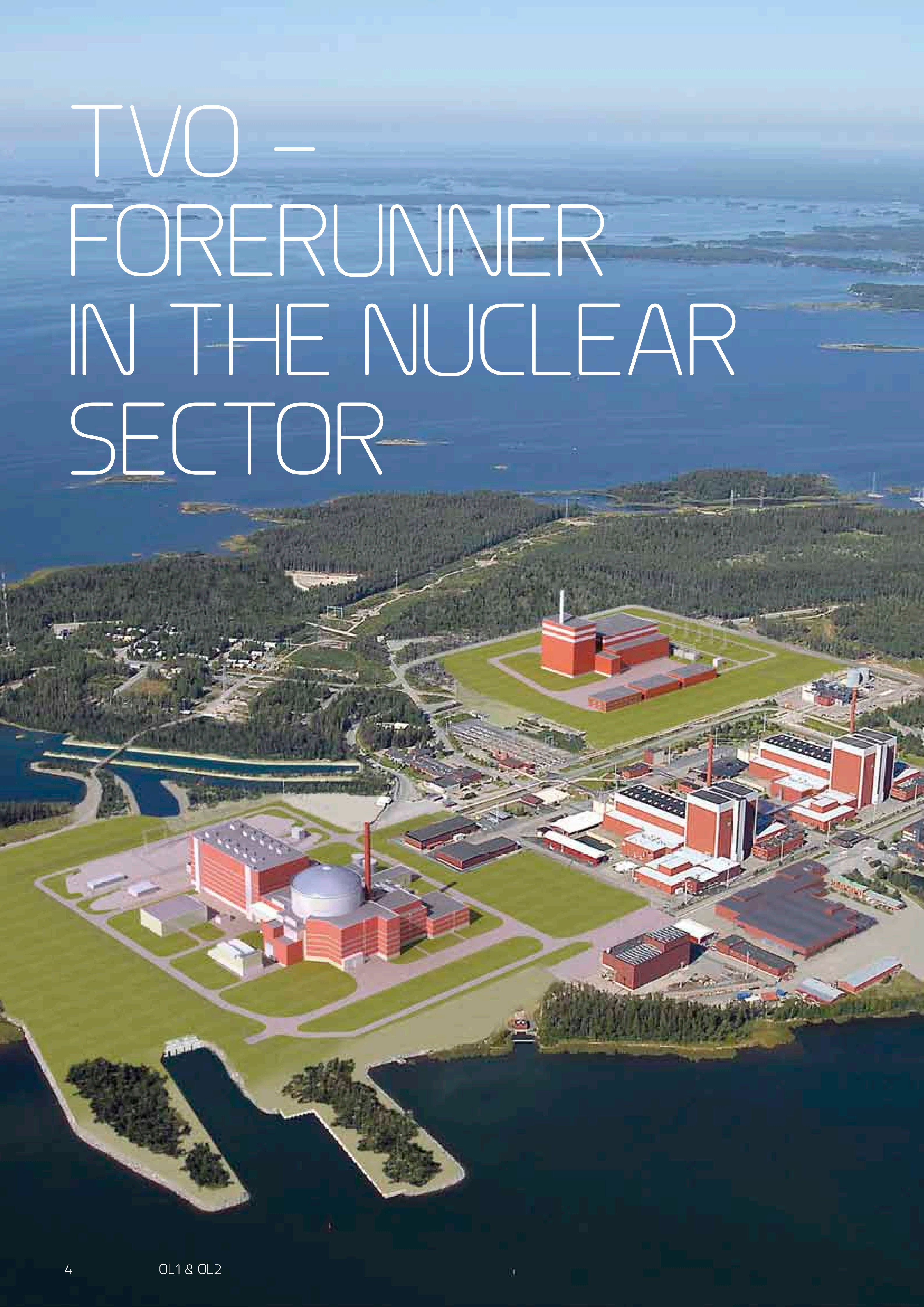
OL1&OL2 Nuclear power plant units

Teollisuuden Voima Oyj – Well-being with nuclear electricity

Publisher: Teollisuuden Voima Oyj
Domicile: Helsinki, Business ID 0196656-0
Layout: Advertising agency Briiffi Oy
Photos: TVO
Place of printing: Laine Direct Oy

TVO – FORERUNNER IN THE NUCLEAR SECTOR



Teollisuuden Voima Oyj (TVO) is an unlisted public company founded in 1969. Its mission is to produce electricity for its owners at cost price. TVO owns and operates two nuclear power plant units, Olkiluoto 1 (OL1) and Olkiluoto 2 (OL2), and is building a new plant unit, Olkiluoto 3 (OL3), at Olkiluoto in Eurajoki, Finland.

In July 2010, the Finnish Parliament ratified the Government's favorable decision-in-principle concerning the construction of the Olkiluoto 4 (OL4) nuclear power plant unit. Furthermore, TVO is a shareholder in the Meri-Pori coal-fired power plant.

The production of the existing nuclear power plant units at Olkiluoto accounts for approximately one-sixth of Finland's electricity consumption. Approximately half of the electricity produced by TVO goes to industrial consumers through the company's owners, and the other half goes to the service sector, agriculture, and households.

Solid nuclear power expertise

The safe operation of a nuclear power plant requires both up-to-date technology and competent personnel. The high competence of the personnel ensures proper attention is paid to all duties at all times and in all circumstances. TVO continuously organizes training events in order to maintain the professional skills and competence of its personnel. In addition, the power uprates and modernization of OL1 and OL2 and other extensive development and construction projects have helped the company to develop its nuclear power competence.

TVO carries out research and development (R&D) in three focus areas: safety, nuclear power technology, and environmental and nuclear waste management.

The R&D operations support the safe, reliable, and efficient use of the OL1 and OL2 plant units and the economic efficiency of production. Nuclear waste management, the purpose of which is to ensure the safety of the final disposal of operating waste and to prepare for the final disposal of spent nuclear fuel, constitutes an entity of its own.

TVO participates actively in international nuclear power research. The largest cooperation projects are related to European nuclear energy programs and workgroups. In the Nordic countries, TVO primarily cooperates with other nuclear power companies.

Internationally, TVO participates in the operations of WANO (World Association of Nuclear Operators), an organization consisting of nuclear power operators.

Top performance in international comparison

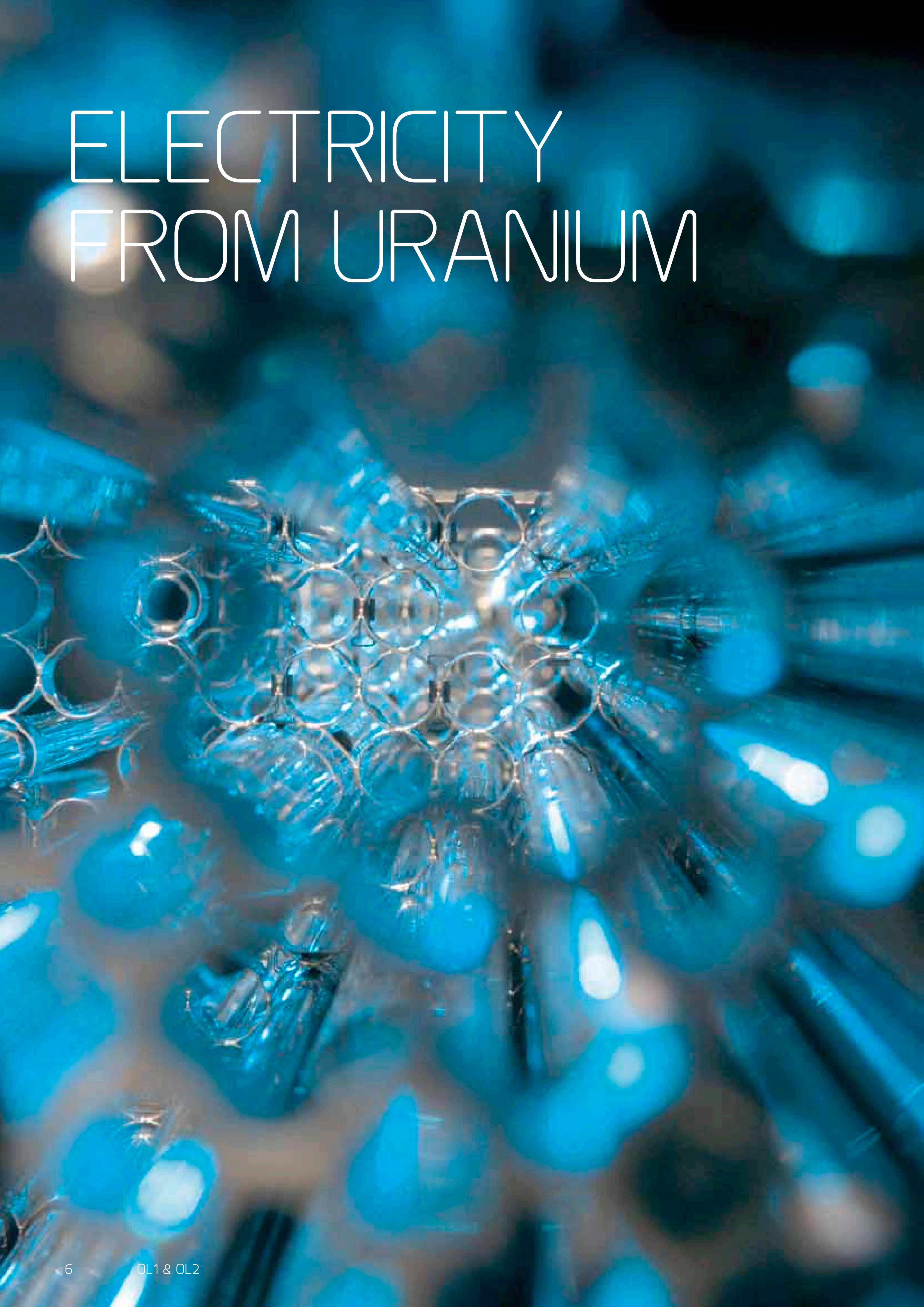
The capacity factors of the Olkiluoto power plant units, very high even by international standards, testify to TVO's nuclear power competence and the reliable operation of the plant units. Ever since the early 1990s, the capacity factors of the plant units have remained between 90 and 97 per cent.

Safety culture at TVO

As a nuclear power company, TVO has committed itself to a high standard of safety culture based on principles according to which all issues are treated in accordance with their safety significance and all operations aim to ensure high reliability and security of supply. Transparent reporting of any deviations, continuous development of operations, and strict observance of approved practices and instructions serve as evidence of our commitment to a high standard of safety culture. Safety, and all factors contributing to it, are always put before any financial objectives.

TVO aims to be an acknowledged pioneer in its field. The ways to achieve this are responsibility, proactivity, following the principle of constant improvement, and working in good, transparent cooperation with our various stakeholders.

ELECTRICITY FROM URANIUM

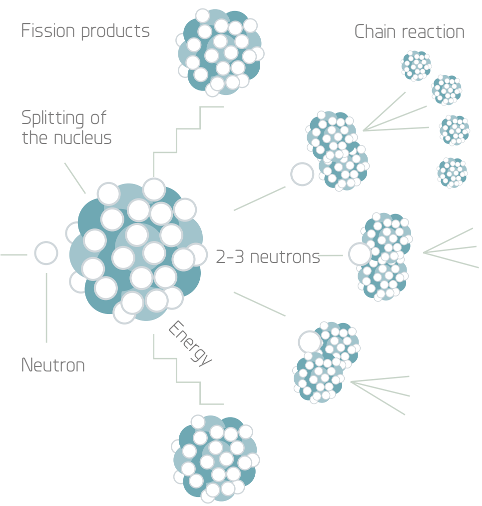


In terms of operating principle, nuclear power plants are thermal power plants where the production of energy is based on the generation of heat in the uranium fuel. The heat is generated through a fission (splitting) reaction and a controlled chain reaction of fissions.

In the fission reaction, a neutron collides with a uranium (U-235) nucleus, which splits into two smaller atomic nuclei. The fission reaction produces two or three new neutrons, fission products, and heat. The neutrons produced in the fission reaction are hurled out of the nucleus at high speed. Some of these released neutrons cause further fission reactions, initiating a chain reaction of fissions.

The average velocity of the neutrons released in the fission reaction is approximately 20,000 kilometers per second. In the reactor, the velocity of the neutrons is slowed down to a few thousand meters per second, which multiplies the likelihood of splitting the uranium nuclei. At the OL1 and OL2 plant units, demineralized water is used as moderator.

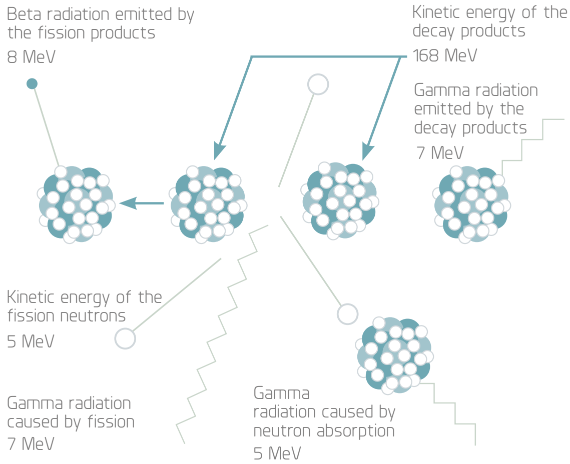
Most of the fission products are radioactive. When the radioactive fission products decay, energy called decay heat is released. As the decay heat keeps heating up the fuel even after the reactor is shut down, the cooling of the reactor must be ensured in all situations.



The splitting, or fission, of a uranium nucleus generates heat, which heats up the uranium fuel and vaporizes the water surrounding it.

Energy distribution in fission

Each fission of a uranium nucleus releases some 200 megaelectron-volts (MeV) of energy, approximately 83 per cent of which consists of the kinetic energy of the fission products. The production of one watt of power requires 3.1 x 10^{10} fissions per second. At the OL1 and OL2 plant units, each fuel assembly can be used to produce an approximate total of 70 million kilowatt-hours (kWh) of energy.



The distribution of the energy released in the fission of U-235 between different types of radiation and the kinetic energy of the fission products.

Nuclear power around the world

There are seven major power plant reactor types currently in commercial use worldwide. Most of these reactors are pressurized water or boiling water reactors, collectively referred to as light water reactors. Regular purified and demineralized water is used as both coolant and moderator in both of these reactor types.

The most common reactor type in the world is the pressurized water reactor (PWR). More than 60 per cent of all reactors are pressurized water reactors. The second most common type is the boiling water reactor (BWR), accounting for one in five of all reactors.

NUCLEAR POWER PLANTS IN COMMERCIAL OPERATION

Reactor type	Main Countries	Fuel	Coolant	Moderator
Pressurised Water Reactor	US, France, Japan and Russia	Enriched UO_2	Water	Water
Boiling Water Reactor	US, Japan and Russia	Enriched UO_2	Water	Water
Gas-cooled Reactor (Magnox & AGR)	UK	Natural U, enriched UO_2	CO_2	Graphite
Pressurised Heavy Water Reactor, "CANDU" (PHWR)	Canada	UO_2	Heavy water	Heavy water
Light Water Graphite Reactor (RBMK)	Russia	Enriched UO_2	Water	Graphite
Fast Neutron Reactor	France, Japan and Russia	PuO_2 and UO_2	Liquid sodium	–

Source: World Nuclear Industry Handbook

OL1 AND OL2 PLANT UNITS

TVO's OL1 and OL2 nuclear power plant units are identical and are equipped with boiling water reactors. The current net electrical output of both units is 880 megawatts (MW).

OL1 and OL2 began commercial operations in 1979 and 1982, respectively. The plant units were supplied by the Swedish company AB Asea Atom. Asea Atom supplied the first unit on a turnkey basis and the second one with construction work undertaken by TVO.

The major subcontractors employed in the construction project were STAL-LAVAL Turbin AB (turbine plant), ASEA AB (electrical equipment, generator), Uddcomb Sweden AB (reactor pressure vessel), Finnatom (reactor internals, mechanical components), Oy Strömberg Ab (electrical equipment), and the Atomirakennus consortium (OL1 civil engineering works). The OL2 construction work was carried out by a Finnish-Swedish consortium, Jukola.

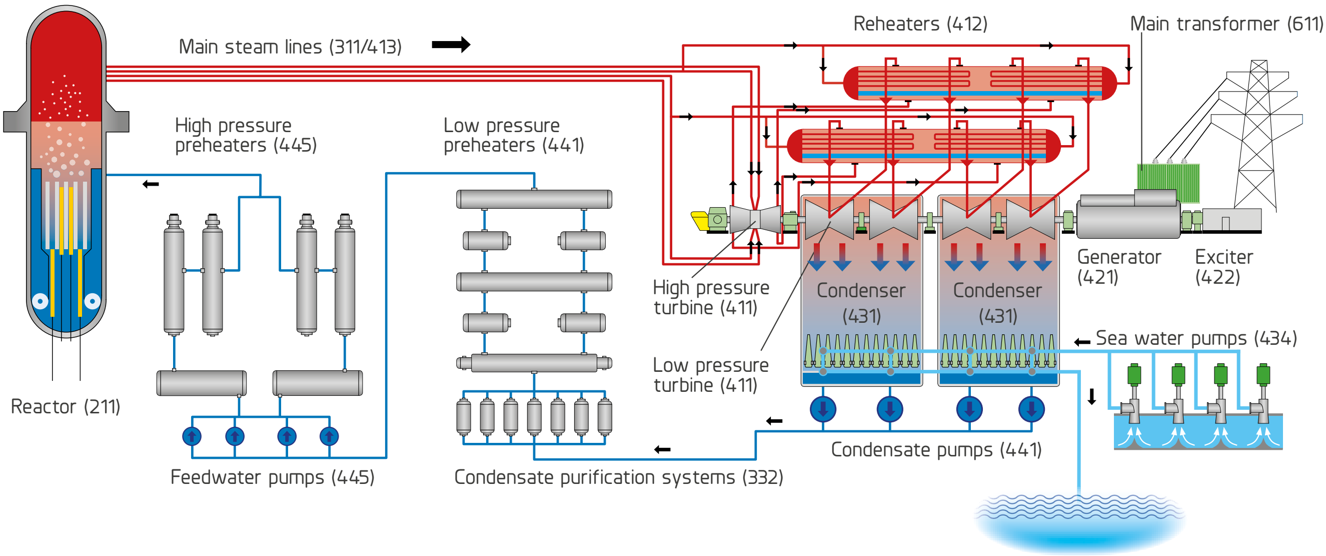
The main process of OL1 and OL2

In the boiling water reactors of OL1 and OL2, water passes through the fuel assemblies in the reactor core and boils into steam. The power of the reactor is controlled with control rods and recirculation pumps.

The steam generated in the reactor is lead to the high pressure (HP) turbine through four main steam lines. After the steam has yielded part of its energy in the HP turbine, it is lead to the reheaters, where it is dried and reheated, and then lead to the low pressure (LP) turbines. The turbines rotate a generator connected onto the same shaft. The generator produces electricity to the national grid.

The steam exiting the LP turbines is condensed back to water in the condenser with the help of a sea water cooling circuit. Using the condensate pumps, the condensed water is pumped through the purification system and the condensate preheaters to the feedwater pumps, which pump the water through the preheaters and back into the reactor as feedwater. The heated cooling water is lead back into the sea.

THE FLOW DIAGRAM OF THE OL1 AND OL2 PLANT UNITS



Always in an as-new condition

TVO maintains the OL1 and OL2 plant units continuously in an as-new condition by pursuing a carefully planned, long-term maintenance schedule, and alternating between refueling and maintenance outages.

Each device and component has a maintenance and replacement schedule that is followed during annual outages. Through good advance planning, TVO strives to prevent the failure of equipment and parts with significance to safety or production by replacing them in accordance with the replacement schedule.

Carefully scheduled outages

The annual outages begin every spring with an approximately week-long refueling outage in which part of the uranium fuel is replaced and the necessary maintenance operations and repairs are carried out, together with any preparatory work for the following year's maintenance outage. The annual outage operations then continue with the maintenance outage of the other plant unit. In addition to refueling, periodic inspections, preventive maintenance, and repairs, all major modification and modernization work is carried out during the maintenance outage.

In addition to the refueling and maintenance outages, both plant units undergo a longer, more extensive maintenance outage roughly every ten years to allow for major plant modifications.

Modernizations

The plant units are developed through modernization projects aimed at improving their safety, reliability, and performance.

