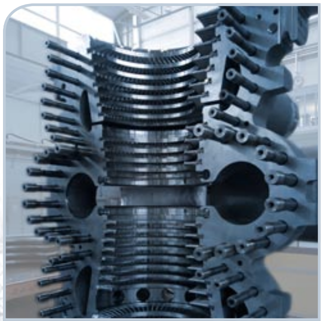
Nuclear Power Plant Unit Olkiluoto 3



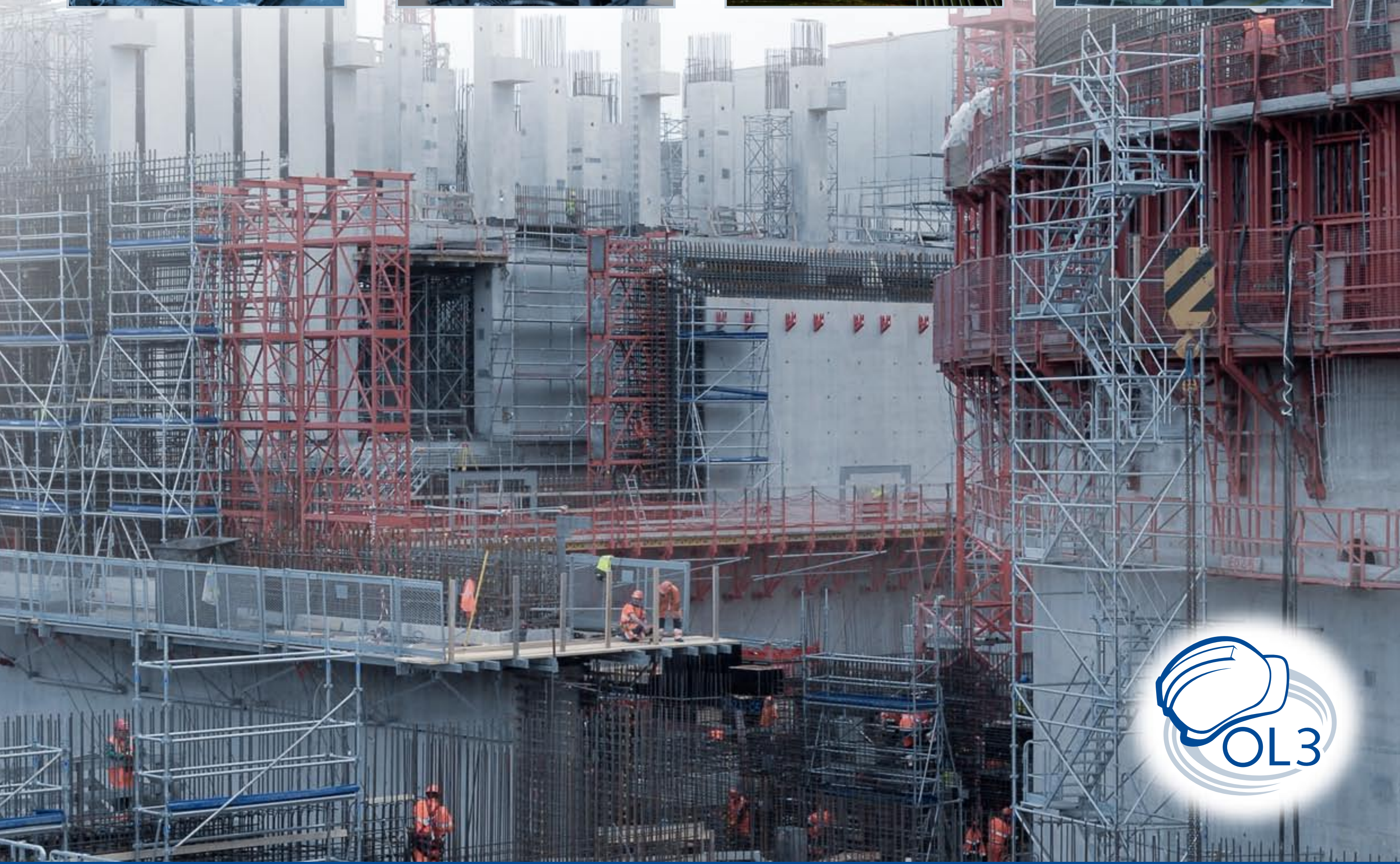
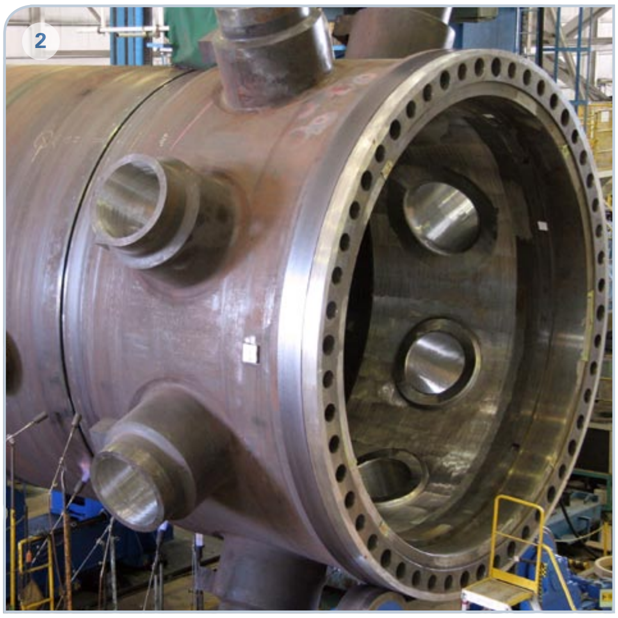


Photo: Areva



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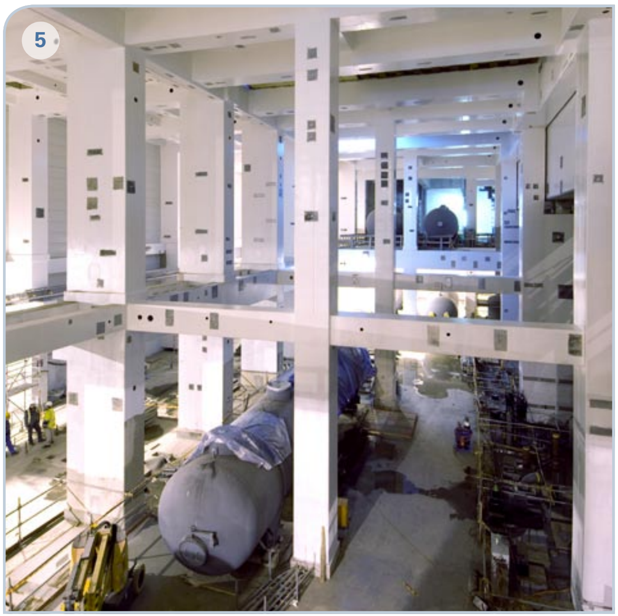

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1. Installation of the steam generator tubes

2. Reactor pressure vessel

3. The construction site in early 2008

4. Steam generator primary head undergoing cladding

5. Feedwater preheaters at level 0 in the turbine plant

TVO – a world-class nuclear power company

Teollisuuden Voima Oyj (TVO) is a Finnish public limited company established in 1969. The operating idea of the company is to produce electricity for its stakeholders at cost price. TVO is the developer, owner and operator of the Olkiluoto nuclear power plant.

At present, the production of the current nuclear power plant units at Olkiluoto (OL1 and OL2) covers about one sixth of the total electricity consumption in Finland. As the need for electricity production capacity is growing, TVO is now building a third power plant unit, Olkiluoto 3 (OL3), in accordance with a Decision in Principle ratified by Parliament. OL3 will be a unit with an output of approximately 1,600 MWe, which will almost double the production capacity of the Olkiluoto power plant.

High level of nuclear power expertise

TVO employs about 700 people. Because of the low personnel turnover, many current employees have been involved with the Olkiluoto power plant units from the outset and have thus acquired almost 30 years of experience in running and maintaining a nuclear power plant. This expertise is also being used and further developed in the construction of the OL3 unit.

Throughout its existence, TVO has been giving its personnel further training and improving their competence. The development of nuclear technology has been followed for instance by participating in international development programmes for new reactor types. This has kept the company up-to-date with technology and helped maintain active contacts with experts in the field.

The company's nuclear expertise has also been enhanced in the upgrading and modernization projects performed at OL1 and OL2 and in other development and construction projects. Over the years, modernization projects have helped to maintain the safety of the Olkiluoto power plant as well as its production capacity and economy.

World-class performance

TVO's nuclear expertise is clearly indicated by the high capacity factors of the Olkiluoto plant units, which for years have ranked among the top by international comparison. The capacity factors of OL1 and OL2 have varied between 93% and 98% since the early 1990s.

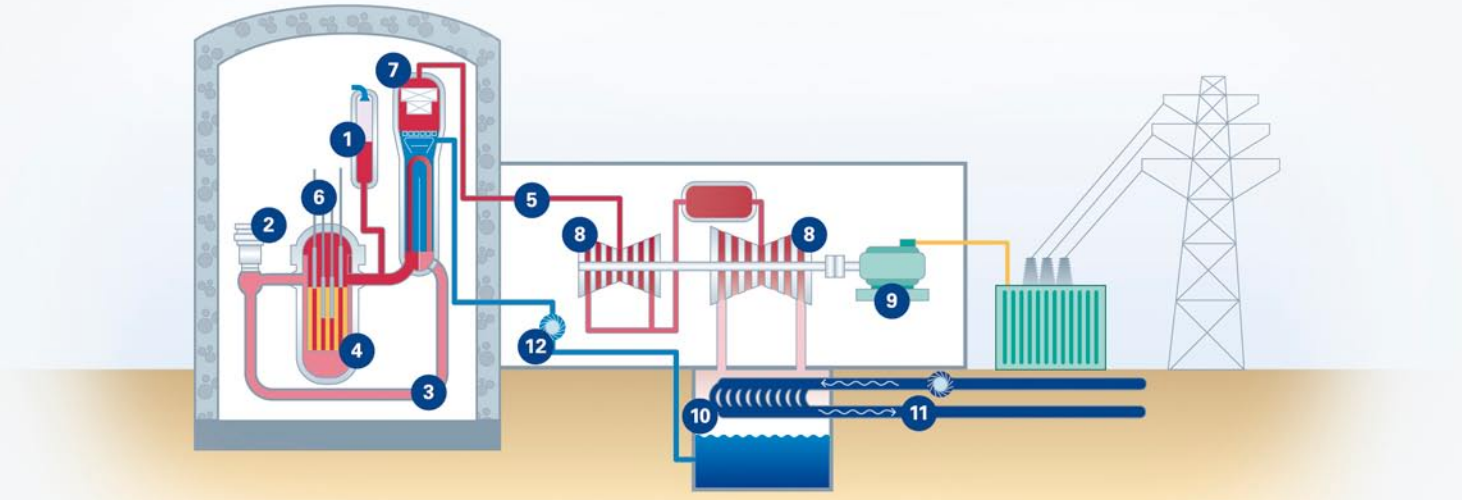
The high capacity factors indicate reliability of operation. This has been made possible by meticulous and proactive planning of annual outages and modifications.

Also, the radiation exposure doses of Olkiluoto personnel are among the lowest by international comparison.

TVO operating philosophy

As a nuclear power company, TVO is committed to a high-level safety culture. Every issue affecting plant safety is treated according to its safety significance and safety has priority in decision-making. High safety and production reliability are the cornerstones of TVO's business. Safety and safety factors always take priority over financial considerations.

The vision of TVO is to remain a world leading nuclear power generating company highly valued by the society. To achieve this goal, TVO acts responsibly, proactively and transparently, following the principles of continuous improvement in close cooperation with interest groups.



Olkiluoto 3 – progressive and moderate evolution

Electricity consumption growth is expected to continue in the future. The added capacity brought by OL3 will meet this increased demand and compensate for the decreasing output of ageing power plants. The unit will also, together with the use of renewable energy, promote the implementation of the Kyoto Protocol, contribute to the stability and predictability of electricity prices and reduce Finland's dependence on imported electricity.

It was on this basis that TVO submitted an application to the Government in November 2000 concerning a Decision in Principle for the building of a new nuclear power plant unit. The Government adopted a Decision in Principle, and Parliament ratified the Decision in Principle on 24 May 2002. The Decision in Principle states that building the new nuclear power plant unit is in the interest of society as a whole.

After a call for tenders, in December 2003 TVO took the decision to invest in the construction of a power plant unit with a Pressurized Water Reactor (PWR) with an output of approximately 1,600 MWe at Olkiluoto. The type of the unit is known as a European Pressurized Water Reactor (EPR). The unit is being built on a turnkey basis by a consortium formed by AREVA NP and Siemens. AREVA NP is delivering the reactor plant, and Siemens is delivering the turbine plant.

Experienced power plant suppliers

Both of the principal suppliers are leaders in their respective fields. AREVA NP has delivered the principal components for a total of 100 light-water reactor units – 94 pressurized water reactors (PWR) and 6 boiling water reactors (BWR). The most recently commissioned PWR units for which AREVA NP supplied the principal components are Civaux 1 and 2 in France, which went on stream in 1997 and 1999, respectively. AREVA NP also delivered the principal components to units which went on stream in Brazil (Angra 2) and China (Ling Ao 1 and 2) in 2002.

Siemens is one of the leading power plant suppliers in the world. The combined output of the power plants delivered by Siemens exceeds 600 GWe.

Technology based on solid practical experience

OL3 is an evolutionary unit compared with the current power plant units, meaning that its basic design is based on the proven technology of existing power plants. Its development was based on plants commissioned in France (N4) and Germany (Konvoi).

Safety features in particular have been developed further. The unit was originally designed to allow for the management of a severe reactor accident (cooling of core melt) and a large aircraft crash (double shell of the reactor containment building).

Germany (Konvoi)		
Neckarwestheim 2	1,269 MWe	1989
Isar 2	1,400 MWe	1988
Emsland	1,290 MWe	1988
France (N4)		
Chooz 1	1,450 MWe	1996
Chooz 2	1,450 MWe	1997
Civaux 1	1,450 MWe	1997
Civaux 2	1,450 MWe	1999

Operating principle of a pressurized water reactor (PWR)

A PWR plant has two circuits for heat transfer. Water is kept under high pressure by the ***pressurizer (1)*** *and circulated by the* ***reactor coolant pumps (2)*** *in the* ***primary circuit (3)****, which transfers the heat from the* ***reactor (4)*** *to the* ***secondary circuit (5)*** *in the* ***steam generator (7)****. Reactor power is controlled by* ***control rods (6)****. The pressure in the secondary circuit is much lower than in the primary circuit, which makes the water in the steam generator boil. The steam from the steam generator makes the* ***turbine (8)*** *rotate. The turbine rotates the coaxially mounted* ***generator (9)****, generating electricity for the national grid. The steam from the turbine is cooled back to water in the* ***condenser (10)*** *with* ***sea water (11)****. Condensate water is fed back to the steam generator with* ***feedwater pumps (12)****, and the warm sea water is pumped back into the sea.*

Above:
Steel bender installing the steel bars to reinforce the concrete of the base slab.
Below:
Concreting the inside of the steel liner.

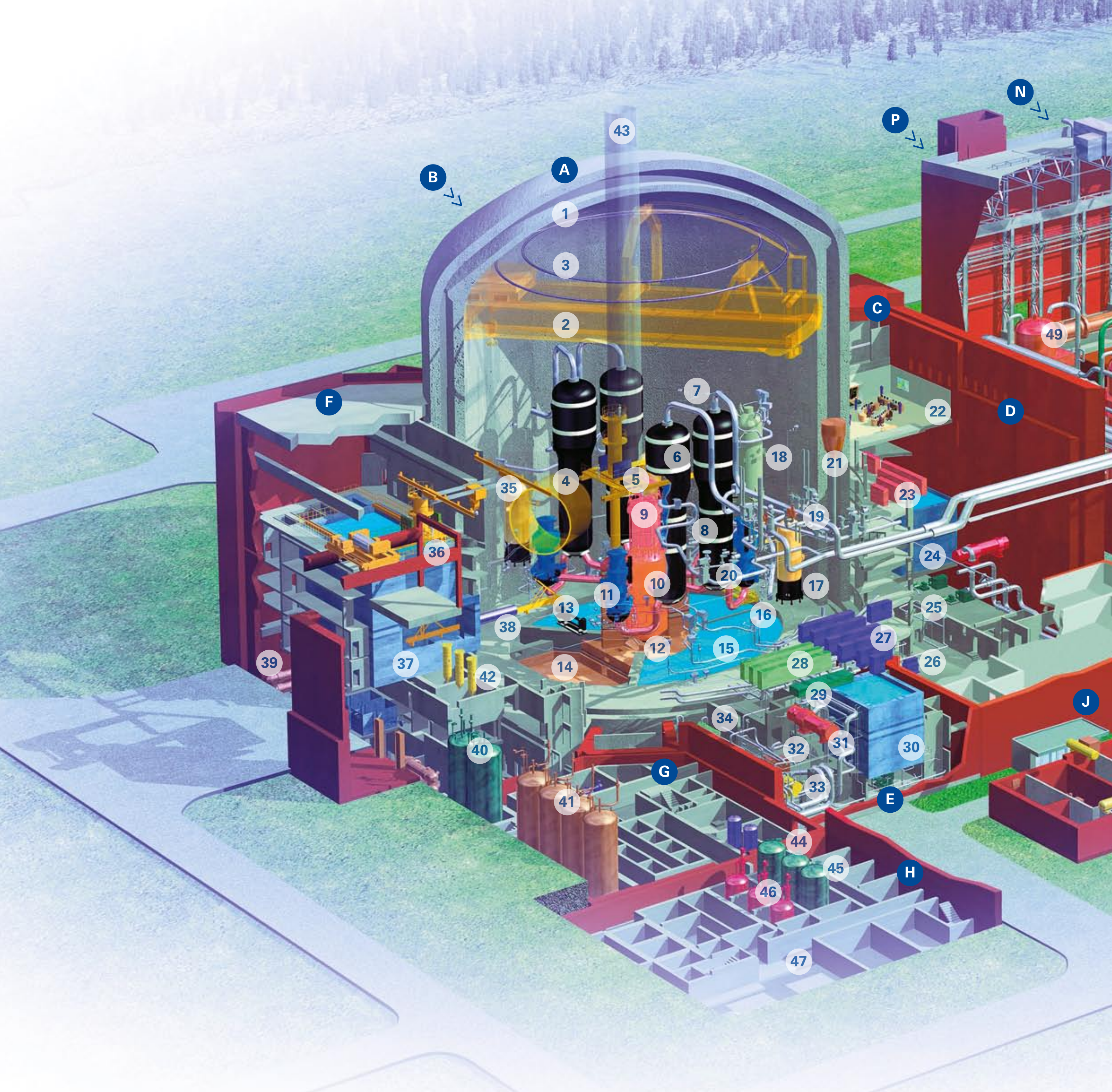
60 years service life

In addition to safety, the design of OL3 emphasizes economy in particular. The efficiency rate of the new unit, for instance, is 37% – some four percentage points higher than the original efficiency of OL1 and OL2.

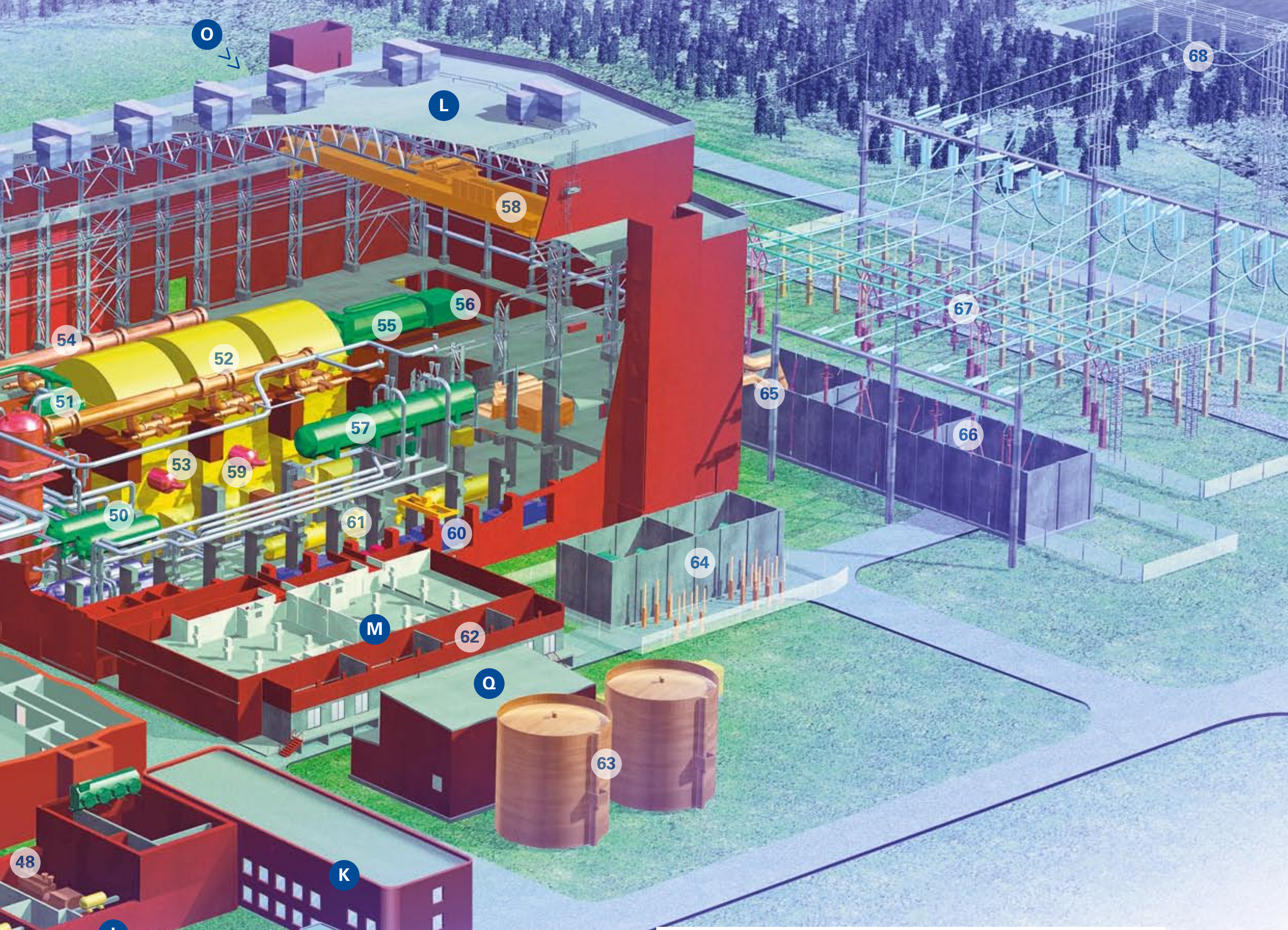
The design is based on an expected service life of 60 years for the largest structures and components and 30 years for the more easily replaceable structures and components. Allowing in advance for such replacements enables the unit to have an economic service life of at least 60 years.

