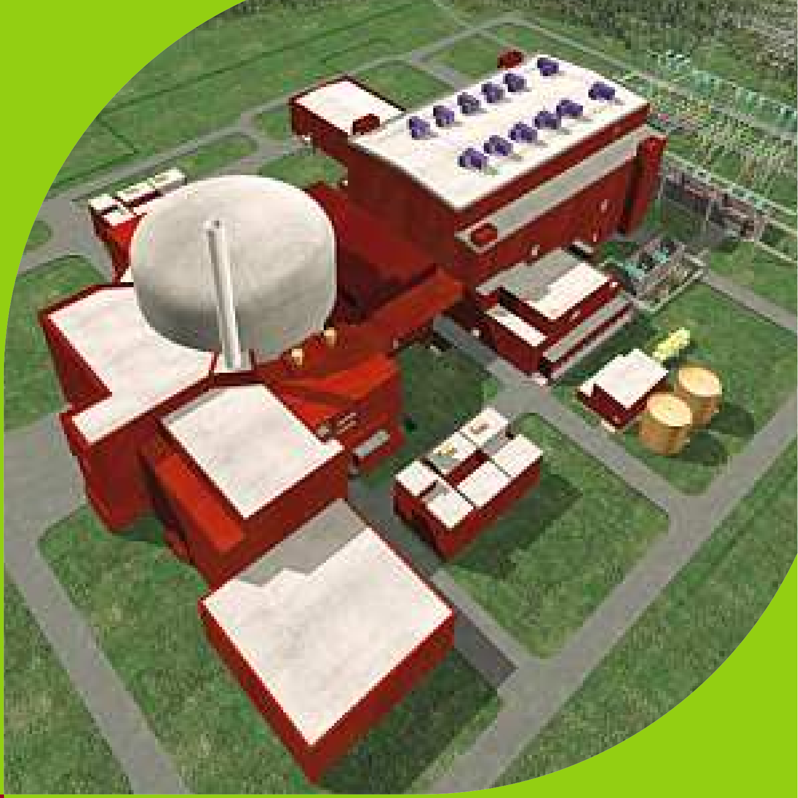


The Path
of Greatest Certainty

A Generation III+ nuclear power plant

> Readers accustomed to Anglo-Saxon units can use the following table to convert the main units from the International Metric System.

1 meter (m)	=	3.2808 feet
	=	39.370 inches
1 square meter (m^2)	=	10.764 square feet
1 cubic meter (m^3)	=	219.97 imperial gallons
	=	264.17 US gallons
1 kilogram (kg)	=	2.2046 pounds
1 tonne (t)	=	0.984 long ton
1 bar	=	14.504 psi

> Conversion of temperature (°C into °F)

Temp. °C x 9/5 + 32	=	Temp. °F

> All pressures are expressed in absolute bar.

> FOREWORD

The need to secure long-term energy supplies, stabilize energy costs and combat global warming, argues in favor of a wide and diverse energy mix. Against this backdrop, nuclear power, which is proving increasingly competitive, safe, reliable and environmentally friendly, has a vital role to play.

As a world expert in energy, AREVA creates and offers solutions to generate, transmit and distribute electricity; its businesses are long-term, and cover every area of civil nuclear power generation to meet electricity needs.
This encompasses the front end of the fuel cycle (uranium mining, conversion and enrichment, nuclear fuel fabrication), reactor design, construction, maintenance and services, the back end of the fuel cycle (treatment, recycling, transport and logistics, clean-up), and finally transmission and distribution of electricity from the generator to the high and medium voltage grids.

The EPR™ reactor is AREVA's Generation III+ PWR (Pressurized Water Reactor). It has been designed to satisfy the needs of electrical utilities for a new generation of nuclear power plants, offering increased levels of safety and competitiveness, and meeting more efficiently tomorrow's energy requirements.
The EPR™ reactor is already under construction in Finland, France and China, and is currently undergoing licensing or pre-licensing in the US and UK.

Generation III+... we're making it happen...

EPR™ by AREVA

The Path of Greatest Certainty

Energy supply certainty

The EPR™ reactor is a 1,600 + MWe PWR. Its evolutionary design is based on experience from several thousand reactor-years of operation of Light Water Reactors worldwide, primarily those incorporating the most recent technologies: the N4 (Chooz B1-B2 and Civaux 1-2) and KONVOI (Neckarwestheim-2, Isar-2 and Emsland) reactors currently in operation in France and Germany respectively. The EPR™ design integrates the results of decades of research and development programs, in particular those carried out by the CEA (French Atomic Energy Commission) and the German Karlsruhe research center. Through its N4 and KONVOI filiation, the EPR™ reactor totally benefits from an uninterrupted evolutionary and innovative process; it has a proven technology based on 87 PWRs built throughout the world.

Thanks to a number of technological advances, the EPR™ reactor is at the forefront of nuclear power plants design. Significant continuous improvement has been incorporated into its main features:

- the reactor core and its flexibility in terms of fuel management,
- the reactor protection system,
- the instrumentation and control (I&C) system, the operator friendly human-machine interface and computerised control room of the plant,
- the large components such as the reactor pressure vessel and its internal structures, the steam generators and the primary coolant pumps.

AREVA NP's Saint-Marcel and JSPM plants (in Chalon and Jeumont) have gathered over thirty years of experience in the manufacturing of nuclear heavy components and are keeping it up to date.

➡ **The EPR™ design relies on a sound and proven technology.**

➡ **Continuous in-house design and manufacturing cooperation for a better optimization.**

➡ **Design and licensing, construction and commissioning, operability and maintainability of EPR™ units benefit from the long lasting and worldwide experience and expertise of AREVA.**

Safety first and foremost

The EPR™ technology offers a significantly enhanced level of safety: major safety systems consist of four separate subsystems, each capable of performing 100% of the safety function. Moreover functional diversity ensures that in case of total loss of a safety system, in spite of its redundancy, the safety function can be performed by another system. In order to achieve its high level of safety, the EPR™ reactor also features major innovations, especially in further preventing core meltdown and mitigating its potential consequences. The EPR™ design also benefits from enhanced resistance to external hazards, including aircraft crash and earthquake. Together, the EPR™ operating and safety systems provide progressive responses commensurate with the potential consequences of abnormal occurrences.

Project and licensing certainty

The French-German cooperation set up to develop the EPR™ technology brought together, from the start of the project:

- power plant vendors, Framatome and Siemens KWU (whose nuclear activities have since been merged to form Framatome ANP, now AREVA NP),

> Building on experience

Enhanced safety level and competitiveness

N4

Chooz B1&2, Civaux 1&2.

Solid basis of experience with outstanding performance

KONVOI

Neckarwestheim-2, Isar-2 and Emsland.

- EDF (Électricité de France) and the major German utilities presently grouped in E.ON, EnBW and RWE Power,
- the safety authorities from both countries to harmonise safety regulations.

The EPR™ design takes into account the expectations of utilities as stated by the "European Utility Requirements" (EUR). It complies with the specific requirements formulated by the French and German safety authorities for the next generation of nuclear reactors.

The Finnish electricity utility Teollisuuden Voima Oy (TVO) signed a contract with the AREVA and Siemens consortium to build a turnkey EPR™ unit at the Olkiluoto site in Finland. The construction permit was obtained in February 2005.

On January 23, 2007, EDF ordered AREVA's 100th nuclear reactor, which is being built in France, on the Flamanville site. The construction permit was awarded on April 10, 2007.

On November 26, 2007, AREVA and CGNPC signed a contract for the supply of two EPR™ Nuclear Islands on the new site of Taishan in China in the context of a long-term cooperation agreement.

And on April 23, 2008, E.ON chose the EPR™ reactor as its reference design for the new NPPs in the United Kingdom.

AREVA's supply chain is integrated, comprehensive and time-tested, which confers certainty to its projects:

- expertise is all within the company, at all levels,
- the procurement schedule is controlled internally and therefore more flexible,
- specific customer or regulator requirements are more efficiently addressed.

➡ **The EPR™ power plant is under construction in Finland, France and China, and is currently undergoing licensing or pre-licensing in the US and UK.**

➡ **The integration of design and manufacturing strengthens AREVA's supply chain and, as a result, project certainty.**

Predictable business performance

The forthcoming generation of nuclear power plants will have to demonstrate its competitiveness also in deregulated electricity markets.

Thanks to an early focus on economic performance during its design process, the EPR™ technology offers significantly reduced power generation costs, about 20% lower than those of large combined-cycle gas plants.

This high level of competitiveness is achieved through:

➡ **a unit power in the 1,600 + MWe range, providing an attractive cost of the kWe installed,**

➡ **a 36-37% overall efficiency depending on site conditions (presently the highest value ever for water reactors),**

➡ **a design for a 60-year service life,**

➡ **an enhanced and more flexible fuel utilisation,**

➡ **an availability design target above 92%.**

Significant advances for sustainable development

The EPR™ reactor due to its optimized core design and higher overall efficiency offers many significant advantages in favor of sustainable development, typically:

- **7-15% saving on uranium consumption per produced MWh,**
- **10% reduction on long-lived actinides generation per MWh, through improved fuel management,**
- **10% gain on the "electricity generation" versus "thermal release" ratio,**

(compared to 1,000 MWe-class reactors).

➡ **Energy supply certainty with the evolutionary design, operational flexibility and shortened outages.**

➡ **Engineering certainty for customers through evolutionary design.**

➡ **Licensing certainty with construction license obtained in France and in Finland, licensing process launched in the United States, the United Kingdom and China.**

➡ **Procurement certainty for critical components directly sourced from AREVA's existing integrated facilities.**

➡ **Project certainty with ongoing building experience and established supply chain.**

➡ **Business performance certainty with an efficiency up to 37%, flexible fuel management, low operational maintenance costs.**

> INTRODUCTION

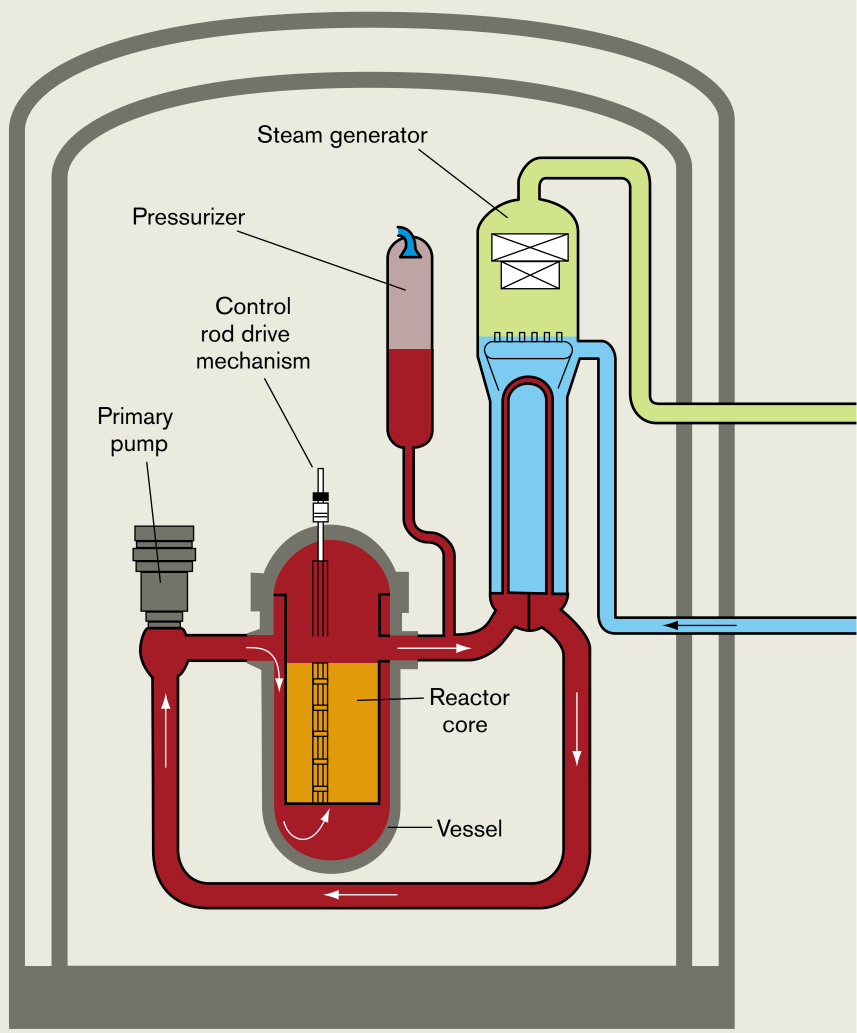
In a nuclear power plant, the reactor is the component where the heat, necessary to produce the steam, is generated by the fission of atomic nuclei.
The steam produced drives a turbine generator, which generates electricity.
The nuclear steam supply system is the counterpart of the coal, gas or oil-fired boilers used in fossil-fuelled power plants.

In Pressurized Water Reactors (PWR) such as the EPR™ power plant, ordinary (light) water is utilized to remove the heat produced inside the reactor core by the nuclear fission phenomenon. This water also slows down (or moderates) neutrons (the constituents of atomic nuclei that are released in the nuclear fission process). Slowing down neutrons is necessary to sustain the nuclear reaction (neutrons must be moderated to be able to break down the fissile atomic nuclei).

The heat produced inside the reactor core is transferred to the turbine through the steam generators.
Only heat is exchanged between the reactor cooling circuit (primary circuit) and the steam circuit used to feed the turbine (secondary circuit). No exchange of cooling water takes place.

The primary cooling water is pumped through the reactor core and the tubes inside the steam generators,
in four parallel closed loops, by coolant pumps powered by electric motors.
Each loop is equipped with a steam generator and a coolant pump.

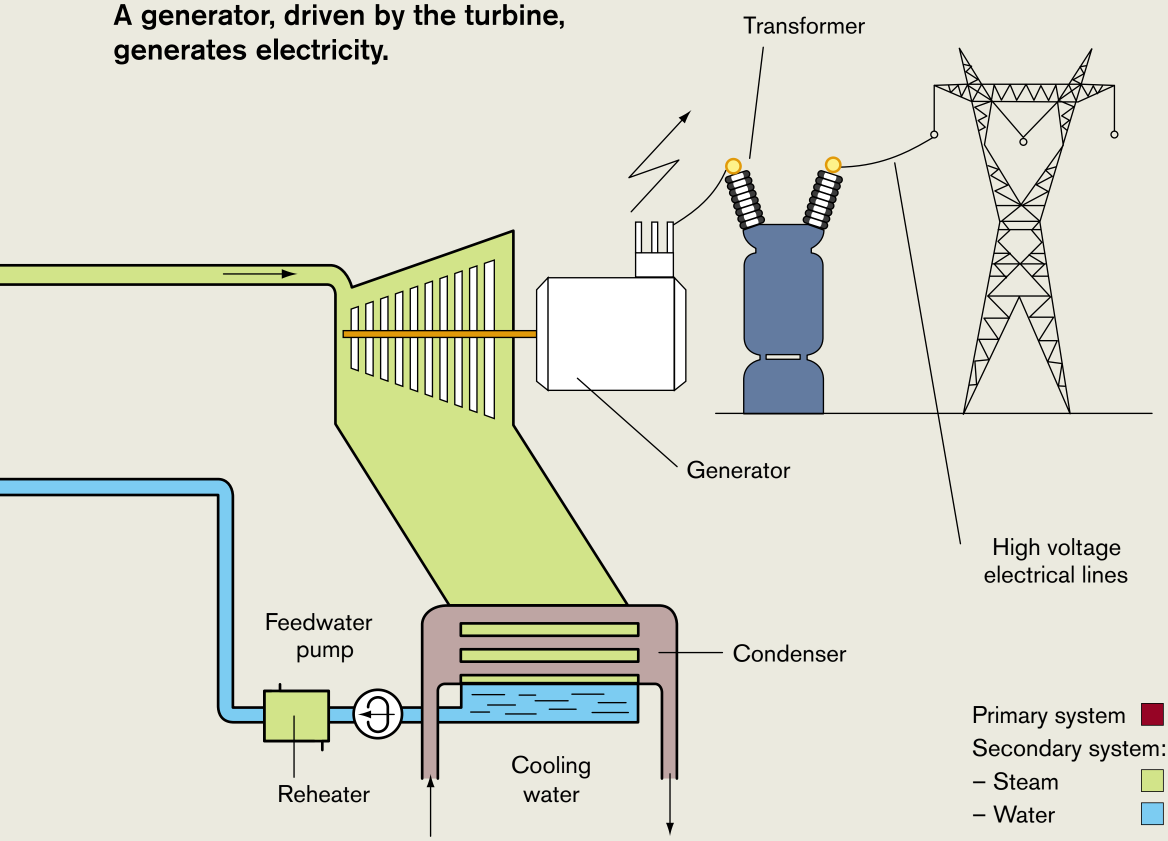
The reactor operating pressure and temperature are such that the cooling water does not boil in the primary circuit but remains in the liquid state.
A pressurizer, connected to one of the coolant loops, is used to control the pressure in the primary circuit.