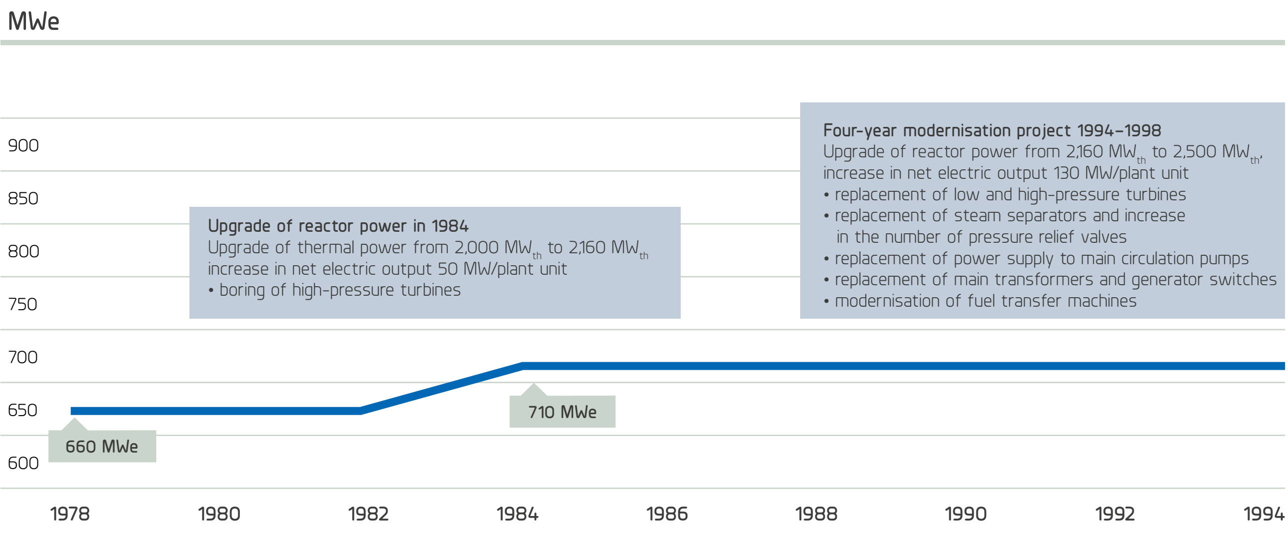
The first modernization project was carried out in 1984, when the reactor power of both plant units was uprated. As the power uprate resulted in an increased steam flow through the turbine, the bore of the HP turbines was increased by removing blade stages. Later in the mid-1980s, new condenser piping and HP turbine blading were installed in both plant units. The new blading improved the steam expansion efficiency of the turbines.

Between 1994 and 1998, both units underwent an extensive modernization program (MODE), which involved some 40 major projects. The program included the replacement of the reactor's steam separator, the generator, and the main transformer, the modernization of the internals of the LP turbines and the turbine control and protection system, and the modification of the HP turbine at both units.

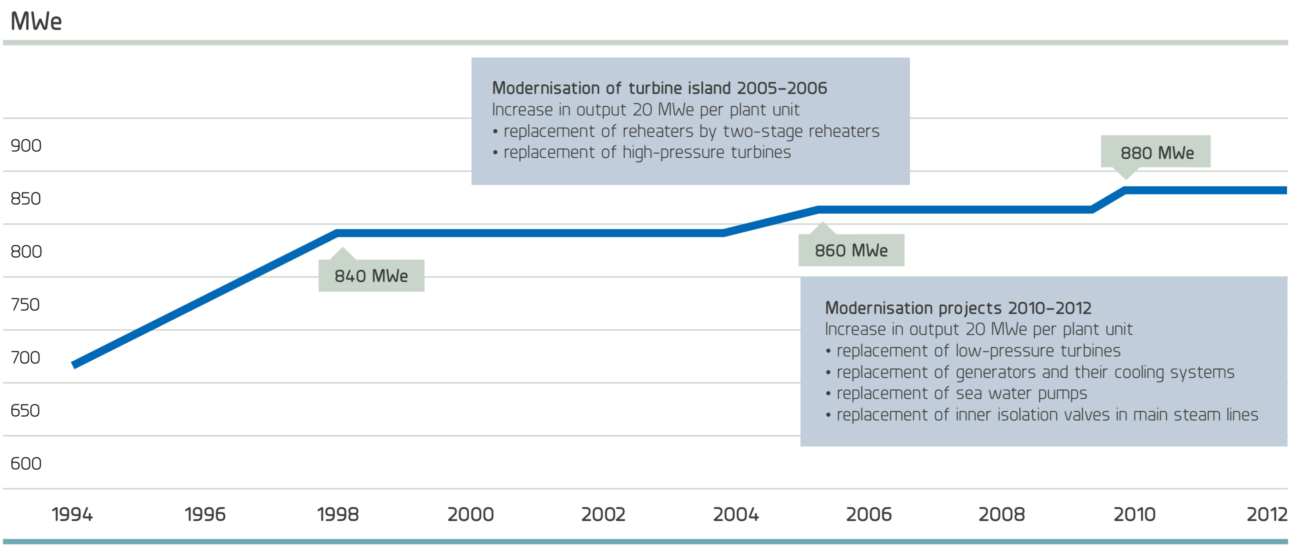
The modernization of the turbine plant continued with the Turbine Island Modernization (TIMO) project, carried out in conjunction with the annual outages of 2005 and 2006. In the course of the project, the reheaters, the HP turbine, the turbine plant automation, the steam dryer, and the 6.6 kilovolt (kV) medium voltage switchgears were modernized at both plant units.

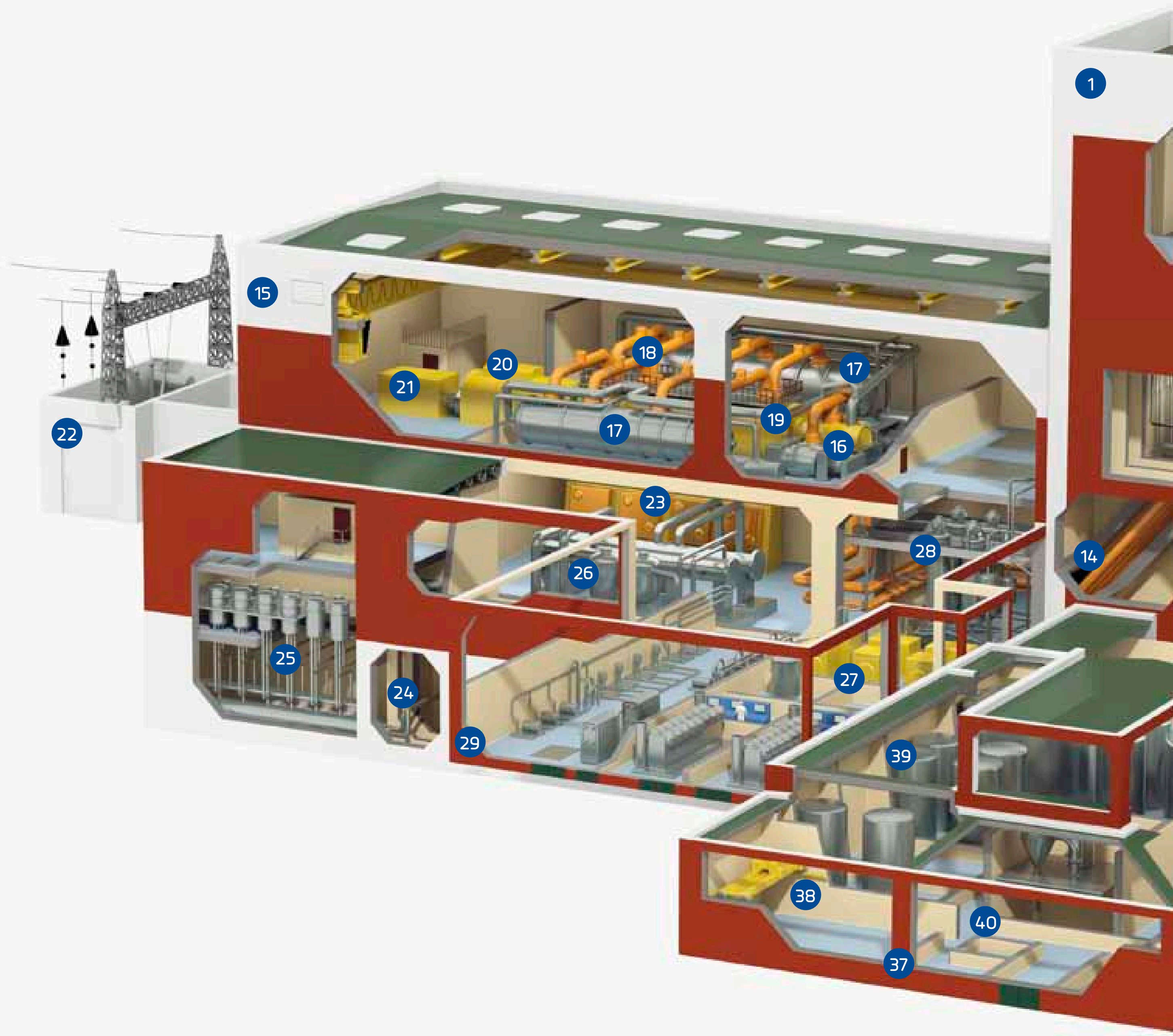
In 2010–2012, the process continued with the replacement of the generator and the modernization of the LP turbines at both plant units.

MAJOR MODIFICATION PROJECTS AT OLKILUOTO 1978–1994



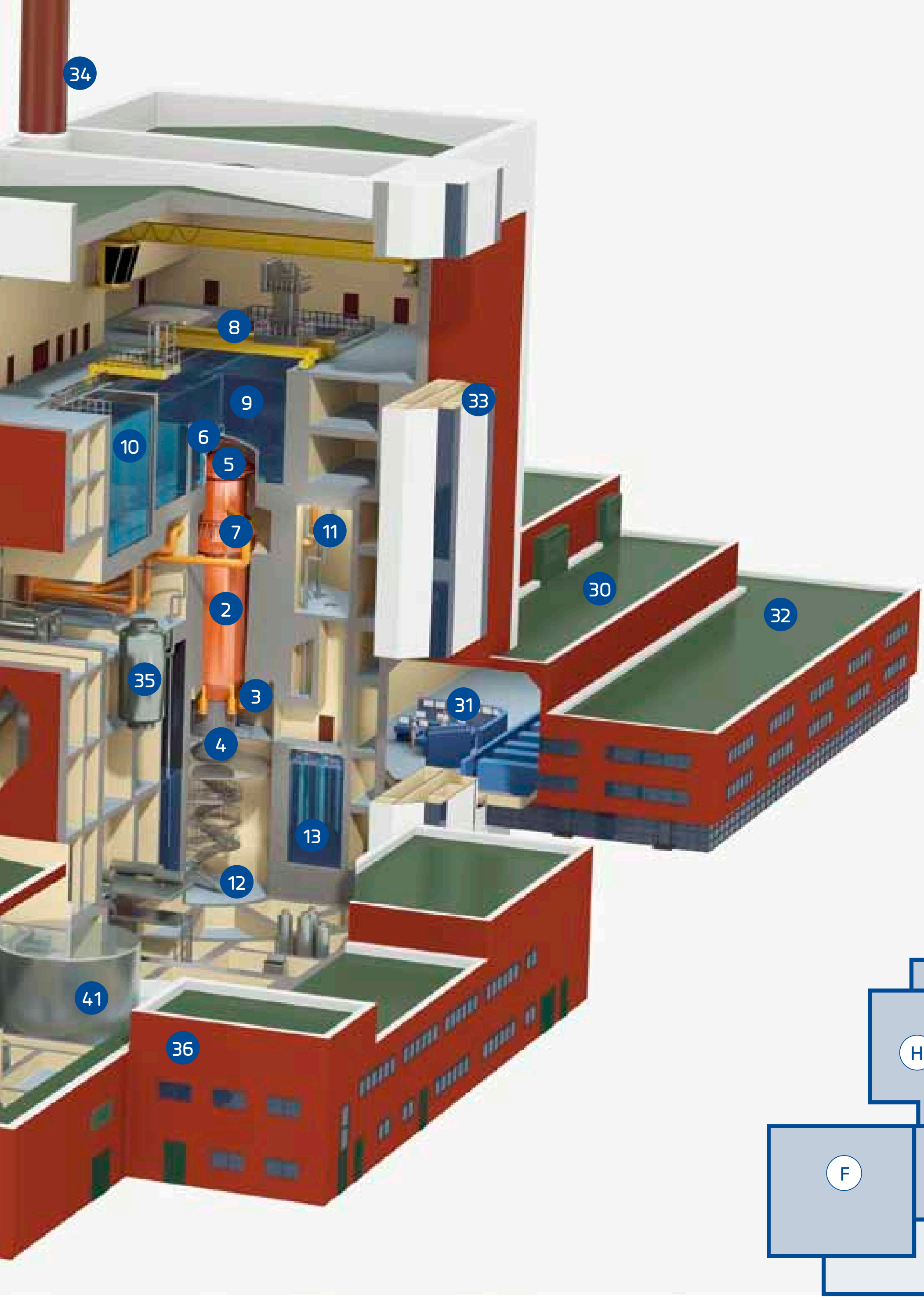
MAJOR MODIFICATION PROJECTS AT OLKILUOTO 1994–2012

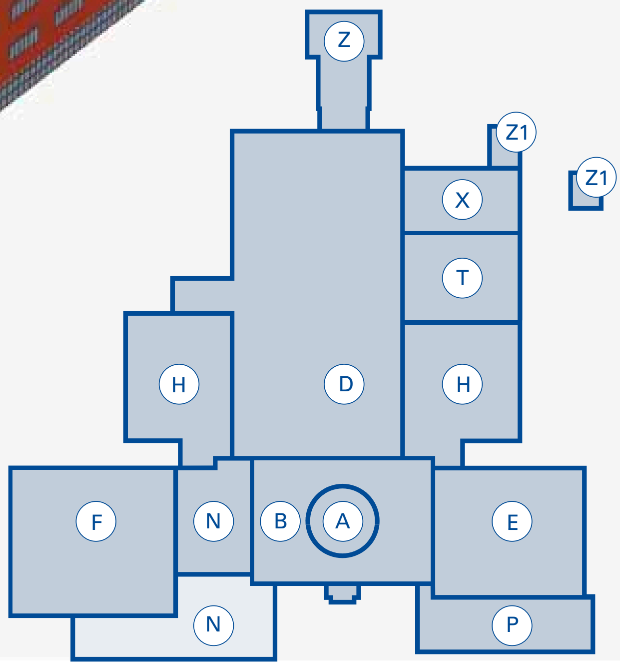




A CROSS-SECTION OF THE OL1 AND OL2

1. Reactor building
2. Reactor pressure vessel
3. Recirculation pumps
4. Control rod drives
5. Reactor pressure vessel cover
6. Containment cover
7. Main steam lines
8. Reactor service bridge
9. Reactor pool
10. Fuel pool
11. Upper drywell of containment
12. Lower drywell of containment
13. Condensation pool of containment
14. Main steam lines
15. Turbine building
16. High pressure turbine
17. Reheater
18. Main steam lines to low pressure turbines
19. Low pressure turbines
20. Generator
21. Exciter
22. Main transformer
23. Condenser
24. Condensate line
25. Condensate purification system
26. Low pressure preheaters
27. Feedwater pumps
28. High pressure preheaters





29. Auxiliary systems building
30. Control building
31. Main control room
32. Entrance building
33. Lift
34. Ventilation stack
35. SAM scrubber
(filtered venting system of the containment)
36. Active workshop/laboratory building (only OL1)
37. Radioactive waste building
38. Low and intermediate level radioactive waste storage
39. Liquid waste storage tanks
40. Intermediate waste handling
41. Make-up water tank

Unit layout

OL1 and OL2

only OL1

A Containment
B Reactor building
D Turbine building
E Main control room
F Radioactive waste building
H Auxiliary buildings
N Active workshop/laboratory building (only OL1)
P Entrance building
T Cooling water supply
X Switchgear
Z Main transformer
Z1 Startup transformers

Reactor plant

Reactor building

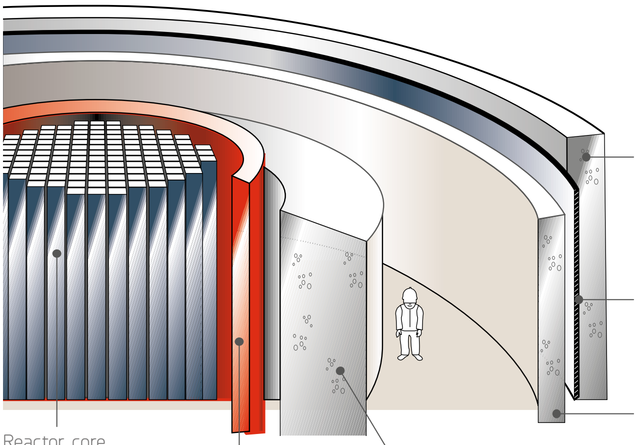
The 63-meter-tall reactor building is the highest and most dominant building of both plant units. It houses the reactor containment and numerous other rooms reserved for containment- and reactor-related auxiliary systems. The reactor building serves as a secondary containment.

Located at the top of the building, the reactor hall houses the reactor pool, fuel pools with storage racks, the reactor internals storage pools, the reactor service bridge used for refueling operations, and the overhead crane used for the lifting of the containment cover, the reactor pressure vessel cover, and other heavy components.

Dry storage facilities used for receiving and storage of fresh fuel are located below the reactor hall.

The bottom part of the reactor building houses important safety systems, such as the emergency cooling systems.

THE REACTOR PRESSURE VESSEL IS ENCLOSED IN A CONTAINMENT MADE OF CONCRETE AND STEEL



Reactor containment

At the OL1 and OL2 plant units, the reactor containment is a part of the reactor building. The reactor containment is a gas-tight cylindrical structure constructed of pre-stressed concrete. The pressure control of the containment is based on the pressure suppression principle. The purpose of the containment is to prevent the release of radioactive substances into the environment in potential accident situations.

Basic structure

The containment is divided into the upper drywell, the wetwell, and the lower drywell. The upper drywell houses the piping associated with the operation of the reactor. The control rod drive units and the recirculation pump motor service compartment are located in the lower drywell below the reactor. The wetwell comprises the condensation pool and a gas plenum located above the pool. The cylindrical part of the containment, which was constructed using the slipform method, extends to the top of the reactor pressure vessel.

The annular space located in the lower part of the containment houses the condensation pool. Blowdown pipes run vertically from the upper drywell to the condensation pool. The condensation pool holds 2,700 cubic meters of water, which is sufficient to condense the steam exiting the reactor.

In case of a rupture or a leak in the piping associated with the reactor pressure vessel, the released steam is condensed in the condensation pool. This also serves to decrease the containment pressure. The condensation pool water can be cooled.

The containment can be accessed through personnel airlocks located at the floor level of the lower and upper drywells.

All equipment that requires regular maintenance during normal operation is located outside the containment. A removable cover forms the top of the containment above the reactor. The cover is made of steel and fixed into place with 120 bolts. The cover is removed for reactor maintenance and refueling.

Tightness of the containment

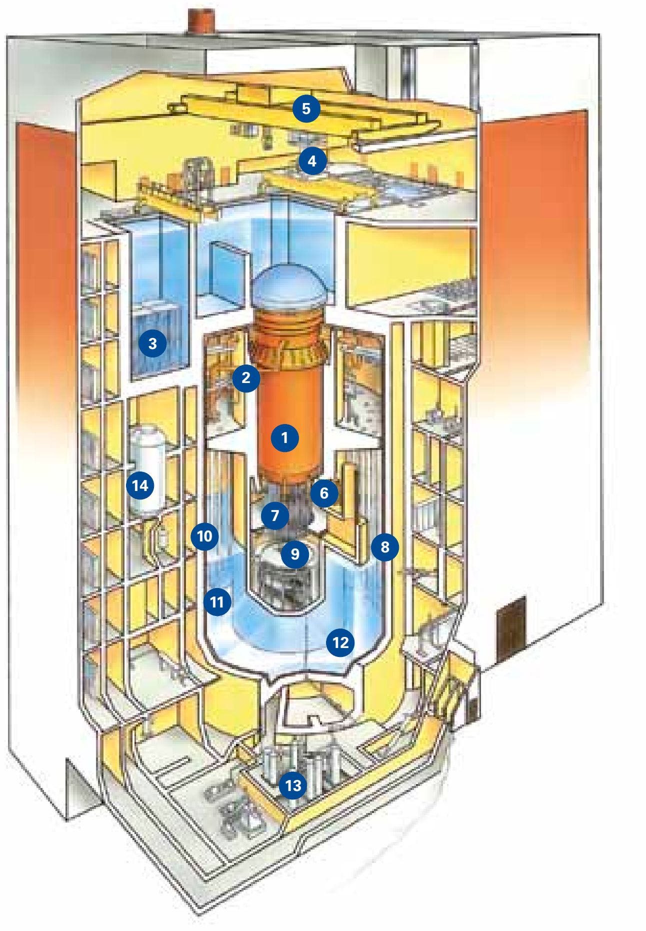
The tightness of the containment is ensured by the top cover of the containment and a steel plate liner embedded in the concrete. The concrete protects the steel plate liner against corrosion, temperature changes, hot water, steam jets, and missiles that may occur in the event of a pipe rupture.

During the operation of the plant unit, the containment is kept filled with nitrogen gas. Furthermore, the containment is equipped with stationary systems for controlled combustion of any hydrogen released in possible accident situations. This prevents the accumulation of hazardous combustible gas mixtures inside the containment following a loss of coolant accident.

In a possible accident situation, the steam is lead from the reactor's relief and safety valves to the condensation pool through the downstream piping of each valve. In case of a condensation pool bypass, the rupture disk of the overpressure protection line breaks, preventing a rapid containment pressurization. In a severe accident situation, a depressurization line equipped with a filter (SAM filter) can be used to depressurize the containment.