Compared with similar units recently commissioned in Europe, OL3 will have a reactor output about 1% greater and an electricity output about 10% greater.

OL3 is being delivered as a turn-key project. TVO has been responsible for site preparation and for the expansion of the infrastructure at Olkiluoto. Site preparation has involved earthmoving, excavation, road building, electrical power supply for the construction site and the building of the tunnels for the cooling water. The actual construction work that is the responsibility of the AREVA NP – Siemens consortium began in 2005.



A ***Reactor building***
1 *Inner and outer containment building*
2 *Reactor building main crane (polar crane)*
3 *Containment heat removal system: sprinklers*
4 *Equipment hatch (large components)*
5 *Refuelling machine*
6 *Steam generator*
7 *Main steam lines*
8 *Main feedwater lines*
9 *Reactor control rod drives*
10 *Reactor pressure vessel*
11 *Primary circuit reactor coolant pump*
12 *Primary circuit main coolant lines*
13 *Primary circuit volume control system heat exchangers*
14 *Core melt spreading area*
15 *Emergency cooling water storage (In-containment refueling water storage tank, IRWST)*
16 *Intake screens for the cooling system for reactor emergency cooling and containment heat removal system*
17 *Hydraulic accumulator of the reactor emergency cooling system*
18 *Primary circuit pressurizer*
19 *Main steam valves*
20 *Feedwater valves*
21 *Main steam system safety valve and relief valve exhaust silencer*
B ***Safeguard building division 1***
C ***Safeguard building division 2***
22 *Main control room*
23 *Computer room*
24 *Emergency feedwater tank*
D ***Safeguard building division 3***
25 *Emergency feedwater pump*
26 *Medium head safety injection pump*
E ***Safeguard building division 4***
27 *Switchgear room*
28 *Instrumentation & control room*
29 *Battery rooms*
30 *Emergency feedwater tank*
31 *Component cooling system heat exchanger*
32 *Low head safety injection pump*
33 *Containment heat removal system heat exchanger (sea water circuit)*
34 *Containment heat removal system heat exchanger*
F ***Fuel building***
35 *Fuel building crane*
36 *Refuelling machine*
37 *Fuel pools*
38 *Fuel transfer tube*
39 *Fuel pool cooling system heat exchanger*
G ***Reactor plant auxiliary building***
40 *Coolant supply and storage system*
41 *Coolant supply and storage system*
42 *Offgas delayer*
43 *Ventilation stack*
H ***Radioactive waste processing building***
44 *Liquid waste collecting tank*
45 *Monitoring tanks*

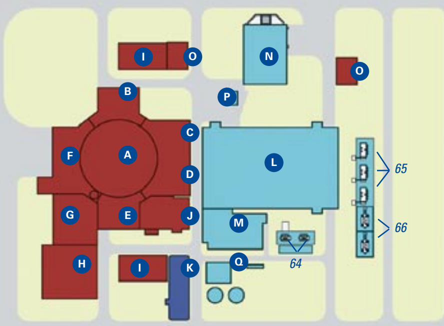


Olkiluoto 3 building responsibilities

AREVA ANP's scope of supplies and services comprises the entire nuclear island which includes the design, procurement and supply of the mechanical and electrical components and plant instrumentation and control (I&C) equipment, fuel for the first core, a simulator and building construction as well as erection and initial startup.

Siemens Power Generation's scope of supplies and services comprises the entire turbine island with the turbine generator set. This includes design, procurement and supply of the electrical and mechanical components, the turbine I&C equipment and building construction as well as erection and initial startup.

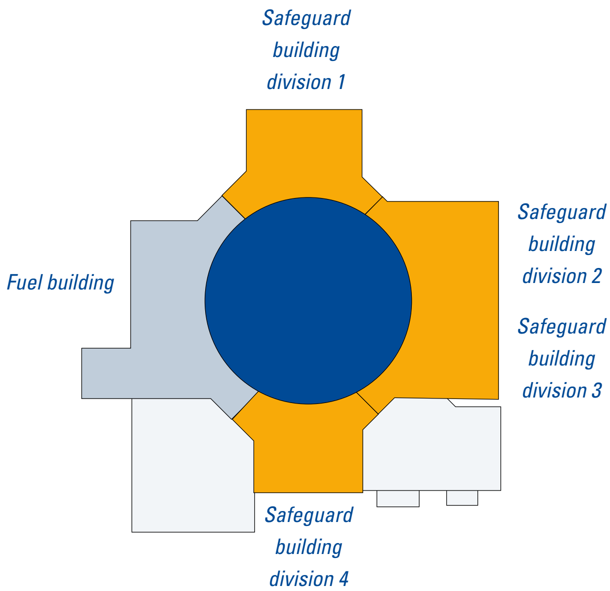
TVO as owner is responsible for the licensing process and is responsible for site infrastructure and excavation, grid connection and some auxiliary buildings.

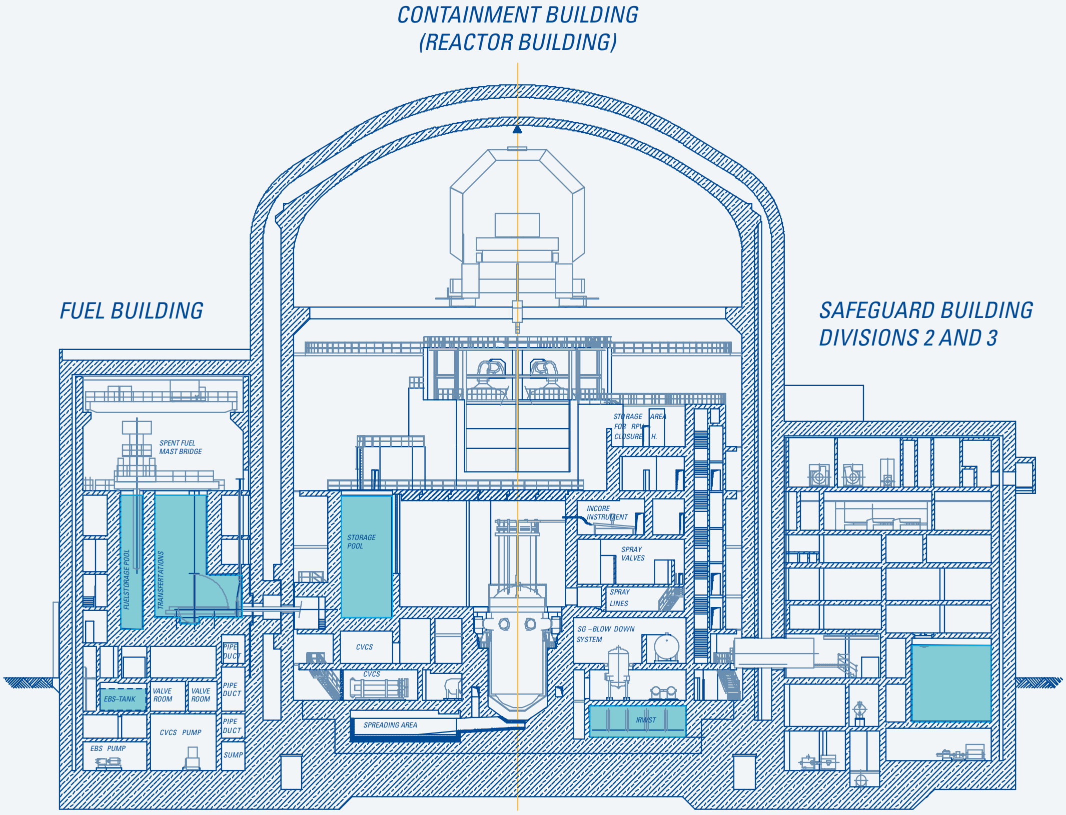


46 Concentrate tanks
47 Drum storage area
I Emergency power generating building
48 Emergency diesel generators
J Access building
K Office building
L Turbine building
49 Moisture separator/reheater
50 High-pressure feedwater preheaters
51 High-pressure turbine
52 Low-pressure turbine
53 Condensers
54 Cross over lines
55 Generator
56 Exciter
57 Feedwater tank
58 Turbine building main crane
59 Low-pressure feedwater preheater
60 Feedwater pumps
61 Low-pressure feedwater preheater
M Switchgear building
62 Transformer boxes
N Circulating water pump building
O Essential service water pump building
P Anti-icing pumps
Q Auxiliary boiler building
63 Demineralized water storage tanks
64 Auxiliary stand-by transformer
65 Unit transformers
66 Auxiliary normal transformers
67 Switchyard
68 High-voltage lines

Computer graphics: Images & Process

The reactor building is surrounded by the fuel building and four independent safeguard building divisions.





One unit, many buildings

The new OL3 power plant unit is being built to the west of the existing ones. The buildings in the new complex can be roughly divided into three parts: the nuclear island, the turbine island, and auxiliary and support buildings.

Nuclear island

The principal components of the nuclear island are the reactor containment, the fuel building and safeguard building divisions surrounding it. The reactor primary circuit is housed in a gas-tight and pressure-resistant double-shelled containment building, also known as the reactor building.

The fuel building, which houses pools for fresh and spent fuel, is on the south side of the reactor building and is about 50 m long, about 20 m wide and more than 40 m high. In addition to fuel storage, it is connected to workshop areas. Flanking the fuel building are the reactor plant auxiliary building and waste management building; the latter is used for handling low-level waste and intermediate-level waste.

The reactor building, fuel building and safeguard building divisions are designed to be able to withstand various types of external hazards such as earthquakes and pressure waves caused by explosions. All these buildings are built on the same base slab.

The reactor building, the fuel building and two of the safeguard building divisions are designed to withstand a crash by a large aircraft.

Reactor containment building

The OL3 reactor unit has a double-shelled containment building in reinforced concrete.

The shape of the building was chosen for strength and on the basis of construction technology. The inner containment is a prestressed cylinder in reinforced concrete with an elliptical cover. It is designed to withstand temperature and pressure loads that may be caused by pipe breaks. The massive outer containment is a cylinder in reinforced concrete that shares the same base slab as the inner containment and protects it against external hazards. This massive double-shell structure is a new safety feature which the earlier power plants do not have.

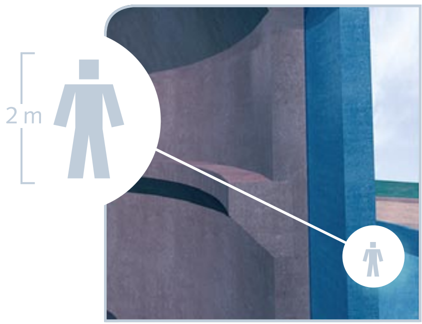
Preventing release of radioactive material in case of an accident sets extreme requirements on the leak-tightness of the containment building, which has an inner liner of steel for this reason. The tightness of the building is closely monitored. Any leaks which occur are arrested between the inner and outer shells of the containment building, then filtered and delayed in the annulus ventilation system before being conveyed to the ventilation stack.

Personnel access and material transport to the containment building are managed through special airlocks during normal operation. The airlocks have double-sealed doors at both ends; it is impossible to open both ends of the airlock at the same time. Personnel access is at ground level and on the service floor at about 19 m level.

The big equipment hatch on the maintenance platform is used during construction and annual outages for bringing large components and devices into the containment building. The 750-tonne main crane of the reactor building, located above the containment building service floor, can lift the reactor pressure vessel and the four steam generators one at a time.

The reactor building has an external diameter of about 57 m, a volume of about 80,000 m^3 and a total height excluding underground levels of about 70 m. The ventilation stack is about 100 m high.

The containment building is designed to withstand a crash by a large airliner or a jet fighter.



Safeguard buildings

The OL3 plant unit has parallel redundant safety systems which are physically separated from each other to ensure safe operation under all circumstances. The safety systems are divided into four independent subsystems, each of which is housed in a separate safeguard building division. All four buildings have their own low head and medium head safety injection systems, a residual heat removal system, an intermediate cooling system, a sea water cooling system, and an emergency feedwater system. The electrical and instrumentation and control systems are located on the upper levels of the safeguard building divisions. The control room is located in one of the safeguard building divisions.

Buildings 2 and 3 are between the reactor building and the turbine island, and buildings 1 and 4 are on opposite flanks of the reactor building. Each of the buildings is about 30 m long, 20 m wide and 30 m high.

The power plant unit has four emergency diesel generators suppling power to the safety systems in case of loss of offsite power. There are also two additional diesel generators, station blackout diesels, independent of the above four. The emergency and station blackout diesel generators ensure that the safety systems have power supply even under abnormal circumstances.

Turbine island

The turbine building is almost 100 m long, 60 m wide and 60 m high, including underground levels. Its volume is about 250,000 m^3. Adjacent to it are the sea water pumping station and switchgear building. The main transformers and plant transformers are located to the north of the turbine building.

Auxiliary and support buildings

Beside safeguard building divisions 2 and 3, there is an access building, which contains locker rooms and washrooms, and a monitored accessway to the radiation-controlled area. There is a bridge from the access building to the office building, where radiation-controlled office space is available during annual outages. The power plant area also contains separate buildings for housing diesel generators, the sea water system buildings (mainly underground), and a number of minor support buildings.


The tightness of the inner containment is ensured with a steel liner consisting of a bottom head and top head and eight rings between them.

Primary circuit main components

1 Reactor pressure vessel
2 Main coolant line, hot leg
3 Steam generator
4 Reactor coolant pump
5 Main coolant line, cold leg
6 Pressurizer

PRIMARY CIRCUIT

The OL3 primary circuit system consists of four individual loops. It is designed for a service life of 60 years and constructed to withstand the loads caused by every conceivable situation of operation or accident.

Primary circuit main functions

In each of the four loops comprising the primary circuit, the coolant leaving the reactor pressure vessel at a temperature of 328°C goes through the main coolant line hot legs to the steam generators, where heat is transferred to the secondary circuit. The coolant, its temperature now approximately 296°C, is returned by the reactor coolant pump to the reactor through the inlet nozzles. Inside the reactor pressure vessel, the coolant first flows down outside the reactor core. From the bottom of the pressure vessel, the flow is reversed up through the core, where the coolant temperature increases as it passes through the fuel rods and the assemblies formed by them.

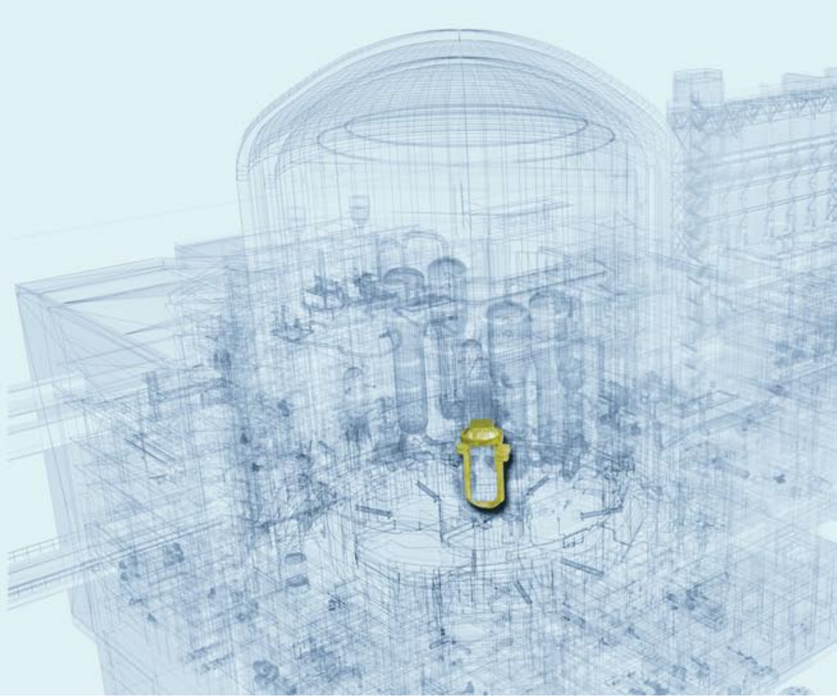
The pressurizer connected to the primary circuit keeps the pressure in the reactor high enough to prevent the coolant from boiling. Under normal conditions, the circuit is full of water which effectively transfer heat from the reactor core. Connected to one of the four individual loops, the pressurizer is larger in volume compared with the existing power plants so that it can better respond to any pressure transients during operation. This helps smooth pressure spikes and extends the useful life of the main components of the primary circuit.

The safety systems are designed so that in abnormal events they are able to perform a rapid shut-down of the reactor, known as a reactor scram. This ensures that the reactor releases as little energy as possible while also helping reduce pressure with maximum efficiency and keeping the actuation of the safety valves to a minimum.

Reactor cooling system properties

Reactor thermal power	4,300 MWth
Primary circuit flow	23,135 kg/s
Primary coolant flow per loop	28,330 m^3/h
Coolant temperature in the cold leg	296°C
Coolant temperature in the hot leg	328°C
Primary circuit design pressure	176 bar
Primary circuit operating pressure	155 bar
Secondary circuit design pressure	100 bar
Main steam pressure under normal conditions	78 bar
Main steam pressure during hot shut-down	90 bar

kuva: Areva

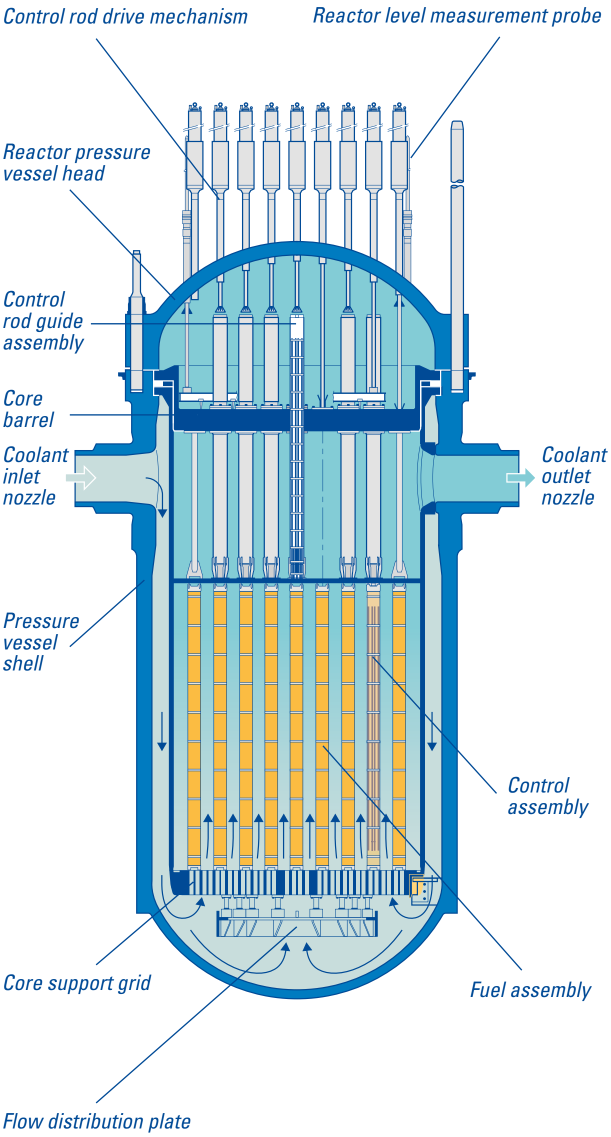


Properties of the reactor pressure vessel and its inner structures

Reactor pressure vessel	
Design pressure	176 bar
Design temperature	351°C
Life time (capacity factor 90%)	60 years
Inside diameter (under cladding)	4,885 mm
Wall thickness (under cladding)	250 mm
Bottom wall thickness	145 mm
Height with closure head	12,708 mm
Base material	16 MND 5
Cladding material	stainless steel
	(less than 0.06% cobalt)
Mass with closure head	526 t
End of life fluence level (E > 1 MeV)	
- design value	2.65×10^{19} n/cm^2
- expected value	ca. 1×10^{19} n/cm^2
Base material final RT_{NDT}	
(final ductile-brittle transition temperature)	ca. 30°C
Closure head	
Wall thickness	230 mm
Number of penetrations:	
- control rod mechanisms	89 pcs
- dome temperature measurement	1 pcs
- instrumentation	16 pcs
- coolant level measurement	4 pcs
Base material	16 MND 5*
Cladding material	stainless steel
	(less than 0.06% cobalt)
Upper inner structures	
Upper support plate thickness	350 mm
Upper core plate thickness	60 mm
Main material	Z3 CN 18-10 / Z2 CN 19-10**
Lower inner structures	
Lower support plate thickness	415 mm
Lower inner structure material	Z3 CN 18-10 / Z2 CN 19-10**
Neutron reflector	
Material	Z2 CN 19-10**
Weight	90 t

* low-alloy ferrite steel
** austenitic stainless steel

Cross-section of reactor pressure vessel and internal structures



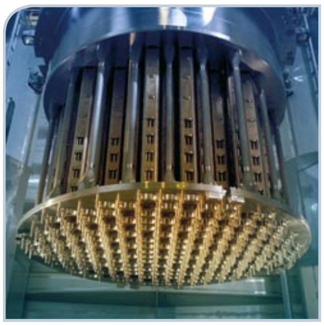
Reactor pressure vessel and internal structures

Pressure vessel

The reactor pressure vessel contains the reactor core. Both the pressure vessel and the vessel head are made of forged ferrite steel. They are also clad with stainless steel on the inside to prevent corrosion.