Feedwater entering the secondary side of the steam generators absorbs the heat transferred from the primary side and evaporates to produce saturated steam. The steam is mechanically dried inside the steam generators then delivered to the turbine. After exiting the turbine, the steam is condensed and returned as feedwater to the steam generators.

A generator, driven by the turbine, generates electricity.

➡ **The following chapters provide a detailed explanation and description of a nuclear power station based on an EPR™ reactor.**



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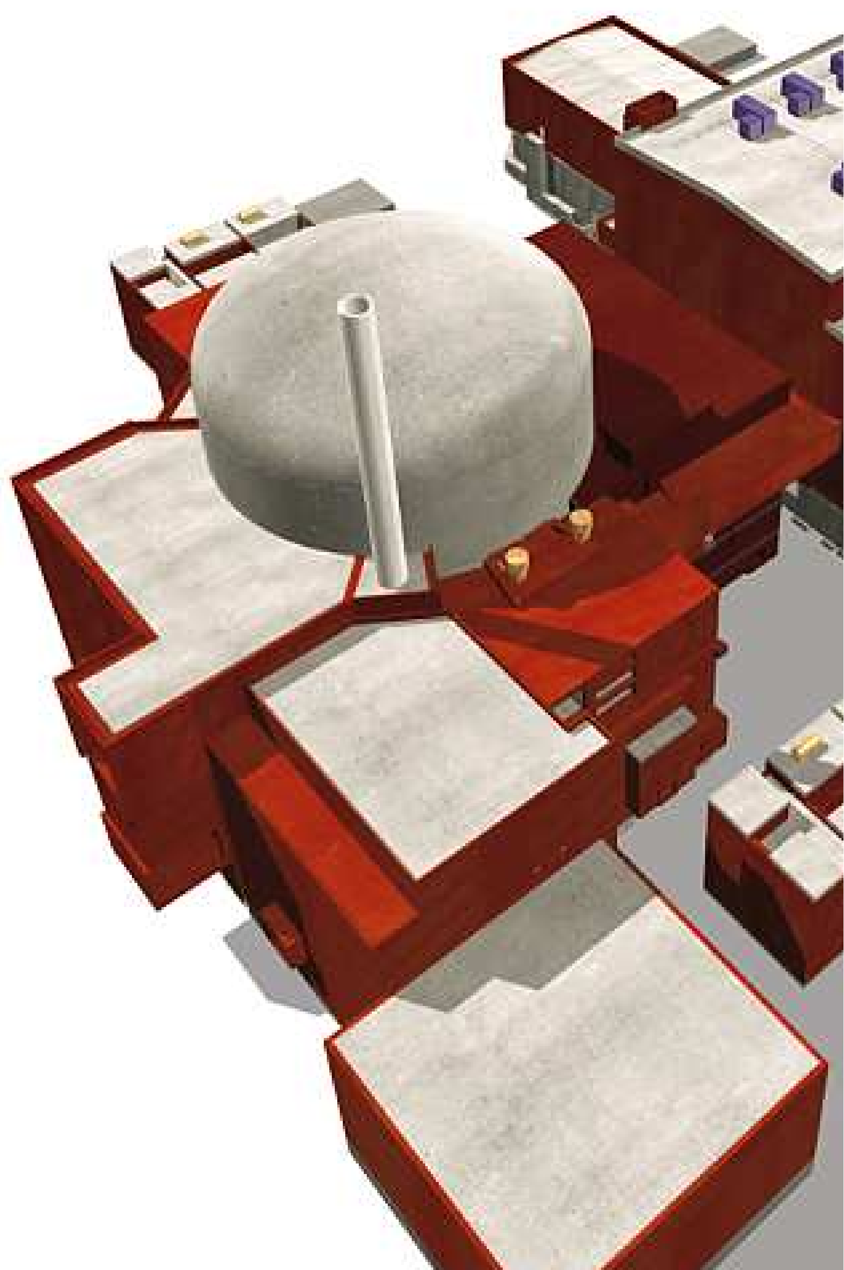
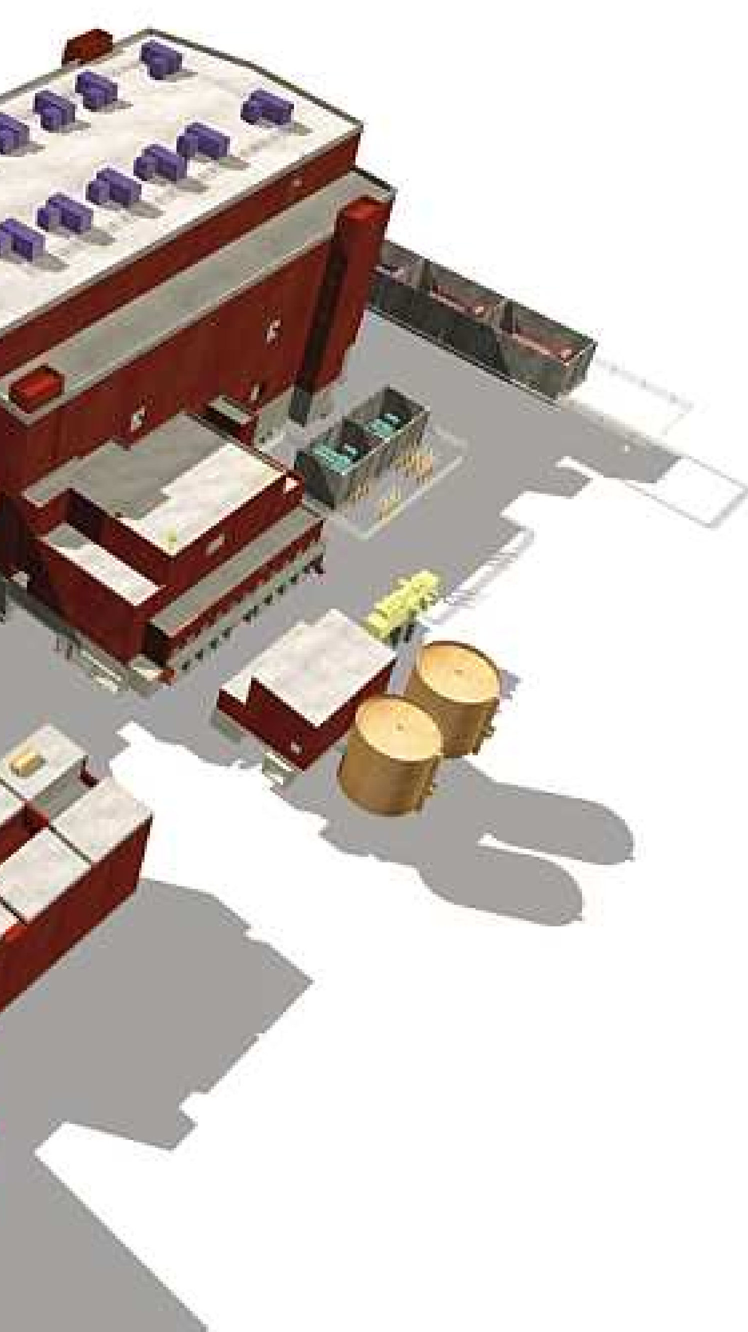
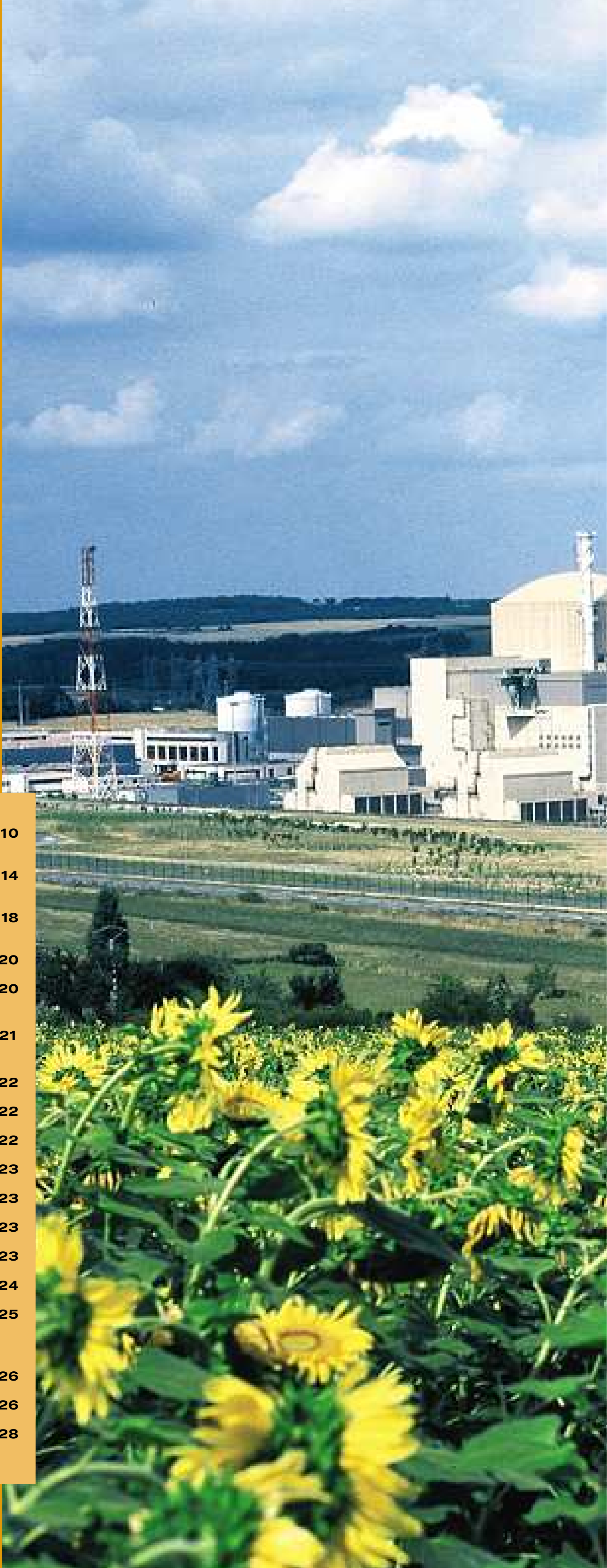


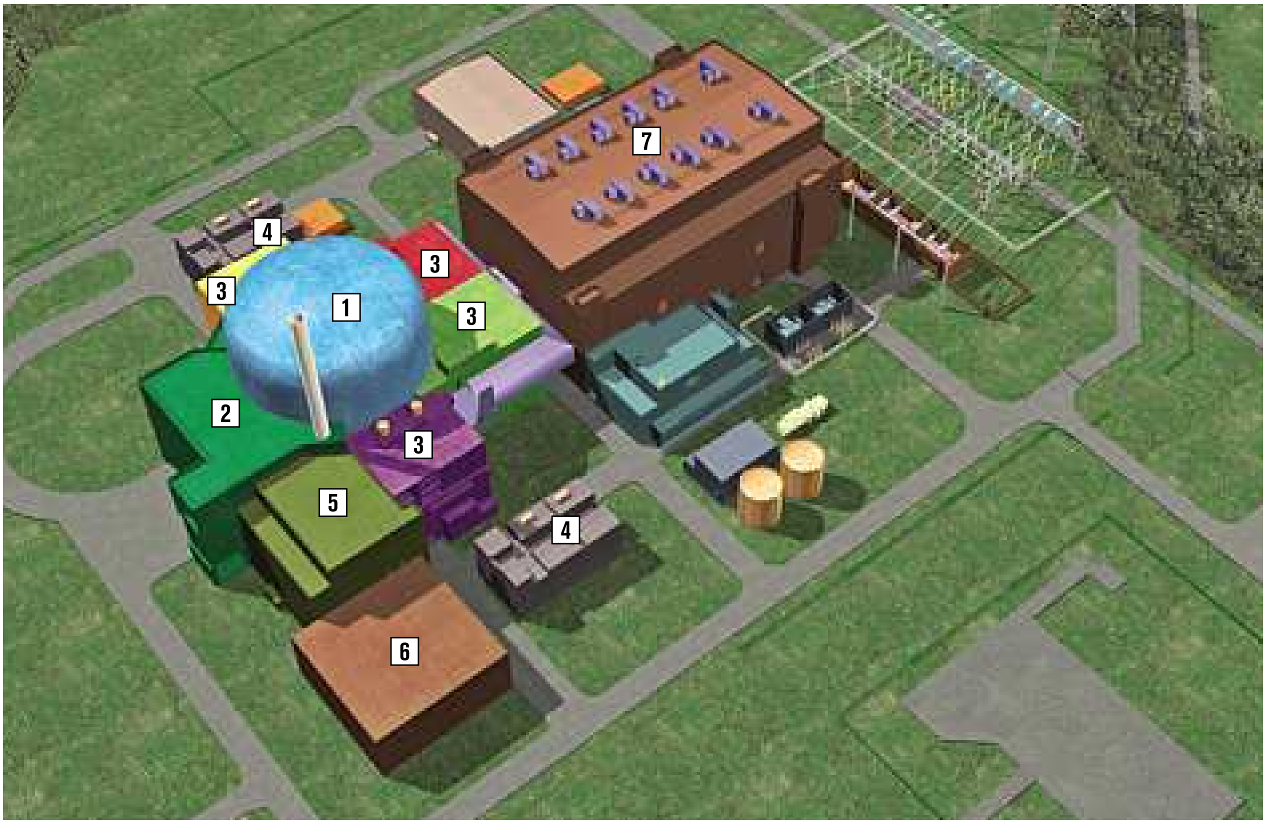




EPR™ NUCLEAR ISLAND

Civaux nuclear power plant, France
(N4, 1,500 MWe)

EPR™ REACTOR LAYOUT



1 Reactor Building

The Reactor Building located in the center of the Nuclear Island houses the main components of the Nuclear Steam Supply System (NSSS) as well as the In-Containment Refueling Water Storage Tank (IRWST). Its main function is to prevent the release of radioactive materials into the environment under all circumstances, including possible accident conditions. It consists of a cylindrical pre-stressed concrete inner containment with a metallic liner, surrounded by an outer reinforced concrete shell.

The main steam and feedwater valves are housed in dedicated reinforced concrete compartments adjacent to the Reactor Building.

The primary system arrangement is characterized by:
- a pressurizer located in a separate area,
- concrete walls between the loops and between the hot and cold legs of each loop,
- a concrete wall (secondary shield wall) around the primary system to protect the containment from missiles that could be caused by the failure of pressurized equipment, and to provide shielding against radiation produced by the primary system.