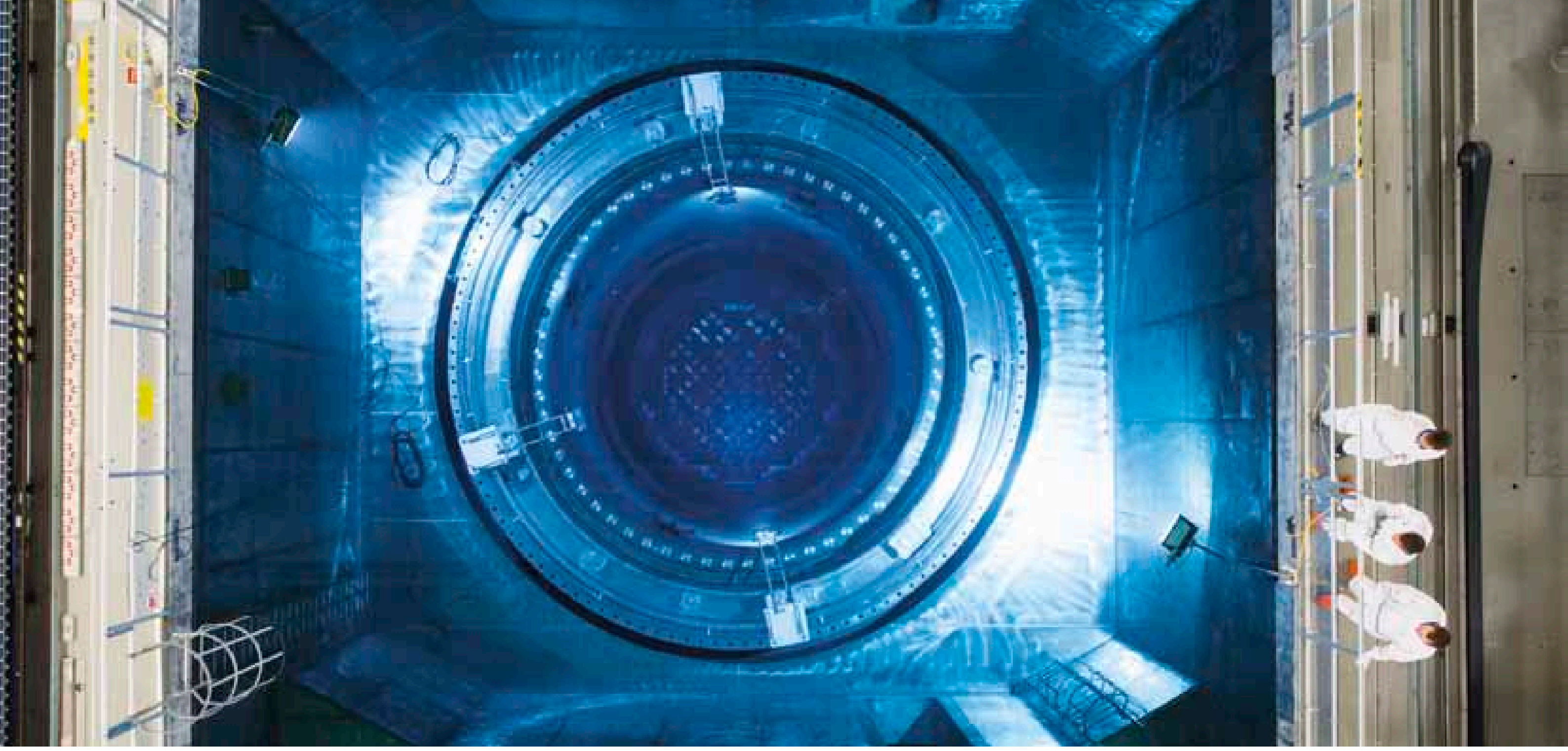
The lower drywell can be flooded with water by opening the supply line from the condensation pool. The containment can be flooded with water from an outside source using the filling lines.

The tightness of the containment is checked regularly, three times during a 12-year period. The maximum inspection interval is five years.



CROSS-SECTION OF THE REACTOR BUILDING AND THE CONTAINMENT

1. Reactor pressure vessel
2. Main steam lines
3. Fuel pool
4. Reactor service bridge
5. Reactor hall crane
6. Recirculation pumps
7. Control rod drives
8. Containment
9. Control rod service platform
10. Blow-down pipes
11. Embedded steel liner
12. Condensation pool
13. Scram system tracks
14. SAM-scrubber



The reactor pressure vessel seen from above. The closure cover bolt holes on the pressure vessel flange are sealed with plugs. The closure cover is surrounded by the containment seal, which in turn is surrounded by the containment cover attachment flange.

Reactor

The reactors of the OL1 and OL2 plant units are of the boiling water type. A reactor consists of a pressure vessel, a reactor core, a steam separator, a steam dryer, a moderator tank, control rods, recirculation pumps, and other, smaller components.

The reactor pressure vessel is made of low-alloy steel, and its inner surface is lined with stainless steel. The reactor is located in the middle of the containment. It is surrounded by a biological shield constructed of a thick layer of special concrete, which the neutron radiation occurring inside the reactor cannot penetrate.

The most significant pressure vessel nozzles are the steam, feedwater, and cooling nozzles. All major pipe nozzles are located above the reactor core. This ensures that the core remains submerged even in the event that one of the pipes associated with the operation of the reactor becomes damaged.

The pressure vessel internals are held in position by means of flexible support beams fastened to the pressure vessel closure cover. When the cover has been removed, the internals can be lifted out of the reactor without opening any bolt connections. With the exception of the moderator tank support skirt and the pump deck, which are welded to the reactor pressure vessel, all the reactor internals are removable. The reactor internals are designed to enable fast and safe refueling operations.

The reactor pressure vessel is supported on the upper part of the biological shield by means of a welded-on support skirt. The pressure vessel support skirt is located near the primary system pipe connections. This structure minimizes the stress on the piping caused by thermal expansion. Furthermore, the location of the skirt allows for more space for carrying out the maintenance of the recirculation pumps.

The thermal insulation of the closure cover is fastened to the inside of the containment cover, and it is removed together with the cover when the reactor is opened. There are no pipe connections in the closure cover. Instead, the connections are located in the reactor pressure vessel body. This allows for easy opening of the reactor pressure vessel closure cover.

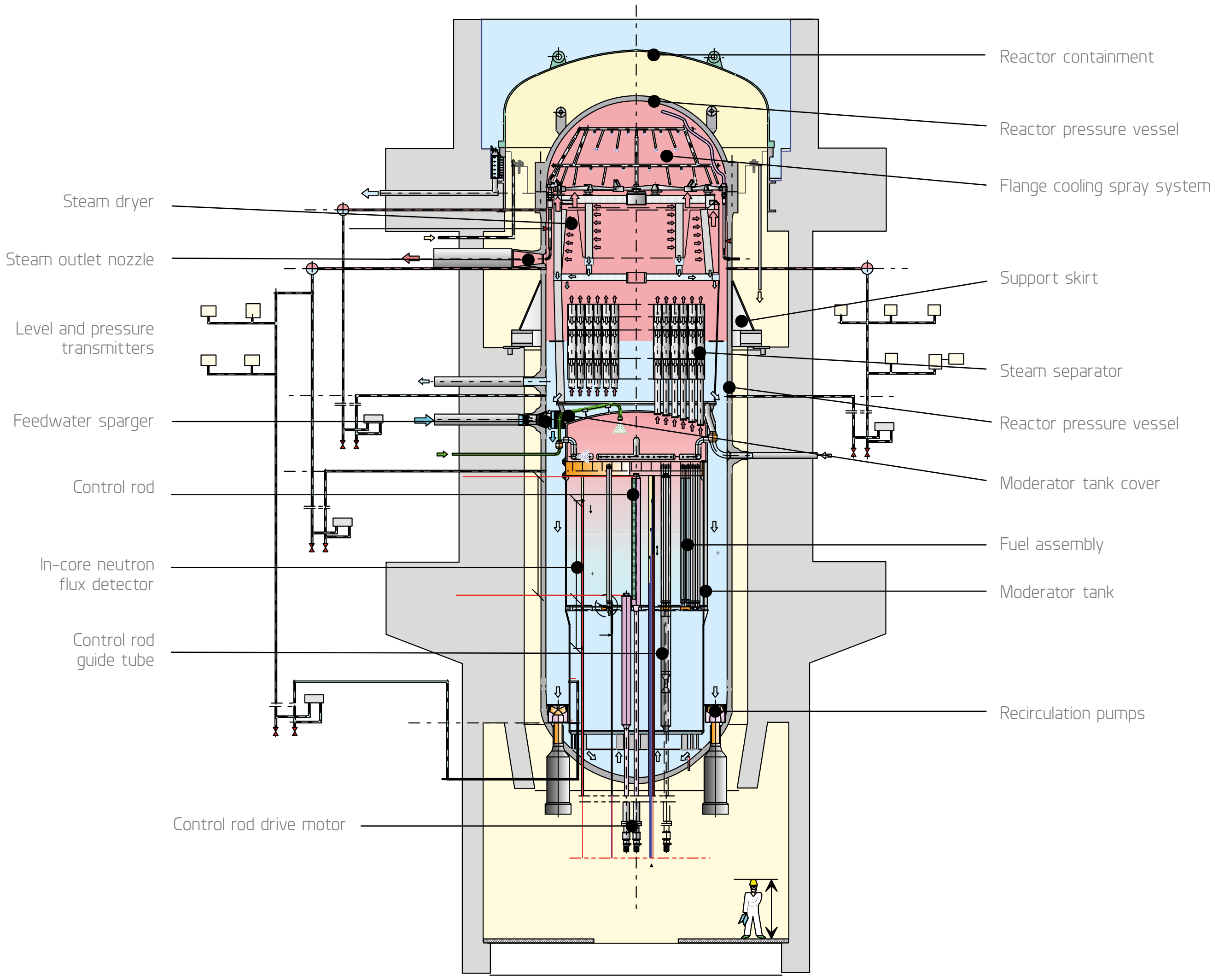
Steam separator and steam dryer

The moisture content of the steam generated in the reactor must be decreased before it is lead to the turbine plant. This is done with the help of the steam separator and the steam dryer.

The guide vanes of the steam separator set the mixture of steam and water in a rotating motion. This causes the majority of the water to come into contact with the walls of the separator pipe, from where it flows to the annular space, to be pumped into the core again. Treatment in the steam separator decreases the moisture content of the steam to just one to three per cent.

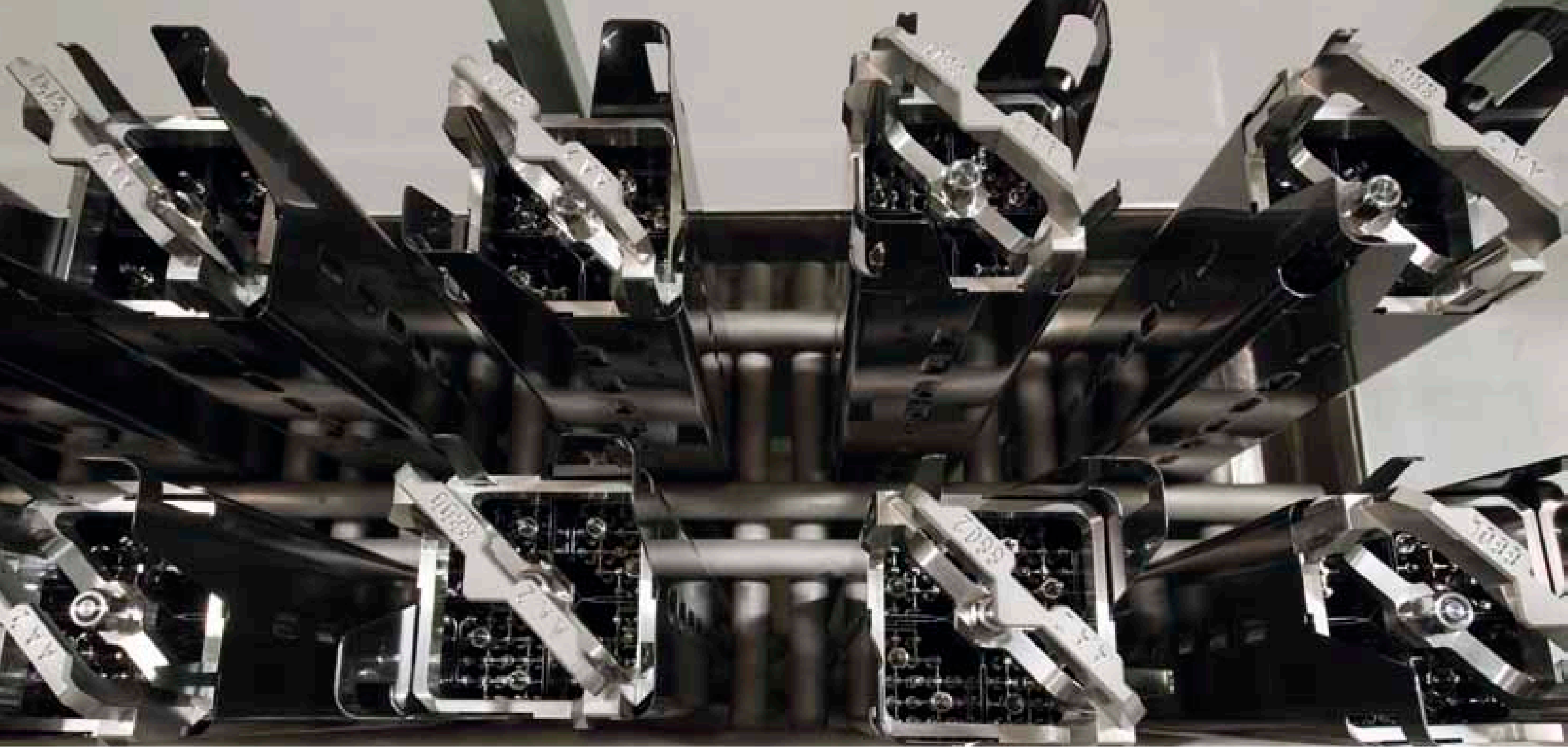
From the steam separator, the steam is lead to the steam dryer. The purpose of the steam dryer is to separate the remaining water from the steam by forcing the steam flow through a specifically designed sheet pack. The water separated from the steam flows down to the annular space. After treatment in the steam dryer, the remaining moisture content of the steam is approximately 0.01 per cent.

SECTIONAL VIEW OF THE REACTOR PRESSURE VESSEL



REACTOR PRESSURE VESSEL

Inner diameter	mm	5,540	Operation pressure	bar	70
Inner height	mm	20,593	Design temperature	°C	300
Wall thickness, carbon steel (ASME A533B, A508Gr2)	mm	134	Operation temperature	°C	286
Thickness of stainless steel liner	mm	5	Weight of vessel	ton	524
Design pressure	bar	85	Weight of cover	ton	107


Slightly under one quarter of the fuel in the reactor is replaced with fresh fuel every year.

Reactor core and fuel

Each reactor core of the OL1 and OL2 plant units consists of 500 fuel assemblies, control rods, and various detectors. The reactor's operation and power distribution are monitored with the help of 112 neutron detectors located evenly around the core. The detectors are connected to the protection system, which automatically gives a reactor scram command in case that the power increases too rapidly.

Uranium fuel and fuel assembly

The uranium fuel consists of small sintered uranium dioxide (UO_2) pellets. The pellets contain uranium enriched for fissile U-235. The fuel is enriched to 3–5 per cent.

The fuel pellets are packed inside tubes made of a zirconium metal alloy. The ends of the tubes are sealed with plugs to create airtight fuel rods. The rods are bundled into assemblies using 6–8 spacers and tie plates placed at the top and bottom of the assembly. The geometry of the assembly depends on the fuel type.

A burnable absorber (Gd_2O_3) is used in the fuel design. The absorber is added to some of the fuel pellets in each assembly. It reduces the power peaking factor and compensates for the excess reactivity during the first half of an operating cycle.

The fuel assemblies are placed in fuel channels, which guide the cooling water flow to the fuel rods. Each fuel assembly contains slightly under 100 fuel rods.

Initially designed as an 8 x 8 matrix, the fuel assemblies were first redesigned as a 9 x 9 matrix and then as the 10 x 10 matrix currently in use. The 10 x 10 fuel type has features that enable reactor power uprates and more efficient use of fuel.

Compared with TVO's earlier fuel designs, fuel assemblies of the 10 x 10 design have lower linear heat rating, and using this type of fuel improves the transfer of heat from the fuel to the coolant. Furthermore, the 10 x 10 assemblies contain variously shaped internal water channels which improve reactor core behavior at high power levels and in transient conditions. In addition to the water channels, the assemblies contain partial-length rods that serve, among other things, to improve reactor stability.

Procurement of fuel

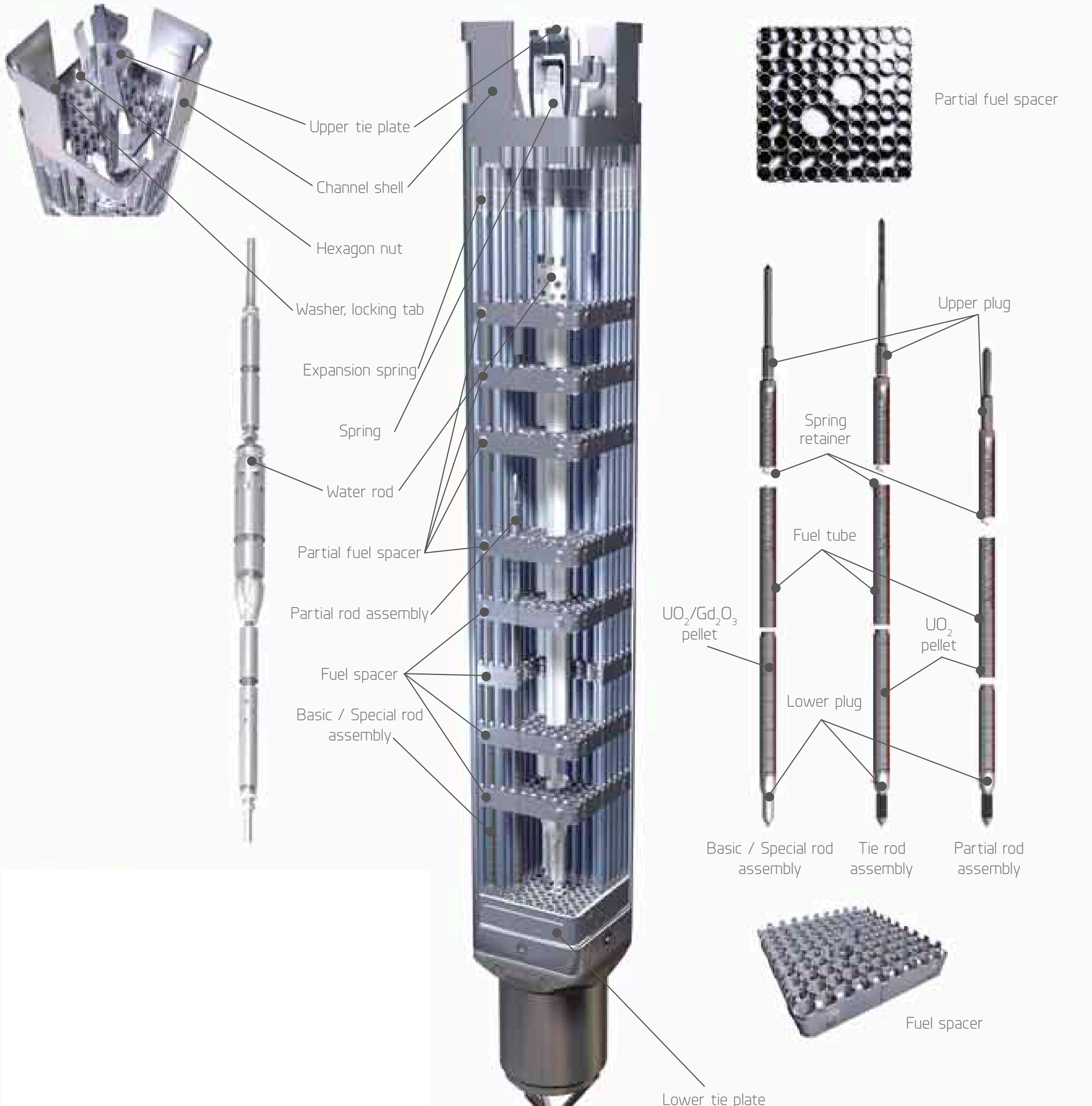
TVO's plant units OL1 and OL2 annually need a total of about 40 tons of low-enriched uranium for fuel. TVO obtains its fuel through a decentralised supply chain and there are several suppliers for each stage of the chain.

TVO has long-term contracts with leading uranium suppliers which TVO monitors and assesses on a continuous basis. Uranium is only acquired from suppliers who meet the strict requirements specified by TVO.

Leading uranium suppliers have mining operations in many countries. Kazakhstan, Canada, Australia and Namibia are the states that produce the largest amount of uranium.

The fuel is delivered to Olkiluoto as ready-to-use fuel assemblies. As fresh fuel emits very little radiation, it can be transported to Olkiluoto by ship or truck.