The pressure vessel is supported by beams which rest on the support ring in the top part of the reactor cavity, under the eight primary circuit pipes. The vessel head is fastened with bolts and a sealing gasket.

To manufacture the reactor with as few welding seams as possible, the flange and nozzle area of the pressure vessel is forged from a single piece of metal. There are no welding seams between the flange and the nozzles. Combined with the structure of the nozzles, this ensures that there is a considerable distance and a large volume of water between the nozzles and the top of the core. This minimizes the exposure of the structures to neutron radiation.



Reactor pressure vessel upper inner structures (Chooz 1, France).

Internal structures

The internal structures of the reactor pressure vessel support the fuel assemblies in the core, enabling the reactivity of the core to be controlled by the control rods and the fuel to be cooled with water under all circumstances. The inner structures are partly removed during refuelling and can be completely removed for an inspection of the inner wall of the pressure vessel.

The pressure vessel also contains upper internal structures, whose function is to support the top of the fuel assemblies and to keep them correctly aligned axially. These structures include the control rod guide thimbles, whose fastenings and beams are fixed to the control rod support plate and the upper core support plate.

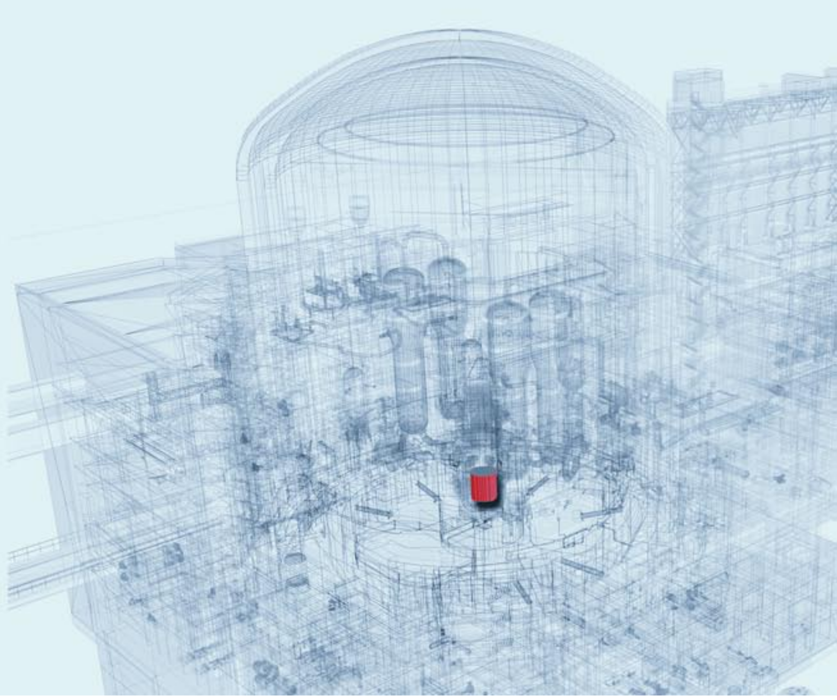
Core barrel

The flange of the core barrel rests on the machined flange of the pressure vessel, and is kept in place by a large spring. The fuel assemblies rest on a perforated core support plate, made of forged stainless steel and welded to the core barrel. Each fuel assembly is positioned by two pins 180° apart.

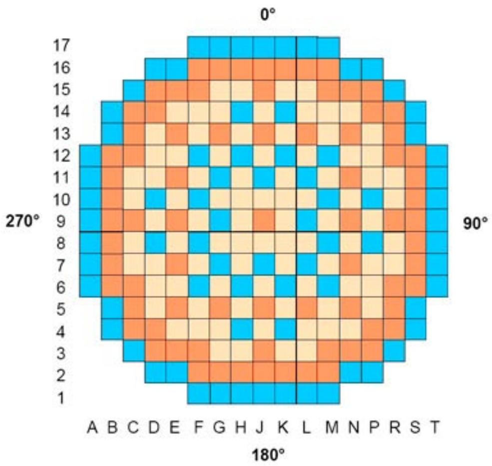
Neutron reflector (heavy reflector)

There is a steel neutron reflector, heavy reflector, around the polygonal core, between the core and the cylindrical core barrel. The reflector reduces the number of neutrons escaping from the core and flattens the power distribution. It also reduces the exposure of the pressure vessel to the neutron radiation that reduces ductility in its material, and also dampens any pressure spikes which the internal structures and fuel in the reactor might be exposed to in case of pipe break.

The heavy reflector consists of pieces of stainless steel piled up and linked together. The tie rods bolted to the core support plate keep the pieces in place axially. The heat generated in the steel by gamma radiation is absorbed by the primary coolant flowing through cooling ducts in the reflector.



Initial core loading

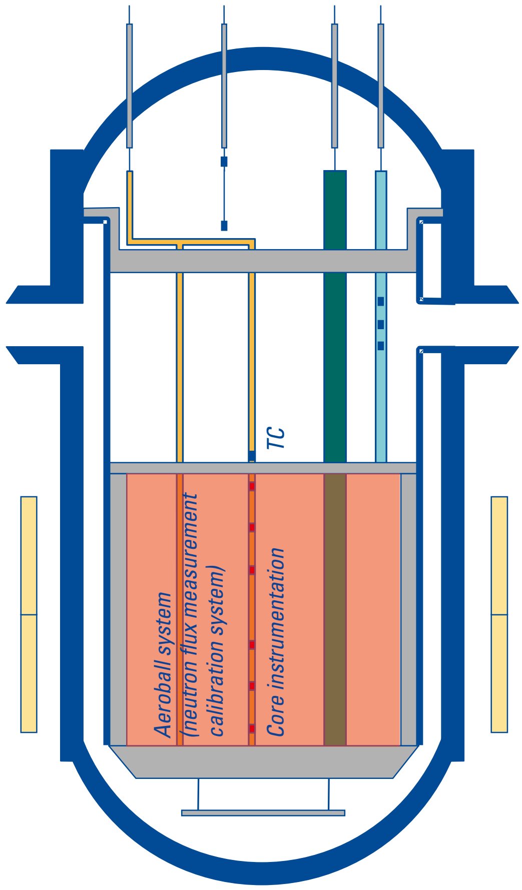


Low enriched assembly without gadolinium

Medium enriched assembly with gadolinium

High enriched assembly with gadolinium

In-core instrumentation



- *12 lance yokes, each comprising:*
  3 core outlet temperature sensors
  6 in-core neutron flux detectors
  3-4 aeroball probes
- *89 control assemblies*
- *4 water level probes*
- *core external neutron flux measurements*
- *TC temperature measurement*

Reactor core properties

Reactor thermal power	4,300 MWth
Operating pressure	155 bar
Primary coolant temperature in the inlet	296°C
Primary coolant temperature in the outlet	329°C
Equivalent diameter	3,767 mm
Active core height	4,200 mm
Number of fuel assemblies	241 pcs
Number of fuel rods	63,865 pcs
Average linear heat rate	156.1 W/cm

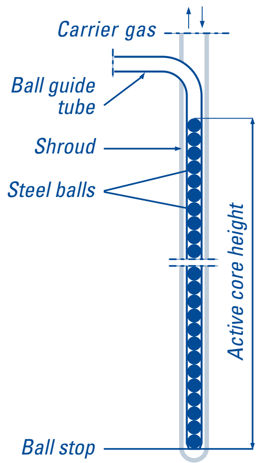
Reactor core and fuel

The OL3 reactor core consists of 241 fuel assemblies identical in structure. For the initial core loading, the assemblies are divided into three groups according to their enrichment level. The two groups with the highest levels of ^{235}U also contain gadolinium, which acts as a neutron absorber and thus reduces the reactivity of the initial phase of the reactor's operation and flattens the power distribution.

The number and properties of the fuel assemblies replaced annually depend on the fuel management plan chosen, particularly the load pattern and the length of the refuelling interval.

The refuelling interval of the reactor core can be 12 to 24 months.

The primary coolant, due to its composition, is a significant neutron moderator and reflector. The coolant conveys heat from the core at a pressure of approximately 155 bar and a temperature of 312°C on average. The primary coolant contains boron, which absorbs some of the neutrons. Adjusting the boron level helps control changes in reactivity that are fairly slow, such as the impact of fuel burn-up. Rapid changes in reactivity and in power output are controlled using the control assemblies.



Aeroball system

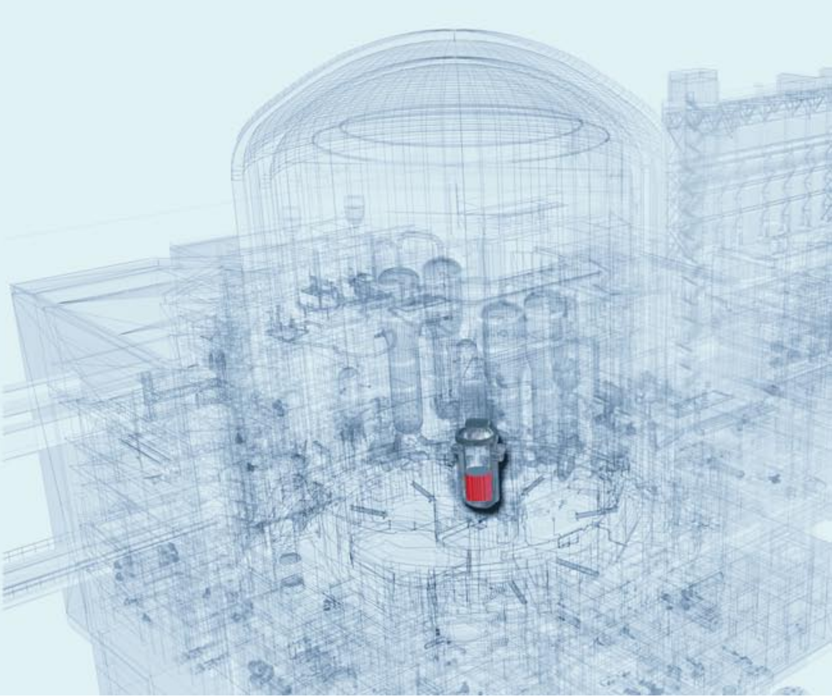
Balls made of a vanadium alloy are fed into 40 narrow tubes from above the reactor and pneumatically propelled to the reactor core through guide tubes in the fuel assemblies. The activation of the balls in one tube is measured at 36 points. The results are used to calibrate the devices used to measure the neutron flux in the reactor core.

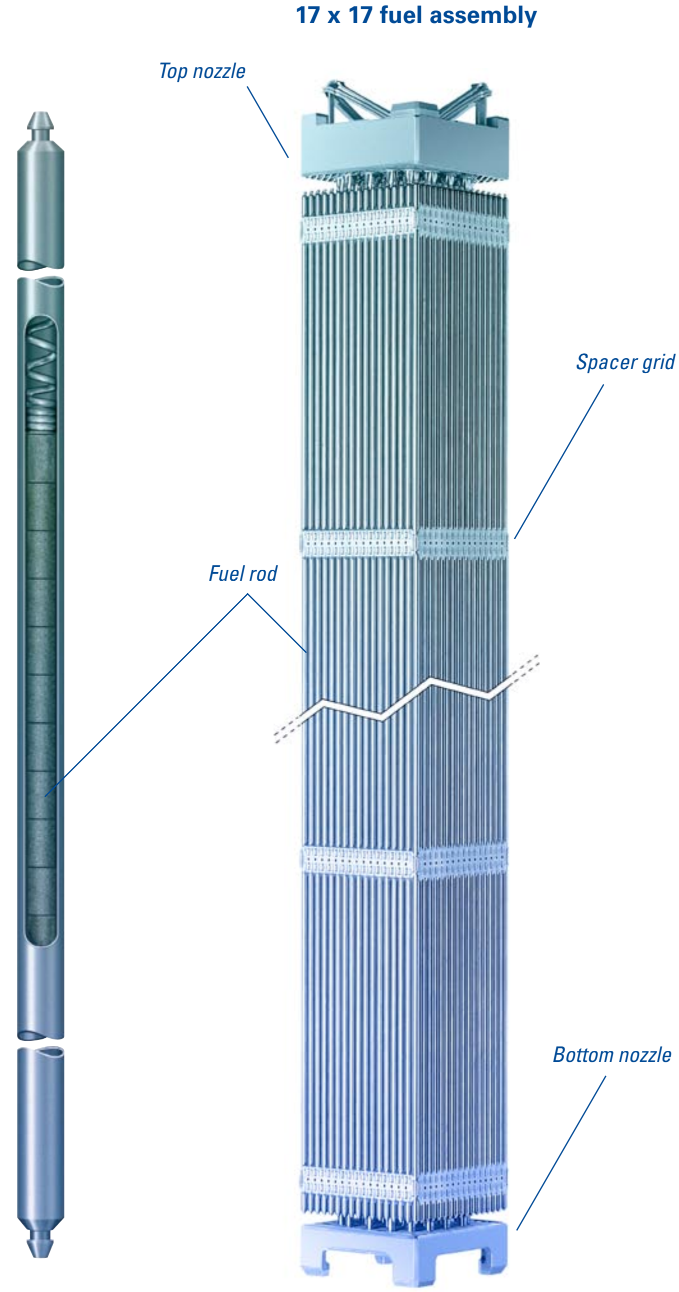
The main core properties and operational conditions have been selected to achieve a high thermal power and low fuel costs. The OL3 reactor core is also designed to be adaptable to various refuelling intervals and operating situations.

Core instrumentation

The core power is measured with both internal and external instrumentation. The fixed in-core instrumentation comprises neutron flux and temperature measurements monitoring the distribution of the neutron flux in the core and the temperature distribution in the upper part of the core. Ex-core instrumentation is used for power measurement and also for monitoring core sub-criticality during outages. All the penetrations required for core instrumentation are in the pressure vessel head.

The core power distribution is also measured at regular intervals using the aeroball system. The results thus achieved are used for calibrating fixed in-core neutron flux measurement devices.





Fuel properties

Fuel	uranium dioxide UO_2
Fuel assembly type	17 x 17 HTP
Number of fuel rods per assembly	265 pcs
Number of guide thimbles per assembly	24 pcs
Number of spacer grids per assembly	10 pcs
Length of fuel assembly	4.8 m
Weight of fuel assembly	735 kg
Width of fuel assembly	213.5 mm
Cladding material	M5™
UO_2 pellet density	10.45 g/cm^3
Fuel discharge burnup	45 MWd/kgU

Fuel assembly

A fuel assembly consists of fuel rods, spacer grids and top and bottom nozzles. The guide thimbles, spacer grids and the end pieces form the supporting structure of the assembly.

The fuel rods form a 17 x 17 matrix. Each fuel assembly contains 265 fuel rods, 24 guide thimbles and 10 spacer grids, tied together by end pieces at either end.

The bottom nozzle is shaped to distribute coolant flow evently. There is also a debris filter at the lower end to prevent any foreign objects that may end up in the primary circuit from entering the fuel assembly; such objects could mechanically damage it. The top nozzle has a leaf spring set on each side to achieve the force with which the fuel assemblies are kept stationary against the primary coolant flow.

The eight middle spacer grids in the fuel assembly are made of zirconium alloy. They have flow guides to enhance heat transfer from the fuel rods. The uppermost and lowermost spacer grids are made of nickel-based alloy because of their higher strength requirements.

The fuel supplier for the OL3 reactor is AREVA NP.

Fuel rods

A fuel rod is a tube containing compressed ceramic pellets of uranium dioxide (UO_2). The rods are welded hermetically leak-tight and pressurized using helium. The power of the reactor comes from the fission of the uranium in the pellets, mainly the isotope ^{235}U. The enrichment level of the pellets varies, being just under 5% at its highest. In some of the fuel rods, the fuel pellets are made of an alloy of UO_2 and Gd_2O_3, the latter helping to reduce reactivity and to flatten the power distribution in fresh fuel rods.

The cladding tubes of the fuel rods are made of a zirconium alloy. The cladding is the first barrier to the release of radioactive emissions as it separates the fuel and their fissile products from the primary coolant. There is space for fission gases within the fuel rod, which reduces the pressure increase caused by gases released from the uranium pellets in the nuclear reaction. The pellets are held in place by a spring inside the top of the fuel rod.

Fuel handling

Fresh fuel assemblies are stored either in the fresh fuel dry storage or in storage racks in the fuel pools where spent assemblies are also stored. During a refuelling outage, some of the spent fuel assemblies in the reactor are replaced with fresh ones. For example, if the reactor is being operated at 12-month cycles, one quarter of fuel is replaced annually. Different kinds of fuel assemblies are placed in the reactor in compliance with the restrictions on the reactor core and fuel use.

Fuel assemblies are moved between the reactor and the fuel building through the fuel transfer tube. There is a fuel handling machine in the reactor building and in the fuel building.

Core unloading takes about 40 hours in all, and core reloading plus a final core inspection using the camera in the refuelling machine takes about 45 hours. The final inspection is intended to ensure the correct placement of fuel assemblies in the core, following the refuelling plan. The Finnish Radiation and Nuclear Safety Authority (STUK), Euratom and the IAEA all participate in each final inspection to ensure the appropriate handling and safeguard measures of reactor fuel.

Spent fuel assemblies that have been in the reactor are kept under water at all times for cooling and radiation protection. Although 1 m of water would be sufficient radiation protection, at Olkiluoto the fuel assemblies are always kept under at least 3 m of water.

Spent fuel assembly handling

After being removed from the reactor, spent fuel assemblies are kept in the spent fuel pools in the fuel building for a few years to cool them off. At the same time, the radioactivity of the spent fuel decreases substantially.

After sufficient cooling, the spent fuel is transported to an interim storage facility at the power plant site using a spent fuel cask which is docked below the spent fuel pool using a transfer facility.

Before placement in the final repository, the spent fuel is kept in interim storage for several decades. During this time, the radioactivity and heat output of the fuel decrease to less than 1/1000 of their original values, making the further handling of the fuel much simpler.

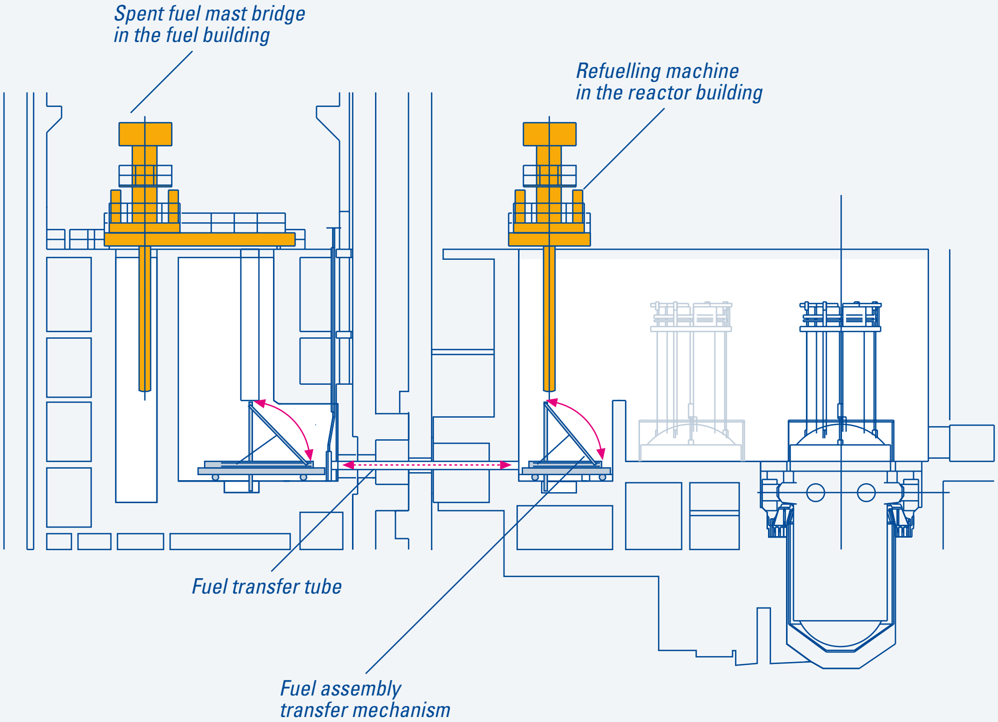
The final repository for spent fuel is being built at Olkiluoto by Posiva Oy, a company which is jointly owned by TVO and Fortum Power and Heat Oy, who will also be responsible for its operation. The spent fuel from the nuclear power plant units in Loviisa will also be deposited at Olkiluoto. Final placement will begin in 2020.