2 Fuel Building

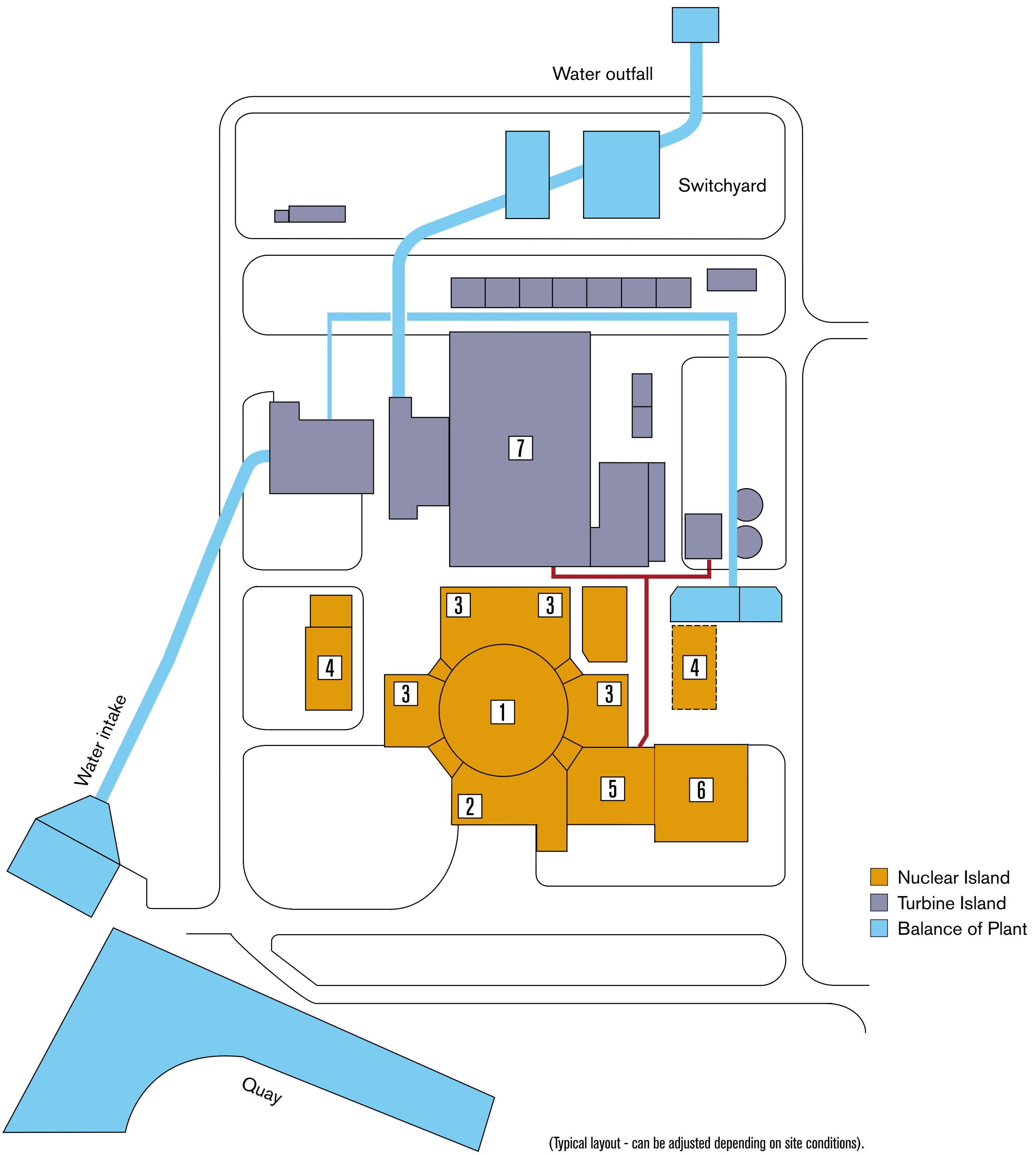
The Fuel Building, located on the same basemat that supports the Reactor Building and the Safeguard Buildings, houses an interim fuel storage pool for fresh and spent fuel and associated fuel handling equipment. Operating compartments and passageways, equipment compartments, valve compartments and the connecting pipe ducts are separated within the building. Areas of high activity are separated from areas of low activity by means of shielding facilities. The lower part of the building houses the fuel pool cooling system, the extra borating system, and the chemical and volume control system. The redundant trains of these systems are in two separate divisions of the building that are physically separated by a wall.

3 The Safeguard Buildings

The four Safeguard Buildings house key safety systems such as the Safety Injection System and the Emergency Feedwater System, and their support systems. These safety systems are divided into four trains each of which is housed in a separate division located in one of the four Safeguard Buildings.
The combined Low Head Safety Injection System and Residual Heat Removal System is arranged in the inner radiologically controlled areas, whereas the Component Cooling and Emergency Feedwater Systems are installed in outer areas classified as radiologically non-controlled. The Main Control Room is located in one of the Safeguard Buildings.

4 Diesel Buildings

The two Diesel Buildings house the four emergency Diesel generators, two Station Black Out Diesel (SBO) Generators and their support systems. The SBO are used to supply electricity to the safety trains in the event of a complete loss of electrical power. The physical separation of these two buildings provides additional protection.



(Typical layout - can be adjusted depending on site conditions).

5 Nuclear Auxiliary Building

Part of the Nuclear Auxiliary Building (NAB) is designed as a radiologically non-controlled area in which parts of the Operational Chilled Water System are located. Special laboratories for sampling systems are located at the lowest level. The maintenance area and some setdown areas used during the refueling phase are arranged on the highest level. All air-exhausts from the radiologically controlled areas are routed, collected and controlled within the Nuclear Auxiliary Building prior to release through the stack.

6 Waste Building

The Waste Building is used to collect, store and treat liquid and solid radioactive waste.

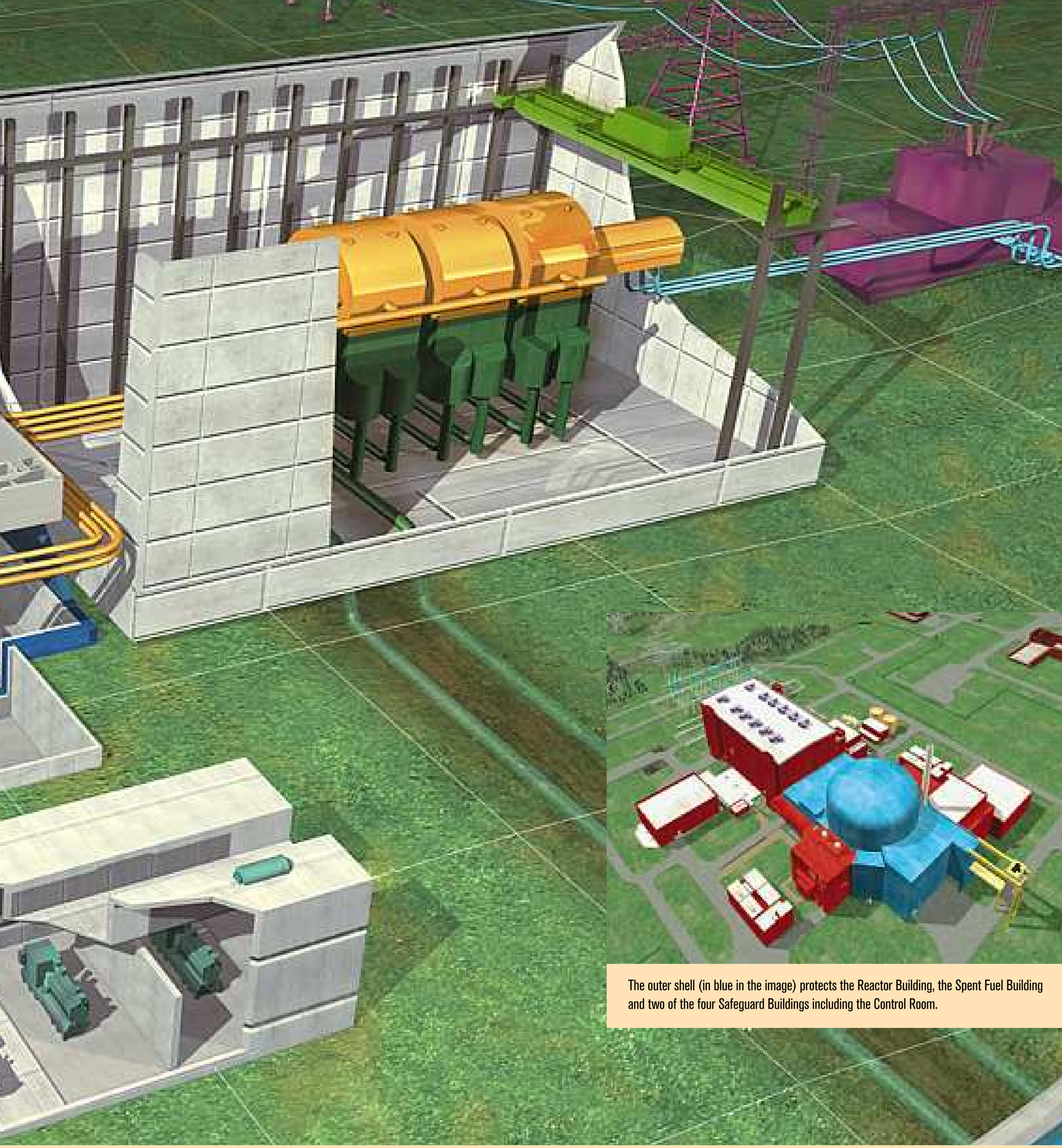
7 Turbine Building

The Turbine Building houses all the main components of the steam-condensate-feedwater cycle. It contains, in particular, the turbine, the generator set, the condenser and their auxiliary systems.

➡ **The EPR™ reactor layout offers unique resistance to external hazards, especially earthquake and aircraft crash.**

- **To withstand major earthquakes, the entire Nuclear Island stands on a single thick reinforced concrete basemat. The building height has been minimised and heavy components and water tanks are located at the lowest possible level.**

- **To withstand the impact of a large aircraft, the Reactor Building, Spent Fuel Building and two of the four Safeguard Buildings are protected by an outer shell made of reinforced concrete. The other two Safeguard Buildings are geographically separated. Similarly, the Diesel generators are located in two geographically separate buildings.**



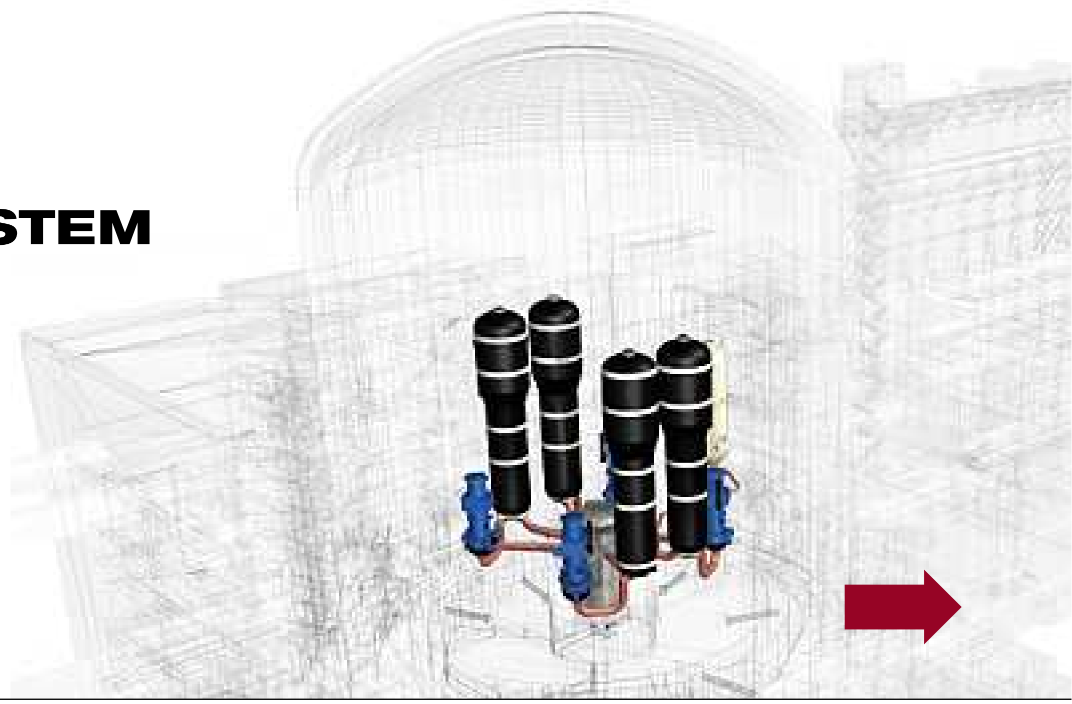
The outer shell (in blue in the image) protects the Reactor Building, the Spent Fuel Building and two of the four Safeguard Buildings including the Control Room.

➡ **The EPR™ Nuclear Island design offers major advantages to operators, especially for radiation protection and ease of maintenance.**

- **The layout is optimized and based on the strict separation of redundant systems.**

- **Maintenance requirements were systematically taken into account at the earliest stage of the design. For example, large setdown areas have been established to make maintenance operations easier for operating personnel.**

PRIMARY SYSTEM



PRIMARY SYSTEM CONFIGURATION

The EPR™ primary system is of a well-proven 4-loop design to which the French 1,300 MWe and 1,500 MWe N4 reactors as well as the German KONVOI reactors belong.

In each of the four loops, primary coolant leaving the reactor pressure vessel through an outlet nozzle passes into a steam generator, which transfers heat to the secondary circuit. The coolant then passes through a reactor coolant pump before being returned to the reactor pressure vessel through an inlet nozzle. Inside the reactor pressure vessel, the coolant flows downward in the annular space between the core barrel and the vessel, then it makes an upward U turn and flows through the core to extract the heat generated by the nuclear fuel.

A pressurizer, part of the primary system, is connected to one of the four loops. Its main role is to maintain the primary pressure within a specified range.

The main components of the EPR™ reactor, reactor pressure vessel, pressurizer and steam generators are of a larger volume than similar components in previous designs, providing additional operational and safety margins.

Integration of design and manufacturing

Customers benefit greatly from the fact that heavy component design and manufacturing activities are brought together within the AREVA group. The possibility, unique in the nuclear market place, of having a very close connection between the two is important for project success. This organisation implemented by AREVA NP since many years, is a great advantage for utilities. It provides the responsiveness needed to achieve optimized design, manufacturing, schedule and cost to obtain the best solutions.

The increased free volume in the reactor pressure vessel, between the inlet/outlet nozzles and the top of the core, provides a higher water volume above the core and thus additional time before core uncovering in the event of a postulated loss of coolant accident. This gives the plant operator more time to counteract such event.

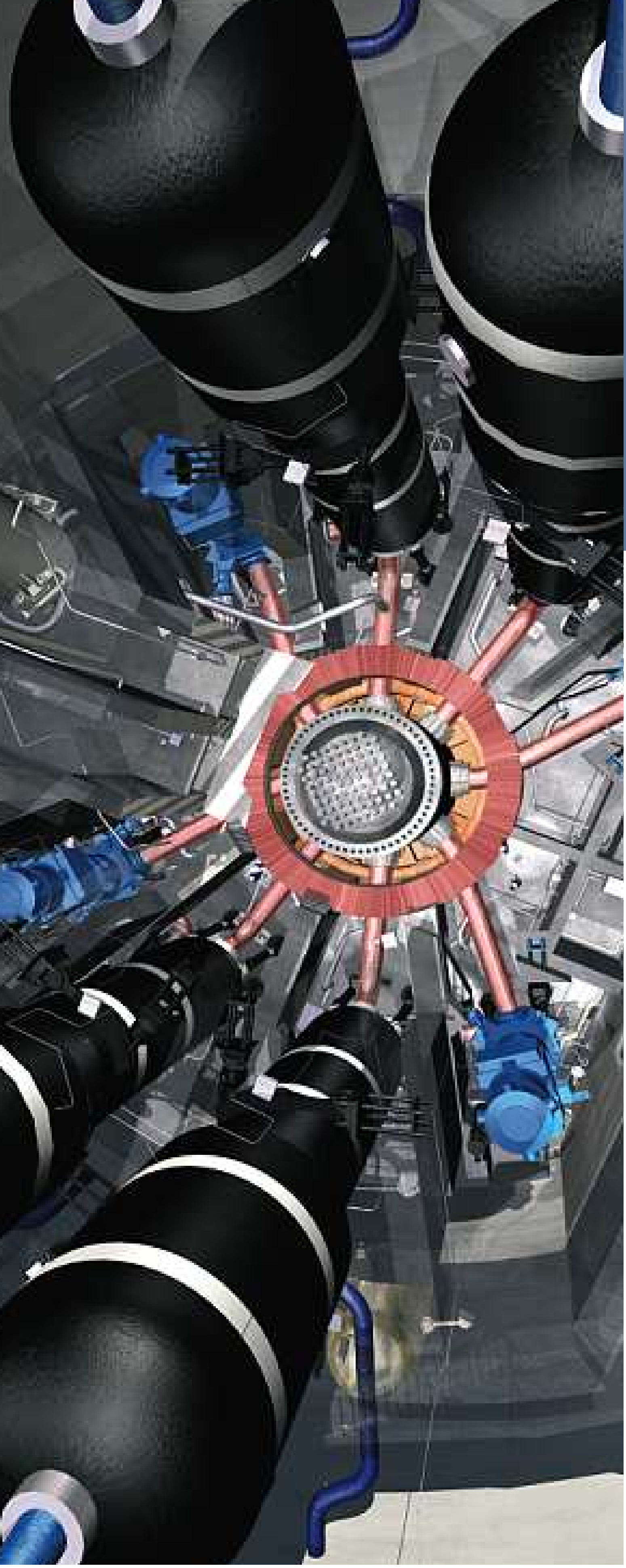
This increased volume is also beneficial in shutdown conditions in the hypothetical case of loss of the Residual Heat Removal System function.