THE STRUCTURE OF GE-14 TYPE FUEL ASSEMBLY



CORE

Number of fuel assemblies		500
Total fuel weight	tnU	85–90
Core diameter (equiv.)	mm	3,880
Core height	mm	3,680

FUEL

Fuel rods per assembly		91-96
Fuel rod outer diameter	mm	approx. 10
Cladding material		Zirkaloy-2 (Zry-2)
Weight of fuel assembly (incl. channels)	kg	approx. 300
Uranium fuel per assembly	kgU	175

Refueling

When a reactor is operated in a one-year cycle, slightly less than a quarter of the fuel assemblies in the reactor core are typically replaced during each cycle. The amount of fuel replaced is determined by its excess reactivity, which corresponds to the energy to be generated during the cycle.

Fuel assemblies with different characteristics are placed in the reactor so that the restrictions on the use of the core and the fuel can be complied with. Every year, a reactor-physical measurement of the fuel assemblies is performed to determine the U-235 enrichment level, burnable neutron absorber content, and placement in the assembly of each fuel rod in the refueling batch, taking into account the anticipated durations of future cycles.

Fuel remains in the reactor for three to five operating cycles. In addition to the condition of the fuel assemblies, the condition of other core components, such as control rods and neutron detectors, is controlled in conjunction with refueling. As the control rods wear in use, they are replaced at intervals.

Reactor operation and power control

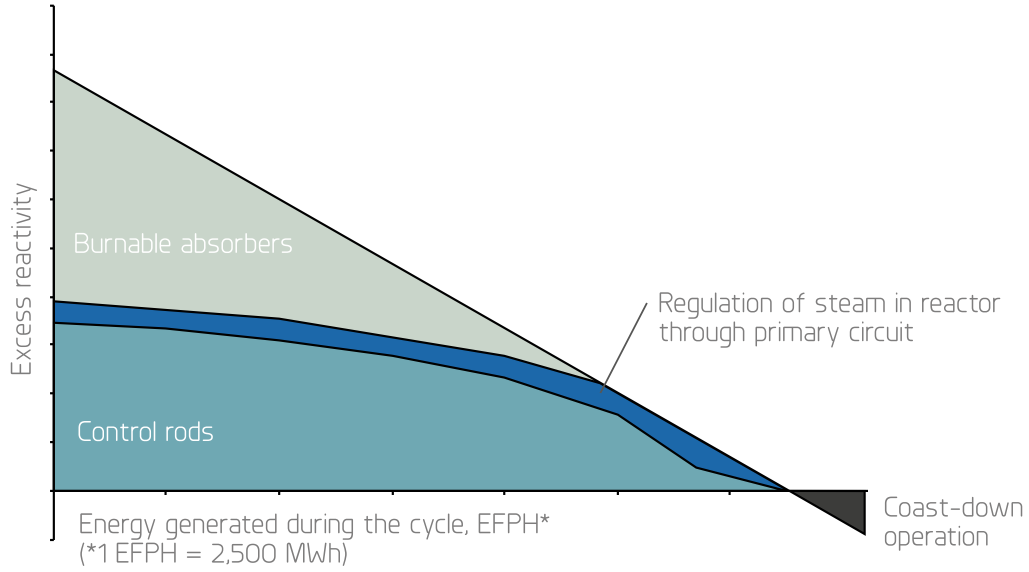
During the operating cycle, excess reactivity in the reactor is absorbed by the control rods in the reactor core and the burnable absorber in the fuel assemblies, and by the boiling of the reactor core coolant, regulated through the recirculation flow.

Excessive reactivity is at its highest at the beginning of the cycle. As the cycle progresses and the burnable absorber is consumed, excessive reactivity decreases, which reduces the need for maneuvering the control rods at various points of the cycle. Once a sufficient amount of the burnable absorber has been consumed, reactivity required for power operation can be released by retracting the control rods in small increments. At the end of the cycle, all the control rods are fully retracted, and reactivity is maintained for a while by increasing the recirculation flow until the reactor power slowly begins to decline.

In addition to reactivity control, the control rods are used for adjusting the power distribution in the reactor core and for controlling the reactor power. Minor power changes are implemented by adjusting the recirculation flow.

Spent fuel assemblies are transferred from the reactor to the fuel pool using the reactor service bridge.

REGULATING REACTIVITY



Excess reactivity during the operating cycle is absorbed by burnable absorber, the control rods and the boiling of coolant regulated through the primary circuit.

Fresh fuel is stored in the dry storage facilities.

The boron contained in the control rod attenuates the chain reaction by absorbing neutrons.

Control rods

The number of fissions, and simultaneously, the chain reactions of uranium and the core power distributions, are controlled with the help of control rods. The control rods are 121 in number, and their drives are located below the pressure vessel.

Each control rod controls a group consisting of four fuel assemblies, or a supercell. The control rods contain boron, which absorbs, or captures, neutrons and so attenuates the chain reaction. In a scram, the chain reaction can be quickly stopped with the control rods. In this case, the rods are hydraulically launched upwards to the reactor core with the help of nitrogen pressure. It takes the rods less than four seconds to reach the core.

The control rods are divided into 14 scram groups, five of eight rods each and nine of nine rods each. Each scram group is controlled by a scram module comprising a water tank, a compressed nitrogen container, and a scram valve connecting the tank and the container.

The control rods are divided into scram groups so that the reactivity couplings between the rods belonging in the same scram group are negligible. Due to this, the malfunction of one scram group only results in the loss of one control rod. In addition to the control rods, the reactor can also be shut down using the boration system. The shutdown is performed by pumping borated water into the reactor. The boration system comprises a boron tank and two mutually independent circuits equipped with piston pumps.

Control rod drives

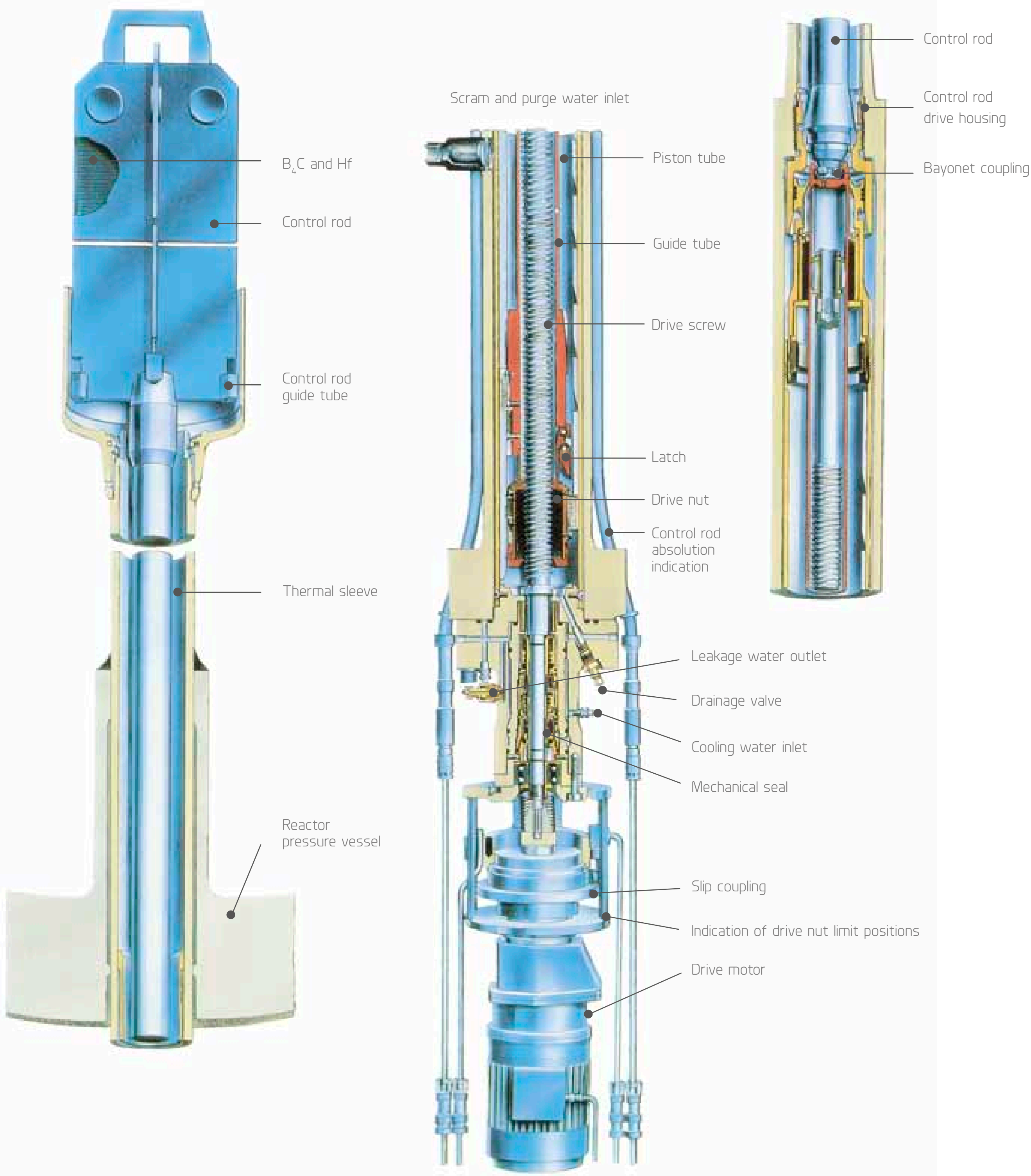
The start-up of the reactor is initiated by retracting the control rods in a pre-defined sequence. The control rod drives provide two different systems for maneuvering the control rods: an electro-mechanical system for normal operation and a hydraulic system for scram situations.

The drives allow for slow-motion movement and accurate positioning of the control rods. The drives' ability to maneuver the control rods as groups improves the controllability of the plant unit.

The control rod drives are continuously purged with water from the reactor water clean-up system in order to keep the gaps clean. This also serves to minimize contamination caused by radioactive substances and thus to reduce occupational exposure to radiation during maintenance.

The power supply to the scram system and the electro-mechanical drives is arranged so that an electrical fault cannot simultaneously render both the scram function and the electro-mechanical drive inoperable.

CONTROL ROD DRIVES



CONTROL RODS

Number of control rods		121
Absorber length	mm	3,650
Total length	mm	6,380
Absorber material		Boron (B_4C) and Hafnium (Hf)

The water flow rate in the reactor is approximately 8,000 kg/s.

Recirculation system

The recirculation flow is a water circulation flow within the reactor pressure vessel. The water flows through the annular space down to the bottom of the pressure vessel and is then pumped up through the middle part of the vessel and the reactor core. The water cools the core. Part of the water flowing through the core boils, generating steam for the turbine.

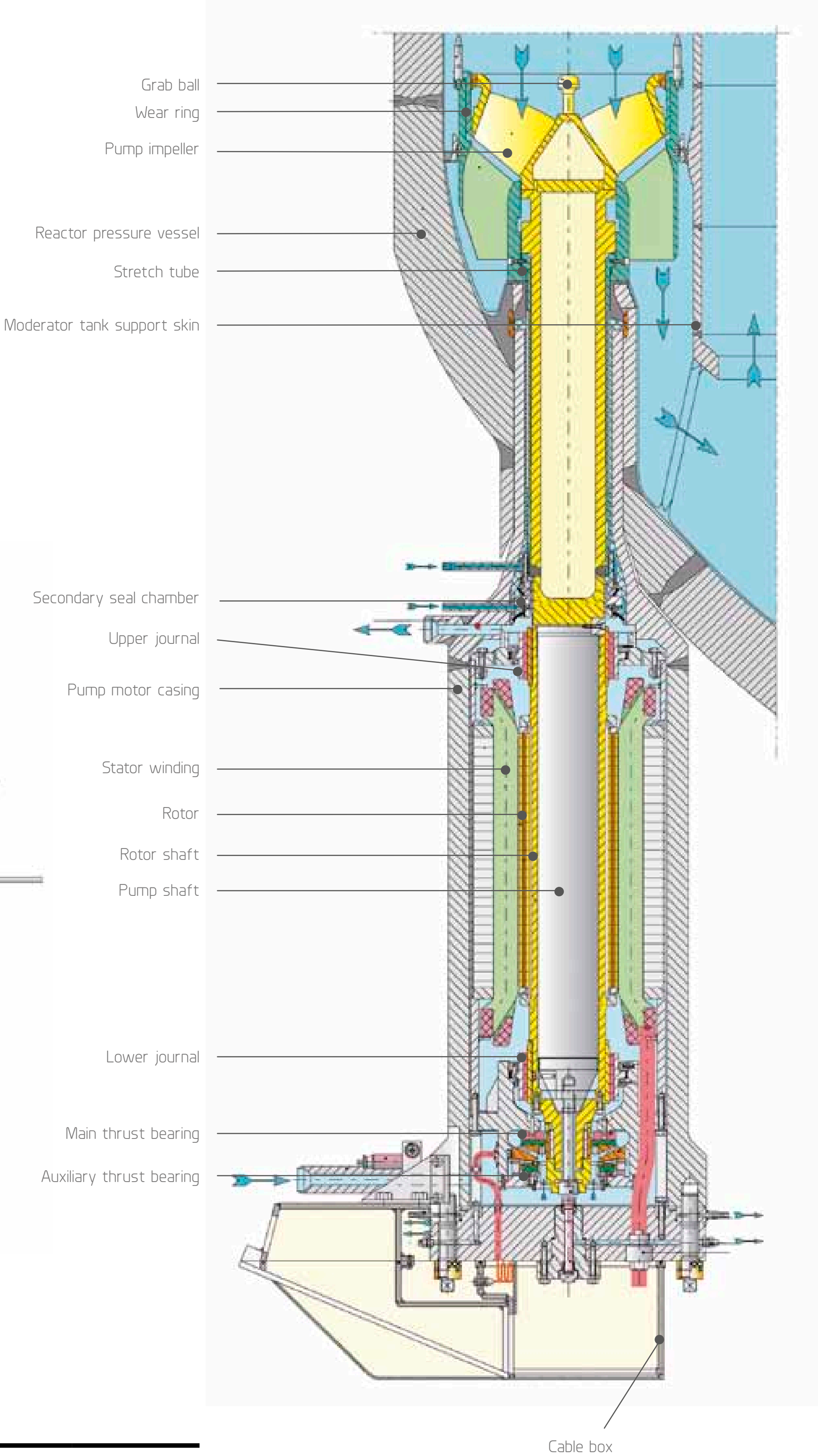
The recirculation flow is maintained by six internal recirculation pumps attached to the bottom of the reactor pressure vessel. As the circulation pump design is based on the use of wet motors, shaft seals are not needed. The motor housing forms an integral part of the reactor pressure vessel. Internal circulation pumps provide a number of advantages over external pumps:

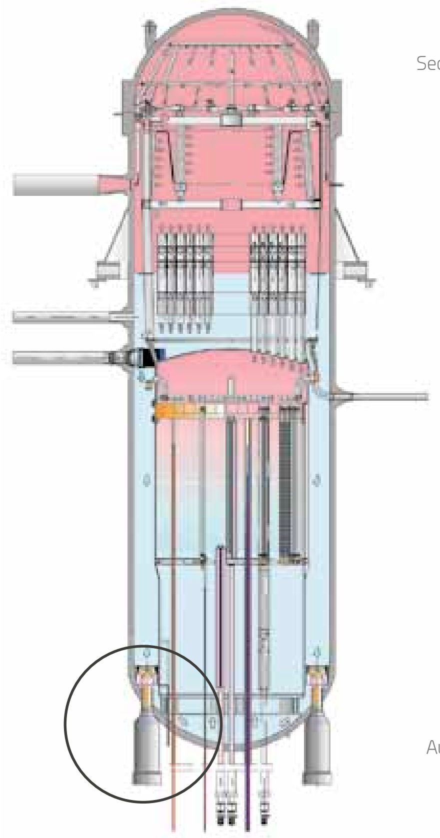
- No risk of major pipe rupture below the top of the reactor core
- Compact containment design
- The low pressure drop in the recirculation system improves natural circulation and decreases the need for auxiliary power
- The reduced radiation level in the drywell below the reactor contributes to very low occupational exposure during maintenance and inspection of the pump motors
- A significant reduction in the number of welds on the primary circuit

A split shaft design allows for convenient assembly and disassembly. The pump shaft extends into the hollow motor shaft, and power is transmitted from the motor shaft through a coupling that can be disassembled from the bottom of the motor housing. A pump motor or impeller can thus be removed or replaced without draining the reactor pressure vessel.

When reactor power exceeds 70 per cent, power control is accomplished by changing the speed of the recirculation pumps. In full power operation, all six recirculation pumps are running, creating a flow equal to 90–100 per cent of the maximum flow. The reactor power control system controls the speed of the pumps. Depending on fuel burnup, the recirculation flow rate in full power operation varies approximately between 7,600 and 8,360 kg/s.

RECIRCULATION PUMP





RECIRCULATION PUMP

Normal power operation, 6 pumps		
Rated speed	rpm	approx. 1,350
Head	m	approx. 25
Motor power	kW	740

Turbine plant

Turbines and the generator

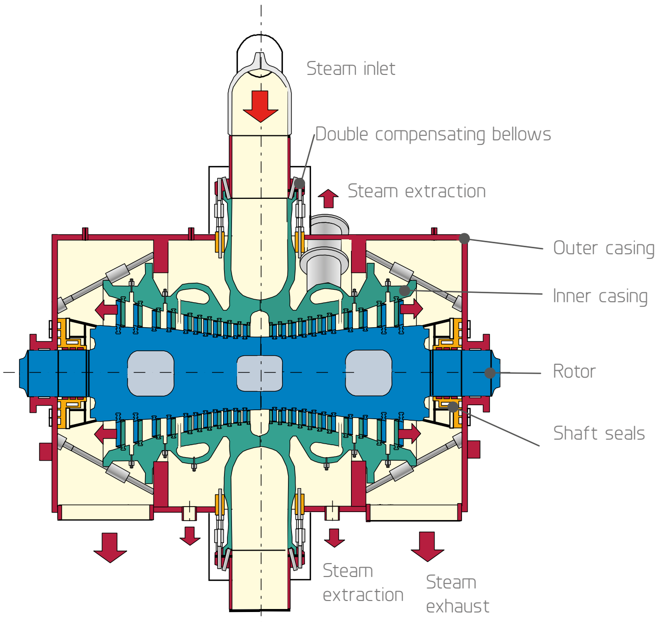
Steam is lead from the reactor to the high pressure (HP) turbine through four main steam lines, each with a control valve and an emergency stop valve built into the same casing. The steam pressure at the inlet of the HP turbine is approximately 62 bar. The steam is lead to the turbine at the middle, and it expands towards both ends of the turbine. As the steam expands, it yields energy and forces the turbine to rotate as it passes through the leading blades and running blades.

From the HP turbine, the steam is lead via undercurrent pipes into two consecutive moisture separators and onward into the reheaters, located one on each side of the turbine. The reheating is performed partly with extraction steam from the HP turbine and partly with live steam from the main steam lines. Before the steam is lead to the low pressure (LP) turbine, its temperature is increased to approximately 250 °C. Reheating improves the efficiency of the plant unit and reduces the erosion of the LP turbines.

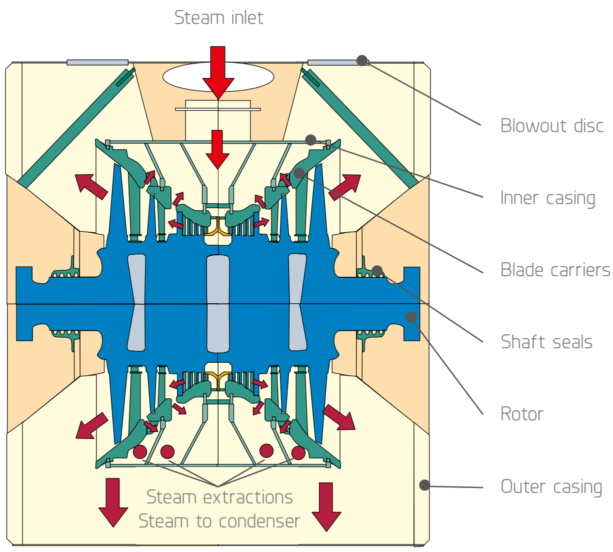
The reheated steam is supplied to the LP turbines through eight crossover pipes equipped with combined control and emergency stop valves. The HP and LP turbines are equipped with steam extraction points for preheating the condensate and the feedwater.

The steam can be lead directly into the condenser through the turbine bypass valves. Turbine bypass is used during plant startup and shutdown and in the event of generator load loss.

HP TURBINE



LP TURBINE



High pressure turbine

The HP turbine generates approximately 40 per cent of the total power output of the plant unit.

It is of the double flow type. The steam flow is symmetrical; steam enters the turbine at the middle and exits at the ends. The main parts of the HP turbine are as follows:

- A welded outer casing
- A cast inner casing
- A forged and welded rotor
- Shaft seals at both ends

The turbine is of the dual casing type, with both casings split into two parts. The upper and lower parts of the casings are bolted together through their dividing planes.