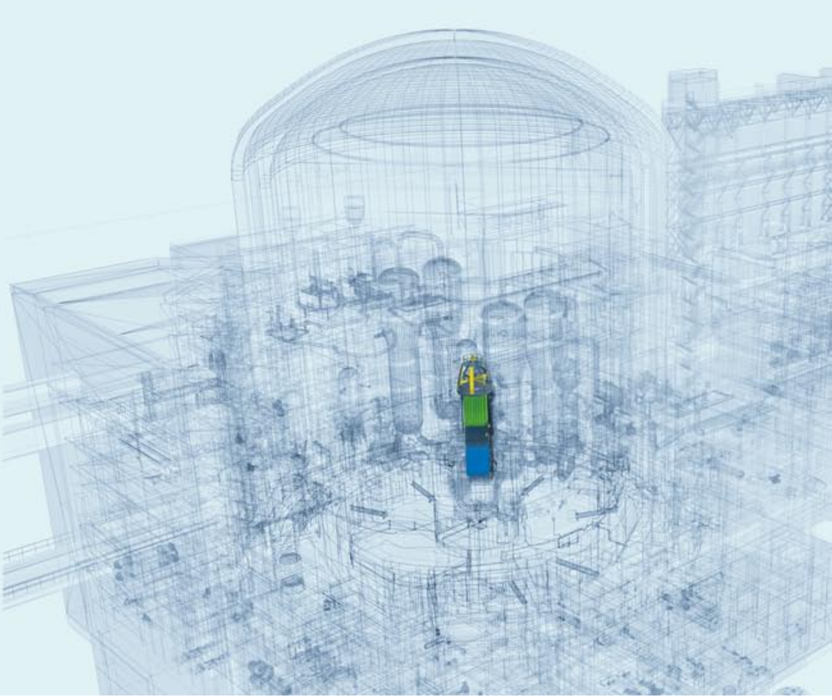
Transferring fuel out of and into the core

The refuelling machine lifts a fuel assembly out of the reactor core and transfers it to the transfer container, which is in a vertical position. The transfer mechanism turns the transfer container to a horizontal position and moves it from the reactor building through the transfer tube to the fuel building. The container is again turned to a vertical position, and the spent fuel mast bridge lifts the fuel assembly out and transfers it to the spent fuel storage rack in the spent fuel pool.

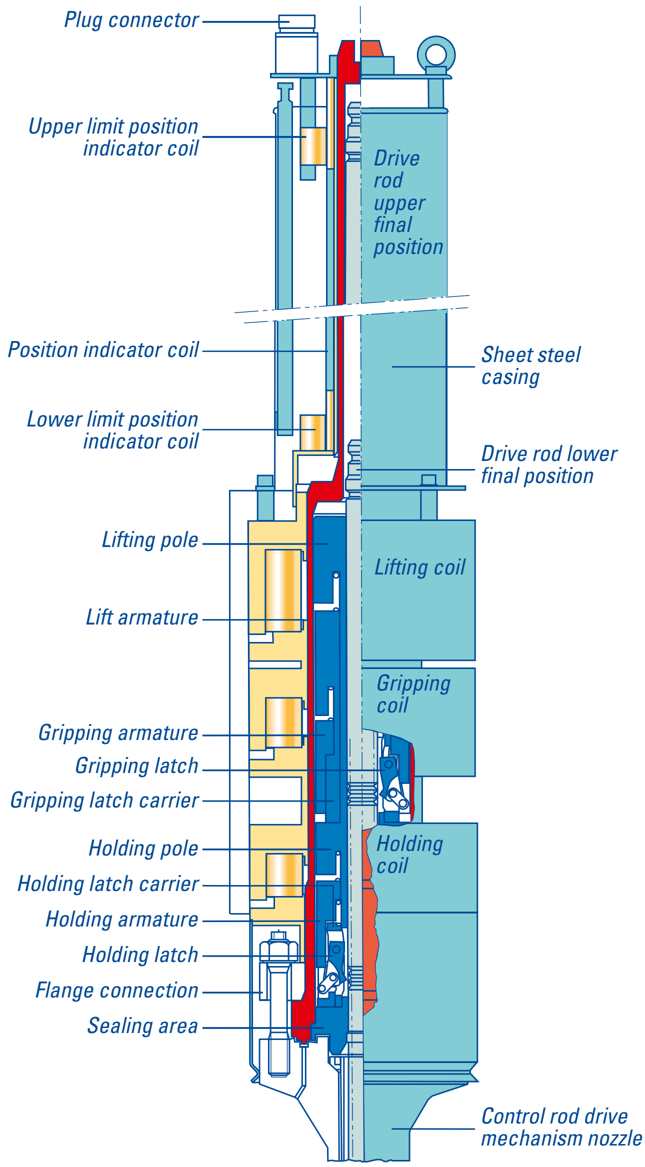
Installing new fuel assemblies in the core is performed using the same process in reverse.

Fuel transfer systems in the reactor building and fuel building





Cross-section of control rod drive mechanism



Control rod system properties

Rod cluster control assemblies	
Number	89 pcs
Weight	61.7 kg
Control rods per assembly	24
Absorber	
B4C part (upper part)	
- natural boron	19.9% B^{10} atoms
- specific weight	1.79 g/cm³
- external diameter	8.47 mm
- length	1,340 mm
AIC part (lower part)	
- weight composition: silver, indium, cadmium (%)	80,15, 5
- specific weight	10.17 g/cm³
- external diameter	8.65 mm
- length	2,900 mm
Cladding	
Material	stainless steel
Surface treatment (external surface)	ion nitrification
External diameter	9.68 mm
Internal diameter	8.74 mm
Filling gas	helium
Control rod drive mechanisms	
Number of drive mechanisms	89 pcs
Weight	403 kg
Lifting power	>3,000 N
Travel range	4,100 mm
Stepping speed	375 mm/min or 750 mm/min
Maximum scram time allowed	3.5 sec
Materials austenitic and martensitic stainless steel	

Reactor operation and control

The control assemblies are one system to control the reactor power. In addition to short-term power control, they also flatten vertical power distribution in the reactor core. In the long term, decreasing the boron content helps compensate for the loss of reactivity due to fuel burnup.

Control rod system

The control rod system is a part of the reactor power control system. It consists of the control assemblies formed with control rods, the control rod drive mechanisms and the control rod drive mechanism operating system. The system is used for controlling the reactor power and for a reactor scram. The control rods enter the core through guide thimbles in the fuel assemblies.

The control rod system is governed by the reactor control, surveillance and limitation system and manually by the control room operators. The reactor scram is triggered automatically by the protection system or its back-up system, a hardwired back-up system. An operator may also trigger the reactor scram manually.

The individual control rods of the reactor control assemblies move in the guide thimbles in the fuel assemblies. These guide thimbles are also used for placing instrumentation and neutron sources.

Control assemblies

There are 89 identical control assemblies. Each consists of 24 identical absorber rods attached to a single mount. The rods contain materials that absorb neutrons (silver, indium, cadmium and boron carbide). When the rods are completely inserted into the core, they almost totally cover the active length of the fuel assemblies.

The control assemblies are divided into separate control groups. The majority of them, 53 elements, are in the shut-down bank, which executes a rapid shut-down of the reactor, or reactor scram, if necessary. The remaining 36 elements control the temperature of the primary circuit and flatten vertical power distribution in the reactor core.

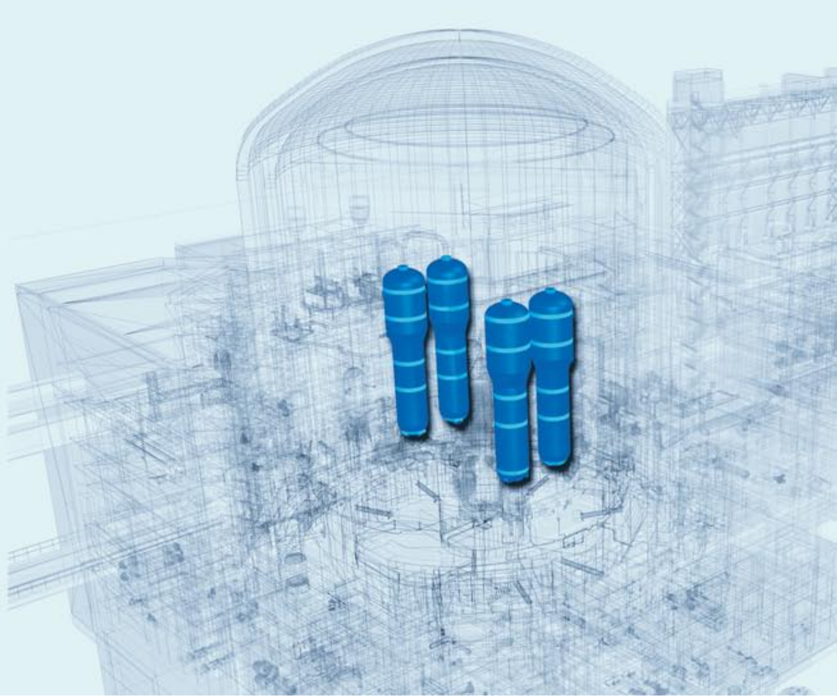
The control assemblies in the control bank are further divided into quadruplets, which are used in various drive sequences and insertion sequences depending on the refuelling interval in progress. The current insertion sequence and control assembly banks can be changed at any time regardless of the current reactor power.

The control bank in operation is regularly changed at intervals of about 30 days of power operation. This avoids fuel discharge burnup from affecting the effectiveness of the control and equalizes the burnup.

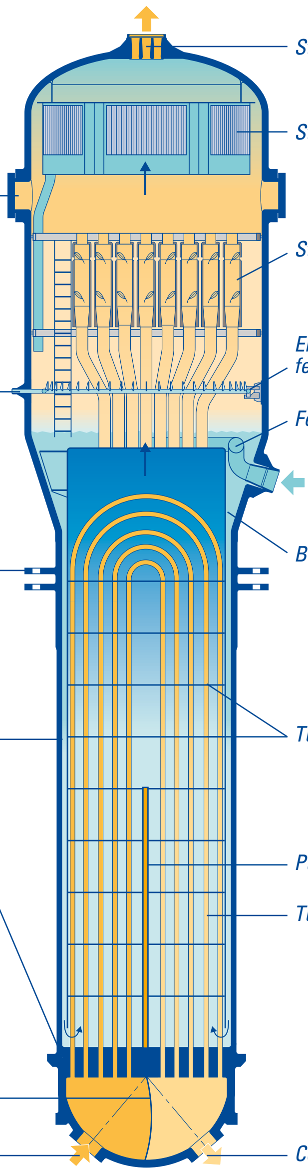
Control rod drive mechanisms

A control rod drive mechanism consists of the pressure housing with flange connection, the latch unit, the drive rod, the coils and their housings. The role of the control rod drive mechanisms in controlling the reactor is to move the 89 control assemblies throughout the length of the core and to keep them at any location required. Their secondary role is to drop the control assemblies into the reactor, thus stopping the chain reaction and shutting the reactor down in a number of seconds, particularly in a scram situation. When the reactor scram signal is activated, all operating coils are de-energized, the latches are retracted from the rod grooves, and the control assemblies drop into the core by force of gravity.

The control rod drive mechanisms are installed into adapters welded to the reactor pressure vessel head. Each drive mechanism is a separate entity that can be installed and removed independently of the others.



Cross-section of steam generator



Steam generator properties

Number of steam generators	4 pcs
Heat transfer surface per steam generator	7,960 m^2
Primary circuit design pressure	176 bar
Primary circuit design temperature	351°C
Secondary circuit design pressure	100 bar
Secondary circuit design temperature	311°C
Heat transfer tube external diameter / wall thickness	19.05 mm / 1.09 mm
Number of tubes	5,980 pcs
Triangular pitch	27.43 mm
Total height	23 m
Materials	
Tubes	Inconel 690 alloy, heat treated
Shell	18 MND 5*
Cladding tube sheet	Ni-Cr-Fe alloy
Tube support plates	13% Cr-treated stainless steel
Other	
Total weight	500 t
Feedwater temperature	230°C
Main steam moisture content	0.25%
Main steam flow	2,443 kg/s
Main steam temperature	293°C
Main steam saturated pressure	78 bar
Pressure during hot shut-down	90 bar

*low-alloy ferrite steel

Primary coolant circuit

Steam generators

A steam generator is a heat exchanger which transfers heat from the primary coolant circuit to the water in the secondary circuit. As in a typical heat exchanger, the contents of the primary and secondary circuits never come into direct contact with one another. The steam generator in an EPR power plant unit is of the vertical type.

The primary coolant passes through U-shaped tubes in the steam generator. The feedwater of the secondary circuit, which is to be turned into steam, circulates inside the shell of the steam generator. The steam separators and steam dryer at the top of the secondary circuit portion separate the steam from the water. The separated water returns down along the outer shell of the steam generator. The feedwater pipes continously refill the secondary side of the steam generator with water equivalent to the mass of steam fed into the turbine.

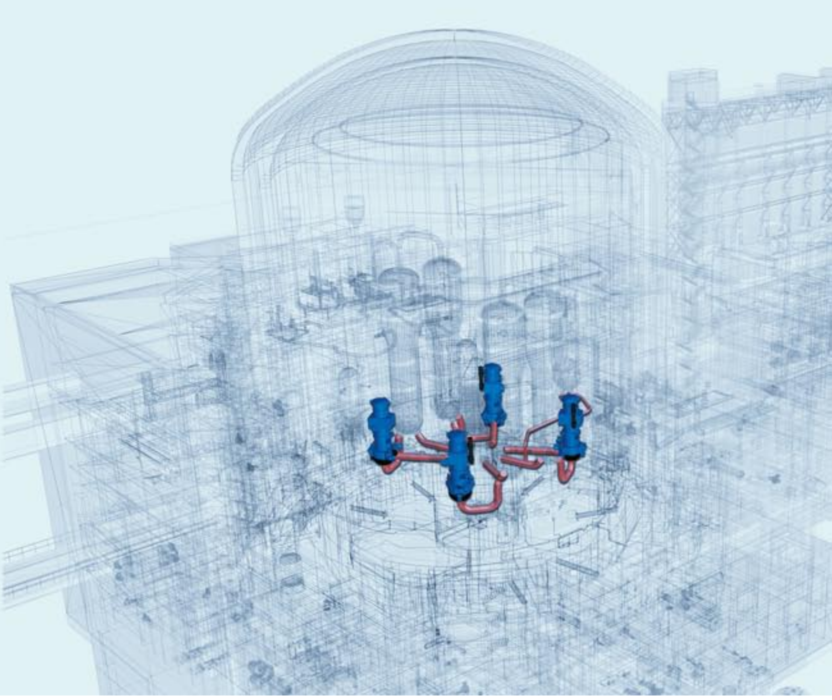
The axial feedwater preheater enables not only a larger heat exchange area but also a saturation pressure of 78 bar, which is a significant factor in the high efficiency (37%) of the power plant unit. The tubes in the steam generator are made of wear-resistant and corrosion-resistant alloy called Inconel 690, which has a cobalt content of less than 0.015%. The shell of the steam generator is made of 18 MND 5 steel.

The design concept, with the cold feedwater being mixed with only 10% of the warmer recirculated water, ensures a larger temperature differential and hence a more efficient heat transfer. As a result, the main steam pressure of the OL3 steam generator is 3 bar higher per unit of heat exchange area than that of power plant units which the design is based on. The efficiency of the steam generator is achieved through the asymmetrical conveying of feedwater into a discrete channel separated from the walls of the steam generator.

In the design of the OL3 steam generators, particular attention was paid to the prevention of cross-flows in the secondary circuit and of the adverse effects caused by thermal layering due to the efficient heat exchange. The steam space has been enlarged, increasing the steam volume.

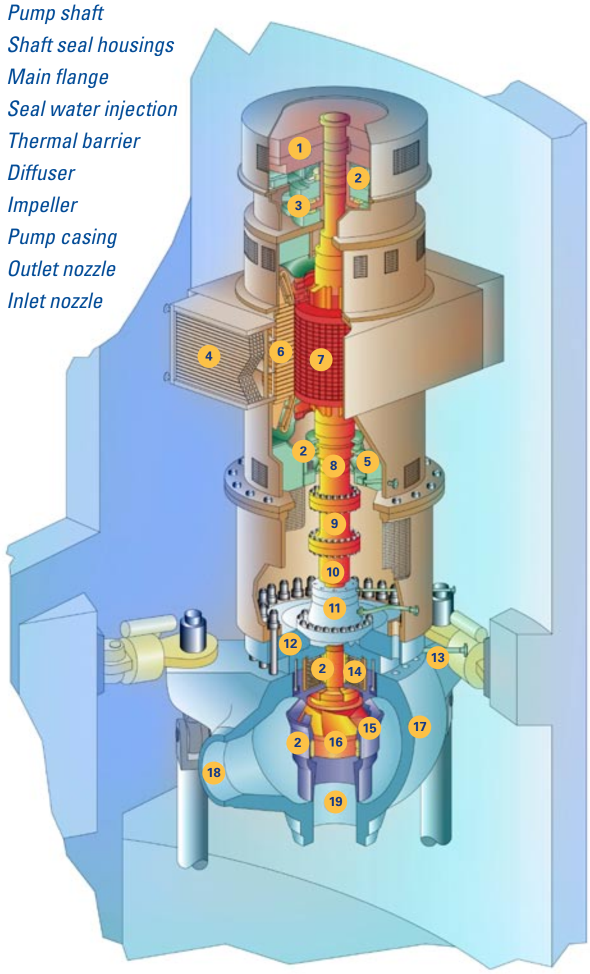
On the other hand, the steam generator also has a higher water volume than in the power plant units upon which the design is based. This improves the safety margin and increases the grace period in a situation where all feedwater systems malfunction and no cooling water is available for feeding into the steam generator.

kuva: Areva



Cross-section of reactor coolant pump

1. *Flywheel*
2. *Radial bearings*
3. *Thrust bearing*
4. *Air cooler*
5. *Oil cooler*
6. *Motor (stator)*
7. *Motor (rotor)*
8. *Motor shaft*
9. *Spool piece*
10. *Pump shaft*
11. *Shaft seal housings*
12. *Main flange*
13. *Seal water injection*
14. *Thermal barrier*
15. *Diffuser*
16. *Impeller*
17. *Pump casing*
18. *Outlet nozzle*
19. *Inlet nozzle*



Reactor coolant pump and pipe properties

Pump	
Number of pumps	4 pcs
Design pressure	176 bar
Design temperature	351°C
Primary coolant flow	28,330 m^3/h
Design head	100.2 m ± 5%
Seal water injection	1.8 m^3/h
Seal water return	0.680 m^3/h
Speed	1,465 rpm
Total height	9.3 m
Total weight without water and oil	112 t
Motor	
Rated power	9,000 kW
Frequency	50 Hz
Main circulation pipes	
Internal diameter	780 mm
Wall thickness	76 mm
Material	Z2 CN 19-10*
Pressurizer connection pipe	
Internal diameter	325.5 mm
Thickness	40.5 mm
Material	Z2 CN 19-10*

*low carbon stainless austenitic steel

Reactor coolant pump

The reactor coolant pumps provide forced circulation of water through the reactor coolant system. This circulation removes heat from the reactor core to the steam generators, where it is transferred to the secondary circuit. In each of the four loops of the primary circuit, the reactor coolant pump is located between the steam generator outlet and the reactor inlet.

The reactor coolant pumps have hydrostatic bearings, which ensure a low vibration level. The OL3 reactor coolant pumps have three separate shaft seals and an additional standstill seal which is operated by gas pressure.

A reactor coolant pump consists of three main parts: the pump itself, the shaft seals and the motor.

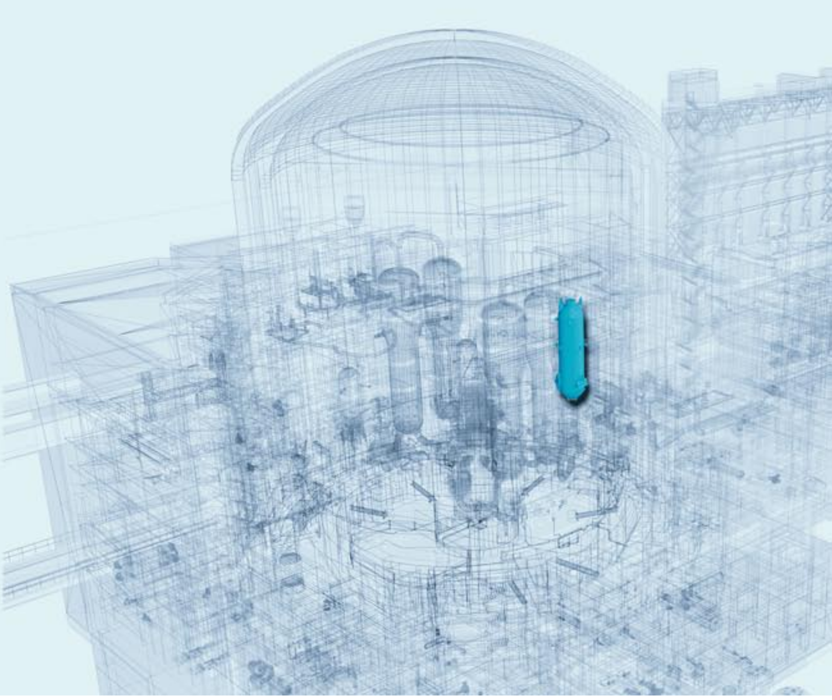
The pump hydraulic cell consists of the impeller, the diffuser and the suction adapter. The pump shaft is in two parts connected by a spool piece which can be removed for seal maintenance. The shaft is supported on three bearings: two oil-lubricated bearings in the motor and one hydrostatic bearing at the impeller. There is a double-action thrust bearing at the top of the motor shaft, under the flywheel, to compensate axial forces.