Larger water and steam phase volumes in the pressurizer smooth the response of the plant to normal and abnormal operating transients, allowing extended time to counteract accident situations and an increased equipment lifetime.

The larger volume of the steam generator secondary side results in an increased secondary water inventory and steam volume, which offers several advantages:

- during normal operation, transients are smoother and the potential for unplanned reactor trips is therefore reduced;

Cattenom, France (4 x 1,300 MWe): inside a reactor building.



Computer-generated image of the EPR™ primary system

CHARACTERISTICS	DATA
Reactor coolant system	
Core thermal power	4,590 MWth*
Number of loops	4
Nominal flow (best estimate)	28,315 m^3/h
Reactor pressure vessel inlet temperature	295.2°C
Reactor pressure vessel outlet temperature	330°C
Primary side design pressure	176 bar
Primary side operating pressure	155 bar
Secondary side	
Secondary side design pressure	100 bar
Saturation pressure at nominal conditions (SG outlet)	77.2 bar
Main steam pressure at hot standby	90 bar

* Depending on specific customer requirements.

- in hypothetical steam generator tube rupture scenarios, the combination of a larger steam volume and the use of a setpoint for the safety valves of the steam generators above the safety injection pressure, prevent liquid from being released into the environment, reducing the potential for radioactivity release outside the reactor containment;
- in case of a total loss of the steam generator feedwater supply, the increased mass of water in the secondary system extends the dry-out time sufficiently to enable operators to recover feedwater supplies or to apply other countermeasures.

In addition, the primary system design pressure has been increased in order to reduce the actuation frequency of the safety valves, which is also an enhancement in terms of safety.

➡ **The increased volume of the primary system is beneficial in smoothing the effects of many types of transients.**

➡ **The primary system design pressure has been increased to reduce the frequency of safety valve actuation.**

➡ **The management of steam generator tube rupture scenarios prevents any liquid release outside the reactor containment.**

➡ **The large steam generator secondary side water inventory increases the time available to take action in case of assumed total loss of secondary feedwater.**

The design of the EPR™ components includes many improvements with respect to previous designs. The most noteworthy are summarized below.

REACTOR PRESSURE VESSEL

- The absence of penetrations through the RPV bottom head increases its resistance in postulated core meltdown accidents and removes the need for the corresponding in-service inspection and potential repairs.
- A reduced number of welds and improved weld geometry compared to existing French and German 4-loop designs decrease the need for in-service inspections, facilitate non-destructive examination and reduce the duration of inspections.
- The residual cobalt content of the stainless steel cladding is specified at a low value of less than 0.06% to contribute to the reduction in the radiation source term.

Reactor pressure vessel monobloc upper shell for the Olkiluoto 3 (Finland) EPR™ reactor pressure vessel.

STANDSTILL SEAL (REACTOR COOLANT PUMP)

The shaft seals are backed up with a standstill seal that closes once the pump is at rest and all seals of the leak-off lines are closed. The standstill seal creates a sealing surface with a metal-to-metal contact ensuring the shaft tightness in case of:

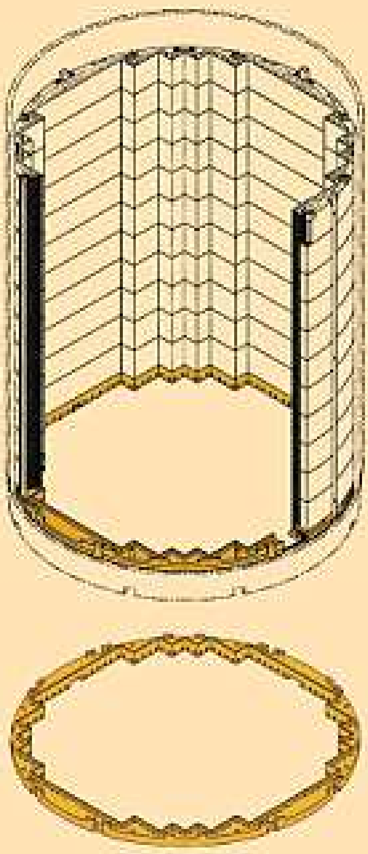
- simultaneous loss of water supplies from the Chemical and Volume Control System and the Component Cooling Water System used to cool the shaft sealing system,
- cascade failure of all the stages of the shaft sealing system.

This feature ensures that even in case of total station blackout or failure of the main seals no loss of coolant would occur.

Neutron reflector

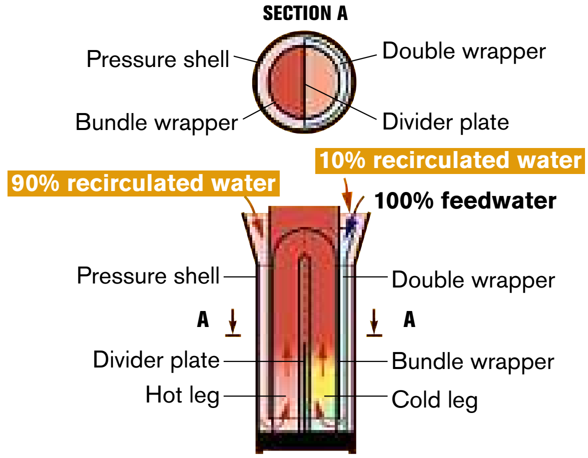
The Neutron reflector is a stainless steel structure, surrounding the core, made of rings piled up one on top of the other. It is an innovative feature that gives significant benefits:

- **by reducing the flux of neutrons escaping from the core, the reflector ensures that a greater neutron fraction is available to take part in the chain reaction process. The result is improved fuel utilisation, making it possible to decrease the fuel cycle cost;**
- **by reducing the flux of neutrons escaping from the core, the reflector protects the reactor pressure vessel against aging and embrittlement induced by fast-neutron fluence, helping to ensure the 60-year design life of the EPR™ reactor pressure vessel.**



AXIAL ECONOMIZER (STEAM GENERATOR)

To increase the heat transfer efficiency, the axial economizer directs 100% of the cold feedwater to the cold leg of the tube bundle, and about 90% of the hot recirculated water to the hot leg. This is done by adding a wrapper to guide the feedwater to the cold leg of the tube bundle and a partition plate to separate the cold leg from the hot leg. This design improvement increases the steam pressure by about 3 bar compared to a conventional steam generator.



PRESSURIZER

The pressurizer has a larger volume to smooth the operating transients in order to:

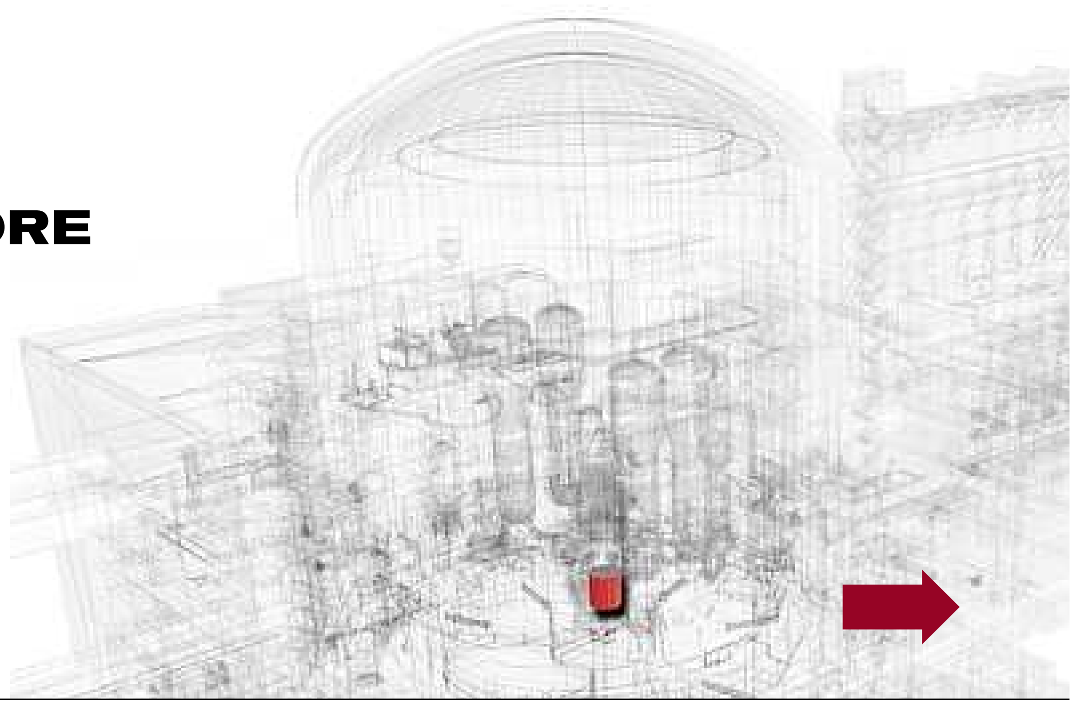
- ensure the equipment 60-year design life,
- increase the time available to counteract an abnormal operating situation.

Maintenance and repair (safety valves, heaters) are facilitated and radiological doses are reduced.

A dedicated set of valves for depressurising the primary circuit is installed on the pressurizer, in addition to the usual relief and safety valves, to prevent the risk of high pressure core melt accident.

Computer-generated image of the EPR™ pressurizer head with its safety and relief valves.

REACTOR CORE



The reactor core contains the fuel material in which the fission reaction takes place, releasing energy. The reactor internal structures support the fuel assemblies, channel the coolant and guide the control rods which control the fission reaction.

The core is cooled and moderated by water at a pressure of 155 bar and a temperature in the range of 300°C. The coolant contains soluble boron as a neutron absorber. The boron concentration in the coolant is varied as required to control relatively slow reactivity changes, including the effects of fuel burnup. Additional neutron absorbers (gadolinium), in the form of burnable absorber-bearing fuel rods, are used to adjust the initial reactivity and power distribution. Instrumentation is located inside and outside the core to monitor its nuclear and thermal-hydraulic performance and to provide input for control functions.

The main features of the core and its operating conditions have been selected to obtain not only high thermal efficiency of the plant and low fuel cycle costs, but also extended flexibility for different irradiation cycle lengths and a high level of manoeuvrability.

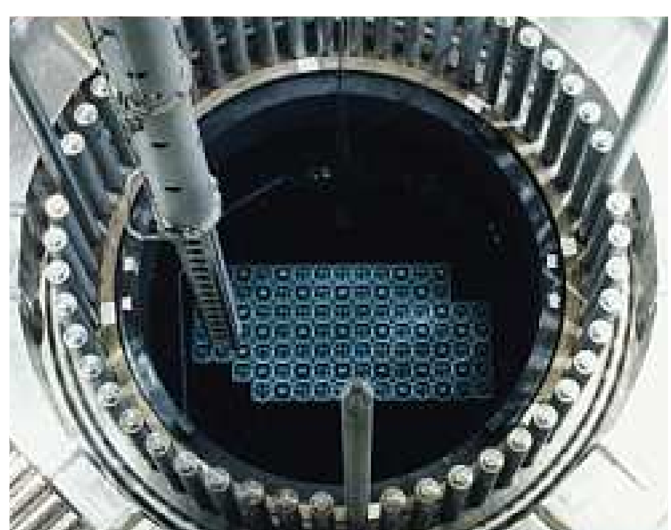
Core instrumentation

The ex-core instrumentation is used to monitor the process to criticality and the core reactivity change, it can also measure the core power.

The reference instrumentation used to monitor the power distribution in the core is an "aeroball" system. Vanadium balls are periodically inserted in the core. Their activation level is measured, to give values of the local neutron flux which are used to construct a three-dimensional power map of the core.

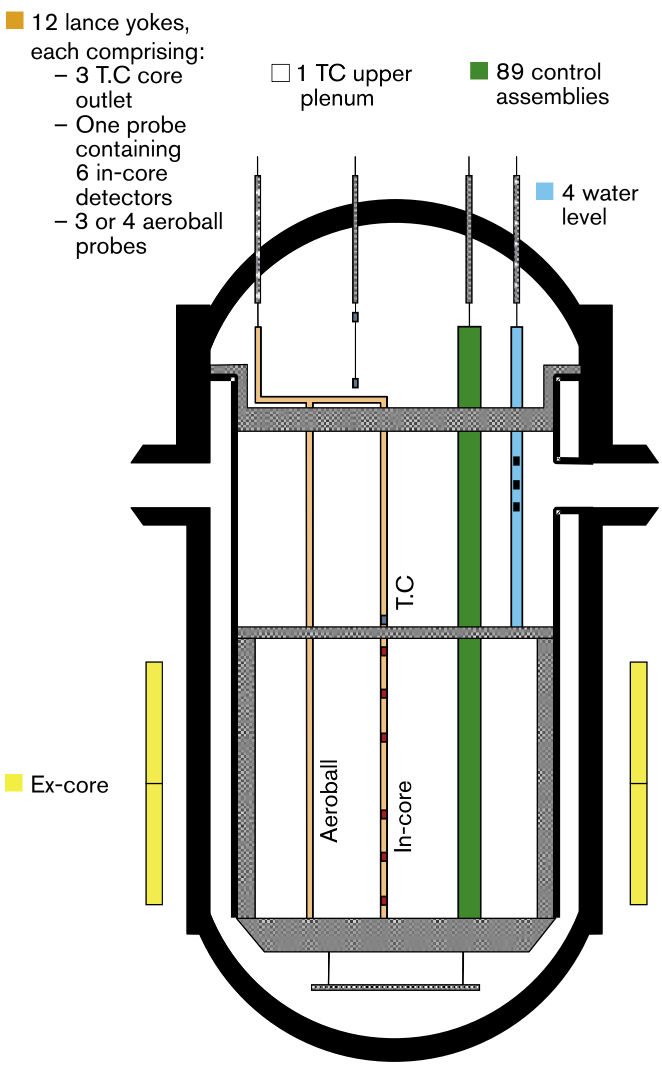
The fixed in-core instrumentation consists of neutron detectors and thermocouples, that are used to measure the neutron flux distribution in the core and the temperature distribution at the core outlet.

The in-core instrumentation is introduced through the vessel head. Therefore, the bottom of the reactor pressure vessel is free from any penetration.



Isar-2 unit, Germany (KONVOI, 1,300 MWe): fuel loading operation.