The steam is lead into the inner casing through two inlet pipes located at the middle of the turbine, one at the top and one at the bottom side. This ensures that the steam does not come into contact with the outer casing. Part of the steam is extracted through holes in the inner casing and lead to the extraction space between the casings and then onwards to the extraction pipes.

The outer casing is sealed off from the turbine hall atmosphere by means of double compensating bellows at the steam inlet pipes and by means of shaft seals at the turbine shaft. The outer casing is constructed from plates and forgings welded together to form a flat-ended cylinder. A reinforcement ring, serving as an anchoring point for adjustable support rods, is installed midway between the middle and each end of the outer casing. These rods receive the axial forces caused by the steam. The inner casing is fastened to the outer casing, which is in turn fixed to the foundation slab.

Low pressure turbine

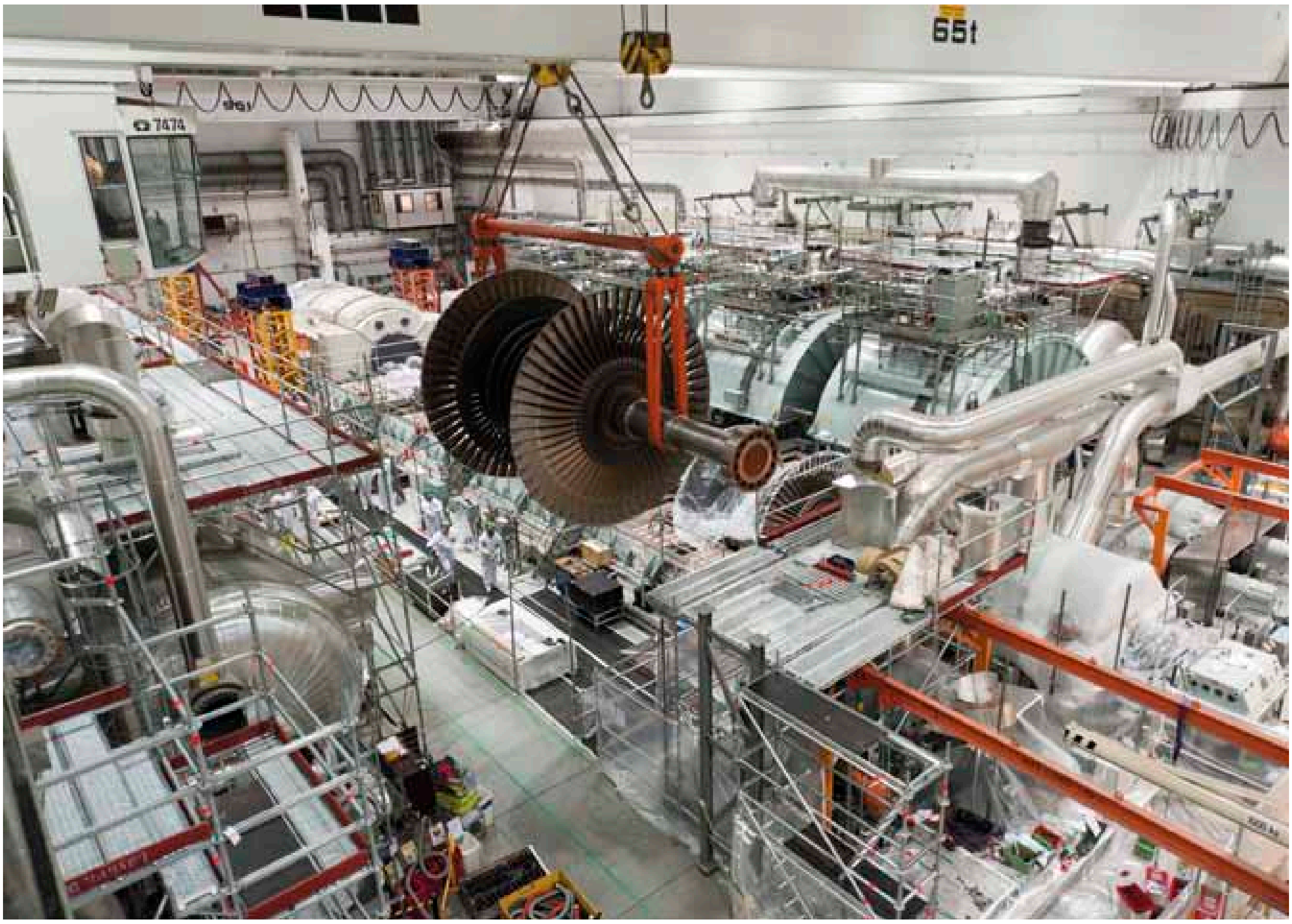
Each of the four LP turbines generates approximately 15 per cent of the total power output of the plant unit, and together, they account for some 60 per cent of the total output.

The LP turbines are double-flow, symmetrical, reaction-type turbines. Their main parts are as follows:

- A welded outer casing
- A welded inner casing
- A forged and welded rotor
- Three leading blade carriers
- Shaft seal housings at both ends

Like the HP turbines, the LP turbines are of the dual casing design. The blade carriers are fastened to the inner casing, which in turn is fastened to the lower part of the outer casing base. Steam is extracted between the blade carriers into the extraction space between the inner casing and the blade carriers, and then lead onwards to the extraction pipes. The lower part of the outer casing is designed to form a rectangular channel, which is welded to the condenser inlet opening.

Each LP turbine is equipped with two rupture disks, which protect the turbine against overpressure in case that other safety equipment fails to function.



The OL1 and OL2 turbine plants were modernized in the course of the annual outages of 2010–2012. The modernization included, for example, the replacement of the LP turbines and the generators.

Generator and exciter

Generator

The turbine drives the rotor of the generator, installed on the same shaft as the turbine. The generator converts the kinetic energy of the turbines into electric energy. The active power of the generator is 990 MW (1,100 megavolt-amperes (MVA) x 0.9). The generator is connected to an exciter, the power of which is 4.2 MVA. All surfaces that come into contact with water are made of stainless steel.

The brushless AC exciter of the generator is equipped with rotating rectifiers. The diode rectifier is protected by fuses mounted in modules on the exciter rotor. This design allows for the inspection of the fuses during normal operation and easy replacement of the fuse modules.

All the key components in which heating occurs due to electrical losses are equipped with direct water cooling systems. These include the rotor and stator windings and the output busbars. The iron core of the stator is cooled with circulating air, which is then lead through an air/water heat exchanger.

As the generator is located outside the radiation shield of the turbine, it is accessible during the normal operation of the plant unit.

TURBINE PLANT

Turbine

Nominal rating	MW	910
Live steam pressure	bar	67
Live steam temperature	°C	283
Live steam flow	kg/s	1,260
Rated speed	rpm	3,000
High Pressure turbine	Axial, 2-flow	
High Pressure control valves		4
Low Pressure turbine	Axial, 2-flow	
Low Pressure intercept valves		8
Exhaust area	m^2	8 x 7.1
Last stage		
Blade length	mm	867
Overall diameter	mm	3,468

Generator

Nominal rating	MW	990
Power factor, nominal	cos	0.9
Rated voltage	kV	20
Voltage range	%	95–108
Frequency	Hz	50
Cooling, rotor/stator		water/air
Exciter		brushless

Low pressure preheaters

Condensate and feedwater

Once the steam has yielded its energy in the turbines, it is lead to the condenser, located below the turbines. In the condenser, the steam condenses into water on the surface of sea water-cooled condenser pipes. Approximately seven meters long pipes are made of titanium. They are bundled together as assemblies, each of which contains some 2,600 pipes. There are a total of 20 of these assemblies in the condenser. The water generated in the condensation process is called condensate.

The condenser is mounted transversely in relation to the turbine shaft. It is divided into two sections, one for each pair of LP turbine casings. Each section contains two water chambers, which also function as condensate storage tanks.

In order to maximize the recovery of usable energy from the steam, an underpressure is maintained in the condenser. The underpressure increases the expansion of the steam and, consequently, the total power.

Condenser		
Cooling surface	m^2	27,700
Cooling medium		sea water
Cooling water flow	m^3/s	38
Vacuum at full load	bar	0.05
Temperature rise	°C	10
Feedwater		
Preheating stages		5
Final feedwater temperature	°C	185

Condensate and feedwater control

Condensate is pumped, with the help of condensate pumps, via the condensate purification system and the low pressure (LP) preheaters to the feedwater pumps. There are four condensate pumps. During normal operation, three of them are running, and one is in standby. The condensate pumps are five-stage centrifugal pumps.

Condensate is heated in three LP preheaters. During each heating stage, the temperature of the condensate rises by approximately 30 degrees. Consequently, the condensate reaches an approximate temperature of 120 degrees before it enters the feedwater pumps.

The main condensate flows out from the condenser at an approximate rate of 750 kg/s. Additionally, the extraction steam from the LP and HP turbines condenses in the preheaters, generating so-called preheater drains. The flow rate of the preheater drains is approximately 500 kg/s. The main condensate and the drains are combined and lead through the condensate purification system to the LP preheaters.

Downstream of the LP preheaters, the pressure of the condensate water is increased with four feedwater pumps until it exceeds the reactor pressure. The water exiting the pumps is referred to as feedwater. During full power operation, the total flow rate of feedwater is approximately 1,250 kg/s.

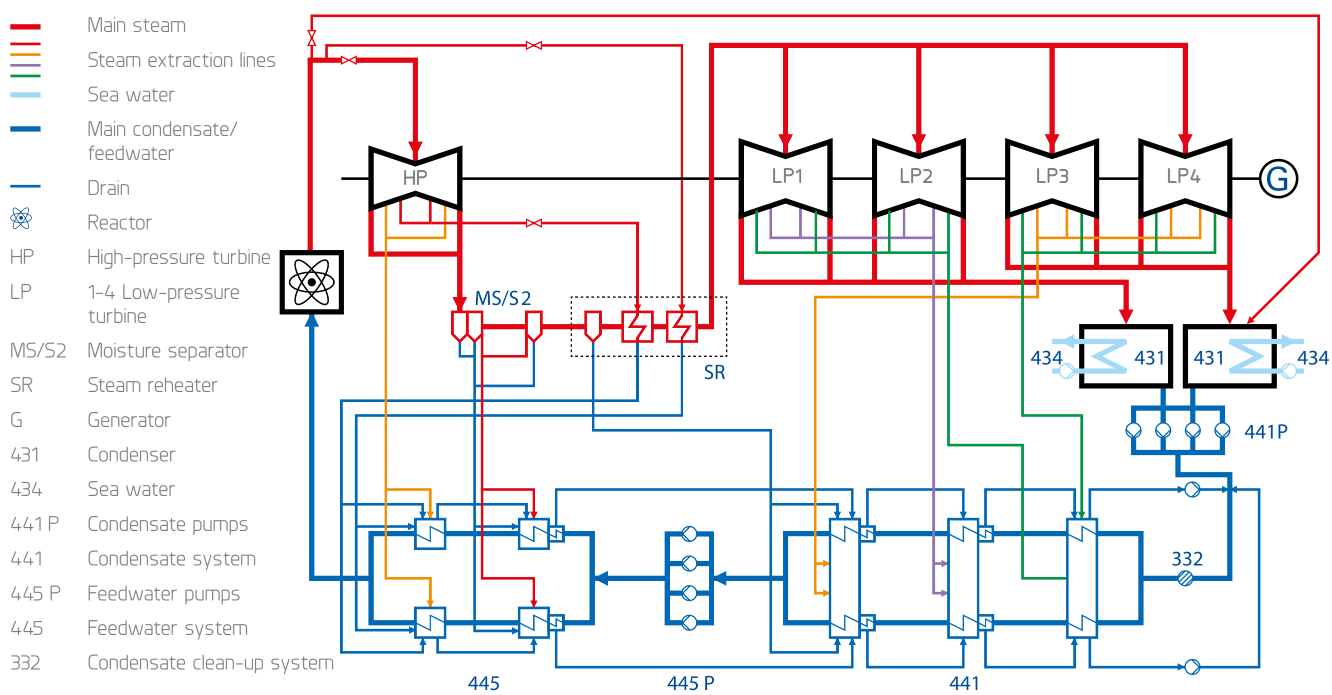
Feedwater is heated further in two high pressure (HP) preheating lines, both of which comprise two successive HP preheaters. After the final heating, the temperature of feedwater is approximately 185 degrees. While the steam used for the first heating stage is taken from the HP turbine outlet, the steam used for the second heating stage is taken from the HP turbine extraction points.

Feedwater is lead to the reactor through four feedwater pipes and a feedwater distributor. Located inside the reactor, the distributors distribute the water evenly in the reactor.

Both the LP and HP preheaters are divided into two parallel 50% circuits, each of which is equipped with a bypass system. The condensate pumps are installed in a 4 x 33% unit arrangement. The OL1 feedwater pumps are installed in a 4 x 25% unit arrangement, and the OL2 feedwater pumps, in a 4 x 33% unit arrangement. The pumps are driven by electric motors. The feedwater flow is controlled by adjusting the speed of the feedwater pumps with hydraulic switches.

Feedwater pumps

CONDENSATE AND FEEDWATER SYSTEM




Screening and pumping building

Sea water circuit

Cooling water from the sea is lead to both plant units through an underground cooling water tunnel. The water is first lead to a screening and pumping building, where the sea water intake channel is divided into four separate channels. Each channel is equipped with a motor-operated intake valve, mechanical sea water treatment equipment, fine screens, and travelling band screens.

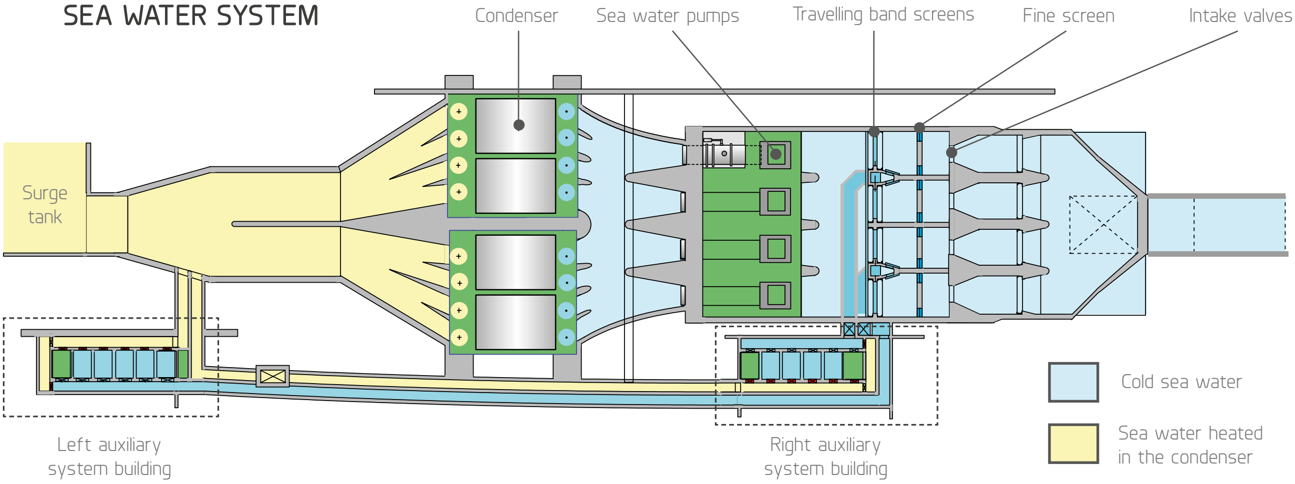
The sea water is pumped into the condenser with the main seawater pumps. From the condenser, the water is lead into the surge pool, and from there, through an underground tunnel into the sea.

The sea water pumps are of the vertical propeller type. They are located in the cooling water intake channel. The pumps supply the cooling water to a header located upstream of the condenser water chambers. As the stop and check valves are arranged in the inlet of the cooling water pipes, water can be supplied to all the water chambers even in the event that one of the pumps stops.

The temperature of the sea water rises by approximately 10 degrees as it passes through the condenser. Some 38 cubic meters of water are pumped through the condenser every second at both plant units.

The surge pool functions as a shock absorber protecting the condenser in the event that the main sea water pumps stop. If the intake of cooling water is prevented for some reason, cooling water for sea water-cooled systems can be lead in from the outlet side. In this case, the normal water flow direction in the cooling water channels will be reversed.

SEA WATER SYSTEM



Electric systems and electricity transmission

The electric systems of the plant units fall into two categories. One of the systems is related to the generation and transmission of electricity to the external grid, and the other, to the supply of auxiliary power to the plant unit both under normal and transient conditions.

The former consists of the generator, the generator bus, the generator breaker, the main transformer, and the 400 kV line and the switchyard. The latter includes the auxiliary power transformers and the auxiliary power distribution systems.

Main transformer

The purpose of the main transformer is to transform the 20 kV voltage of the electricity fed to it from the plant unit's main generator to the 400 kV level required for transmission in the national grid. From the transformers, the electricity is lead through plant cabling to Fingrid Oyj's 400 kV substation and onwards to the national main grid. When the plant unit is shut down, the transformer is used to transform the 400 kV voltage to suit the needs of the plant's auxiliary power distribution.

In the event of a prolonged voltage drop in the 400 kV grid, undervoltage protection trips the 400 kV breaker. Consequently, the plant is disconnected from the grid, and the electricity produced is fed solely to its auxiliary power distribution system.

The rated output of the main transformer of each plant unit is 1,000 MVA. The main transformers are three-phase units equipped with forced oil/forced air cooling.

Generator buses

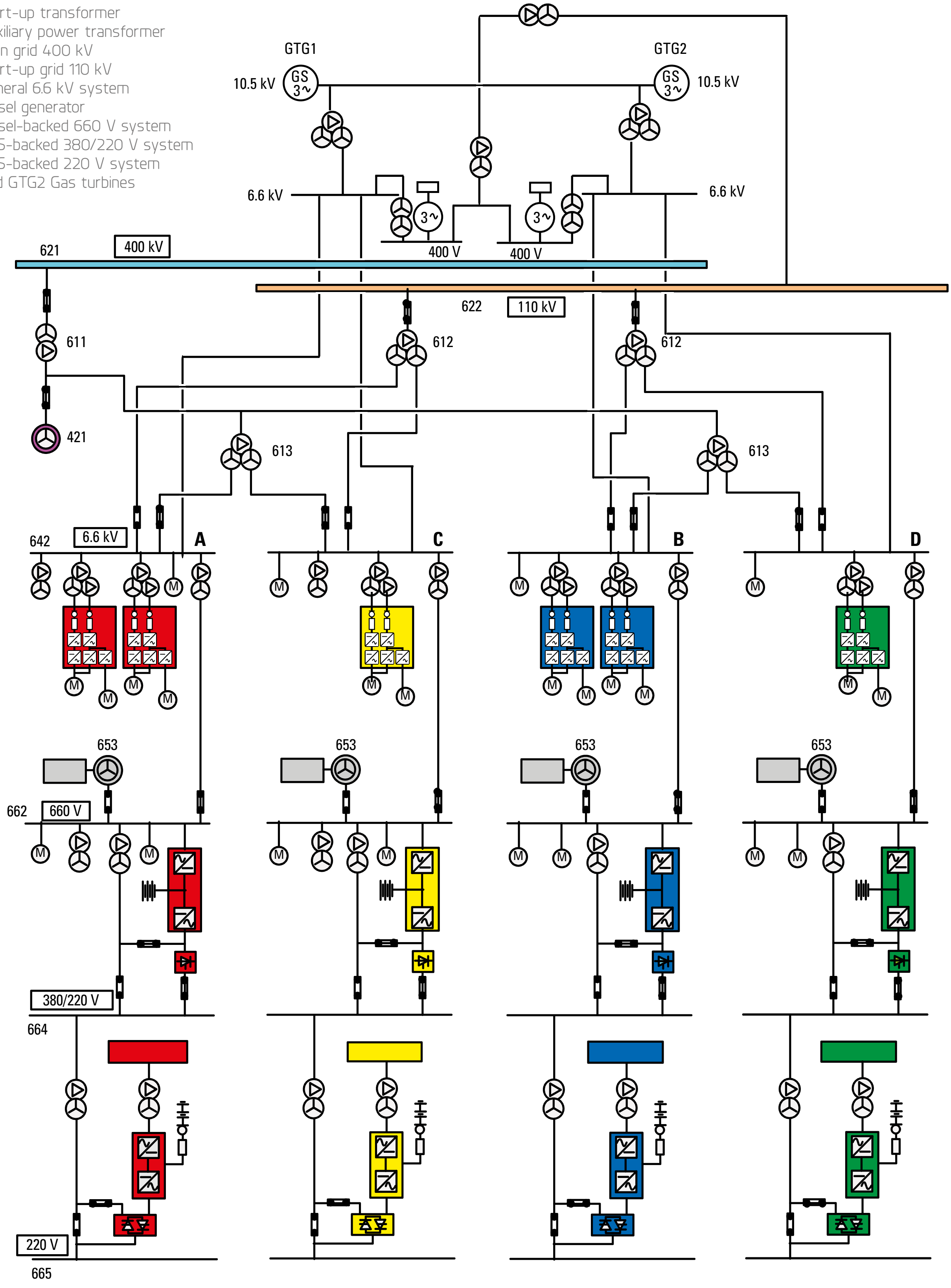
The purpose of the generator buses is to transmit the electrical power generated by the generator through the main transformer to the grid, and to transmit the auxiliary power through the auxiliary power transformers to the plant unit.