Reactor coolant pump at the Jeumont plant in France (N4, 1,500 MWe).

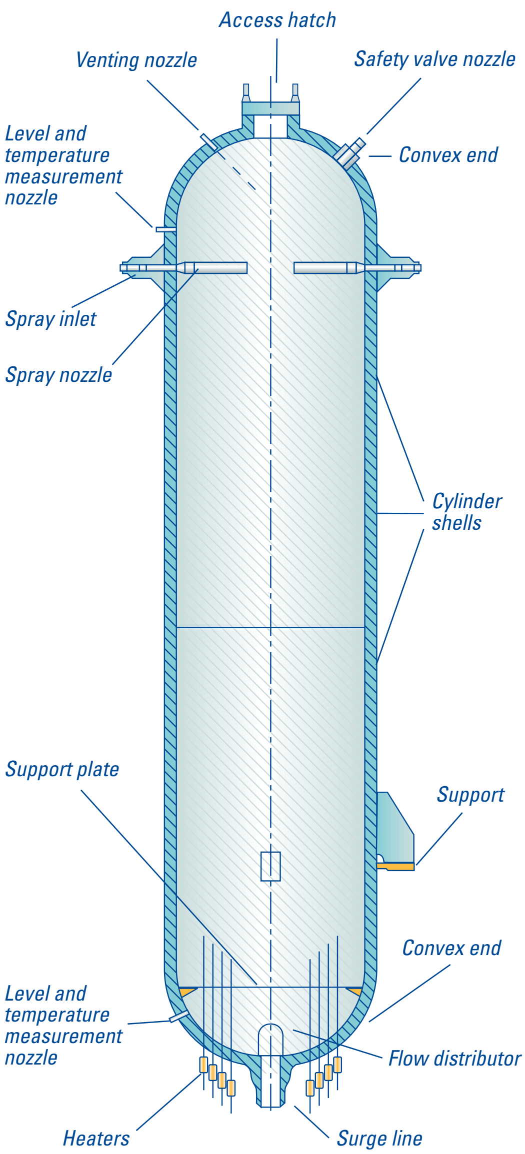
The shaft seal system consists of three dynamic seals assembled into a cartridge and a standstill seal. The first seal is a hydrostatically controlled leakage seal, which takes the full primary pressure. The second seal is a hydrodynamic seal which receives the remaining pressure but can also withstand the entire primary pressure if necessary. The third seal is also hydrodynamic and is a backup leak seal. The standstill seal ensures that no primary coolant is lost in the event of a loss of power or the simultaneous malfunction of all shaft seals when the pump is stopped.

When the pump is in operation, the shaft seals are cooled and lubricated with seal injection water which is injected below the seals at a pressure slightly higher than that of the primary coolant. The third shaft seal, which is a backup to the first two, receives its cooling water from the demineralized water distribution system.

The motor is a drip-proof squirrel-cage asyncronous motor. A spool piece placed between the pump and the motor shafts and the shaft seal housing structure enable maintenance to be carried out on the seal pack without removing the motor.



Cross-section of pressurizer



Pressurizer properties

Design pressure	176 bar
Design temperature	362°C
Total volume	75 m^3
Total length	14.4 m
Base material	18 MND 5*
Cylindrical shell thickness	140 mm
Number of heaters	108
Total weight, empty	150 t
Total weight, filled with water	225 t
Number of safety valves and capacity under design pressure	3 x 300 t/h
Relief valve capacity under design pressure (doubled for valves)	1 x 900 t/h

* low-alloy ferrite steel

Pressurizer

The pressurizer contains primary coolant in its lower part and steam in its upper part. The pressurizer is part of the primary circuit and is connected through a surge line to the hot leg of one primary loop. The purpose of the pressurizer is to keep the pressure in the primary circuit within specified limits.

The pressure in the primary circuit is controlled by regulating the steam pressure. For this purpose, the pressurizer has heaters in its lower part to produce steam and a spray system in its upper part to condense steam into water.

The pressure-relief and safety valves at the top of the pressurizer protect the primary circuit against excessive pressure. There are two parallel pressure-relief lines with valves which the operators can use, in the case of a severe accident, to relieve pressure quickly in the primary circuit: the primary coolant released from the primary circuit is discharged to the pressurizer relief tank, where a rupture disk breaks and releases the coolant into the containment building. There the steam condenses into water, which is collected in the emergency cooling water storage tank at the bottom of the containment building and pumped back into the reactor.

The maintenance platform running around the pressurizer facilitates heater replacement and reduces radiation doses during valve maintenance.

All components of the pressurizer shell, except for the heater penetrations, are made of forged ferrite steel with two layers of cladding. The material is the same as in the reactor pressure vessel. The heater penetrations are made of stainless steel and are welded using a corrosion-resistant alloy. The pressurizer supports are welded to its frame.

Compared with plants which the design of OL3 is based on, the volume of the pressurizer has been increased in order to smooth the response to operational transients.

Main coolant lines

The main coolant lines of the four loops that form the primary circuit and the pressurizer surge line are part of the reactor coolant system in the reactor building. The main coolant lines convey the primary coolant from the reactor pressure vessel to the steam generators and onward to the reactor coolant pumps, which return the coolant to the pressure vessel. One of the four loops is connected to the pressurizer.

Each of the four loops has three parts: the hot leg from the reactor pressure vessel to the steam generator, the crossover leg from the steam generator to the reactor coolant pump, and the cold leg from the reactor coolant pump to the reactor pressure vessel.

The main circulation pipes are made of forged austenitic stainless steel, which is resistant to thermal fatigue and can be inspected using ultrasound.

kuva: Areva

1 *Moisture separator reheater (MSR)*
2 *High-pressure turbine*
3 *Low-pressure turbine*
4 *Condenser*
5 *Generator*

SECONDARY CIRCUIT

The purpose of the steam-water secondary circuit in the turbine plant is to convert the thermal energy of the main steam entering from the nuclear island into electrical energy through the turbine and generator as efficiently as possible and to return the secondary-circuit feedwater to the steam generators in the reactor plant. There is no radioactivity in the secondary circuit because the water of the primary and secondary circuits are separated from each other.

Main steam system

The main steam generated in the steam generators belonging to the primary circuit is fed to the turbine plant through the four main steam lines. The main steam is fed to the high-pressure (HP) turbine through the high pressure turbine stop and control valves located in each main steam line. Every main steam line has a relief train, safety valves and an isolation valve in the event of abnormal operation. The steam is conveyed through the relief system and the safety valves straight into the atmosphere.

The exhaust steam from the HP turbine is dried and reheated in the moisture separator reheaters (MSR). The reheating is performed in two stages, using extracted steam from the HP turbine extraction A7 and from the main steam extracted between the HP turbine stop and control valves.

From the MSRs, the reheater steam goes through the LP turbine stop and control valves to the three LP turbines.

The exhaust steam from the LP turbines is condensed in three separate sea water condenser units. In addition to condensing the steam from the LP turbines, the turbine bypass steam is also condensed in these condenser units.

The purpose of the turbine bypass steam system is to control the main steam pressure depending on the power plant operation mode.

Main condenser and condensate system

There are three condensate extraction pumps (CEP), two pumping the main condensate from the condenser condensate chambers (hot wells) to the feedwater storage tank through the low-pressure feedwater preheating system. The third pump acts as a stand-by pump.

The main condensate is preheated in four low-pressure feedwater heating stages to improve the efficiency of the steam-water process. The main condensate system also contains a mechanical condensate purification system for removing impurities.

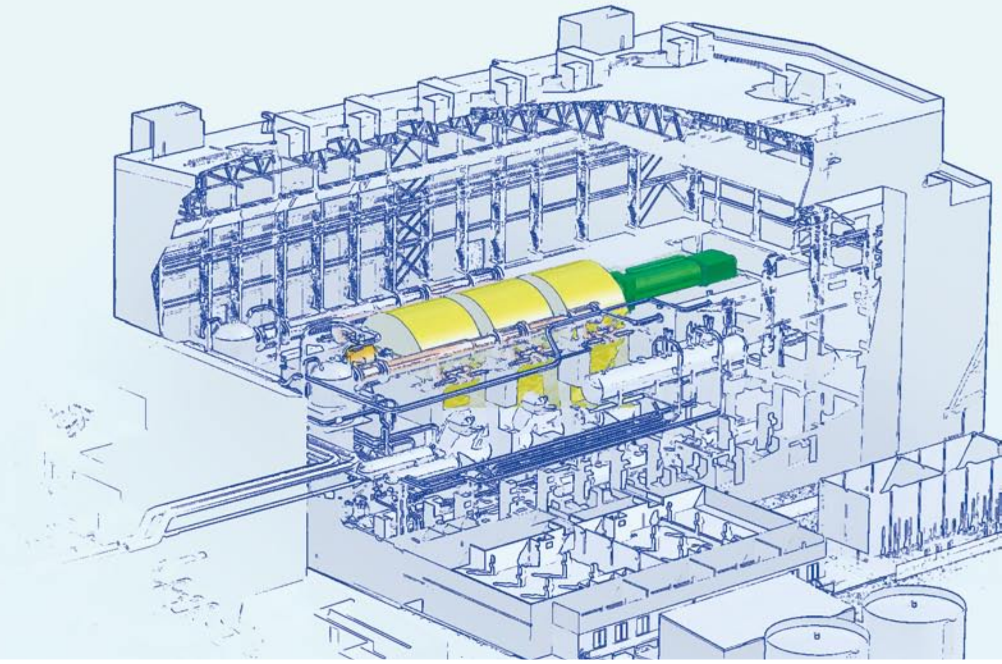
Feedwater system

There are four feedwater pumps, three pumping feedwater from the feedwater storage tank through the high pressure feedwater preheating system to the steam generators. The fourth pump acts as a stand-by pump.

The feedwater is preheated in three feedwater heating stages in two trains, each train consisting of two high-pressure feedwater preheaters and the reheating stage 2 condensate coolers. The steam is extracted into the high-pressure feedwater preheaters from the HP turbine extractions A7 and A6. From the preheating system, the feedwater is conveyed through the feedwater valves in the safeguard building divisions into the steam generators.

The OL3 LP turbines are double-flow turbines with running blades attached to blade wheel discs shrunk on to the turbine shaft.

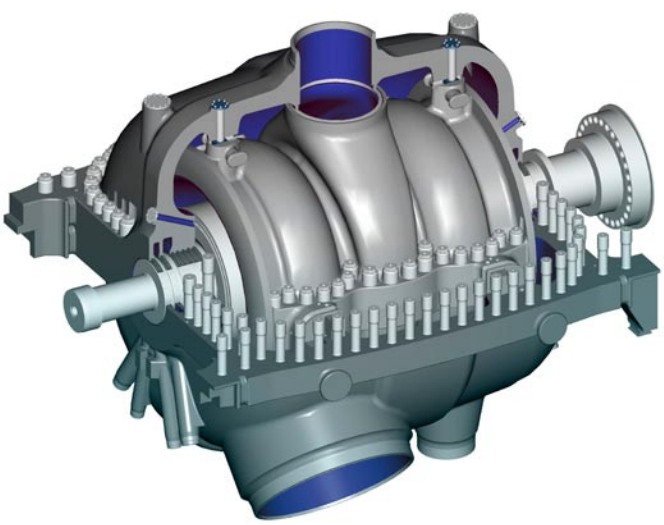
(Source: Siemens)



Turbine plant main figures

General	
Gross electrical output	1,720 MWe
Net electrical output	1,600 MWe
Main steam pressure (HP turbine)	75.5 bar
Main steam temperature	290°C
Steam flow	2,443 kg/s
Rated speed	1,500 r.p.m.
HP turbine	1
LP turbine	3
Last expansion stage	
- exhaust area	30 m^2
- last stage blade (LSB) airfoil length	1,830 mm
- overall diameter	6,720 mm
Length of turbine-generator rotor train	68 m
Condenser	
Cooling surface	110,000 m^2
Cooling medium	sea water
Cooling water flow	53 m^3/s
Vacuum at full load	24.7 mbar abs.
Sea water temperature rise	12°C
Feedwater	
Preheating stages	7
Final feedwater temperature	230°C

The HP turbine is a double-flow turbine consisting of inner and outer casing structures split horizontally.



Turbines and generator

The thermal energy generated in the reactor is converted to mechanical energy by the turbines and then to electricity by the generator. The high 1,600 MWe power output of OL3 is partly due to the high efficiency of the turbine-generator set.

The single-shaft turbine-generator set consists of one HP turbine and three LP turbines, a generator and an exciter. Each turbine rotor is mounted on two bearings, i.e. there are double bearings between each turbine module.

The rated speed of the turbine-generator is 1,500 r.p.m., and its shaft length is 68 m. The planned service life of the replaceable components of the turbine is 30 years, and the planned service life of the turbine plant as a whole is 60 years.

Turbine bearing structures being installed at the turbine hall floor level. The bearing pedestals are being aligned and installed on the turbine foundation.

HP turbine

The OL3 HP turbine produces about 40% of the gross power output of the power plant unit (650 MWe). It is a admission double-flow reaction turbine consisting of following main components:

- inner casing (cast, machined)
- outer casing (cast, machined)
- rotor (6.26 m and 100 t, forged and machined)
- 12 expansion stages, stationary blade and running blade stages

The inner and outer casings of the HP turbine are formed with horizontally split inner and outer casing constructions. The inner casing is attached to the outer casing construction. The stationary blades of the HP turbine and the running blade seal strips are attached to the HP turbine inner casing. The shaft seal constructions are attached to the HP turbine outer casing.

The HP turbine rotor is machined from the forging. The running blades of the rotor and the stationary blade seal strips are attached to the rotor machined blade and seal strip grooves.

LP turbines

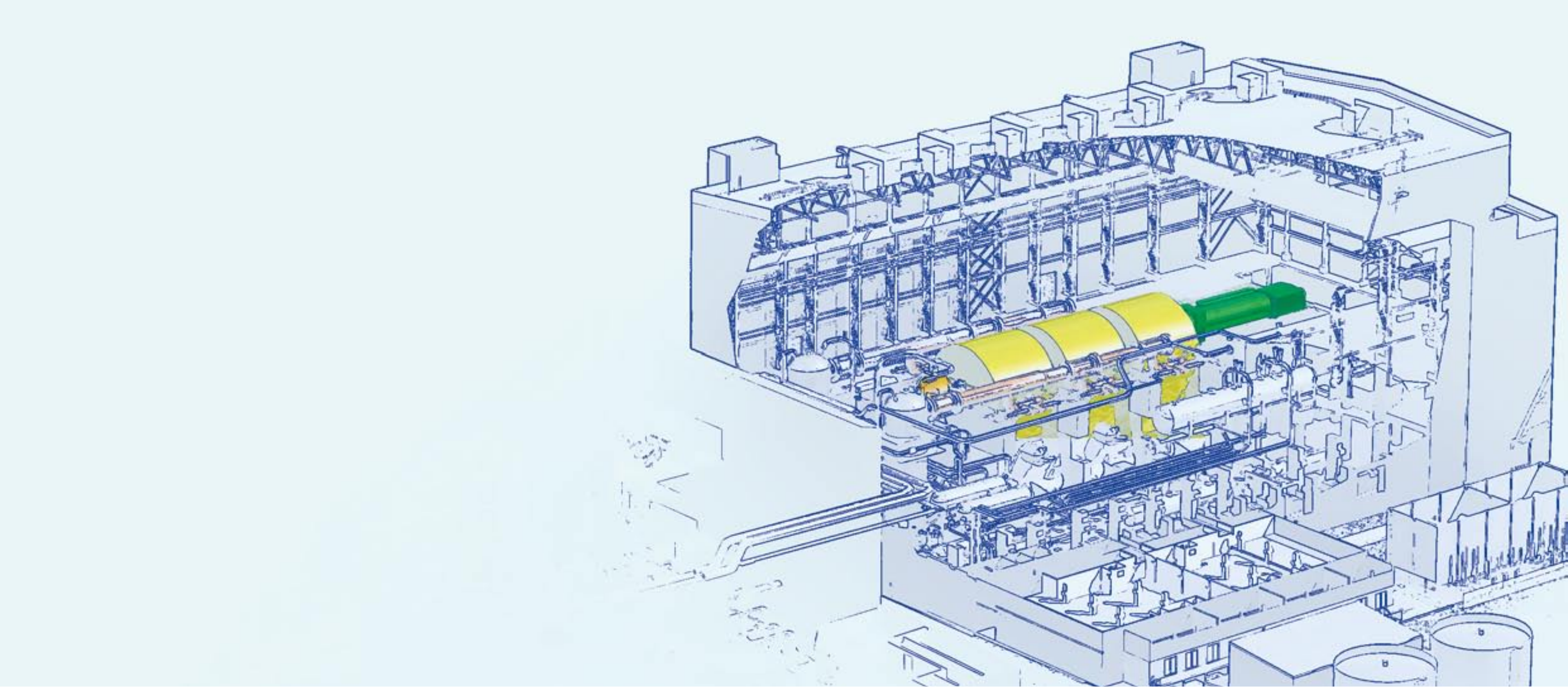
The three OL3 LP turbines produce approximately 60% of the gross power output of the power plant unit (approximately 320 MWe each). LP turbines are double-flow reaction turbines consisting of following main components:

- inner casings
- outer casings
- 9 expansion stages, stationary blade and running blade stages (6 stages with shrouded blades and 3 stages as free-standing blades)
- rotor (forged and machined spindle shaft where shrunk-on fitted forged and machined blade wheel discs)

The inner and outer casings of the LP turbines consist of inner and outer casing constructions split horizontally. The inner casing of an LP turbine is attached to the turbine foundation structure, and the outer casing is welded permanently to the condenser construction, which is supported by the base foundation structures. The stationary blades and running blade seal strips are attached to the inner casing structures. The thermal expansion of the outer casing structures is separated from the inner casing and rotor construction of the LP turbines.

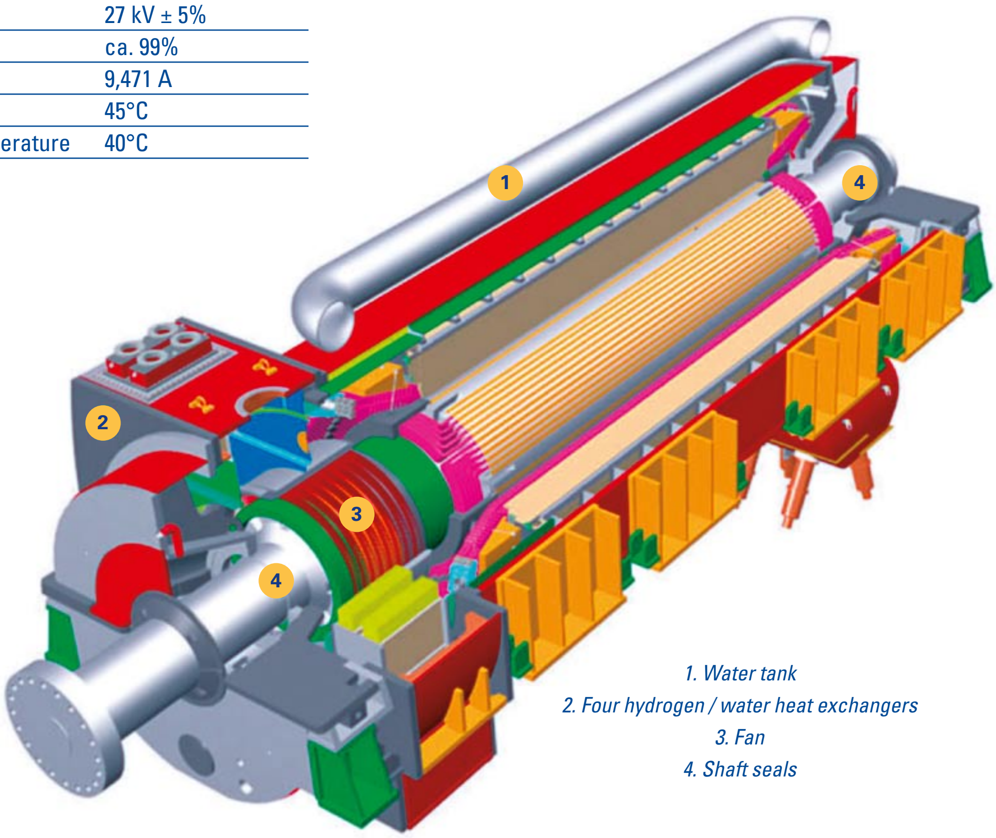
The LP turbine rotor consists of a through-bored spindle shaft with eight blade wheel discs (four for each flow) shrunk-on fitted. The coupling flanges of the LP turbine rotors are also partly secured to the rotor shaft with a shrink-on fit.

