Olkiluoto nuclear power plants related to the Council of State's Decision (395/91)

On 14.2.1991 the Council of State issued the general regulations for the use of nuclear energy dealing with nuclear power plant safety, physical protection and emergency response arrangements as well as the disposal of reactor waste. The new safety regulations are applicable, with some exceptions, to operating nuclear power plants. The regulations have been prepared by the Finnish Centre for Radiation and Nuclear Safety.

The new safety regulations are stringent and reformative internationally compared. Both domestic and international R&D has been taken into account. The safety regulations are much more stringent than those in force when the Loviisa and Olkiluoto nuclear power plants were built. One of the most significant safety enhancing requirements laid down by the new regulations is that the containment shall be designed in provision against a severe accident.

In the spring of 1991 the Finnish Centre for Radiation and Nuclear Safety conducted the safety assessments of the Loviisa and Olkiluoto nuclear power plants. The assessments were based on the Council of State's regulations and the YVL-guides issued by the Finnish Centre for Radiation and Nuclear Safety. General principles, radiation exposure and releases of radioactive material, nuclear safety and the operation of the plants were assessed.

The safety assessment indicated that the Olkiluoto nuclear power plant meets the safety requirements. The Loviisa nuclear power plant meets the requirements with the exception of certain requirements related to the ensuring of safety functions and provision for accidents. Taking into account the provisions of the Decision of the Council of State about applicability to operating nuclear power plants, the Finnish Centre for Radiation and Nuclear Safety has seen the continued operation of the Loviisa plant acceptable, however. Approval was justified by several features characteristic of the Loviisa power plant which substantially decrease its susceptibility to transients and constitute a considerable safety margin in comparison with most other nuclear power plants. Safety of the Loviisa plant is thus assessed to be comparable with the safety of plants of an equal age operating in other Western industrialized countries. Furthermore, there are several projects under way at the plant to ensure safety in conformity with the new regulations as well as practicably prossible.

The safety assessments have been published in full as the reports STUK-B-YTO 81 and STUK-B-YTO 82 (in Finnish) of the Finnish Centre for Radiation and Nuclear Safety.

APPENDIX 1

REGULATORY CONTROL OF NUCLEAR FACILITIES

The regulatory control performed 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.

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