In-core instrumentation

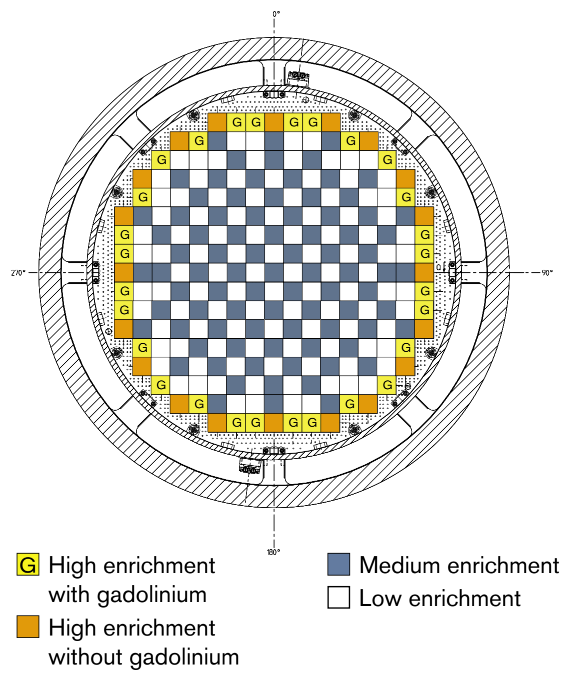


TC: Thermocouple

CHARACTERISTICS	DATA
Reactor core	
Thermal power	4,590 MWth*
Operating pressure	155 bar
Active fuel length	4,200 mm
Number of fuel assemblies	241
Number of fuel rods	63,865
Average linear heat rate	166.7 W/cm

* Depending on specific customer requirements.

Typical initial core loading



- **The EPR™ core is characterized by considerable margins for fuel management optimization.**
- **Several types of fuel management (fuel cycle length, IN-OUT/OUT-IN) are available to meet utilities' requirements.**
- **The main features of the core and its operating conditions give competitive fuel management cycle costs.**
- **The EPR™ core also offers significant advantages in favor of sustainable development in comparison with current PWR designs:**
  - **7-15% saving on uranium consumption per produced MWh,**
  - **10% reduction on long-lived actinides generation per MWh (through improved fuel management).**

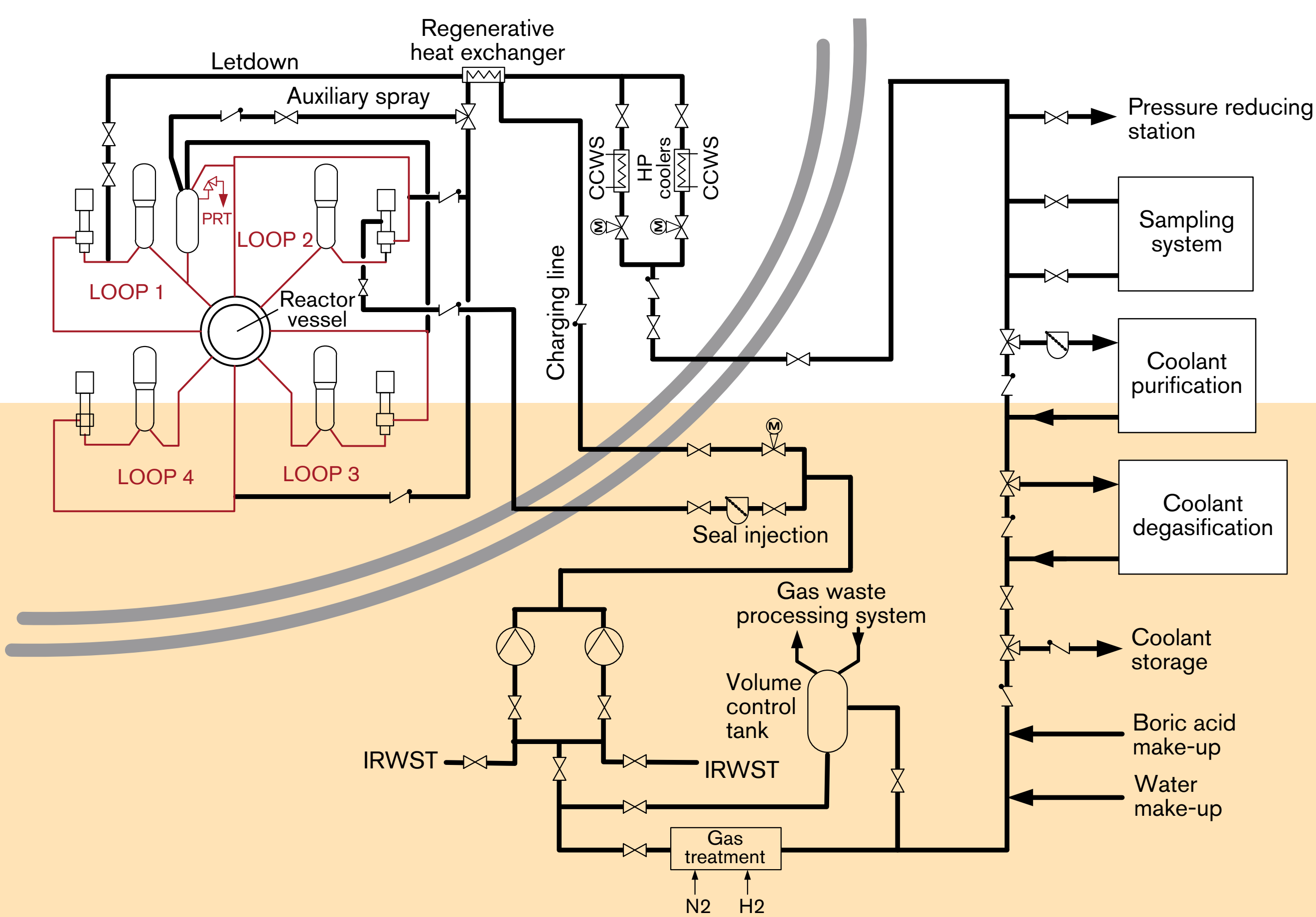
SYSTEMS

CHEMICAL AND VOLUME CONTROL

The **Chemical and Volume Control System (CVCS)** performs several operational functions.

- Continuous control of the water inventory in the **Reactor Coolant System (RCS)** during all normal plant operating conditions, using the charging and letdown flow.
- Adjustment of the RCS boron concentration by injecting demineralized or borated water for control of power variations and during plant start-up or shutdown, or to compensate for core burnup.
- Ensuring the continuous monitoring of the boron concentration of all fluids injected into the RCS, and controlling the concentration and nature of dissolved gases in the RCS by injecting hydrogen into the charging flow and degassing the letdown flow.
- Adjustment of the RCS water chemical characteristics by injection of chemical conditioning agents into the charging flow.
- Ensuring a high flow rate capability for primary coolant chemical control, purification, treatment, degassing and storage.
- Injection of cooled, purified water into the **Reactor Coolant Pump (RCP)** seal system to ensure cooling and leaktightness of the seals and collection of the seal leakage flow.
- Supply of borated water to the RCS up to the concentration required for cold shutdown conditions for any initial condition.
- Reduction of RCS pressure to **Residual Heat Removal System (SIS/RHRS)** operating conditions, by diverting charging flow to the auxiliary pressurizer spray nozzle to condense steam in the pressurizer.
- Filling and draining of the RCS during shutdown.
- Provision of pressurizer auxiliary spray, if the normal system cannot perform its function; provision of make-up to the RCS in the event of loss of inventory due to a small leak.
- Ensuring the feed and bleed function.

Chemical and Volume Control System



SAFETY INJECTION/ RESIDUAL HEAT REMOVAL

The Safety Injection System (SIS/RHRS) comprises the Medium Head Safety Injection System (MHSI), the accumulators, the Low Head Safety Injection System (LHSI) and **the In-Containment Refuelling Water Storage Tank (IRWST)**. The system performs a dual function being used both in normal operating conditions (in RHR mode) and in the event of an accident.

The system is designed on the basis of a quadruple redundancy, i.e. it consists of four separate and independent trains, thus satisfying the N+2 concept (i.e. the capability of performing its function despite a single failure on one train and the unavailability of another train due to maintenance). Each train provides the capability for injection of water into the RCS via an accumulator, a **Medium Head Safety Injection (MHSI)** pump, and a **Low Head Safety Injection (LHSI)** pump discharging through a heat exchanger at the pump outlet.

During normal operating conditions, operating in RHR mode, the system:

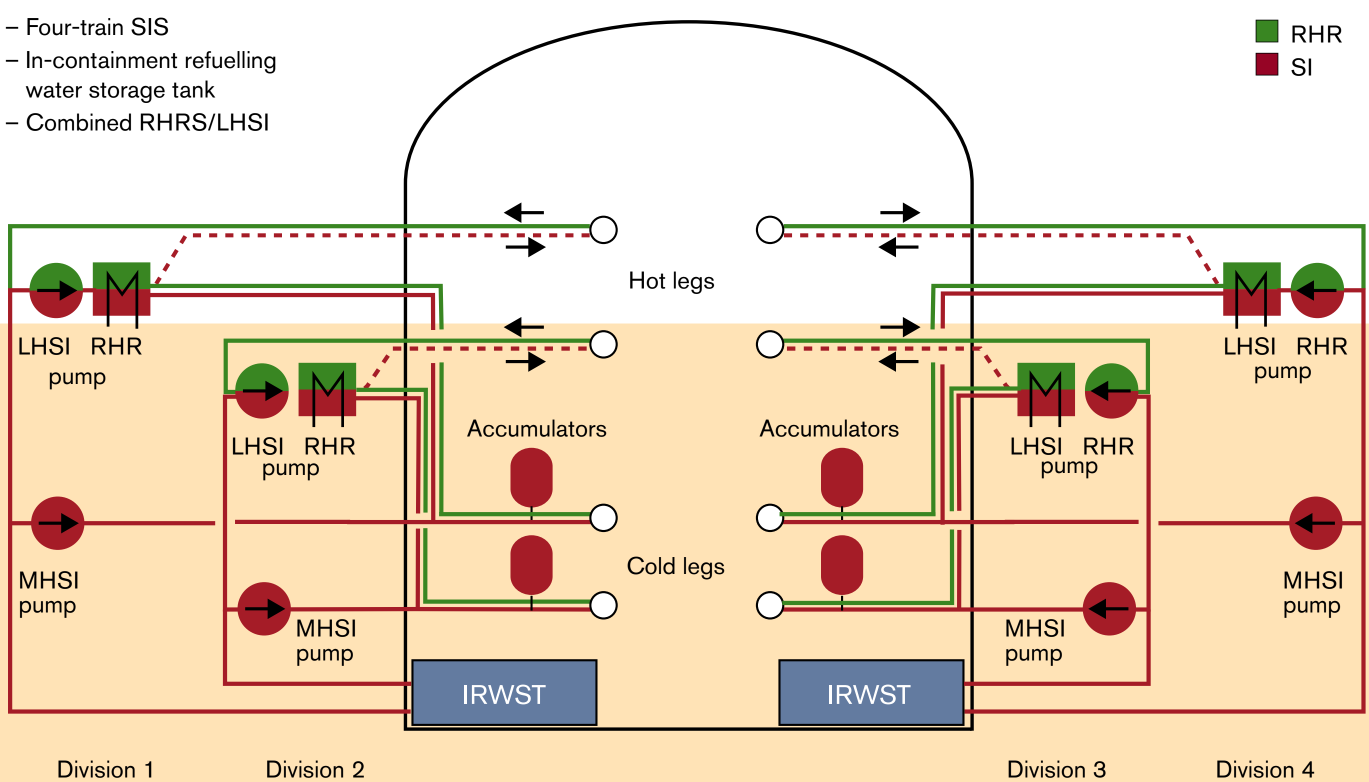
- provides the capability for heat transfer from the RCS to the **Component Cooling Water System (CCWS)** when the RCS temperature is less than 120°C,
- transfers heat continuously from the RCS or the reactor refueling pool to the CCWS during cold shutdowns and shutdown for refueling, as long as any fuel assemblies remain inside the containment.

In the event of an assumed accident the SIS, operating in RHR mode in conjunction with the CCWS and the **Essential Service Water System (ESWS)**, maintains the RCS core outlet and hot leg temperatures below 180°C following a reactor shutdown.

The four redundant and independent SIS/RHRS trains are arranged in separate divisions in the Safeguard Buildings. Each train is connected to one dedicated RCS loop and is designed to provide the necessary injection capability required to mitigate accident conditions. This configuration greatly simplifies the system design.

The design also makes it possible to have extended periods available for carrying out preventive maintenance or repairs. For example, preventive maintenance can be carried out on an entire safety train during power operation.

SI/RHR System



In safety injection mode, the main function of the SIS is to inject water into the reactor core following a postulated loss of coolant accident in order to compensate for the consequence of such events. It is also activated following a postulated steam generator tube rupture or following the loss of the secondary-side heat removal function.

The MHSI system injects water into the RCS at a pressure (92 bar shutoff head) which prevents the system from opening the secondary side safety valves (100 bar) following a steam generator tube leakage. The accumulators and the LHSI system also inject water into the RCS cold legs when the primary pressure is sufficiently low (accumulator: 45 bar, LHSI: 21 bar shutoff head).

IN-CONTAINMENT REFUELING WATER STORAGE TANK (IRWST)

The IRWST is a tank containing a large volume of borated water, which is able to collect water discharged inside the containment in postulated accident conditions.

Its main function is to supply water to the SIS, Containment Heat Removal System (CHRS) and Chemical and Volume Control System (CVCS) pumps, and to flood the corium spreading area in the event of a hypothetical core melt accident.

The tank is located at the bottom of the containment below the operating floor, between the reactor cavity and the radiological shield.

In postulated accident conditions, the IRWST content is cooled by the LHSI system.

Screens are provided to protect the SIS, CHRS and CVCS pumps from debris that might become entrained with IRWST fluid under accident conditions.

EMERGENCY FEEDWATER

The Emergency Feedwater System (EFWS) is designed to ensure that water is supplied to the steam generators when the systems that normally supply feedwater are unavailable.

Its main safety functions are to:

- transfer heat from the RCS to the secondary side via the steam generators, in the period before connection of the RHRS, following any plant incidents other than those involving a significant breach of the reactor coolant pressure boundary; this is done in conjunction with the discharge of steam to the main condenser (if available) or otherwise via the Main Steam Relief Valves or Safety Valves;
- ensure that sufficient water is supplied to the steam generators following a loss of coolant accident or a steam generator tube rupture accident;
- rapidly cool the plant down to LHSI conditions following a small loss of coolant associated with total MHSI failure, in conjunction with steam release to the main condenser (if available) or otherwise via the Main Steam Relief Valves or Safety Valves.

The system consists of four separate and independent trains, each providing injection capability through an emergency feed pump that takes suction from an EFWS tank.

For start-up and normal operation of the plant, a dedicated feed system, separate from EFWS, is provided.

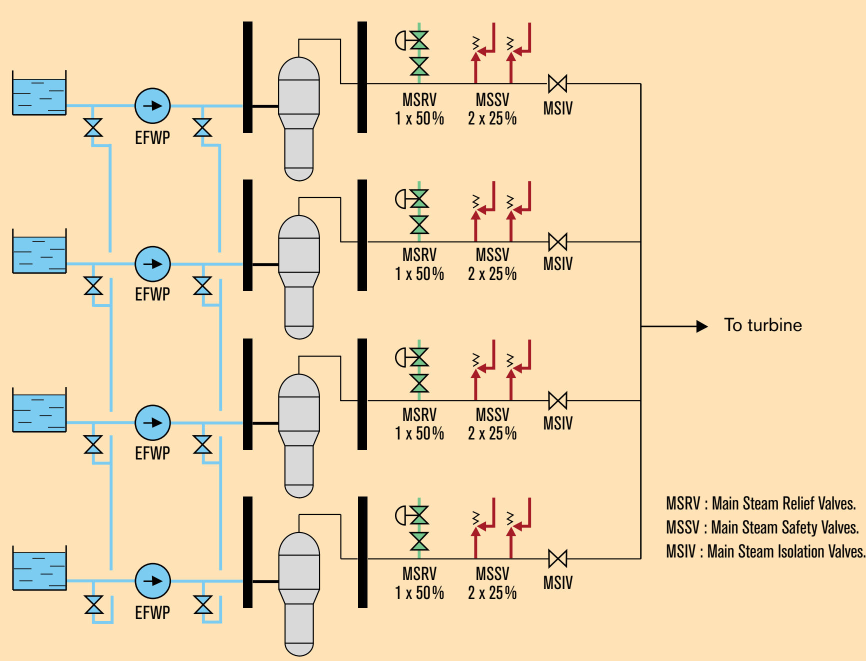
ESSENTIAL SERVICE WATER

The Essential Service Water System (ESWS) consists of four separate safety trains which cool the CCWS heat exchangers using water from the heat sink in all normal plant operating conditions and during incidents and accidents.