The running blades and stationary blade seal strips of the LP turbine are attached to grooves machined in the blade wheel discs. The first six running blade stages are so called drum stages and have blade bands, and the last three blade stages are so called free-standing blades. The exhaust area of the last running blade stage is 30 m^2, produced by the 1,830 mm profile length of the last running stage blades (LSB). The stationary blades in the last stage are hollow vane type, and part of moisture of the expanding steam is separated via cuts on the hollow vane before the LSB stage.



Generator properties

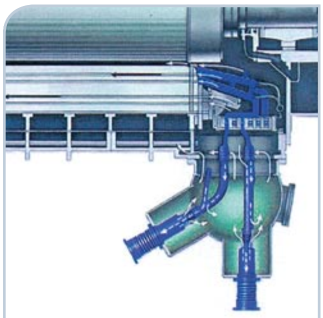
Rated speed	1,500 r.p.m.
Frequency	50 Hz
Effective power	1,793 MWel
Nominal rating	1,992 MVA
Power factor	0.9
Voltage	27 kV ± 5%
Efficiency	ca. 99%
Magnetization current	9,471 A
Cooling water temperature	45°C
Hydrogen cooling medium temperature	40°C



1. Water tank
2. Four hydrogen / water heat exchangers
3. Fan
4. Shaft seals

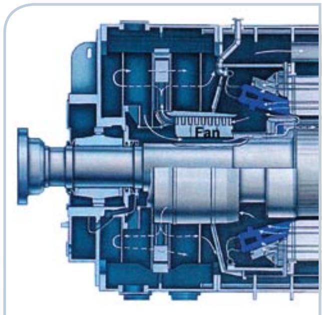
Generator

The OL3 generator is a four-pole, hydrogen-cooled generator with a brushless excitation system. The stator winding and the winding terminals are water-cooled.

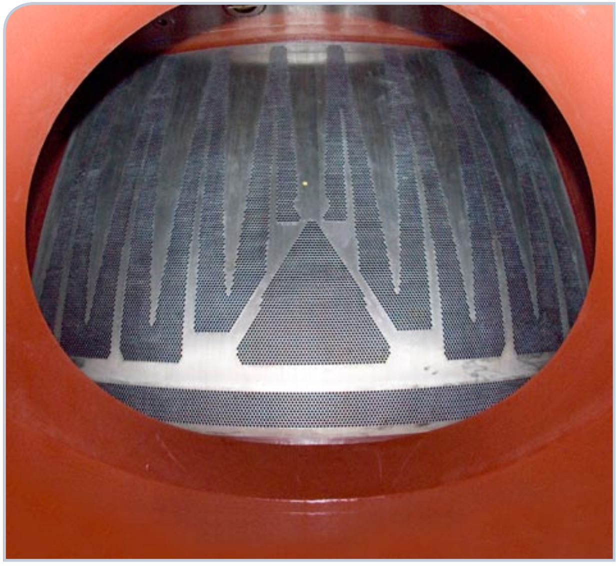


The generator output terminals transfer the electricity generated through the bus duct to the main transformer and onward to the national grid.

The rotor windings are cooled using hydrogen, which is conveyed axially through the windings at a pressure of 5 bar. The hydrogen is cooled in the hydrogen/water heat exchangers. The hydrogen circuit inside the generator is powered by a multi-stage fan mounted on the rotor.



The hydrogen-cooled generator rotor rotates at 1,500 r.p.m., weighs 250 t and is almost 17 m long.



Construction of cooling water tubes for condenser unit.

Sea water chambers in condenser unit installed in place.

One sea water chamber for a condenser section weighs about 250 t. There are six of them in total, two for each LP turbine.

Condenser

The exhaust steam from the LP turbines is condensed into water in the condenser. There is a condenser unit under each LP turbine, divided into two separate sea water chambers. The structural design allows one sea water chamber to be removed and inspected without turbine shut-down.

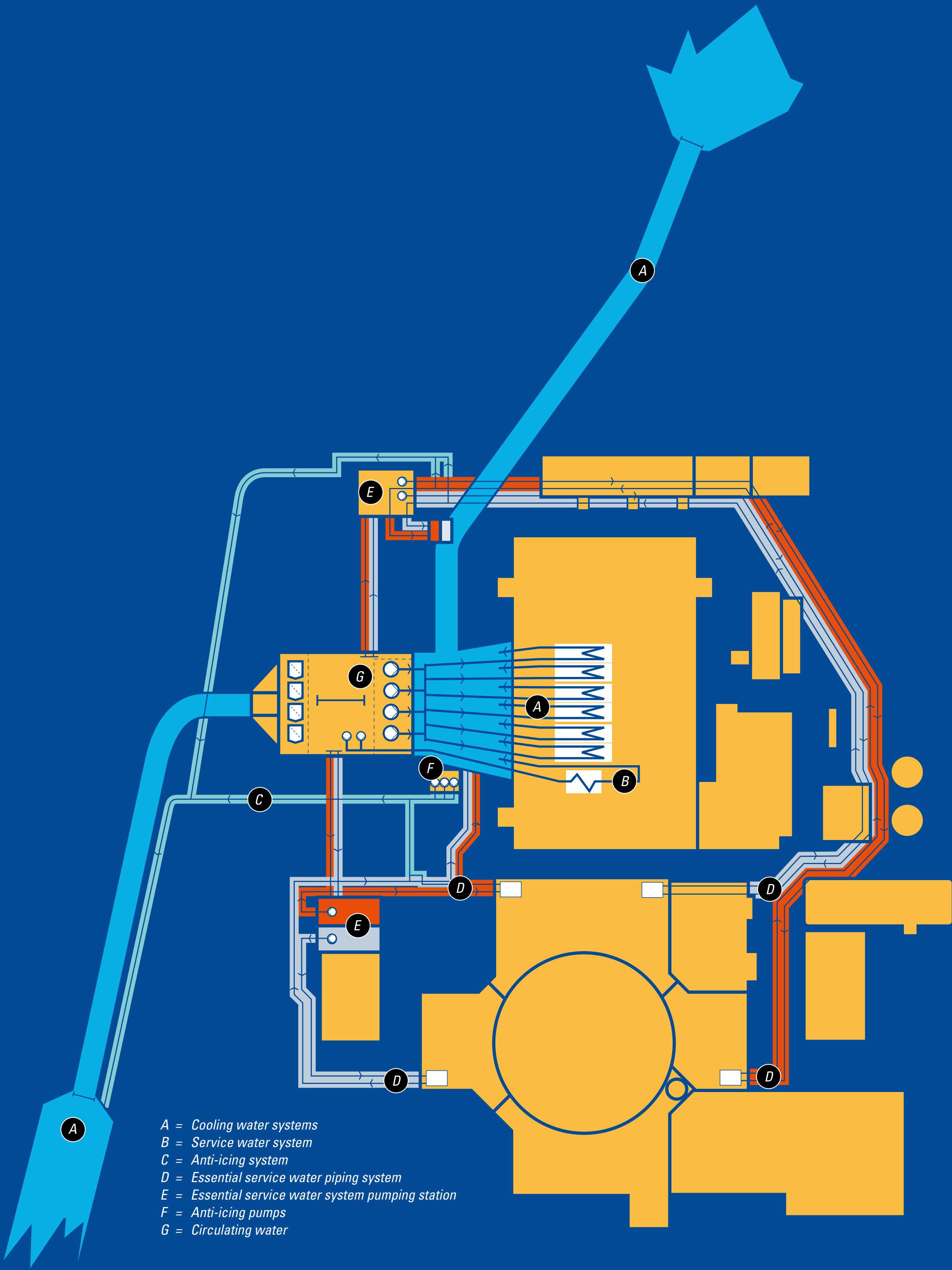
In addition to condensing the exhaust steam from the LP turbines, the condenser receives condensate and gas flows extracted from various process systems.

The condenser has a total cooling surface of about 110,000 m^2. The tube material used is titanium, which is highly resistant to sea water corrosion. The sea water used as coolant is fed into the tubes through the water chambers. The temperature rise of the cooling water in the condenser is about 12°C.

The condenser tubes are cleaned by feeding soft cleaning balls (Taprogge) into the cooling water flow and collecting them once they have passed through the condenser tubes.

The condenser must have a sufficient low vacuum in order to increase the power plant effeciency. The vacuum pump system maintains a sufficient vacuum in the condenser by extracting air and uncondensed gases.

Thermal treatment equipment for condenser welding.



A = Cooling water systems
B = Service water system
C = Anti-icing system
D = Essential service water piping system
E = Essential service water system pumping station
F = Anti-icing pumps
G = Circulating water

SEA WATER COOLING SYSTEMS

Sea water is conveyed along its own underground cooling water tunnel at a rate of 57 m^3/s into the OL3 pump station. Before entering the tunnel, major impurities are filtered out of the sea water with coarse screens. In the pumping station, the water is conveyed through four filtering lines to the sea water pumps. The filtering lines contain a fine screen and a chain basket filter to remove minor impurities from the sea water.

The cooling water intake tunnel has a cross-section of about 60 m^2.

The cooling water pumped by the sea water pumps is conveyed into a sea water condenser through the manifold shown below.

The pumping station contains four sea water pumps, which are vertically mounted in a concrete casing. Each pump conveys about 13 m^3/s of sea water to the condensers. To cool the power plant systems, 4 m^3/s of the total sea water flow is used. From the condenser, the water goes to a seal pit and then through the outfall tunnel to the sea. The outfall channel is shared with OL1 and OL2.

The safety system consists of four parallel trains, each capable of performing the required safeguard function on its own. The four parallel trains are located in separate buildings on different sides of the reactor building to eliminate the possibility of simultaneous failure.

NUCLEAR SAFETY

The general objective is to ensure the safety of the nuclear power plant so that its use causes no radiation risks to the health of employees or of people living in the vicinity, nor any other damage to the environment or property. The general principle is that no radioactive substances must ever be released into the environment.

In case of abnormal operation, OL3 has safety systems consisting of four redundant subsystems, each capable of performing the required safety function on its own.

Three functions are a prerequisite to ensure reactor safety under all circumstances:

1. Control of the chain reaction and of the power generated by it.
2. Cooling of the fuel also after the chain reaction has stopped, i.e. removal of residual heat.
3. Isolation of radioactive products from the environment.

Reactor safety is based on three protective barriers to prevent radioactive releases and on the defence-in-depth principle.

Three protective barriers

The concept of three protective barriers refers to a series of strong and leak-tight physical barriers between radioactive products and the environment. The barriers prevent releases of radioactive products in all circumstances.

First barrier

The uranium fuel in which radioactive products are formed is enclosed in a metal fuel rod cladding.

Second barrier

The primary circuit is a closed circuit made of thick steel. The reactor pressure vessel forms part of this circuit. The uranium fuel encased in metal fuel rods is within this vessel in the reactor core.

Third barrier

The primary circuit is completely enclosed by the leak-tight containment with massive concrete walls. The double concrete walls of the OL3 containment are built on a thick base slab, and the inner containment is covered with a leak-tight metal liner.

Any one of these barriers is tight enough to ensure that no radioactive materials can be released into the environment.

Safety features of OL3

OL3 represents evolutionary technology developed on the basis of the most recent German Konvoi plants and French N4 plants. The operating experience from these plants has been carefully studied and considered for the design of OL3. In the development process, the main focus has been on safety systems and the prevention of severe reactor accidents, as well as minimizing the damage caused by an accident.

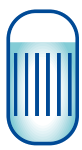
The design of the safety systems is based on quadruple redundancy of systems. It means that the systems consist of four parallel trains, each capable of performing the required safety task on its own. The four trains are physically separated and located in different parts of the reactor building in independent divisions.

Each of the four safeguard building divisions contains a low and medium-pressure emergency cooling system with the closed cooling and essential service water circuits cooling them, the steam generator emergency feedwater system, and the electrical equipment and instrumentation and control systems required for these systems.

1st barrier

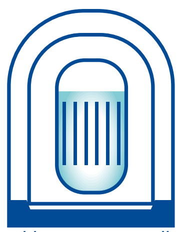
Ceramic uranium fuel enclosed in a metal fuel rod cladding

2nd barrier



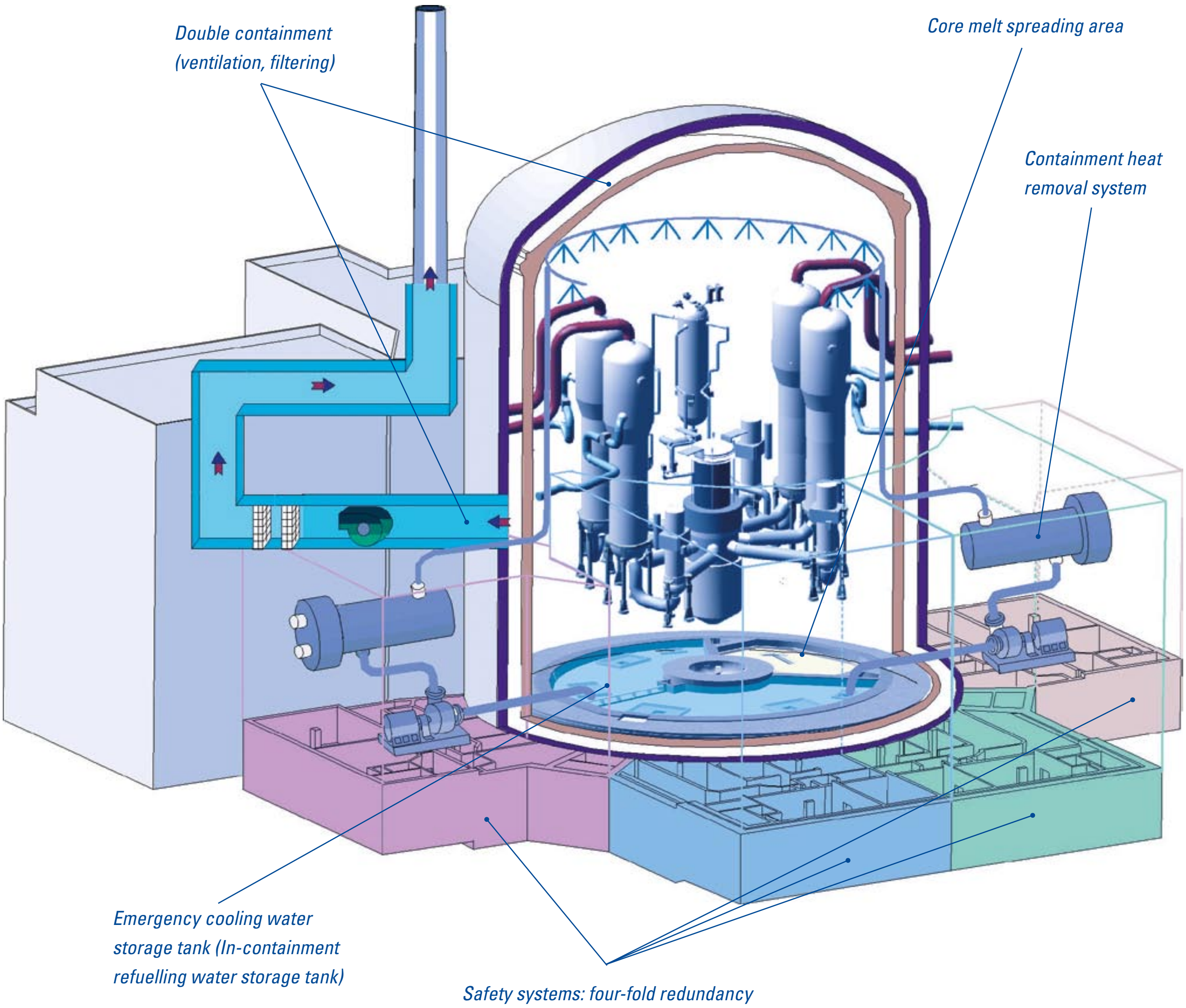
Reactor pressure vessel and primary circuit

3rd barrier



Double concrete walls of the gas-tight containment

Examples of principal safety features of Olkiluoto 3



The emergency cooling systems take their water from the in-containment emergency cooling water storage tank.

The probability of a serious reactor accident has been further reduced compared with earlier power plants by enhancing preventive systems. The OL3 systems have also been further developed to drastically limit the consequences of a severe accident.

Safety design

All the reactor protection and safety functions required to be instantly activated in an abnormal operating situation or accident are based on automatic systems. This allows for a planning period of 30 minutes for corrective actions by the plant control room.

The OL3 safety design is based on the concept that in the event of abnormal operation, the plant will automatically be transferred to a controlled state known as a hot shut-down and further, by manual control, to a stable cold shut-down. The controlled state is achieved by using the emergency feedwater system, the main steam relief train and the primary circuit emergency boron injection system. The level at which the residual heat removal system can operate (30 bar and 180°C) is attained by cooling through the secondary circuit and by lowering the pressure in the primary circuit. The emergency cooling or residual heat removal systems are then used to attain cold shut-down.

The volumes of the largest reactor components, i.e. the pressure vessel, the steam generators and the pressurizer, have been increased over previous plant designs to slow down the time progression of the reactor transients and to give the operators more time to initiate corrective actions.

The large steam volume of the steam generator means that it takes a long time to fill with water from the primary circuit in case of a ruptured heat transfer tube. The steam is conveyed from the damaged steam generator primarily to the condenser through the turbine bypass valves and not straight into atmosphere. When the condenser is not available, environmental releases from any leak between the primary and secondary circuits in the steam generators are minimized by lowering pressure through the turbine bypass relief valves and automatic isolation of the damaged steam generator. The activation pressure levels of the OL3 emergency cooling systems are lower than the pressure levels that open the steam generator safety valves so that in case of a leak between the primary and secondary circuits, the steam generator safety valves will not be actuated.

Emergency core cooling and residual heat removal system

The emergency core cooling system consists of low and medium-pressure injection pumps, nitrogen-pressurized pressure accumulators and the in-containment refuelling water storage tank. Under normal use, the system functions as a residual heat removal system when the plant unit is being powered down to a cold shut-down. The system consists of four separate divisions, each of which can independently pump water into the primary circuit using the low and medium-pressure injection pumps. Each subsystem is housed in its own safeguard building division and feeds into a different one of the four loops of the primary circuit. This arrangement ensures sufficient cooling capacity in case of loss of coolant.

Emergency boron injection

This design concept counteracts the rare event of a failed reactor scram. If the control assemblies fail to drop when the automatic scram conditions are actuated, the reactor coolant pumps stop and the emergency boron injection system, which has two lines and three pumps, starts up. The piston pumps used for emergency boron injection can pump boron-containing water at pressures up to 260 bar.

Residual heat removal

During normal use or in case of an accident, the excess energy and residual heat produced by the fuel can be transferred through the steam generators to the secondary circuit. The steam generators are provided with water through the feedwater system during normal use and the emergency feedwater system in case of an accident.

The emergency feedwater system consists of four separate parallel subsystems that are independent of each other, each of which feeds water into one of the steam generators. Each injection pump has its own emergency feedwater tank. The tanks and systems are housed in separate compartments in the safeguard building divisions.

Residual heat can be removed either through the steam generators to the secondary circuit and then through the condensers to the sea or by release of steam into the outside air through the main steam relief trains. In case of a complete coolant loss in the secondary circuit, pressure in the primary circuit can be lowered by steam discharge into the containment through the pressurizer relief lines or safety valves. In such cases, make-up water is injected into the primary circuit using the low and medium-pressure injection pumps, and the 2,000-tonne in-containment refuelling water storage tank is cooled using an intermediate cooling circuit powered by an emergency diesel generator, or using the independent containment heat removal system. Heat is transferred through the cooling chain formed by the reactor cooling system, the closed cooling water system and essential service water system to the ultimate heat sink. The suction pipes of the safety systems have a guard pipe up to the first isolation valve to prevent water loss in case of a suction pipe break.

Essential service water system

The essential service water system is a safety system consisting of four physically separated pumping chains housed in the four safeguard building divisions. The system transfers heat from the heat exchangers of the closed cooling water system, which cools the safety systems, to the sea.

In addition to the four main chains, the essential service water system has two dedicated pumping chains which form part of the independent heat transfer chain that is used in case of a severe accident.

Preparedness for severe reactor accidents

In the design of OL3, a severe reactor accident is addressed: even if the multiple redundant and independent safety systems were all to fail, the impact of the event beyond the power plant site would be minor in terms of both time and range.

Situations that would result in a release of any significant amounts of radioactive products into the environment have been virtually eliminated.

The integrity of the reactor containment building in case of a core meltdown is ensured with structures that retard the progression of core melt and a passive core melt cooling system. At the bottom of the containment, there is a core melt spreading area consisting of a metal structure (core catcher) covered with a 10 cm layer of sacrificial concrete. The purpose of the catcher is to cool the core melt and to protect the base slab of the reactor building against damage that might lead to leaks. Water circulates in cooling channels under the core melt spreading area, and water will also rise above the core melt. The large area of the core catcher (170 m^2) ensures cooling of the core melt.