The generator buses are made up of single-phase busbars equipped with earthed metal enclosures. Each single-phase busbar has a single-phase breaker. The busbars are also equipped with the necessary earthing switches, voltage and current transformers, and capacitors.

PLANT DISTRIBUTION NETWORK AND EXTERNAL GRID CONNECTIONS

- subsystem A
- subsystem B
- subsystem C
- subsystem D

421 Generator
611 Main Transformer
612 Start-up transformer
613 Auxiliary power transformer
621 Main grid 400 kV
622 Start-up grid 110 kV
642 General 6.6 kV system
653 Diesel generator
662 Diesel-backed 660 V system
664 UPS-backed 380/220 V system
665 UPS-backed 220 V system
GTG1 and GTG2 Gas turbines



Diesel generator

Auxiliary power supply

The entire internal electricity distribution network of the plant is divided into four subsystems (A, B, C and D), which are independent and physically separated from one another.

The plant's auxiliary power distribution supply is divided between safety and operational systems in accordance with the power requirements of the processes in question.

Normally, power is supplied to the plant from the 20 kV busbars between the generator and the main transformer through two plant transformers. During annual outages or a generator shutdown following a disruption, auxiliary power is taken from the 400 kV grid, or from the 110 kV grid through the start-up transformers. The start-up transformer transforms the voltage of the electricity taken from the 110 kV grid to the 6.6 kV level required in the auxiliary power distribution network.

During full power operation, the plant unit uses approximately 30 MW of the total power generated by the generator as auxiliary power. Roughly half of it goes to pumping water into the reactor. The required auxiliary power is distributed to consumers through the plant unit's internal electricity network. DC systems and battery-backed AC systems supply power to various consumers including control systems and motor drives of valves.

Securing emergency cooling

Power supply to the emergency cooling systems of the Olkiluoto power plant is secured in multiple ways. In normal operating conditions, power is supplied from the plant unit's main generator. If the plant unit's main generator is unavailable, power is supplied from the national grids.

Both plant units have four 1.8 MW diesel generators, which start up automatically in case of loss of power. The diesel generators are also able to supply electricity from one plant unit to another through a power link between the plant units. All safety systems are supplied by the diesel-backed system.

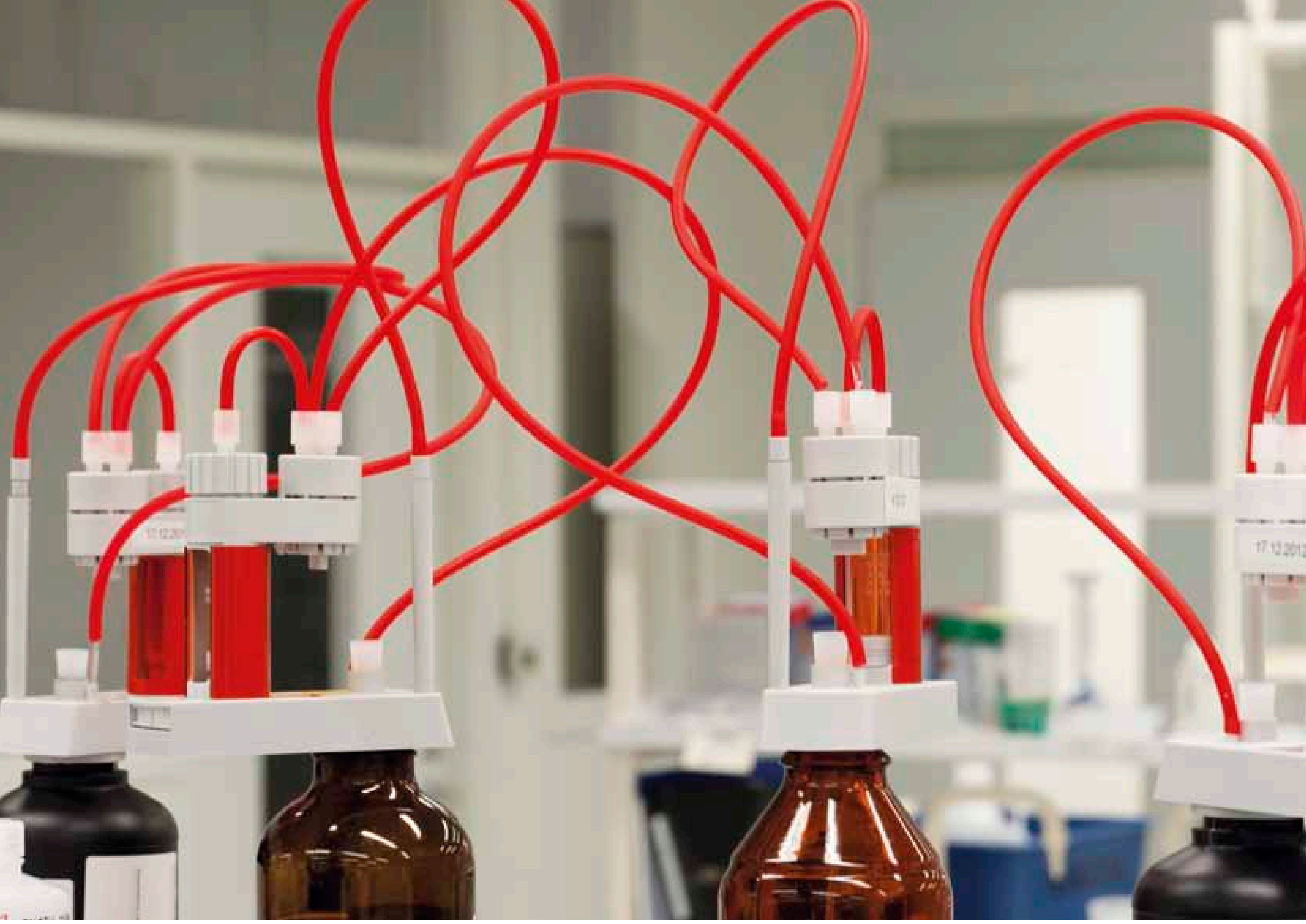
The Olkiluoto back-up power plant (gas turbine plant) is able to supply electricity to both plant units through underground cabling or the 110 kV substation. With special arrangements, the supply of electricity from Paneliankosken Voima's 20 kV grid, or directly from the Harjavalta hydropower plant, is also possible.

The measuring and control circuits of the safety systems are required to operate continuously without disruptions. Consequently, power supply to these circuits is backed up with batteries.

Electricity transmission

The Finnish electric power system consists of power plants, the national grid, local power networks, distribution networks, and electricity consumers. Most of the electric power consumed in Finland is transmitted through the national grid maintained by Fingrid Oyj.

From the plant units, electricity is transmitted to Fingrid Oyj's 400 kV substation, and from there, to the national main grid.



Auxiliary buildings and training center

In addition to the reactor and turbine buildings, the Olkiluoto nuclear power plant units comprise several other buildings. These buildings house the support functions that are solidly linked to the main process.

Control room and access building

The control room building is located adjacent to the reactor building. The plant operations are centrally controlled from the control room building. Each plant unit has its own control room. Operators licensed to operate the plant unit are always present in the control rooms. The control room personnel work in 12-hour shifts. Each control room shift consists of six to seven personnel members, one of whom is the shift supervisor responsible for the control room operations.

The access building is located in front of the control room building. It houses office and amenity facilities and the controlled area shoe boundary.

Auxiliary systems buildings

The auxiliary systems buildings housing the sea water and purified water cooling circuits are located on either side of the turbine hall. The emergency back-up diesel generators are located in the auxiliary systems buildings, two on each side. Furthermore, the auxiliary systems buildings house switchgears.

Training simulator

Cooling water screening plant building

The cooling water screening plant building houses the main sea water pumps and the cooling water screening equipment (fine screens and travelling band screens). The purpose of this equipment is to mechanically separate any impurities from the sea water before it is pumped through the sea water pumps to the turbine condenser.

Switchgear building

The switchgear building houses the 6 kV switchgears supplying the various electric systems of the plant. The electric equipment and significant components relating to the electric supply of the plant are divided into four identical but separate power supply systems.

Waste building

The waste building functions as a storage for both liquid and solid waste. Liquid waste, such as controlled leak waters, waters from floor drains, and filter cleaning waters, are collected in storage tanks for cleaning. The cleaning is performed through decantation and ion exchange filtering.

Solid waste is sorted, measured, and treated according to its level of radioactivity.

At OL1, the laboratory is located in conjunction with the waste building.

Training simulator

TVO continuously organizes training events in order to maintain the professional skills and competence of its personnel. Internal personnel training is mainly organized at the company's own training center at Olkiluoto. Most of the training is related to the company's own operations, in particular plant and operating technology.

The single most important element of the training center is the training simulator providing a training environment that is identical to the actual plant. The simulator comprises a full-scale replica of the OL1 plant unit's control room and a computer system that simulates the plant processes. The computer models can realistically simulate the operation of the power plant.

The simulator is an essential tool in the basic training process of new shift personnel because it enables the practicing of plant control and monitoring operations without interference with the normal operational activities.

A program featuring different operational scenarios is prepared for each simulator exercise. The operator trainees must know how to respond correctly in each of these situations. If necessary, the exercise can be repeated, and any mistakes made previously can be corrected. Simulator training also enables the shift personnel to practice operations during exceptional operating conditions, transients, and accidents. All shift supervisors and operators spend a minimum of two weeks per year in refresher simulator training.

Furthermore, the simulator can be used to develop, test, and practice new control room functions before they are introduced at the plant units.

Water chemistry and water treatment

In boiling water reactor plants, no chemicals are added in the coolant flowing through the primary circuit of the reactor, i.e. the reactor is operated under normal water chemistry. The electrical conductivity of the reactor water is kept as low as possible.

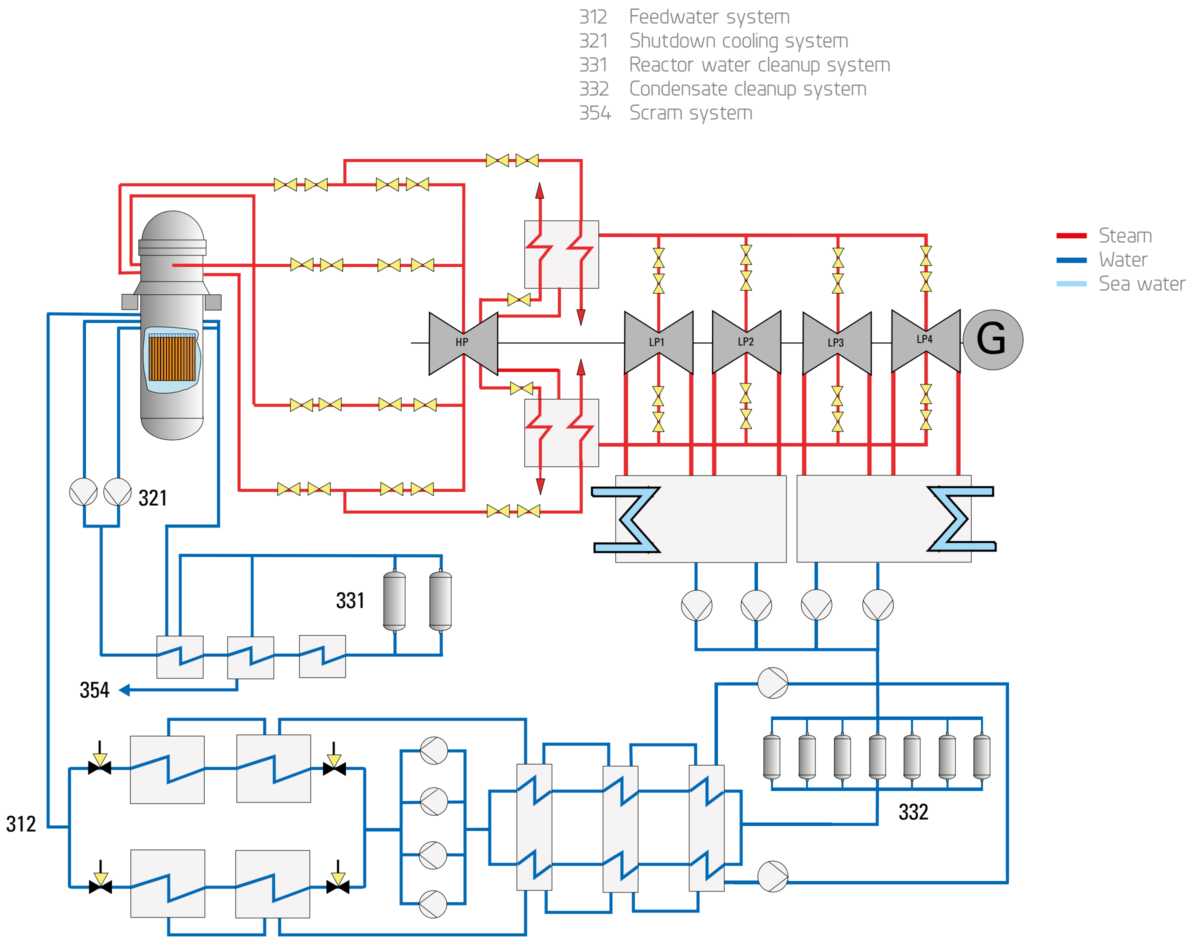
The purity of the reactor water has an impact on the operational reliability of the reactor. Keeping the impurity content of the water as low as possible limits the deposition of crud on the fuel and thus reduces the radioactive contamination of the primary system. This, in turn, helps to reduce occupational radiation exposure. Minimizing the content of particular impurities, such as chloride and sulfate, decreases exposure to stress corrosion.

The primary circuit water is treated with two separate purification systems: the reactor water cleanup system and the condensate cleanup system.

The reactor water cleanup system comprises two deep bed ion exchanger units with radial throughflow. During normal power operation, each cleaning unit is capable of keeping the purity of reactor water on a sufficient level. Thus, the flow can be doubled if required.

One shutdown cooling system pump is capable of generating a sufficient cleanup flow. The flow passes through two heat exchangers and one cooler to one of the ion exchangers and returns to the reactor through the heat exchangers. A part of the water flows through the scram system, cleaning and cooling the control rod drives.

Located upstream of the preheaters, the condensate cleanup system comprises seven filtering lines in parallel arrangement. Six of these lines are equipped with rod-type precoat filters, and one is used without ion exchange resin, i.e. it contains a fluted filter. These filters clean the feedwater returning from the condenser to the reactor both mechanically and through ion exchange accomplished with a thin layer of ion exchange resin on the surface of the filter rods.



Raw water treatment

Raw water is required for the production of power plant process water, personnel drinking and sanitary water, and fire fighting water, as well as for the cleaning of the power plant and its equipment. The raw water is taken from River Eurajoki and pumped to the Korvensuo basin located on Olkiluoto island. The volume of the basin is 140,000 m^3.

The raw water is pre-cleaned in Korvensuo using two parallel Dynasand sand filters with a capacity of 2 x 45 m^3/h. The water is then pumped to the water treatment plant located at the plant site. The water treatment plant is a chemical surface water cleaning plant. The following stages of the water cleaning process are performed at the water plant:

- Mixing of chemicals
- Agitation
- Flotation
- Settling
- Removal of humus and deposits
- Alkalization
- Removal of manganese if required
- Activated carbon filtering
- Chlorination/disinfection

Following the completion of the cleaning process, the water is pumped to the power plant site's water distribution network.

The water demineralizing system is used to produce demineralized water from the tap water produced at the water treatment plant. After demineralization, the water is lead to the storage tanks of the process water distribution systems of the both plant units, and from there, to consumers.

The water demineralization plant comprises two reverse osmosis units and three ion exchange trains. The ion exchange trains share a common humus filter, and each train consists of a strong cation exchanger, weak anion exchanger, strong anion exchanger, and a mixed bed exchanger.

Instrumentation and control systems

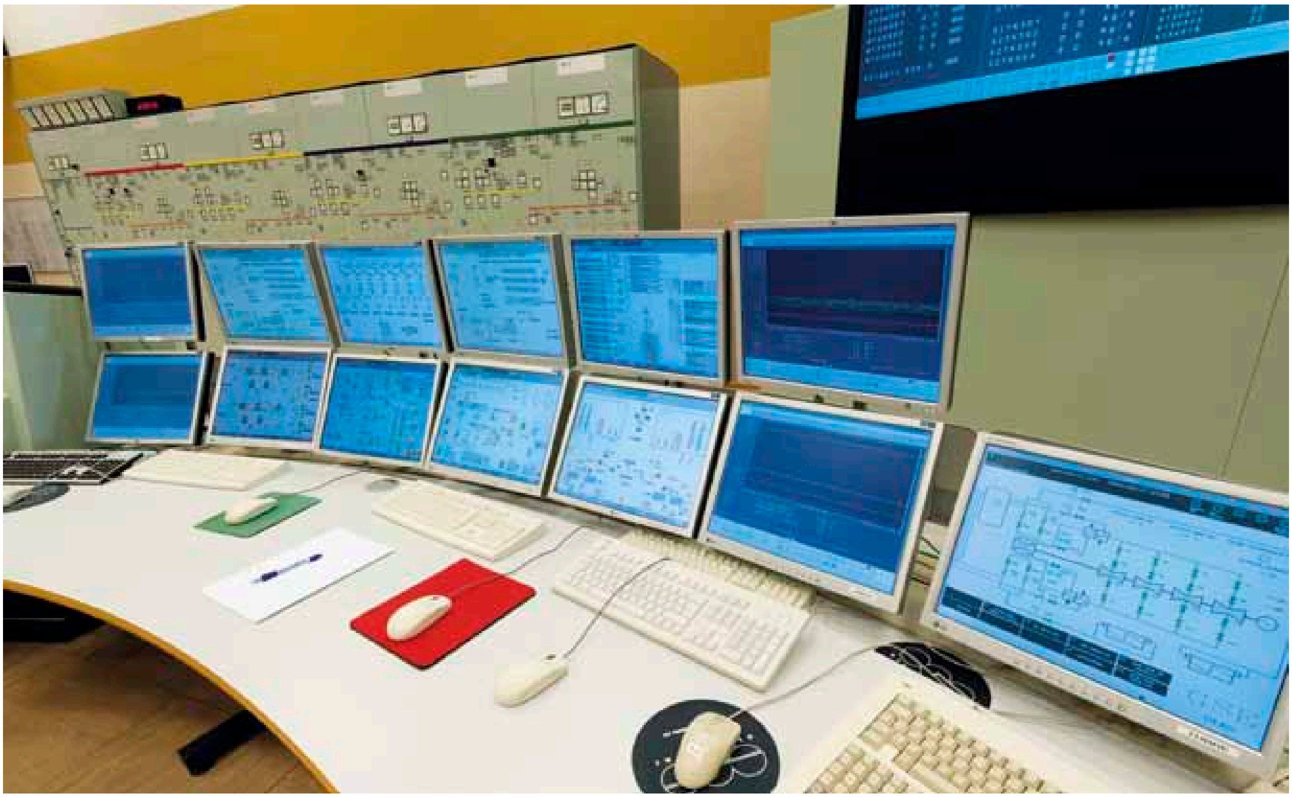
The instrumentation and control systems consist of various instruments that measure processes, various automatic and manual control systems, and systems that display and record measurement and event data.

In keeping with the safety principles, all principal instrumentation systems and their controls are implemented as parallel subsystems. The control logic units of safety-related systems are implemented according to the 2-out-of-4 principle. This means that the plant protection system is automatically activated if two out of the four monitoring systems issue a signal to that effect. The principal functions can also be activated and completed manually.

The main plant controls, such as reactor pressure control and feedwater flow control, are implemented using redundant three-channel controllers. Power control is based on the measurement of generator power and the neutron flux and their feedback. The speed of the recirculation pumps of the reactor is controlled on the basis of the results of these measurements.

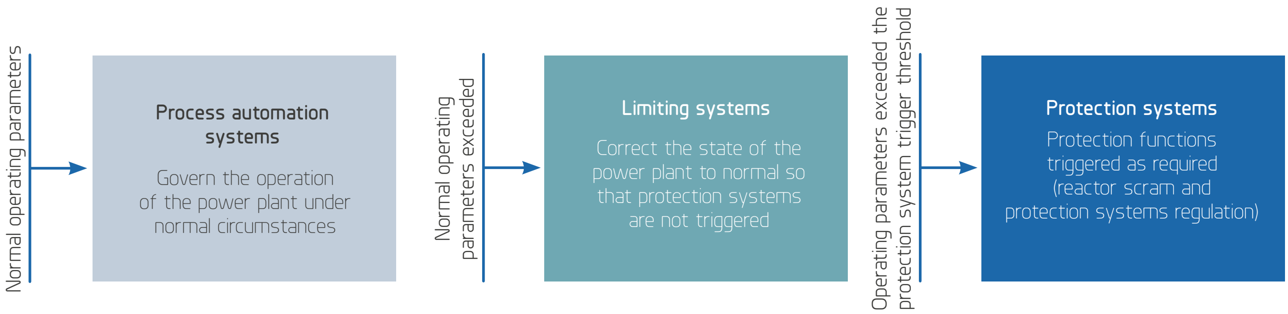
Control measures performed in the control room

The plant unit processes are centrally monitored and controlled in the control room. The states of the various processes are displayed on numerous screens or indicated with meters and indicator lights. Process control is mainly accomplished through computer workstations and control buttons. The control panels behind the control desks are used for controlling and observing certain reactor functions and the operation of the power supply and switchgear equipment.