Emergency Feedwater System (EFWS)

– Interconnecting headers at EFWS pump suction and discharge normally closed.

– Additional diverse electric power supply for 2/4 trains, using two small Diesel generator sets.



ULTIMATE COOLING WATER SYSTEM

The Ultimate Cooling Water System (UCWS) is a diverse system allowing the dedicated cooling system associated with the mitigation of postulated severe accidents to be cooled, or to act as a back up for cooling the fuel pool.

OTHER SAFETY SYSTEMS

The Extra Borating System (EBS) ensures sufficient boration of the RCS for transfer to the safe shutdown state at a boron concentration required for cold shutdown. This system consists of two separate and independent trains, each capable of injecting the total amount of concentrated boric acid required to reach the cold shutdown condition from any steady state power operating state.

The **Main Steam System (MSS)** upstream of the Main Steam Isolation Valves is safety classified. This part consists of four geographically separated but identical trains, each including one main steam isolation valve, one main steam relief valve, one main steam relief isolation valve and two spring-loaded main steam safety valves.

The **Main Feedwater System (MFS)** upstream of the Main Feedwater Isolation Valves is also safety classified. This consists of four geographically separated but identical trains, each including main feedwater isolation and control valves.

In addition to the safety systems described above, other safety functions are performed to mitigate postulated severe accidents, as described in the section dealing with safety and severe accidents.

COMPONENT COOLING WATER

The Component Cooling Water System (CCWS) transfers heat from the safety related systems, operational auxiliary systems and other reactor equipment, to the heat sink via the Essential Service Water System (ESWS) under all normal operating conditions.

The CCWS also performs the following safety functions:

- it transfers heat from the SIS/RHRS to the ESWS,
- it transfers heat from the Fuel Pool Cooling System (FPCS) to the ESWS for as long as any fuel assemblies are located in the spent fuel storage pool outside the containment,
- it cools the thermal barriers of the Reactor Coolant Pump (RCP) seals,
- it transfers heat from the chillers in divisions 2 and 3 and cools the Containment Heat Removal System (CHRS) via two separate trains.

The CCWS consists of four separate safety trains each located in one of the four divisions of the Safeguard Buildings.

OTHER SYSTEMS

Other systems include the Nuclear Sampling, Nuclear Island Vent and Drain, Steam Generator Blowdown, and Waste Treatment Systems.

- The **Nuclear Sampling System** is used for taking samples of gases and liquid from systems and equipment located inside the reactor containment.
- The **Vent and Drain System** collects gaseous and liquid waste from systems and equipment for treatment.
- The **Steam Generator Blowdown System** prevents build-up of solid matter in the secondary side water.
- The **Waste Treatment System** ensures the treatment of solid, gaseous and liquid wastes.

BACK-UP FUNCTIONS AVAILABLE IN THE EVENT OF TOTAL LOSS OF THE REDUNDANT SAFETY SYSTEMS

➡ **The loss of secondary side heat removal is backed up by primary side feed and bleed through an appropriately designed and qualified primary system overpressure protection system.**

➡ **A combined function comprising secondary side heat removal, accumulator injection and the operation of the LHSI Systems can replace the MHSI System function in the event of a small break loss of coolant accident.**

➡ **Similarly, complete loss of the LHSI system is backed up by the MHSI system and by the Containment Heat Removal System (CHRS) for IRWST cooling.**

SAFETY SYSTEMS AND FUNCTIONS

➡ **Simplification by separation of operating and safety functions.**

➡ **Fourfold redundancy is applied to the safety systems and to their support systems whenever maintenance during operation is desired. This architecture allows them to be maintained during plant operation, ensuring a high plant availability factor.**

➡ **The different trains of the safeguard systems are located in four different buildings to which strict physical separation is applied.**

➡ **Because of the systematic application of functional diversity, there is always a diverse system which can perform the desired function and bring the plant back to a safe condition in the highly unlikely event of all the redundant trains of a system becoming simultaneously unavailable.**

POWER SUPPLY

The outline design of the power supply system is shown below.

The Emergency Power Supply is designed to ensure that the safety systems are supplied with electrical power in the event of loss of the preferred electrical sources.

The Emergency Power Supply comprises four separate and redundant trains arranged in accordance with the four division concept. Each train is provided with an Emergency Diesel Generator (EDG) set.

The emergency power supply system is designed to meet the requirements of the N+2 concept.

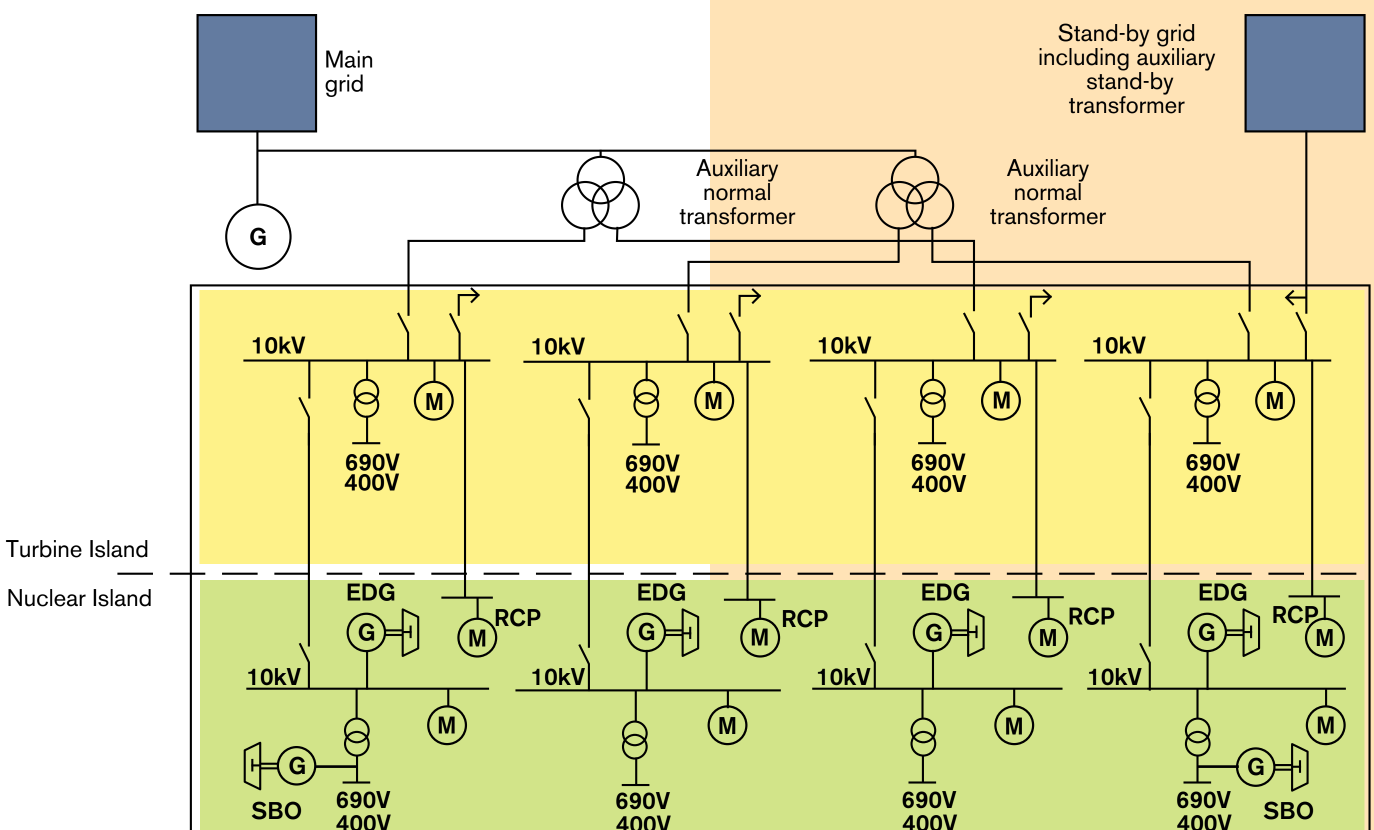
The safety loads connected to the emergency power supply are those required to safely shut down the reactor, remove residual and stored heat, and prevent the release of radioactivity.

In the event of total loss of the four EDGs (Station Black Out – SBO), two additional generators, the SBO Diesel Generators, provide the power necessary to supply the emergency loads.

The SBO Emergency Diesel Generators are connected to the safety busbars of two divisions.

Isar-2, Germany (KONVOI, 1,300 MWe) emergency Diesel generator.

Electrical systems of an EPR™ nuclear power plant (typical)



FUEL HANDLING AND STORAGE

The reactor core is periodically reloaded with fresh fuel assemblies. The spent fuel assemblies are moved to and stored in the Spent Fuel Pool (SFP). These operations are carried out using several handling devices and systems (fuel transfer tube, spent fuel crane, fuel elevator, refuelling machine and spent fuel cask transfer machine).

The underwater fuel storage racks are used for underwater storage of:
- fresh fuel assemblies, prior to loading,
- spent fuel assemblies following fuel unloading from the core and prior to shipment off the plant.

The Fuel Pool Cooling and Purification System (FPCPS) is divided into two subsystems: the Fuel Pool Cooling System (FPCS) and the Fuel Pool Purification System (FPPS).

The FPCS provides the capability for heat removal from the SFP and is designed to keep the SFP temperature at the required level during normal plant operation (power operation and in refuelling outages). This system is arranged in two separate and independent trains with two FPCS pumps operating in parallel in each train. The FPCS also includes a third diverse cooling train to cope with any common mode failure of the two main trains (including loss of the CCWS).

The FPPS comprises a purification loop for the SFP, a purification loop for the reactor pool and the IRWST, and skimming loops for the SFP and the reactor pool. The system includes two cartridge filters, a demineralizer and a resin trap filter used for purification of pool water.

Chooz B1, France (N4, 1,500 MWe) Fuel Building.

INSTRUMENTATION & CONTROL SYSTEM

A nuclear power plant, like any other industrial facility, requires means for monitoring and controlling its processes and equipment. These means, as a whole, constitute the plant Instrumentation & Control (I&C) system, which comprises several subsystems with their electrical and electronic equipment.

The I&C system is basically composed of sensors to transform physical data into electrical signals, programmable controllers to process these signals and provide actuator control and monitoring and control means for use by the plant operators.

The overall design of the I&C system and associated equipment must comply with process, nuclear safety, and operational requirements.

➡ A computerized plant I&C system, supported by modern digital technologies.

EPR™ I&C OVERALL ARCHITECTURE

Within the overall I&C architecture, each subsystem is characterized according to its functions (measurement, actuation, automation, man-machine interface) and its role in safety or operation of the plant.

A multi-level structure

The structure of the EPR™ Instrumentation and Control System is characterized by a four-level organisation:

- **Level 0** corresponds to sensors and actuators;
- **Level 1** carries out the automation functions: it comprises the reactor control and protection systems, the turbo-generator control and protection system, and the system performing all other automation functions (plant control and protection);
- **Level 2** carries out functions related to the human-machine interface that allow the plant to be operated and monitored;
- **Level 3** contains computer applications designed for non-real-time operation (dedicated to so-called “operating” personnel, i.e. staff carrying out operation and maintenance) and applications used outside of the plant. These applications provide operational and maintenance aids (trends, reports…), which assist in off-line analysis of the state of the unit or equipment and interlock management. They also permit interfacing and exchange of data with offsite bodies (power distribution network dispatching, National Emergency Support Centers, etc.).

The architecture is supported by computer aided design (CAD) and a data production organisation, which ensures the consistency of the configuration (Design CAD is used for functional studies and data production CAD for the Instrumentation and Control systems programming).

Safety classification

I&C functions and equipment are categorized into classes depending on their importance to safety. I&C functions are implemented using components with the appropriate quality level for their safety class.

Redundancy, separation, diversity and reliability

EPR™ I&C systems and equipment comply with the principles of redundancy, diversity and separation applied in the design of EPR™ safety-related systems. For example the Safety Injection System and the Emergency Feedwater System, which each consist of four redundant and independent trains, also have four redundant and independent I&C channels.

Each safety-related I&C system is designed to be able to satisfactorily fulfill its function, even if one of its channels is not available due to a failure and a second one is unavailable for preventive maintenance reasons.

The level of availability of the I&C systems performing safety functions is specified so as to comply with the probabilistic safety targets adopted in the EPR™ design.

➡ A quadruple redundant safety-related I&C for a further increase in the level of safety.

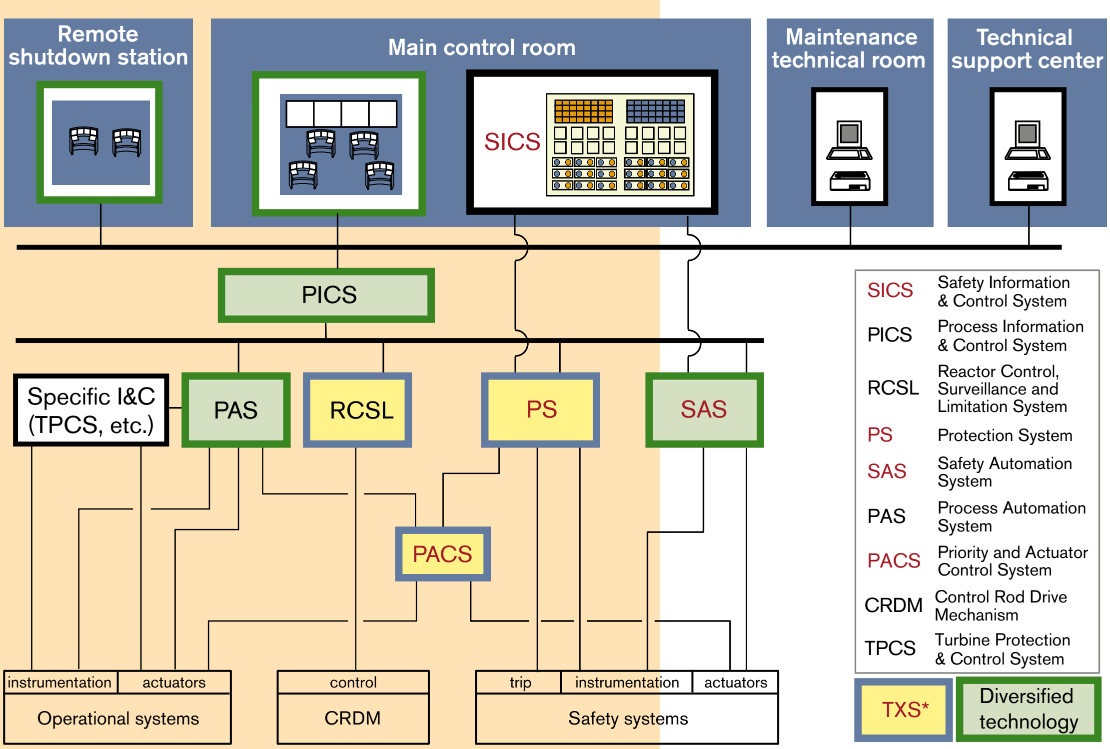
A computerized screen-based control room designed to maximize operator efficiency. Chooz B1, France (N4, 1,500 MWe).

Description of the I&C architecture

Functional safety class*	
F1A	Functions required in case of accident to bring the reactor to controlled state.
F1B	Functions required after an accident to bring the reactor to safe state. Functions intended to avoid the risk of radioactive releases.
F2	Other functions contributing to plant safety (adherence to limit operating conditions, surveillance of safety system availability, protection against the effects of internally-generated hazards, detection/monitoring of radioactive releases, functions used in post-accident operation, etc.).
NC	Non-classified functions.

* Defines Quality Assurance Requirements.

I&C architecture (functional diagram)



* TELEPERM-XS AREVA NP technology.
XXX: safety class F1A and F1B.

ROLE OF THE I&C SYSTEMS

Like all other EPR™ systems, the I&C systems act in accordance with the "defense in depth" concept (see page 32).