If the reactor pressure vessel fails, the core melt is collected at the bottom of the reactor pit. The transfer of core melt from the reactor pit into the spreading area is initiated as a passive event, with the hot core melt forcing its way through the aluminium plug into the core catcher. The 50 cm layer of sacrificial concrete over the aluminium plug melts into the core melt, delaying the failure of the plug until all the core melt has accumulated in the reactor pit under the pressure vessel.

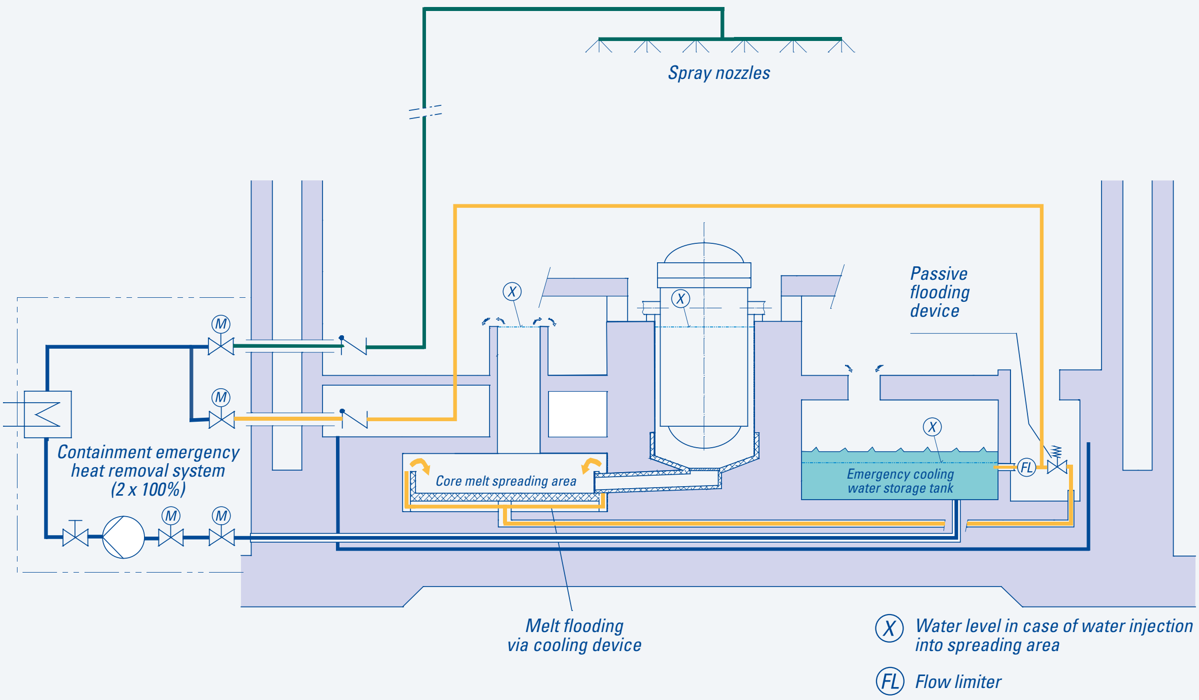
As the core melt enters the spreading area, the cooling system is passively activated. The sacrificial concrete over the core catcher melts into the core melt. Cooling continues as a passive process with water from a tank inside the reactor containment, flowing down by gravity into the channels under the core catcher and onto the core melt.

The efficiency of the cooling system is sufficient to solidify the core melt within a few days, after which the post-accident long-term management can begin.

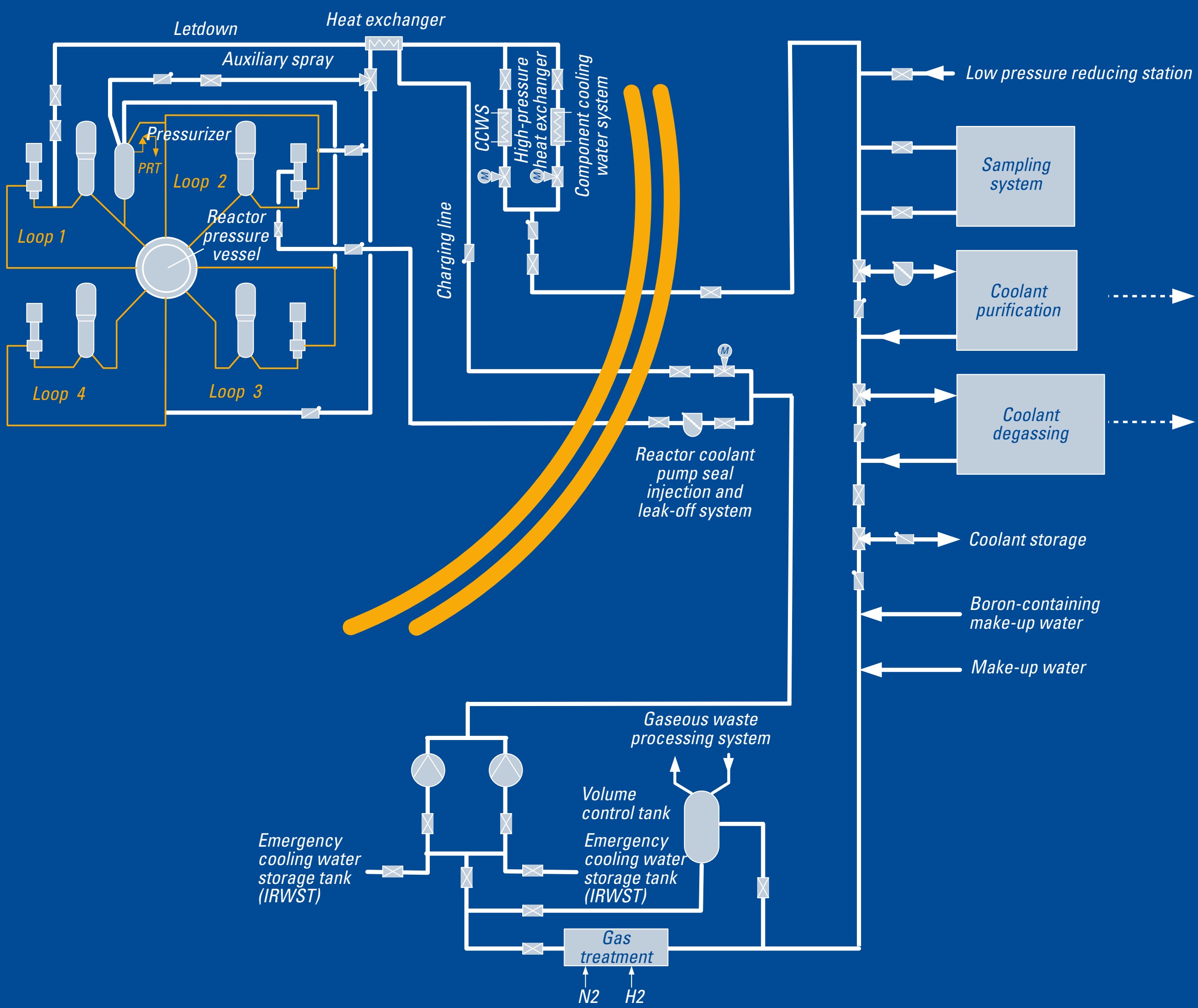

Photo: Areva

Core melt cooling system

In the highly unlikely event of a core meltdown at OL3, the core melt is transferred to the core melt spreading area, where it is cooled and solidified.



Coolant handling system



WATER CHEMISTRY AND VOLUME CONTROL SYSTEMS

OL3 has a total of about 120 process systems for handling liquid, steam and gas flows. The chemical and volume control system of the reactor plant is an essential one, acting as an interface between the high-pressure primary circuit and the low-pressure systems.

The coolant treatment systems manage the boron content in the primary circuit coolant, water chemistry, purification of the circulating coolant, injection and control of chemicals, dissolved gases in the coolant; and the degassing, handling and storage of extracted coolant in various situations. The systems are also used for preparing, storing and injecting the boron solution needed for various systems in the plant. During outages, the systems ensure the availability of make-up water needed in the draining and refilling of the primary circuit.

The most important of the coolant treatment systems is the chemical and volume control system, which is directly connected to the regulation of the chemical and physical properties of the coolant in the primary circuit, e.g. its boron content and volume.

The chemical and volume control system also manages the reactor coolant pump seal injection and leak-off. The volume control system inlet line is also the source of coolant for the pressurizer auxiliary spray system, which helps lower pressure in the pressurizer.

Boron is used in OL3 in the form of boric acid dissolved in water. The boron content of the primary circuit coolant is regulated by adding either pure water or boric acid solution to the coolant fed into the circuit, as required. The volume of the coolant added to and extracted from the primary circuit must be consistent with the running situation.

The boron content of the make-up water added to the primary circuit is monitored with double continuous-action measurement devices that control the automatic safety function.

Boron and make-up water system

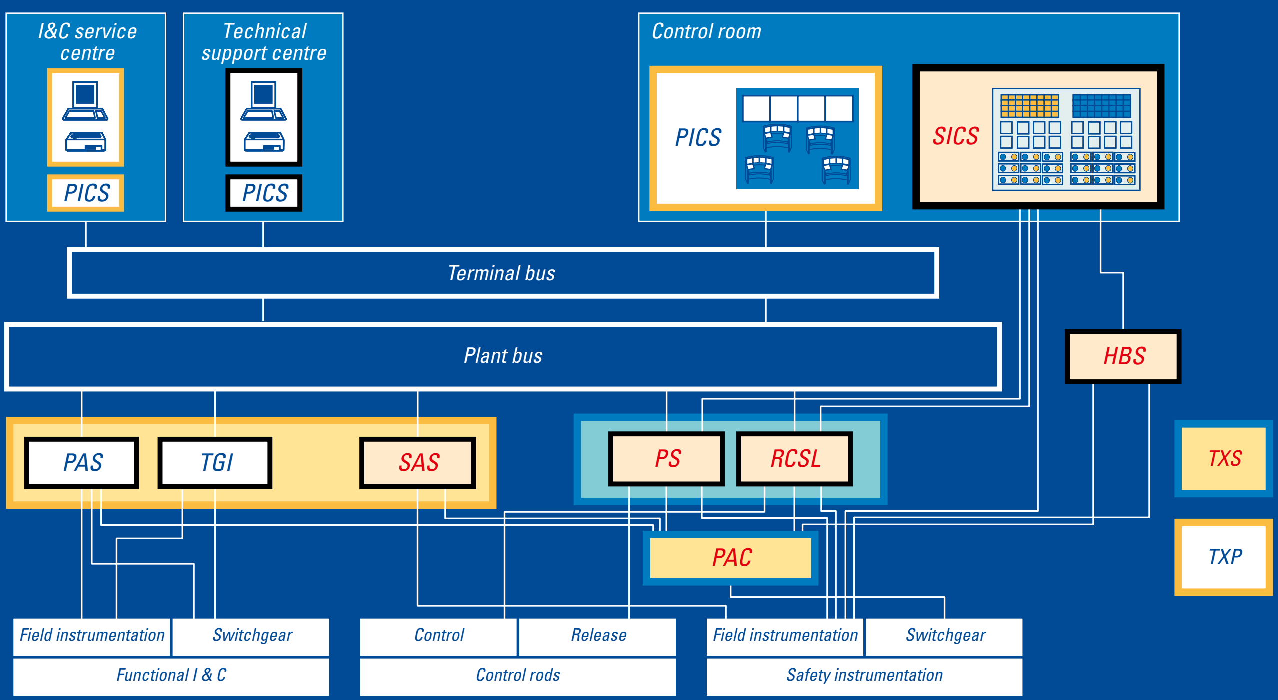
The boron in the coolant is enriched with regard to one of its two natural isotopes (B^{10}, ca. 30–32% by weight). Its purpose is to compensate for residual reactivity in the reactor core. The boric acid solution is stored at a concentration of 4%, which corresponds to about 7,000 ppm of boron. All the solutions required for the plant systems are made from this storage solution, using pure ion-exchanged water for diluting.

Controlling core reactivity

Core reactivity is at its highest at the beginning of the refuelling interval because of the fresh fuel. When fresh fuel is loaded into the core, all control rod assemblies are inserted, and the primary circuit, the reactor pool and the transfer pool are filled with a boron solution whose concentration is about 1,550 ppm. The boron injection system is always used when the reactor is powered down to a cold shut-down, so as to ensure the sub-critical state of the reactor regardless of its temperature. When the reactor is powered up, the control rod assemblies are first retracted, after which the boron level rod in the primary circuit is decreased by diluting until the critical level is reached. The boron level maintained during use is always less than 1,200 ppm.

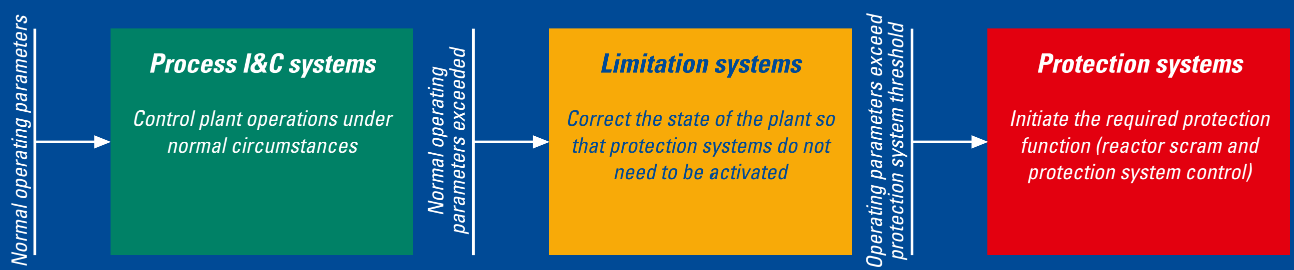
Slow changes in power output over the long term and the decline in the neutron flux due to fuel discharge burnup are compensated for by lowering the boron level gradually until it reaches a level of about 5 ppm just before refuelling.

Instrumentation & control systems architecture



SICS Safety information and control system
PICS Process information and control system
RCSL Reactor control, surveillance and limitation system
PS Protection system
SAS Safety automation system
PAS Process automation system
PAC Priority and actuator control
HBS Hardwired backup systems
TGI Turbine-generator instrumentation
TXS TeleprmXS protection automation system
TXP TeleprmXP automation system

Functional levels of Instrumentation & control system according to the safety concept



INSTRUMENTATION & CONTROL SYSTEMS

Instrumentation & control (I&C) systems consist of measurement devices, control systems and monitoring and surveillance equipment. Monitoring and surveillance equipment is used by the operators to monitor plant operations.

I&C systems of the plant unit are fully automated using tested digital technology, with traditional analogue technology as a backup. The system design of OL3 I&C focuses on safety and flexibility of use.

Functions of the instrumentation & control systems

The I&C systems follow the defence-in-depth principle, with three functional levels:

1. The process I&C systems maintain the situation of the plant unit within normal operating parameters.
2. If normal parameters are exceeded, the limitation systems take a corrective action to restore the normal situation.
3. If the operating parameters exceed any of the protection system threshold values, the reactor protection system automatically initiates the required safety measures (reactor scram and any situation-specific action required).

In accordance with the design concept, the protection I&C manages the initial response to any transient or accident so that no operator intervention is required until 30 minutes after the incident. This gives the operators more time to consider corrective actions and to follow the relevant transient or accident instructions.

The OL3 protection I&C and the safety systems actuated by it are generally four redundant. During the normal operation, the control room personnel use the workstations and displays in the control room to monitor and control the plant unit. If required, the plant unit can be taken into a controlled safe state from a separate remote shut-down station.

Architecture of the instrumentation & control systems

Each subsystem in the I&C system (measurements, controls, instrumentation, user interfaces) is classified according to their functional and safety significance, and they are divided according to their roles into levels 0, 1 and 2.

The I&C systems consist of the following levels:

- The process interface (level 0) consists of sensors and switches.
- The system automation level (level 1) consists of I&C circuits involved in reactor protection, reactor control, surveillance and limitation functions, safety and process automation.
- Process supervision and control (level 2) consists of the workstations and control panels in the main control room, in the remote shut-down station and in the technical support centre, and also the I&C systems which link the user information to the system-level instrumentation.

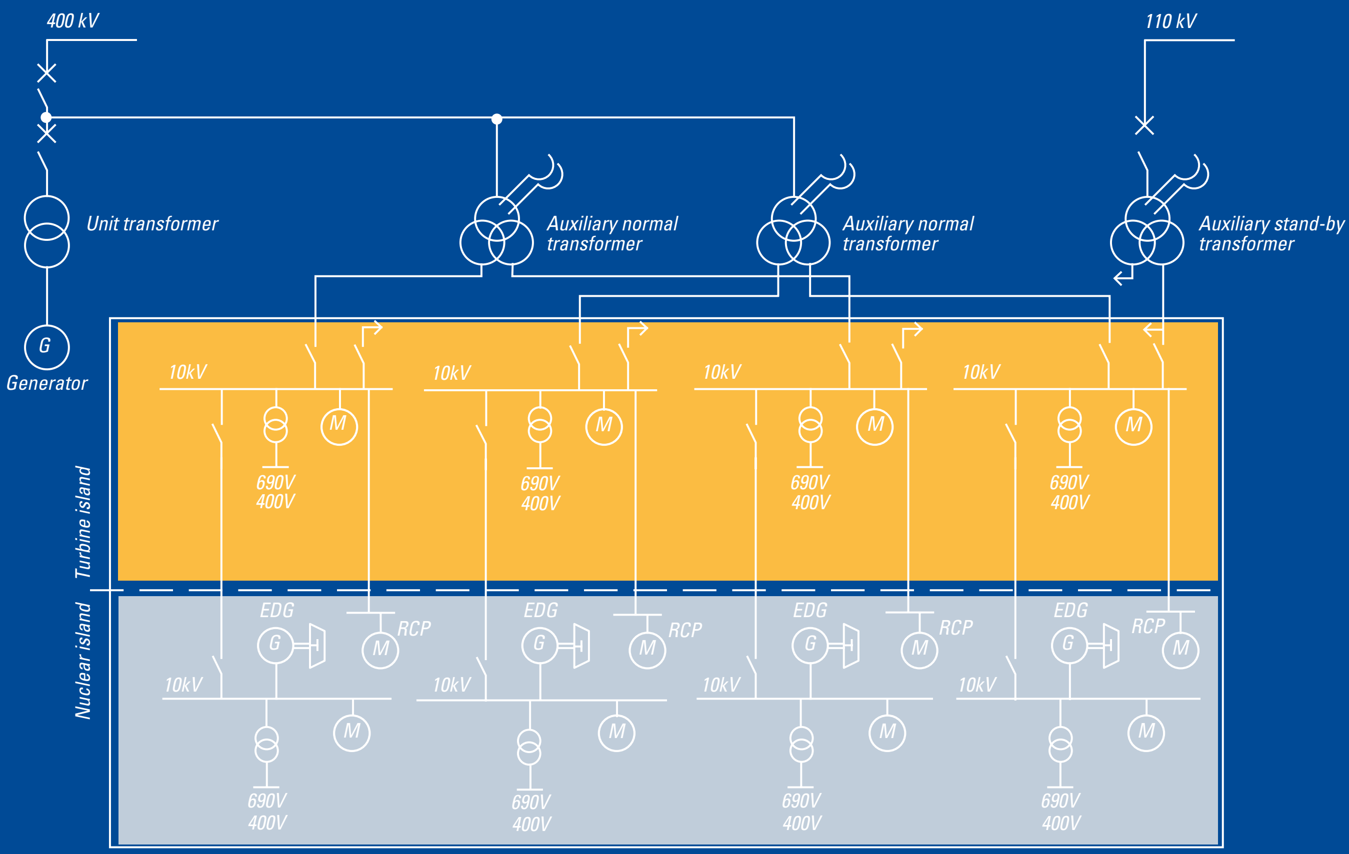
Safety classification of the instrumentation & control systems

The functions and equipment of the I&C systems, just like all other systems, are classified according to their nuclear safety relevance. The equipment used in the I&C systems fulfil the quality requirements required by the respective safety classification.

The OL3 I&C systems, their functions and equipment are designed to comply with the general principles of nuclear safety, including physical and functional separation and redundancy. For example, the emergency cooling system and emergency feedwater system, which each consist of four redundant and independent subsystems, also have four redundant and independent control system channels.

After the activation of the automatic functions of the protection system, actions by operators are needed. The potential of human error in the control room is reduced through redundant and mutually independent control and protection automation systems and advanced display technology. Also, OL3 is equipped with a separate hardwired backup system, which is independent of the digital I&C system.

Simplified schematic of the Olkiluoto 3 power plant unit



ELECTRICAL POWER SYSTEMS

The electrical power systems have two purposes: to transfer the electricity generated into the external grid and to supply and distribute the electricity needed by the power plant itself. The former function involves the generator busbar, the main transformer and the 400 kV switchyard and power line. The latter function involves the auxiliary unit transformers, medium-voltage switchgear, diesel generators and low-voltage distribution network.

The generator busbars between the generator and the main transformer are independent, single-phase busbars with earthed metal cladding. The main transformer consists of three single-phase units. The transformer is cooled with oil running through the coils, which is cooled by a separate, external water-cooling circuit.

The electricity needed by the power plant itself is taken from the 400 kV grid through two auxiliary unit transformers, which are backed up by an auxiliary stand-by transformer connected to the 110 kV grid. These two power supplies are independent of one another.

400 kV power line isolator chain.