The turbine automation control and display workstations

OPERATIONAL LEVELS ACCORDING TO THE SAFETY PRINCIPLES OF THE AUTOMATION SYSTEM



The automation of the plant unit is implemented so that only minimal control measures are required from the shift personnel during normal operation. The control and process equipment of the principal systems are divided into four separate subsystems.

Most of the process measurements are linked to a double-redundant process computer system. The system's terminals enable the operating personnel to monitor the processes. The data is displayed on a variety of general, status, trend, event, and alarm displays. Display tabs can be selected according to the operating condition. A large screen display is available for displaying the status of the turbine plant. The process computer system is also used for long-term storage of measurement and event data. Two parallel computers are used to perform calculations relating to the monitoring of the reactor core.

A dedicated measurement computer is used for recording measurement data holding particular interest from the point of view of the assessment of process transients or disruptions at a sampling frequency of 100 Hz.

Furthermore, the plant unit has numerous analog and computer-based control and monitoring systems, such as the neutron flux measurement and calibration systems, the reactor fuel loading monitoring system, radiation measurement systems for the plant unit and its environment, the control rod position indicating system, a system monitoring the vibration of the turbine and the generator shaft and bearings, and the turbine protection system.

Ventilation systems

The purpose of the Olkiluoto nuclear power plant's ventilation systems is to provide for the ventilation of the various buildings and to prevent the release of radioactive substances in a potential accident situation. Several buildings have their own ventilation systems.

Reactor building ventilation system

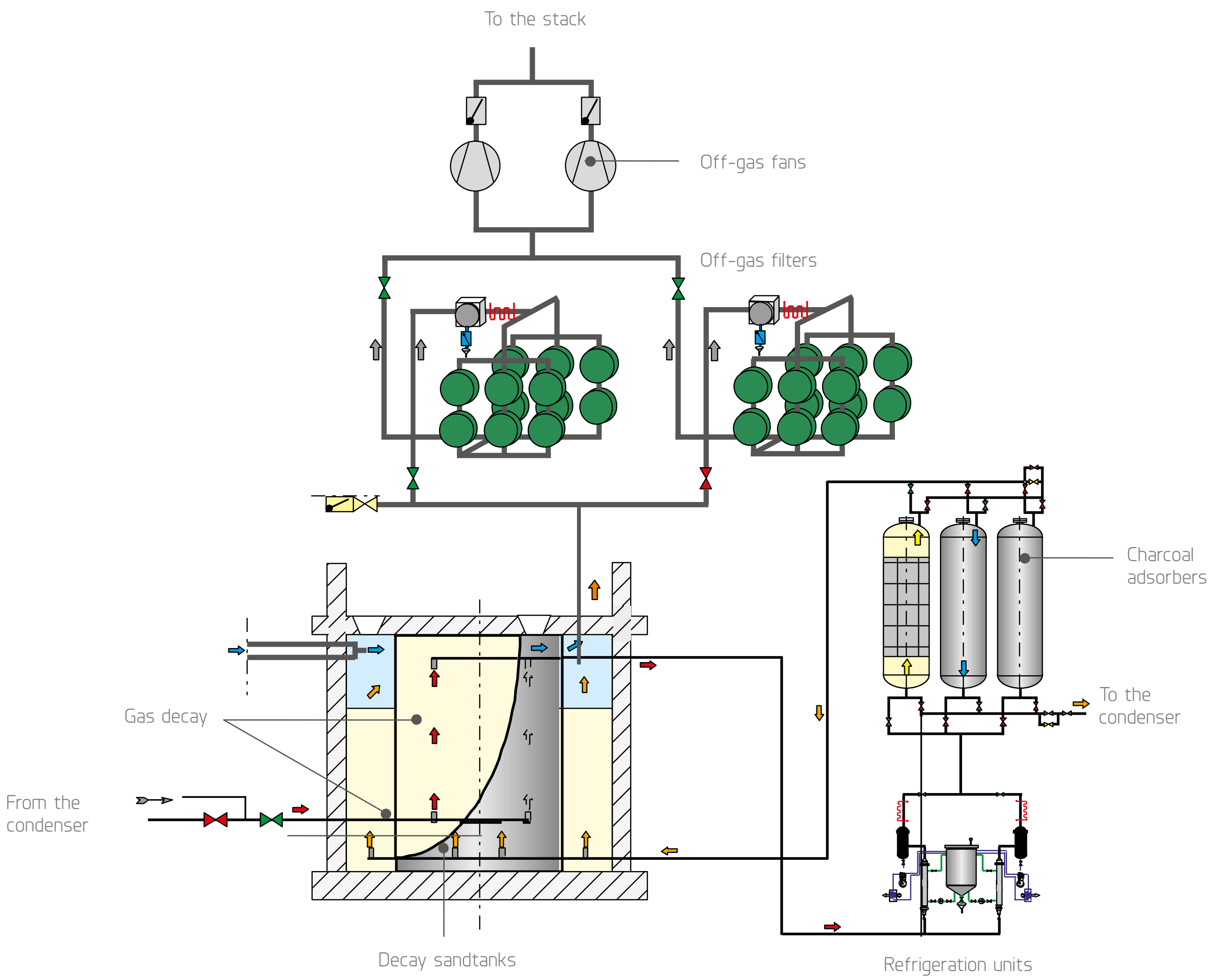
The reactor building ventilation system provides for the ventilation of the reactor building, including the heating, filtering, and distribution of the intake air, and for the maintenance of appropriate room temperatures together with the air cooling system.

Another purpose of the system is to convey exhaust air to the filters of the off-gas system in potential situations where water containing radioactive substances has leaked from the primary circuit to the reactor building. Additionally, the system prevents airborne radioactivity from spreading from areas of high activity to areas of lower activity. The system maintains underpressure in the reactor building.

Turbine building ventilation system

The turbine building ventilation system provides for the heating, cooling, ventilation, and air circulation of the controlled areas of the turbine building and the access buildings. Additionally, it prevents airborne radioactivity from spreading from areas of high activity to areas of lower activity in potential accident situations.

OFF-GAS SYSTEM LIMITS THE EMISSION OF RADIOACTIVE NOBLE GASES FROM THE PLANT UNITS



Off-gas system

The off-gas system limits the emission of radioactive noble gases from the plant units. The system consists of a delay phase and an adsorption phase. The delay phase comprises two sand tanks, and the adsorption phase comprises three activated carbon filters.

The sand tanks of the delay phase slow down the flow of exhaust gas, allowing for the decay of short-lived nuclides. The activated carbon filters are located between the sand tanks together with two parallel cooling units that reduce the moisture content of the exhaust gases. The activated carbon adsorbs radioactive substances, which are periodically flushed back into the condenser. Two of the three activated carbon filters are in use at any given time, with the exhaust gas flow passing through one and the back-flush flow to the condenser passing through the other. The functions of the filters are exchanged according to a predefined program.

After passing through the activated carbon filters, the gas is lead through the second sand tank, and then through the off-gas filter system to the main stack. The off-gas filter system removes 99.9 per cent of the iodine content of the exhaust air.

Radioactive emissions into the air from the Olkiluoto plant units are well below the maximum allowable limits set by the authorities and amount to no more than a few per mil of the allowed level.

NUCLEAR WASTE MANAGEMENT

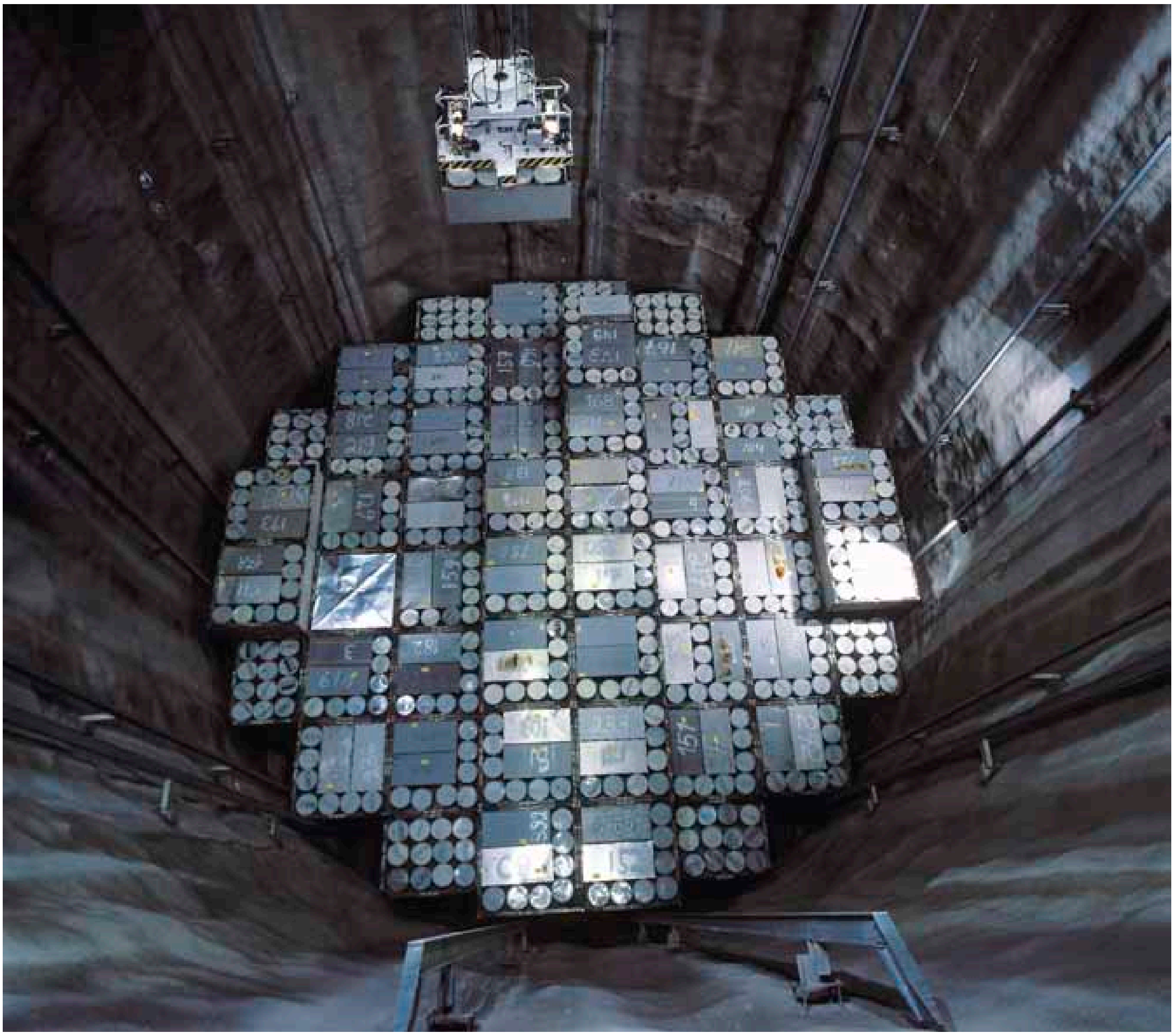
Radioactive waste is generated in the production of nuclear electricity. The waste must be isolated from living organisms until its radioactivity decreases to a harmless level.

The waste is classified as waste cleared after monitoring, low and intermediate level operating waste, high level waste (spent nuclear fuel), and decommissioning waste.

Low level waste includes protective clothing, rubber gloves, and tools used in maintenance operations. Intermediate level waste includes the spent ion exchange resin produced in the cleaning of the process waste water, and the evaporator concentrate. Low and intermediate level waste is disposed of in the low and intermediate waste silos of the operating waste repository (VLJ repository).

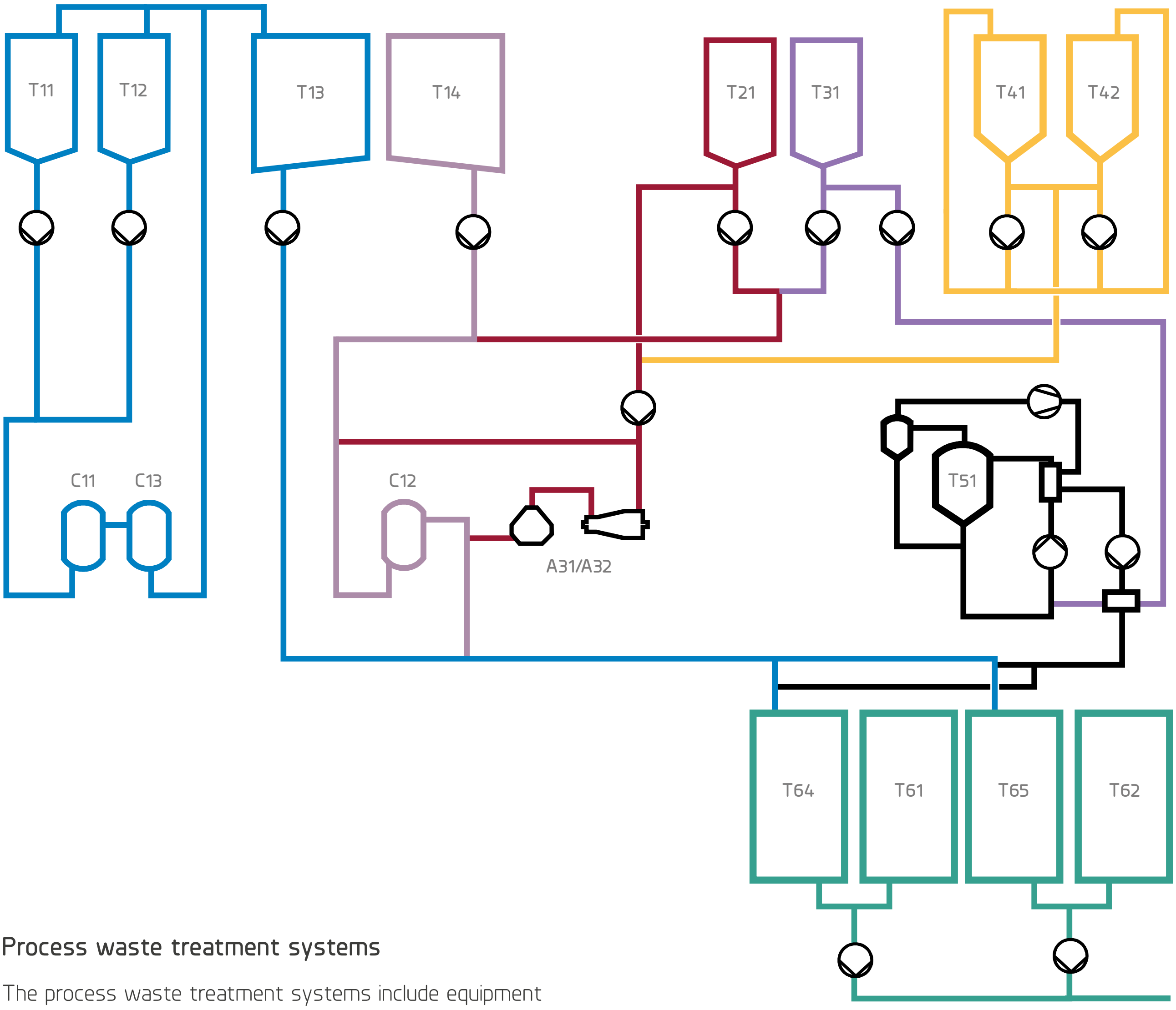
Since the content of radioactive substances in waste cleared after monitoring is extremely small or non-existent, it can be recycled or disposed of at the Olkiluoto landfill site.

Decommissioning waste is created when the power plant units are dismantled after their use is discontinued. Space has already been reserved in the VLJ repository for the final disposal of this waste.



In the operating waste repository (VLJ repository), the concrete containers are transferred into the low level waste (MAJ) and intermediate level waste (KAJ) silos, excavated to the depth of 60–100 meters into the bedrock.

LIQUID WASTE TREATMENT



Process waste treatment systems

The process waste treatment systems include equipment for the processing of both liquid and solid process waste.

At the power plant, liquid process waste is collected with a number of systems, which are used to pump the waste into dedicated reception tanks located at the waste treatment plant. Chemically pure water is filtered and lead through ion exchangers and then reintroduced into the power plant processes.

Water from floor drains and the so-called hot laundry room, as well as other waters containing particulate impurities, are cleaned by spinning, filtering, ion exchange, or evaporation. After the cleaning treatment, these waters are pumped into the sea.

The solid waste processing system includes equipment for handling, sorting, and compression of low level waste as well as for drying and bituminization of intermediate level waste.

T11/T12, T13	Process leakage water storage tanks
T14	Contaminated water storage tank
C11–C13	Ion exchange filters
T21	Laundry water storage tank
T31	Floor drainage storage tank
A31/A32	Decanter and separator equipment
T41/T42	Ion exchange resin storage tanks
T51	Evaporator
T61–T65	Storage tanks for water to be pumped out

Spent fuel is transferred to the interim storage facility in a transfer tank made of spheroidal graphite cast iron. Its walls are 36 centimetres thick, and it weighs 93 tonnes when fully loaded.

Interim storage and final disposal of spent nuclear fuel

After removal from the reactor, spent fuel assemblies are transferred to the fuel pools located in the reactor hall, where they will cool down for approximately four years. At the same time, the radioactivity level of the spent fuel will decrease significantly. The water cools down the fuel and protects the environment against radiation. During the transfer, the fuel assemblies remain under water at all times.

After cooling down for a few years, the assemblies are placed in a sturdy, water-filled transport cask, which is transported in a specially designed vehicle to the on-site interim storage facility for spent fuel (the KPA store). The transport cask accommodates a maximum of 41 fuel assemblies, and it weighs 93 tons fully loaded.

Before final disposal, spent fuel is kept in the water-filled storage pools of the interim storage facility for approximately 40 years. During this time, the radioactivity and heat production of the fuel decrease to less than one-thousandth of the original level, simplifying the packing and processing of the waste.

The spent nuclear fuel final disposal facility will be constructed in Olkiluoto. Posiva Oy, a company owned by TVO and Fortum Power and Heat Oy, is responsible for the construction and use of the facility. The spent nuclear fuel produced in the Loviisa power plant units will also be disposed of in the Olkiluoto repository. Final disposal is scheduled to begin in about 2020.

NUCLEAR SAFETY

Three elements are required to ensure reactor safety under all circumstances: 1) control of the chain reaction and the power it generates, 2) cooling of the fuel even after the chain reaction is shut down, i.e. removing decay heat, and 3) isolation of radioactive substances from the environment.

Safety rests on two main principles: 1) five barriers for radioactive substances: the ceramic fuel, the gas-tight fuel rod, the pressure-resistant reactor vessel, the pressure-resistant reactor containment, and the reactor building; and 2) the defense-in-depth safety principle.

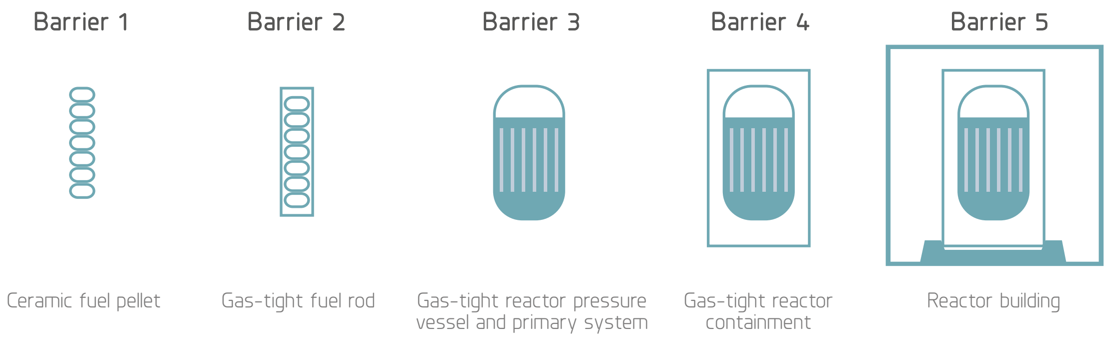
Safe use

The main principle of nuclear safety is that radioactive substances must not escape into the environment under any circumstances. Multiple safety systems are in place to prevent emissions.

The Olkiluoto nuclear power plant units are equipped with multiple, diverse safety systems that enable the personnel to detect transients and bring them quickly under control. Everything is based on the multi-layered, defense-in-depth principle. All functions significant to safety are backed up by several redundant systems and devices, and strict quality requirements and sufficient safety margins are applied in the design of all equipment and functions. An arrangement in which several systems operating on different principles perform the same function is referred to as diversity.