Three lines of defense are implemented:
- the control system maintains plant parameters within their normal operating ranges,
- in case a parameter leaves its normal range, the limitation system performs appropriate actions to avoid the need for the initiation of protective actions,
- if a parameter exceeds a protection threshold, the reactor protection system generates the appropriate safety actions (reactor trip and safety system actuation).

Normally, to operate and monitor the plant, the operators use workstations and a plant overview panel in the Main Control Room. In case of unavailability of the Main Control Room, the plant is monitored and controlled from the Remote Shutdown Station.

Instrumentation

A number of instrumentation channels supply measured data for control systems, surveillance and protection systems, and for information for the control room staff. Multiple-channel acquisition is used for control of important parameters such as the pressure and temperature of the primary coolant and the liquid level in the reactor pressure vessel. Multiple-channel and diverse data acquisition methods are implemented.

Role of the various I&C subsystems

The automation system can be broken down into two subsystems:

The PAS (Process Automation System), which carries out:
- automation and monitoring of the unit in normal operating conditions. The PAS processes F2 and non-classified (NC) functions with the exception of those carried out by the RCSL (defined below) and the control and protection system for the conventional island and site-dedicated equipment;
- the PAS is used for the monitoring and automation of F2 and NC functions to mitigate the consequences of severe accidents and multiple failure events (risk reduction category events);
- limitation actions to anticipate and avoid an eventual trip of the reactor due to a protection system threshold being exceeded.

The SAS (Safety Automation System), the functions of which are:
- managing F1B post-accident processing to take the unit from the controlled state to the safe state;
- preventing significant radioactive releases (F1B);
- management of events which could lead to accidents or limiting accidents.

The PS (Protection System) performs the following functions:
- monitoring of safety parameters in all unit operating conditions;
- enabling, following an initiating event:
  - automatic F1A protection and safeguard actions,
  - automatic F1A commands of the safety support systems;
- possible manual F1A actions.

Diversity of equipment (software and hardware) between the PAS and the PS is implemented in order to reduce the risk of a common mode failure.

The RCSL (Reactor Control Surveillance and Limitation) carries out:
- monitoring of the core and the rod control function;
- monitoring of the core and the reactor coolant system against the limiting conditions of operation;
- limitation actions to anticipate and avoid the possibility of a reactor protection threshold being exceeded.

The PACS (Priority and Actuator Control System) manages the control and monitoring of the actuators used by both the operational and the safety systems. For actuators involved in protection (F1A) or post-accident functions (F1B), the assignment of priorities to commands from the PS (F1A), SAS (F1B) and/or PAS (NC/F2) is managed by the PACS.

The PACS is responsible for four types of functions:
- priority management;
- essential protection of components;
- actuator control;
- actuator monitoring.

Functions are allocated and distributed over several pieces of equipment (switchgear panels and Level 1 equipment).

All the I&C subsystems are implemented using digital equipment.

TELEPERM XS

PS, RCSL and PACS are implemented using the TELEPERM XS technology. TELEPERM XS is AREVA NP's digital I&C platform specifically developed for safety and high-reliability functions in nuclear facilities. Its high functional reliability is achieved thanks to a combination of fail-safe design, fault tolerance, integrated self-checking, structural simplicity and outstanding robustness. Its resistance to environmental conditions such as temperature swings, vibrations, seismic loadings and electromagnetic radiations meets the requirements of international codes and standards (IEC, IEEE, EPRI and KTA). It is complemented by engineering tools and associated equipment supporting all design phases.

In May 2000, the US Nuclear Regulatory Commission issued the generic approval for the use of the TELEPERM XS system platform in all safety applications, including protection systems. TELEPERM XS is also licensed and used in Argentina, Bulgaria, China, Finland, France, Germany, Hungary, Slovakia, Spain, Sweden and Switzerland.

Human-machine interface (level 2)

The EPR™ Control Room comprises:

- **a computerized Main Control System which allows the unit to be run in normal and accident situations. It comprises:**
  – four operator workstations with five standardized operating screens and a dedicated screen for the operating applications (level 3),
  – several Compact Operator Workplaces (COW), i.e., workplaces with a reduced number of screens which can be configured in a control mode or in supervision mode and used for maintenance and outage phases;
- **a mimic panel in the control room which provides a common reference for the various members of the operator team;**
- **a Safety Information and Control System (SICS) to be used if the Process information and Control System (PICS) is not available. It allows the unit to be brought to, and kept in, a safe shutdown state.**

  In order to reduce the risk of a common mode failure, the items of equipment used for the PICS and the SICS are independent.

  In the event of an unavailibility of the control room (e.g. fire), the Remote Shutdown Station (RSS), which is located outside the control room, allows operators to bring the unit to a safe state. The RSS will be given computerized control means with technology which is identical to that of the PICS. The RSS comprises three operator stations.

The architecture of the EPR™ Instrumentation and Control System is evolutionary with regard to existing plants

The main developments have been in the following areas:

- drawing on the lessons of the N4 series and the German KONVOI plants (architecture in four divisions, operator stations with five standardized screens fitted with a signalling strip for alarms, automatic limitation functions…);
- increasing safety and availability of the unit (architecture in four divisions, automation of plant limits…);
- optimizing performance and costs, whilst still being based on mature technological developments (proven Teleperm XS components, computerized mimic panel…).

The EPR™ power plant's computerized control room features control screens providing relevant summary information on the process (computer-generated picture).

SAFETY

Golfech 2, France (1,300 MWe): reactor pressure vessel and internals.

NUCLEAR SAFETY

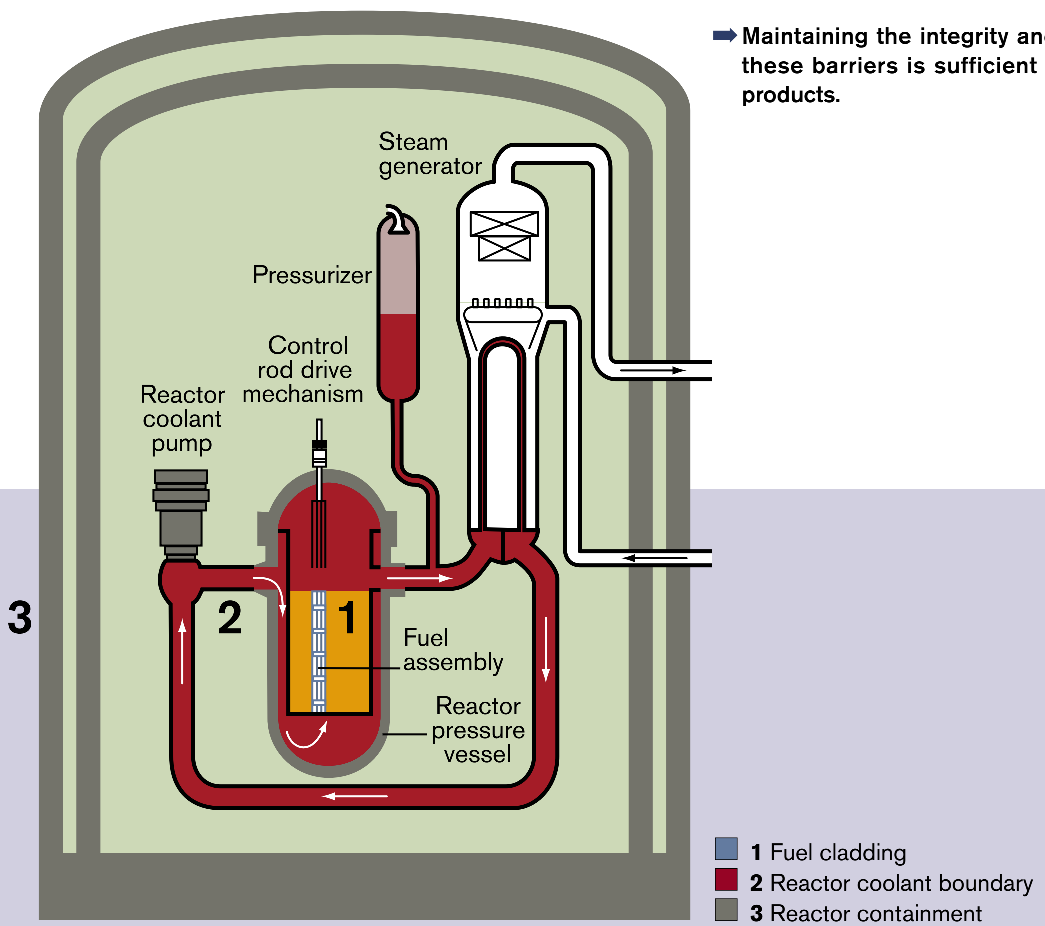
The fission of atomic nuclei, which takes place in a nuclear reactor to generate heat, also produces radioactive substances from which people and the environment must be protected.

Nuclear safety is the set of technical and organisational provisions that are applied in the design, construction and operation of a nuclear plant to reduce the likelihood of an accident and to limit its consequences should it nevertheless occur.

Nuclear reactor safety requires that at all times three basic safety functions should be fulfilled:
- control of the nuclear chain reaction, and therefore of the power generated,
- cooling of the fuel, including removal of residual heat after the chain reaction has stopped,
- containment of radioactive products.

Nuclear safety relies upon two main principles:
- the availability of three protective barriers,
- application of defense in depth.

The three protective barriers



THREE PROTECTIVE BARRIERS

The concept of the "protective barriers" involves placing a series of strong, leak-tight physical barriers between the radioactive materials and the environment to contain radioactivity in all circumstances:
- **first barrier:** the fuel, inside which most of the radioactive products are already trapped, is enclosed within a metal cladding;
- **second barrier:** the reactor coolant system is enclosed within a pressurized metal envelope that includes the reactor vessel which houses the core containing the fuel rods;
- **third barrier:** the reactor coolant system is itself enclosed in a thick-walled concrete containment building (for the EPR™ reactor, the containment is a double shell resting on a thick basemat, the inner wall being covered with a leak-tight metallic liner).

➡ **Maintaining the integrity and leaktightness of just one of these barriers is sufficient to contain radioactive fission products.**

DEFENSE IN DEPTH

The concept of "defense in depth" involves ensuring the effectiveness of the protective barriers by identifying the threats to their integrity and by providing successive lines of defence to protect them from failure:

- **first level:** implementation of a safe design, high quality of construction and safe and reliable operation incorporating lessons from experience feedback in order to prevent occurrence of failures;
- **second level:** means of surveillance for detecting anomalies that could lead to a departure from normal operating conditions, in order to anticipate failures or to detect and intercept deviations from normal operational states in order to prevent anticipated operational occurences from escalading to accident conditions. The most important of this level is the one that automatically shuts down the reactor by insertion of the control rods into the core which stops the nuclear chain reaction in a few seconds;
- **third level:** means of action for mitigating the consequences of failures and preventing core melt down. This level includes use of diverse and redundant systems to automatically bring the reactor to a safe shutdown state. In addition, a set of safety systems, which also have redundancy, are provided to ensure containment of radioactive products;
- **to further extend** the defense in depth approach a failure of all three levels is postulated, resulting in a "severe accident" situation. Means are provided to minimise the consequences of such a situation.

➡ **Applying the defense in depth concept leads to the functions of core power and cooling control being protected by multiple redundant systems: fourfold redundancy is used in the EPR™ technology.**

➡ **Safety functions are ensured by diversified means to minimize the risk of common mode failure.**

➡ **In addition, the components of these systems are designed to automatically move to a safe position in case of a failure or a loss of electrical or power supplies.**

The training for steam generator inspection illustrates:

➡ **the first level of defence in depth relating to the quality of workmanship,**

➡ **the second barrier, as the training relates to steam generator tubes which form part of the primary system.**

Lynchburg technical center (Va, USA): training for steam generator inspection.

EPR™ SAFETY SYSTEMS

A key decision, in line with the recommendations of the French and German safety authorities, was to base the EPR™ design on an evolutionary approach using experience feedback from more than 100 reactors previously built or under construction by AREVA NP. This decision enabled the designers to use experience from the most recently constructed plants (N4 reactors in France and KONVOI in Germany) and to avoid the risk arising from the adoption of unproven technologies.

This approach did not mean that innovative solutions, backed by the results of large-scale Research and Development programs, were excluded. Key innovations have been included in the EPR™ design to help accomplish EPR™ safety systems objectives, in particular with regard to the prevention and mitigation of hypothetical severe (core melt) accidents.

The EPR™ safety approach, motivated by a desire to steadily increase the level of safety, involves a reinforced application of the defense in depth concept:
- by improving preventive measures to reduce the probability of core melt,
- by incorporating features for limiting the consequences of core melt accidents at the design stage.

➡ **A twofold safety approach is used against severe accidents:**
- **reducing their probability by reinforced preventive measures,**
- **drastically limiting their potential consequences.**

DESIGN CHOICES FOR REDUCING THE PROBABILITY OF ACCIDENTS THAT COULD CAUSE CORE MELT

In order to reduce the probability of core melt accidents, below the already extremely low levels achieved in reactors in the French and German nuclear power plant fleet, advances were made in three areas:

The EPR™ technology complies with the safety objectives set down by the French and German safety authorities for future PWR power plants:

➡ **further reduction of core melt probability,**

➡ **practical elimination of accident situations which could lead to a large early release of radioactive materials,**

➡ **need for only very limited protective measures in area and time*, in case of a postulated low pressure core melt situation.**

* No permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long-term restriction in the consumption of food.

- an extended range of operating conditions was taken into account at the design stage,
- equipment and systems were designed to reduce the likelihood of an abnormal situation deteriorating into a severe accident,
- improvements were made in the reliability of operator actions.

Extension of the range of operating conditions considered at design stage

The use of the probabilistic safety assessments

Although the EPR™ safety approach is based mainly on applying the defense in depth concept (which is part of a deterministic approach), the design is supported by probabilistic analyses. These make it possible to identify accident sequences that could cause core melt or result in large radioactivity releases, to evaluate their probability, and to identify their potential causes and countermeasures. The use of probabilistic assessment at the design phase of the EPR™ reactor has been a decisive factor in the choice of technical options to improve the safety level of the reactor.

For EPR™ technology, the probability of an accident leading to core melt is extremely small and below that in the previous-generation reactors:
- below 1/100,000 (10^{-5}) per reactor/year for all types of initiating failure and hazard, which meets the objective set for new nuclear power plants established by the International Nuclear Safety Advisory Group (INSAG) with the International Atomic Energy Agency (IAEA) – INSAG 3 report,
- below 1/1,000,000 (10^{-6}) per reactor/year for events occurring inside the plant, which is a factor 10 reduction compared with the most modern reactors currently in operation,
- below 1/10,000,000 (10^{-7}) per reactor/year for the accident sequences associated with early loss of the radioactive containment function.

Consideration of shutdown states in the design of protection and safety systems

Probabilistic safety assessments highlighted the importance of reactor shutdown states. These shutdown states were systematically taken into account in the EPR™ design, both in risk analysis and in the design of the protection and safety systems.

Greater protection from internal and external hazards

The layout of the safety systems and the design of the civil works structures minimize the risks from hazards such as earthquake, flooding, fire, airplane crash.

The safety systems are designed on the basis of a quadruple redundancy, both for their mechanical and electrical parts and for of the supporting I&C. This means that each system consists of four subsystems, or “trains”, each one capable by itself of fulfilling the entire safety function. The four redundant trains are physically separated from each other and located in four independent divisions (buildings).

Each division includes one train of:

- **the safety injection system for injecting borated water into the reactor vessel in a loss of coolant accident. This consists of a low-head injection system and its cooling loop, and a medium-head injection system,**
- **the steam generator emergency feedwater system,**
- **the electrical and I&C systems supporting these systems.**

The building housing the reactor, the building in which the spent fuel is stored on an interim basis, and the four buildings corresponding to the four divisions of the safety system are provided with special protection against externally generated hazards such as earthquakes and explosions.

Protection against an aircraft crash has been further strengthened. The reactor building is protected by a double concrete shell: an outer thick shell made of reinforced concrete and an inner thick shell made of pre-stressed concrete which is internally covered with a thick metallic liner. The thickness and the reinforcement of the outer shell provide sufficient strength to absorb the impact of a large commercial aircraft. The double concrete wall is extended to the fuel building, and to two of the four safeguard buildings containing the Main Control Room and the remote shutdown station which would be used in emergency conditions.