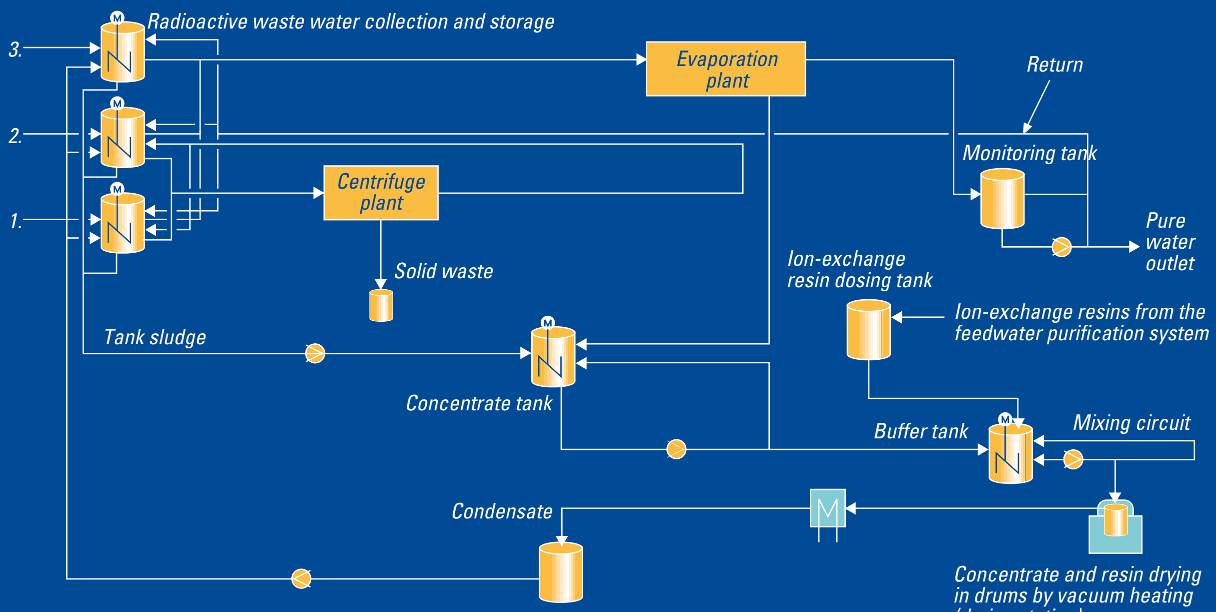
The reactor plant electrical power system is divided into four parallel and physically separated sub-divisions. The power supply to equipment critical for the safety of each division is backed up with a 7.8 MVA diesel generator. The busbars of the diesel generators can also be supplied by the Olkiluoto gas turbine plant.

The systems are designed to ensure sufficient capacity for maintaining nuclear safety even if one division fails and another is simultaneously out of operation due to maintenance.

Safety-critical systems are connected to backed-up electrical power systems. These are systems that ensure safe reactor shutdown and residual heat removal and prevent the spreading of radioactivity.

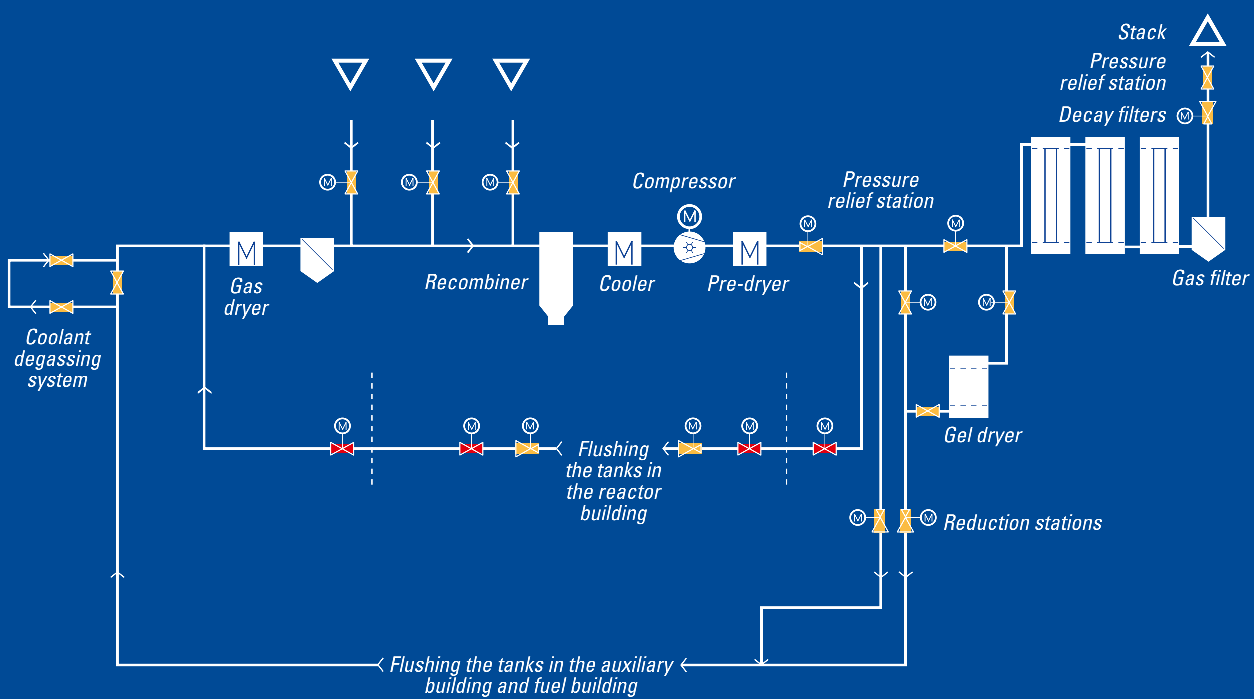
In case of the loss of all external power supplies, the malfunction of all four diesel generators at once, i.e. the complete loss of all AC power, the plant unit has two smaller diesel generators with an output of approximately 3 MVA each. These ensure power supply to safety-critical systems even in such a highly exceptional situation.

Liquid waste handling system schematic



1. Radioactive water from primary circuit and fuel pools, and decontamination water
2. Low-level radioactive water, e.g. from laundry and washrooms
3. Possibly radioactive water from the steam generator dump valves

Gaseous waste handling schematic



RADIOACTIVE WASTE PROCESSING SYSTEMS

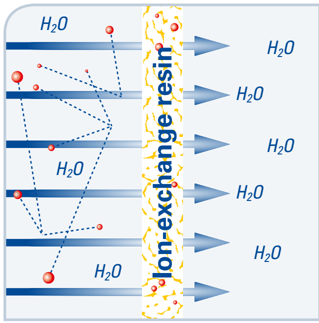
Radioactive waste is classified on the basis of its radioactivity and its physical and chemical properties. Each type of waste is processed appropriately. High-level radioactive waste is kept separate from low-level radioactive waste at all times, and there are separate processing lines for different types of solid, liquid and gaseous waste.

Solid waste

Solid reactor waste is divided into low-level waste and medium-level waste. Low-level waste is mixed waste contaminated with radioactive material. Such material includes fire-resistant fabrics, plastics, protective clothing, tools and components removed from the system. Compactable waste is packed into 200-litre drums, while hard materials are separated into pieces and packed into concrete containers.

Medium-level waste consists of the ion-exchange resins used for cleaning the process water. This mass is dried and solidified into bitumen in 200-litre drums.

Both low-level and medium-level solid waste are placed in the final disposal repository which is located at Olkiluoto shared with OL1 and OL2.



Impurities in the coolant are bound into the ion-exchange resins by a chemical reaction and thus removed from the circuit.

Liquid waste

Radioactive waste water is collected through fixed pipelines into liquid waste storage tanks in the radioactive waste processing building. There are separate collecting tanks for radioactive water from the primary circuit and related systems, for waste water with low-level radioactivity and for possibly radioactive waste water.

The processing of liquid waste depends on its composition. A centrifuge and an evaporator are used to separate solid particles. Chemicals are used to enhance the processing, depending on the nature of the waste water. Biological decomposition using bacteria can also be used for organic substances. The steam from the evaporation process is condensed and collected in a monitoring tank, where it is sampled to ensure that it is clean enough to be discharged out of the plant unit.

The sludges from the storage tanks and the concentrates from the evaporator are packed into 200-litre drums and dried in drum driers, where the remaining water is evaporated by vacuum drying. The resulting condensate is returned to the liquid waste processing system. Ion-exchange resins used to clean process waters can be mixed with the concentrates and dried at the same time for packing into drums.

The filter elements from the mechanical filters in the reactor plant auxiliary systems are packed into 200-litre drums. The drums are placed in interim storage and then taken to the final disposal repository just like the drums of solidified medium-level waste.

Waste oil is measured for radioactivity, packed into 200-litre drums and transferred to the existing waste oil processing facility used by OL1 and OL2.

Gaseous waste

Gaseous radioactive waste mostly consists of the fission gases krypton and xenon dissolved in the primary coolant. These, together with hydrogen, oxygen and any other dissolved gases, are removed from the primary coolant in the coolant degassing system. Gases are also released into the airspace of the tanks in the systems connected to the primary circuit.

In order to minimize gas emissions, the offgas system is based on a semi-enclosed circuit. It consists of two parts: the flushing unit and the delay unit. The flushing unit is designed to receive gas from the degassing system and to flush tanks where gases may be released and to limit their hydrogen content. The delay unit is designed to retain radioactive noble gases (xenon, krypton) so as to decay their radioactivity before their release.

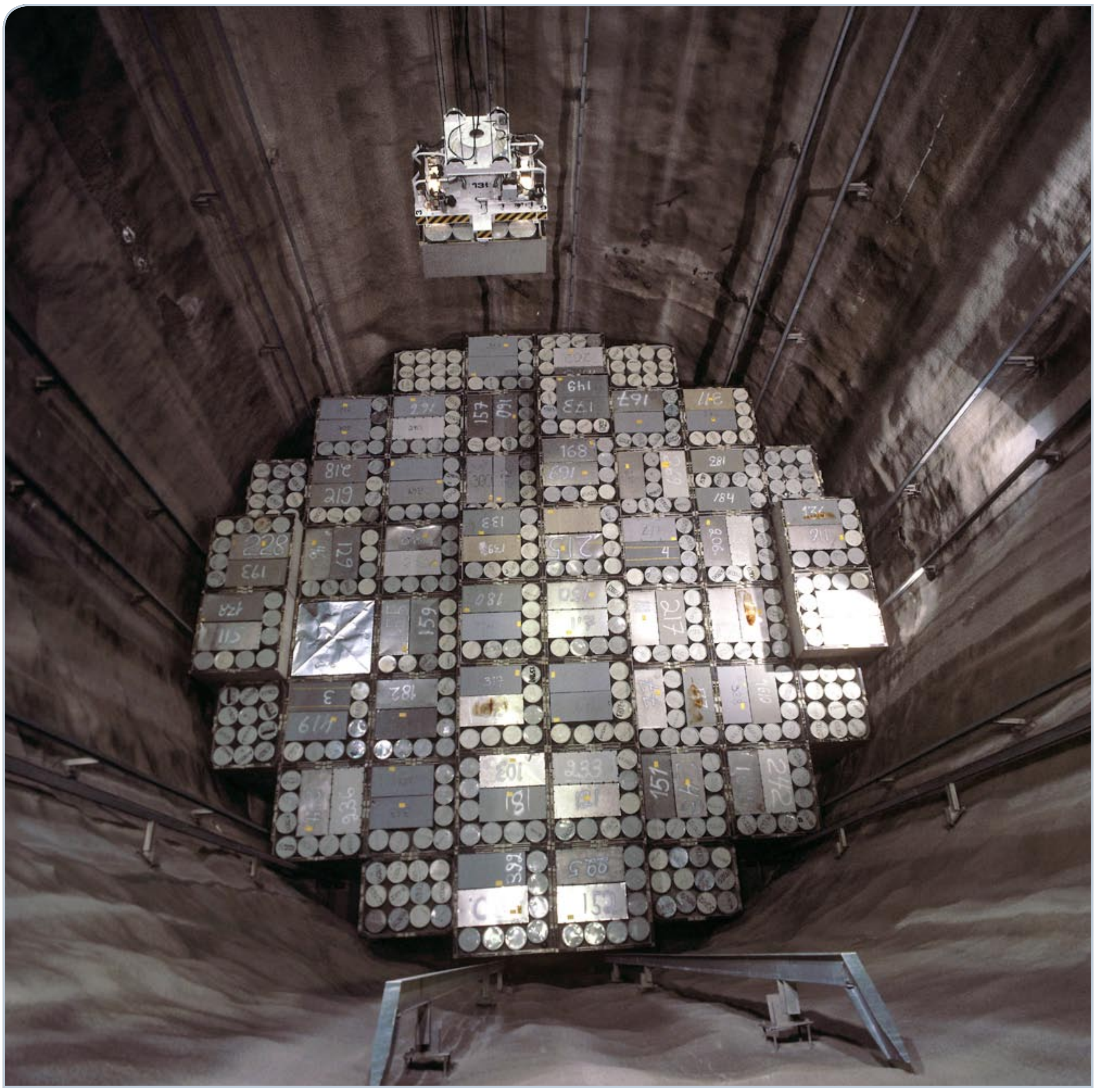
Offgases are delayed, filtered and conveyed from the plant into the atmosphere through a 100-metre-high ventilation stack.

During power operation, the combined gas volume of the tanks in the system remains fairly stable, and it is usually not necessary to vent offgas to the ventilation stack. The gaseous waste processing system is flushed with nitrogen in a closed circuit, and the hydrogen and oxygen content of the gases is limited. The radioactive noble gases remain in the flush circuit and decay each according to their half-life.

During start-up and shut-down, process actions and events such as nitrogen flushing of the reactor pressure vessel head can cause a substantial gas flow to the gaseous waste processing system. The overflow is conveyed from the pressurized part of the system through delay beds into the ventilation stack. The active charcoal filters in the delay beds bind the xenon and krypton until their radioactivity has decayed to an acceptable level. The radioactivity level in the ventilation stack is monitored continuously.

Solid plant waste is packed into 200-litre drums.

A special vehicle takes the waste packages to the Olkiluoto disposal repository.



TRAINING SIMULATOR

Part of the OL3 power plant supply to TVO will include a full-scope training simulator, which will be completed and ready for use one year before the first fuel loading of the power plant unit. The simulator can replicate exactly the functions of the new unit, and the simulator control room is a full-scale replica of the real one. The simulator will mainly be used for operator training before the power plant unit is started up, and subsequently for annual supplementary training.

Simulator control room being tested in the manufacturer's facilities.

The purpose of the training simulator is for personnel to practise all possible events that may occur at the power plant unit, including transients and accidents, and to validate operation, abnormal operation and emergency operation procedures.

The plant supplier is responsible for designing and building the simulator together with several well-known suppliers in the field. The simulator and its auxiliary facilities will be housed in a new annexe to be built at the existing TVO training centre.

Technical data

General

Reactor thermal power	4,300 MWth
Electrical power, gross	1,720 MWe
Electrical power, net	1,600 MWe
Efficiency	ca. 37%
Primary coolant flow	23,135 kg/s
Reactor operating pressure	155 bar
Coolant temperature in the reactor pressure vessel, average	312°C
Coolant temperature in the hot leg	329°C
Coolant temperature in the cold leg	296°C
Electricity output per year	ca. 13 TWh
Sea water flow	57 m^3/s
Service life	ca. 60 years
Building volume	950,000 m^3
Containment volume	80,000 m^3
Containment design pressure	5.3 bar

Reactor core

Number of fuel assemblies	241
Active core height	4.2 m
Core diameter	3.77 m
Total fuel weight	ca. 128 tU
Fuel enrichment level, initial core loading	1.9% – 3.3% ^{235}U
Fuel enrichment level, reloading	1.9% – 4.9% ^{235}U
Fuel consumption per year	ca. 32 tU
Fuel consumption per year	ca. 60 assemblies

Fuel

Fuel	uranium dioxide UO_2
Assembly type	17x17 HTP
Fuel rods per assembly	265
Guide thimbles per assembly	24
Spacer grids per assembly	10
Length of fuel assembly	4.8 m
Weight of fuel assembly	735 kg
Width of fuel assembly	213.5 mm
Cladding material	M5™
UO_2 pellet density	10.45 g/cm^3
Fuel discharge burnup	45 MWd/kgU

Control rods

Number of control rods	89
Absorber length:	
lower part	2,900 mm
upper part	1,340 mm
total length	4,717.5 mm
Absorber material	
lower part	silver, indium, cadmium
upper part	boron carbide

Pressure vessel

Inner diameter	4.9 m
Inner height	12.3 m
Wall thickness	250 mm
Bottom thickness	145 mm
Thickness of stainless steel cladding	7.5 mm
Design pressure	176 bar
Design temperature	351°C
Weight with cover	526 t

Turbine plant

Turbine generator unit	1
Gross electrical output	ca. 1,720 MW
Main steam pressure	75.5 bar
Steam temperature	290°C
Steam flow	2,443 kg/s
Rated speed	1,500 r.p.m.
HP turbine	1
LP turbine	3
HP turbine stop and control valves	4/4
LP turbine stop and control valves	6/6
Last stage	
– exit annulus area	30 m^2
– blade length	1,830 mm
– overall diameter	6,720 mm
Turbine-generator shaft length	68 m

Condenser

Cooling surface	110,000 m^2
Cooling medium	sea water
Coolant flow	53 m^3/s
Vacuum at full load	24.7 mbar
Temperature rise	12°C

Feedwater

Preheating stages	7
Final feedwater temperature	230°C

Generator

Nominal rating	1,992 MVA
Power factor, nominal	0.9
Rated voltage	27 kV ± 5%
Frequency	50 Hz
Rated speed	1,500 r.p.m.
Cooling, stator coils	water
Cooling, rotor	hydrogen
Magnetization current	9,471 A
Cooling water temperature	45°C
Hydrogen cooling medium temperature	40°C

Power supply

Main transformer	3 x 1-phase
Nominal rating	3 x 701 MVA
Rated voltage	410/27 kV
Auxiliary unit transformers	2
Nominal rating	90/45/45 MVA
Rated voltage	400/10.5 kV
Auxiliary standby transformer	1
Nominal rating	100/50/50 MVA
Rated voltage	110/10.5 kV
Emergency power supply	4XEDG and 2XSBO
Nominal ratings	4 x 7.8 MVA and 2 x 3.0 MVA
Turbine plant diesel engine	1
Nominal rating	1.6 MVA

Photo: Areva

1. Ingot of steam generator shell before forging

2. Forging the steam generator shell

3. Closure head of reactor pressure vessel under manufacturing

4. Reactor pressure vessel

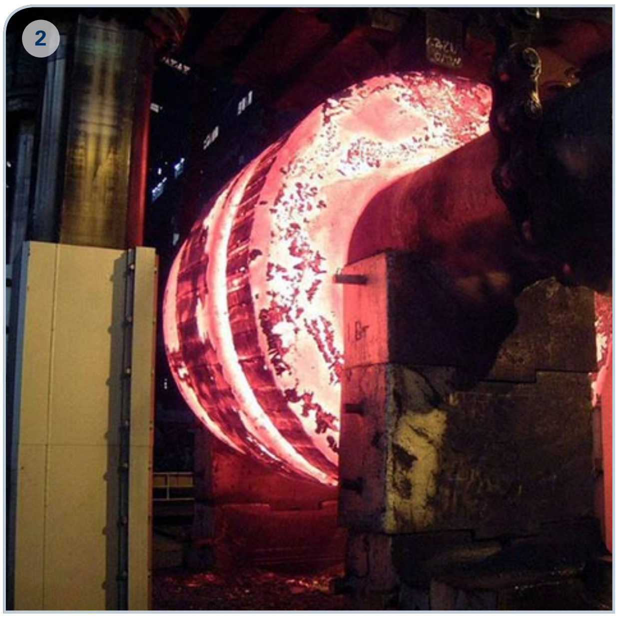


Photo: Areva

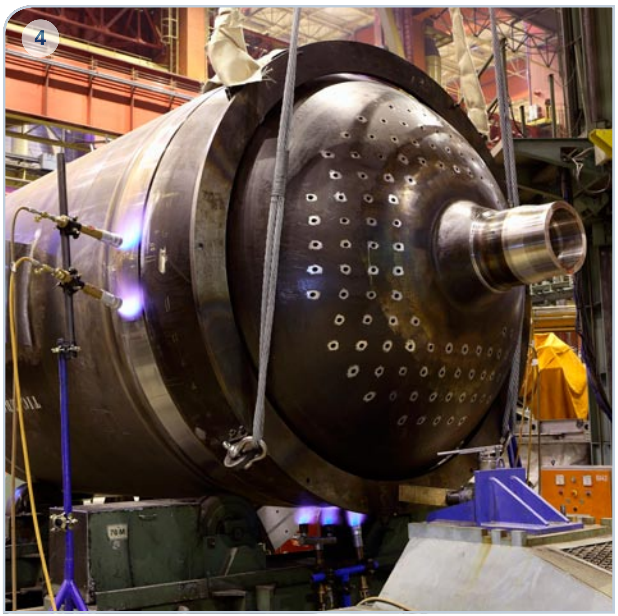
Photo: Areva

Photo: Areva

Photo: Areva

1. *Cladding of the steam generator tubesheet*
2. *Drilling of the steam generator tube support plate*
3. *Mounting of the steam generator tube support plate*
4. *Welding shell and lower head of pressurizer*
5. *Cladding the pressurizer shell*

Photo: Areva



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