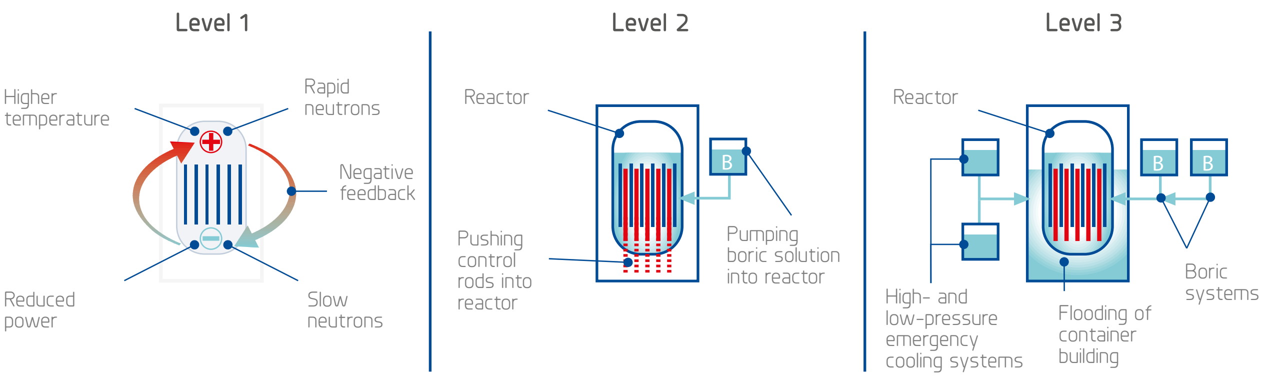
The starting point for the safety concept is that a user error or even a series of equipment faults cannot alone lead to a severe accident. The systems performing the most important safety functions must be able to carry out their functions even if an individual component in any system fails to operate and any component affecting the safety function is simultaneously inoperable due to repair or maintenance.

MULTIPLE BARRIERS



One of the main principles of nuclear safety is the arrangement of multiple barriers between radioactive materials and the environment.

EXAMPLES OF THE DEFENCE-IN-DEPTH WAY OF THINKING



As the reactor temperature rises, its power is reduced, because the increased boiling produces less slow neutrons and so slows down the chain reaction.

The reactor can be closed down in a few seconds by means of two systems with different operating principles.

In an accident situation the safety systems prevent or alleviate the consequences.

The danger caused by the radioactivity of the fuel is minimized by establishing several concentric protection zones. The first barrier against the release of radioactivity is the uranium dioxide fuel pellet, which retains the fission products. The second barrier is the metal tube enclosing the fuel rod, and the third is the reactor pressure vessel. The fourth barrier is the gas-tight containment surrounding the reactor, and the fifth, and outermost, barrier is the massive reactor building.

Physical separation

In provision against single failures, the safety systems of the Olkiluoto power plant units are divided into four redundant subsystems (A, B, C and D). These subsystems are located in physically separated rooms, racks, and cabinets. This type of an arrangement, in which several systems of identical design are connected in parallel to perform the same function, is referred to as redundancy.

This principle is also applied to the electric power supply and control systems. Areas housing equipment belonging to different subsystems are ventilated and cooled by separate ventilation systems.

Emergency core cooling systems

Emergency core cooling is provided by two different systems – the auxiliary feedwater system and the core spray system. The auxiliary feedwater system is a high pressure emergency cooling system. It has sufficient capacity to keep the core flooded in the case of a rupture of any of the pipes connected to the bottom of the reactor pressure vessel.

The core spray system operates at low pressure. It has sufficient capacity to keep the core submerged in the event of a large rupture of any of the pipes located above the reactor core.

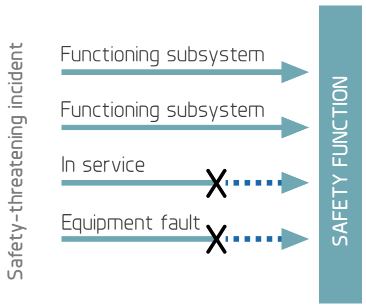
Both systems and the associated auxiliary systems are divided into four independent subsystems. Two of these subsystems are required to cope with a loss of coolant situation. This arrangement allows for easy testing and repairing of the equipment of the different subsystems without limiting plant operation.

Each subsystem is equipped with separate pumps, valves, etc., and is supplied with power from correspondingly separated emergency diesel generators. The auxiliary feedwater system draws its water from special storage pools. Each subsystem has its own, separate pool.

The core spray system is supplied with water from the containment condensation pool. The water from this pool is cooled by the containment vessel spray system, which in turn is cooled with sea water supplied through an intermediate circuit.

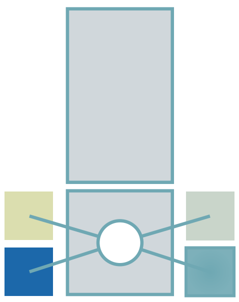
The heat absorbing capacity of the condensation pool will remain sufficient for the removal of residual heat for several hours after reactor shutdown without any external containment cooling.

Parallel principle



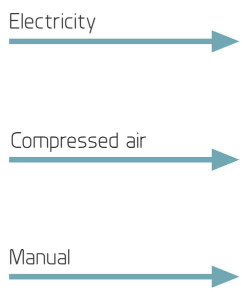
Safety systems comprise several self-replacing parallel subsystems.

Separation principle

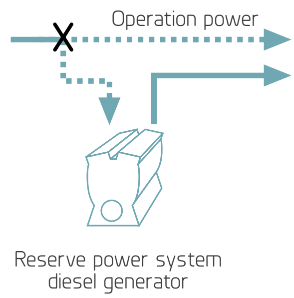


Parallel subsystems in the safety systems are placed so that simultaneous damage to them, e.g. in a fire, is unlikely.

Diversity principle

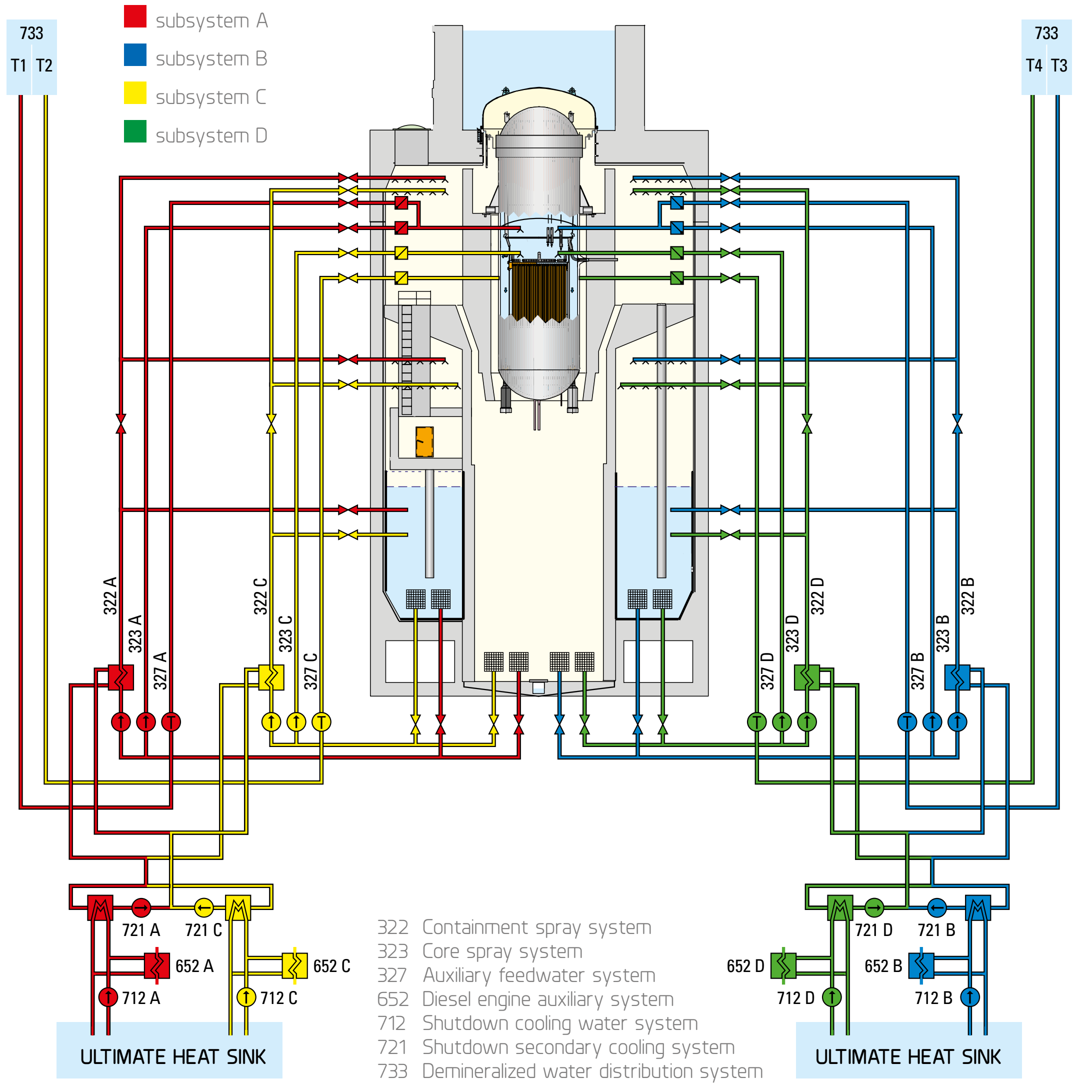


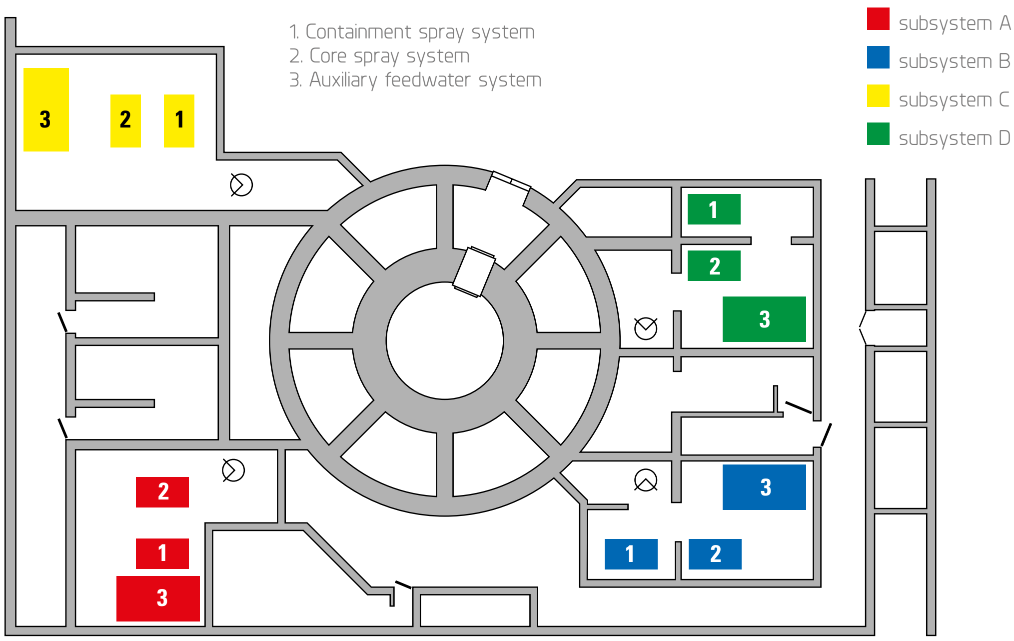
The same function is implemented with systems based on different operating principles.



If the system loses its driving power, it falls back to a state that is as safe as possible for the plant.

EMERGENCY COOLING SYSTEMS OF THE PLANT UNIT





NUCLEAR POWER PLANT AS A RADIATION ENVIRONMENT

The radiation safety of the environment of the Olkiluoto nuclear power plant is continuously monitored with various methods and in cooperation between several parties. Ten continuously operating radiation dose rate measuring stations have been installed in the region surrounding the plant. They report their results, as well as any alarms, automatically. Furthermore, four air samplers and eleven dose meters have been installed in the surrounding region.

Radioactive substances are generated in the reactor pressure vessel. The neutron radiation activates the particles carried to the pressure vessel along with the water, causing them to emit radiation. The water carries these substances further to the various pipe systems. Referred to as activation products, these substances cause the radiation doses incurred by persons working on radiation zones.

Radiation monitoring systems

Radiation levels are monitored with separate radiation monitoring systems in different parts of the plant unit. These systems include the steam line radiation monitors, the off-gas radiation monitors, the stack radiation monitors, the systems radiation monitors, and the room radiation monitors.

If the content of radioactive substances in the main steam pipes is too high, the steam line radiation monitors issue a fuel rod leak alarm and a signal activating an isolation command.

The off-gas radiation monitors issue an alarm in the event of a fuel leak that is too small to be detected by the steam line radiation monitors. Simultaneously, it monitors the functioning of the off-gas system.

The stack radiation monitors continuously measure, among other things, the amount of airborne radioactive substances released into the environment through the main stack. The system continuously registers the releases of noble gases and other isotopes emitting gamma radiation during normal operation. The measurement values are reported quarterly to STUK as official emission measurement results and annually in conjunction with environmental radiation safety reporting.

The systems radiation monitors comprise six measuring channels. The measuring channels monitor the activity of the waste water lead from the liquid waste system to the cooling water channel.

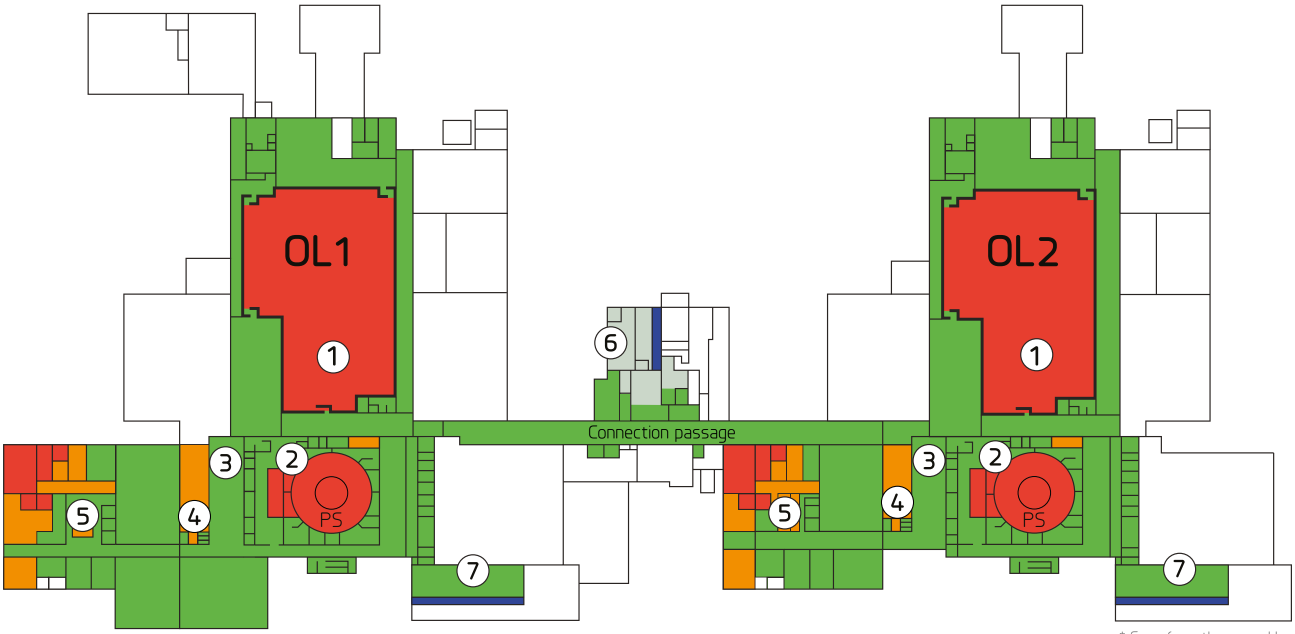
The room radiation monitors monitor the radiation level of the reactor hall and the dose rate in the upper containment drywell and the condensation pool space in accident situations. If the dose rate in the reactor hall is too high, the system issues an alarm and activates the emergency ventilation system.

CONCEPTUAL DRAWING* OF THE CONTROLLED AREA DURING POWER OPERATION

The following dose rates correspond to the classification colours

- < 0.025 mSv/h (< 25 µSv/h)
- 0.025–1 mSv/h (25–1,000 µSv/h)
- > 1 mSv/h (>1,000 µSv/h)

1. Turbine building
2. Reactor building
3. Active workshop
4. Decontamination
5. Waste building
6. Annual outage building
7. Entrance building



* Seen from the ground level.

Controlled area

Rooms housing systems emitting radiation and adjacent spaces are separated from other parts of the plant by thick walls and locked-off rooms and referred to as the controlled area.

In some parts of the controlled area, radioactive substances may be found on surfaces or in the air. The occurrence of airborne radioactive substances is referred to as air contamination, and radioactive substances found on surfaces are referred to as surface contamination.

The facilities of the controlled area have been classified in one of three categories depending on the intensity of radiation and the amount of contamination. The rooms where radiation occurs are marked with green, orange, and red signs. The radiation protection measures to be applied are determined on the basis of the colors of the sign.

The radiation doses of everyone working in the controlled area of the nuclear power plant are monitored and measured using dosimeters. All persons exiting the controlled area must pass through a double monitoring process. This ensures that no radioactive substances are carried outside the controlled area.

Radiation work

Exposure to radiation results in a radiation dose, which must always be kept as low as reasonably achievable. This principle is specified in the Finnish Radiation Act. In Finland, the average annual radiation dose per person is approximately 3.7 millisievert (mSv).

When reference is made to a radiation dose, what is actually meant is usually the effective dose. The unit for effective dose is the sievert (Sv). The unit represents the latent practical harm caused to people by radiation. In practice, the thousandth and millionth fractions of the dose rate unit Sv/h (mSv/h and µSv/h) are also used. The dose rate expresses the radiation dose received by a person within a certain time. Establishment of the dose rate enables the determination of the radiation protection measures required to minimize the radiation doses.

The Finnish Radiation Act and Decree set maximum radiation limits for persons who are exposed to radiation in their work. The maximum allowed radiation dose incurred by a radiation worker over a period of five years is 100 mSv. The dose incurred in the course of a single year must not exceed 50 mSv.

Technical data

General

Reactor thermal power	MW_{th}	2,500
Electrical output, net	MWe	880
Electrical output, gross	MWe	910
Reactor steam flow	kg/s	1,250
Reactor operating pressure	bar	70
Feedwater temperature	°C	185

Core

Number of fuel assemblies		500
Total fuel weight	tnU	85–90
Core diameter (equiv.)	mm	3,880
Core height	mm	3,680

Fuel

Fuel rods per assembly		91–96
Fuel rod outer diameter	mm	approx. 10
Cladding material		Zry-2
Weight of fuel assembly (incl. channels)	kg	approx. 300
Uranium fuel per assembly	kgU	175

Control rods

Number of control rods		121
Absorber length	mm	3,650
Total length	mm	6,380
Absorber material		B_4C and Hf

Reactor pressure vessel

Inner diameter	mm	5,540
Inner height	mm	20,593
Wall thickness, carbon steel (ASME A533B, A508Gr2)	mm	134
Thickness of stainless steel liner	mm	5
Design pressure	bar	85
Operation pressure	bar	70
Design temperature	°C	300
Operation temperature	°C	286
Weight of vessel	ton	524
Weight of cover	ton	107

Recirculation pump

(Normal power operation, 6 pumps)

Rated speed	rpm	approx. 1,350
Head	m	approx. 25
Motor power	kW	740

Turbine plant

Turbine

Live steam pressure	bar	67
Live steam temperature	°C	283
Live steam flow	kg/s	1,250
Rated speed	rpm	3,000
High pressure turbine	Axial, 2-flow	
High pressure control valves		4
Low pressure turbine	Axial, 2-flow	
Low pressure intercept valves		8
Exhaust area	m^2	8 x 7.1
Last stage		
– blade length	mm	867
– overall diameter	mm	3,468

Generator

Nominal rating	MVA	990
Power factor, nominal	cos	0.9
Rated voltage	kV	20
Voltage range	%	95–108
Frequency	Hz	50
Cooling, rotor/stator		water/air
Exciter		brushless

Condenser

Cooling surface	m^2	27,700
Cooling medium		sea water
Cooling water flow	m^3/s	38
Vacuum at full load	bar	0.05
Temperature rise	°C	10

Feedwater

Preheating stages		5
Final feedwater temperature	°C	185

Power supply

Main transformer

Nominal rating	MVA	1,000
Rated voltage	kV	412/20
Cooling form		OFAF

Plant transformers (2)

Nominal rating	MVA	30/16/16
Rated voltage	kV	20/6.9/6.9

Startup transformers (2)

Nominal rating	MVA	40/25/25
Rated voltage	kV	115/6.9/6.9

Auxiliary power supply

General systems	kV ac	6.9/0.69
Diesel-backed	kV	0.69
Diesel generators (4)	MVA	2
Battery-backed	V dc	24–400

www.tvo.fi

Olkiluoto
FI-27160 Eurajoki
Tel. +358 2 83 811
Fax +358 2 8381 2109

Helsinki
Töölönkatu 4
FI-00100 Helsinki
Tel. +358 9 61 801
Fax +358 9 6180 2570

Bryssel
4 rue de la Presse
BE-1000 Brussels
Tel. +32 2 227 1122
Fax +32 2 218 3141

Laine Direct Oy 9/2013 2 000