The other two safeguard buildings which are not protected by the double wall are remote from each other and separated by the reactor building, which prevents them from being simultaneously damaged. In this way, if an aircraft crash were to occur, at least three of the four trains of the safety systems would be available.

Choice of equipment and systems to reduce the risk of an abnormal situation deteriorating into an accident

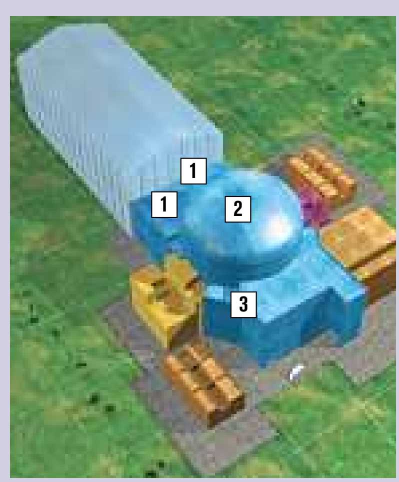
Reduction in the risk of a large reactor coolant pipe break

The design of the reactor coolant system, the use of forged pipework and components, construction with high mechanical performance materials, combined with the measures to allow early leak detection and to facilitate in-service inspections, allow rupture of the major reactor coolant pipework to be excluded from the design basis (i.e. to be “practically eliminated” by design).

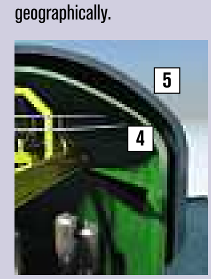
The major safety systems comprise four sub-systems or trains, each capable of performing the entire safety function on its own. There is one train in each of the four safeguard buildings (1) surrounding the reactor building (2) to prevent a simultaneous failure of the trains.

➡ **A set of quadruply redundant safety systems, with independent and geographically separated trains, minimize the consequences of potential internal and external hazards.**

➡ **Protection against aircraft crash is reinforced by use of a strong double-walled concrete shell implemented to shelter the EPR™ reactor.**



The outer shell (5) covers the reactor building (2), the spent fuel building (3) and two of the four safeguard buildings (1). The other two safeguard buildings are separated geographically.



The reactor containment building has two walls: an inner pre-stressed concrete housing (4) internally covered with a metallic liner and an outer reinforced concrete shell (5).

Optimized management of postulated steam generator tube break

Steam generator tube break could potentially result in a transfer of water from the primary system to the secondary system. Following such an event the fall in the primary side pressure would automatically induce a reactor shutdown and then activate safety injection into the reactor vessel. In the EPR™ reactor, the driving pressure of the medium-head injection is set below the set pressure of the secondary system safety valves, which prevents the steam generators from overfilling with water in these circumstances. This has the advantages of avoiding the release of liquid coolant, thus reducing the potential release of radioactivity into the environment, and also considerably reducing the risk of a secondary system safety valve jamming in open position.

Simplification of the safety systems and optimization of their redundancy and diversity

Those safety systems with a quadruple redundancy are spread in four separate divisions.

The system design is straightforward with minimal changes being required to the system configuration whether the reactor is at power or shutdown. This is illustrated by the design of the EPR™ safety injection system and residual heat removal system.

The safety injection system, which would be activated in a loss of coolant accident, is designed to inject water into the reactor circuit to cool the reactor core. In the first phase of injection, water is injected into the cold legs of the reactor coolant system loops (pipework sections located between the reactor coolant pumps and the reactor vessel).

In the longer term, water is simultaneously injected into the cold and hot legs (legs located between the steam generators and the reactor vessel). The requirement for switching from the so-called "direct injection" phase to a "recirculation" phase in previous reactor designs, does not apply to the EPR™ reactor. The EPR™ low head safety injection system is provided with heat exchangers enabling it carry out the core cooling function on its own. The EPR™ reactor is further equipped with a dedicated system for cooling the reactor containment in severe accidents which would be activated by an operator only in the event of a core melt accident.

Residual heat removal is provided by the four trains of the low head part of the safety injection system, which under these circumstances would be configured to remove the residual heat in closed loop mode (suction via the hot legs, discharge into the cold legs). Safety injection remains available for action in the event of a leak or break occurring on the reactor coolant system.

➡ **The safety-related systems are simple, redundant and diverse to ensure high reliability and effectiveness.**

Increased reliability of operator action

Extension of action times available to the operator

The short term protection and safety actions needed in the event of an incident or accident are automated. To ensure a high level of safety, design criteria have been established to set minimum timeframes before operator action is required. In any case, operator action is not required before at least thirty minutes for actions taken in the Control Room, or one hour for actions performed locally on the plant.

The increased volume of the major EPR™ components (reactor pressure vessel, steam generators, pressurizer) increases the response time of the reactor in upset conditions, extending the timescales available to the operators to carry out initial actions.

Increased performance of the human-machine interface

Experience feedback from the design and operation of the N4 reactors, which were among the first plants to be equipped with a fully computerized Control Room, and use of the last generation, yet well proven Teleperm XS safety I&C give the EPR™ reactor a high performance and reliable human-machine interface. Operator actions are based on real time plant data made available by the state-of-the-art EPR™ I&C.

The ergonomics of the EPR™ Control Room benefits from the latest developments in human-machine interface design (computer-generated picture).

➡ **Design of components, high degree of automation, advanced design of I&C and human-machine interface combine to increase the reliability of operator actions.**

DESIGN CHOICES FOR LIMITING THE CONSEQUENCES OF SEVERE ACCIDENTS

➡ **A core melt-accident, in itself highly unlikely, would only require very limited off-site countermeasures both with regard to time and the extent of the affected area.**

In response to the new safety requirements for future nuclear power plants, introduced as early as 1993 by the French and German safety authorities, the plant design must be such that a core melt accident would need only very limited off-site countermeasures in time and space.

The policy of mitigation of the consequences of a severe accident, which guided the design of the EPR™ reactor, therefore aimed to:

➡ **"practically eliminate" situations which could lead to early radiological releases, such as:**
- **high-pressure core melt ejection from the reactor pressure vessel,**
- **high-energy corium*/water interactions,**
- **hydrogen detonations inside the reactor containment,**
- **by-pass of the containment;**

➡ **ensure the integrity of the reactor containment, even in the event of a low-pressure core melt followed by ex-vessel progression, through:**
- **retention and stabilisation of the molten corium* inside the containment,**
- **cooling of the corium.**

➡ **Situations which could generate a significant radioactivity release are "practically eliminated" by design.**

Prevention of high-pressure core melt

In addition to the reactor coolant system depressurisation systems provided on the other reactors, the EPR™ reactor is equipped with valves dedicated to preventing ejection of molten core materials at high-pressure in the event of a severe accident. These valves ensure fast depressurization, even in the event of failure of pressurizer relief lines.

The valves, which are controlled by the operator, are designed to safely remain in open position after their first actuation. Their high-relief capacity enables fast primary depressurisation of the reactor coolant system to a pressure of a few bars, precluding any risk of over-pressurization of the containment through dispersion of corium debris in the event of vessel failure at high pressure.

* Corium: product resulting from the melting of the core components and interaction with the structures it could meet.

Prevention of high-energy corium/water interaction

The high mechanical strength of the reactor vessel prevents it from being significantly damaged by any conceivable reaction, which could occur between corium* and coolant inside the vessel.

The areas of the containment where the corium could come into contact with water after being ejected from the pressure vessel – namely the reactor pit and the core spreading area – are kept "dry" (free of water) in most circumstances. Only when the corium is spread inside the dedicated spreading area, then partially cooled and solidified (and therefore less reactive), is it brought into contact with cooling water.

Containment design against hydrogen risks

In the unlikely event of a severe accident, hydrogen could be released inside the containment in significant quantities. Hydrogen may be produced initially by reaction between the coolant and the zirconium used in the fuel rod cladding, and subsequently by the reaction between the corium and the concrete in the corium spreading and cooling area.

For this reason, the pre-stressed concrete inner shell of the containment is designed to withstand pressures that could conceivably result from the combustion of this hydrogen. Further devices called catalytic hydrogen recombiners are installed inside the containment to keep the average concentration below 10% at all times, to avoid the risk of detonation. Assuming hydrogen combustion by deflagration only, the pressure in the containment will not exceed 5.5 bar.

Corium retention and stabilization to protect the basemat

The reactor pit is designed to collect the corium in the case of ex-vessel melt progression and to transfer it to the corium spreading and cooling area. The floor of the reactor pit is protected by "sacrificial" concrete which is backed-up by a protective layer consisting of refractory concrete.

➡ **Even in the extremely unlikely event of a core melt accident resulting in ejection of molten materials from the reactor pressure vessel, the molten core and radioactive products would be most likely to remain confined inside the reactor building whose long term integrity would be maintained.**

In the event of core meltdown, molten core escaping from the reactor vessel would be passively collected and retained, then cooled in a specific area inside the reactor building.

The dedicated corium spreading and cooling area (core-catcher) consists of a channelled metal structure covered with "sacrificial" concrete. Its purpose is to protect the nuclear island basemat from damage. Its lower section contains cooling channels in which water is circulated. The large spreading surface area (170 m^2) promotes cooling of the corium.

The transfer of the corium from the reactor pit to the spreading area is initiated by a passive device: a steel "plug" that melts due to the heat from the corium.

After spreading, flooding of the corium is triggered by opening of a passively activated valve. It is then cooled, also passively, by gravity injection of water from the refuelling water storage tank located inside the containment and evaporation.

The cooling stabilises the corium in a few hours and ensures its complete solidification in a few days.

Containment heat removal system and long-term residual heat removal device

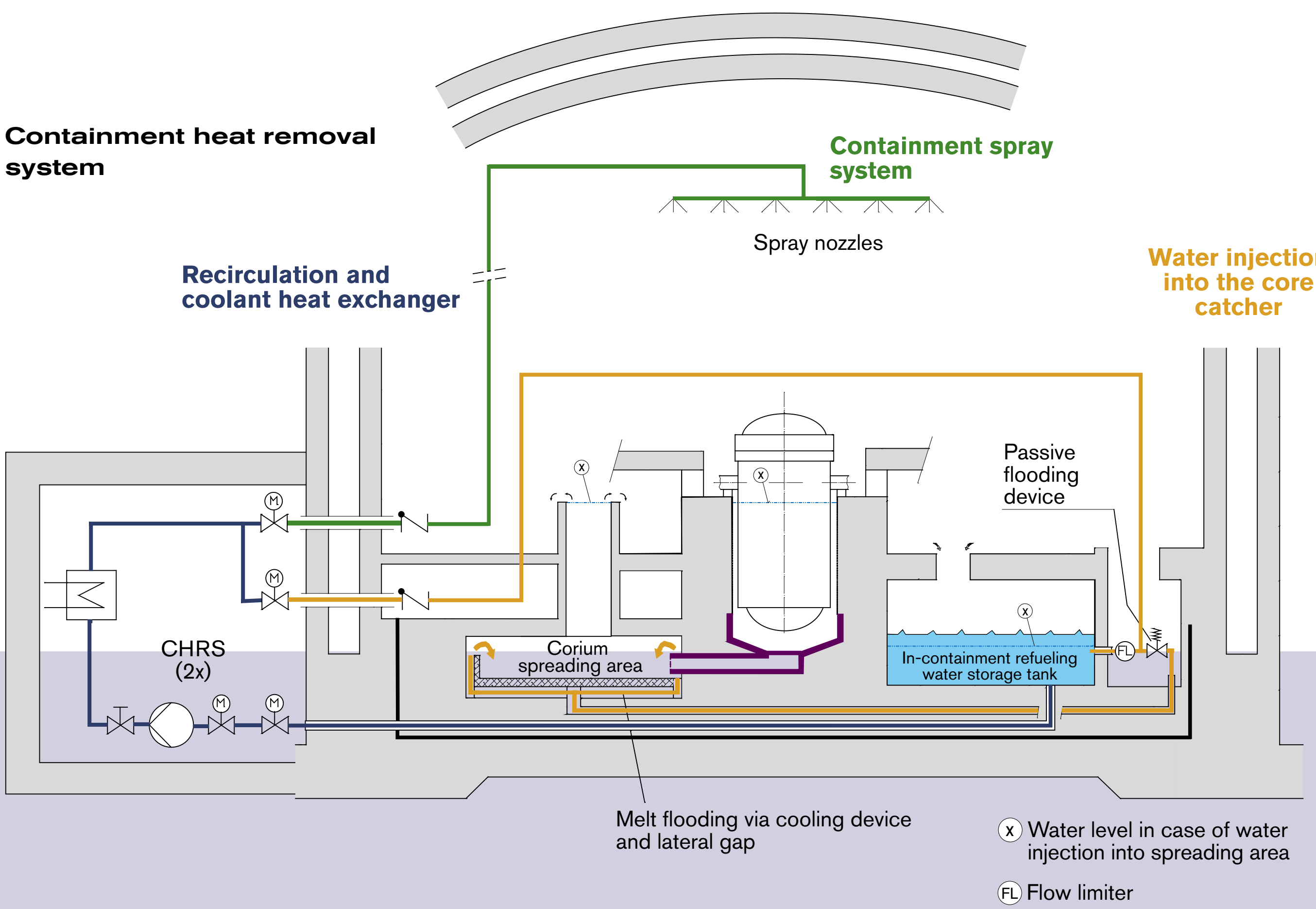
In order to maintain the long-term integrity of the containment in a severe accident means are provided to control the pressure increase inside the containment due to residual heat. A dedicated dual-train spray system with heat-exchangers and dedicated heat sink is provided to fulfil this cooling function. Owing to the thermal inertia of the containment and its internal concrete structures, a long time period is available for the deployment of this system by the operators (at least 12 hours) while the large containment free volume helps to limit the pressure increase after the accident.

A second mode of operation of the containment heat removal system enables it to feed water directly into the core-catcher to cool it.

Collection of inter-containment leaks

In the event of a core melt leading to vessel failure, the containment building would be the only remaining barrier of the three containment barriers; provisions are therefore made to ensure that it remains undamaged and leak-tight. For the EPR™ technology, the following measures are adopted:

- a metal liner internally covers the pre-stressed concrete inner shell,
- the internal containment penetrations are equipped with redundant isolation valves and leak recovery devices to avoid containment bypass,
- the architecture of the peripheral buildings and the sealing systems of the penetrations removes the risk of direct leakage from the inner containment to the environment,
- the inter-space between the inner and outer shells of the containment is maintained at a slightly negative pressure to enable leaks from the inner containment to be collected,
- the above provisions are supplemented by a containment ventilation system and a filter system upstream of the stack.



Two fully redundant trains with specific diversified heat sink

EPR™ REACTOR CONSTRUCTION

Olkiluoto 3 nuclear power plant, Finland June 2009.

EPR™ REACTOR CONSTRUCTION TIME SCHEDULE

The evolutionary approach adopted for the EPR™ design enables its construction schedule to benefit from the extensive construction experience feedback and the continuous improvements in processes, methodologies and tasks sequencing achieved by AREVA NP worldwide.
Provisions have been made in the design, construction, and commissioning methods used to shorten the EPR™ reactor construction schedule as far as possible. Significant examples are as follows.

DESIGN FEATURES

The general design layout of the main safety systems in four trains housed in four separate buildings allows parallel installation works and, later, parallel testing of individual systems.

Location of electromechanical equipment lower levels means that its installation can start early and consequently remove it from critical path, which contributes to the shortening of the construction schedule.

CONSTRUCTION AND INSTALLATION METHODS

Three main principles are applied to EPR™ reactor construction and installation: minimization of the interfaces between civil works and installation of mechanical components, modularisation and piping prefabrication.

Minimization of the interfaces between civil works and installation. The continuing search for optimisation of the interfaces between civil and installation works results in the implementation of a construction methodology "per level" or "grouped levels". This enables equipment and system installation work at level "N", finishing construction work at level "N+1" and main construction work at levels "N+2" and "N+3" to be carried out simultaneously. The methodology is used for all the different buildings except for the Reactor Building, where it cannot apply.

Use of modularization for overall schedule optimization. Modularization techniques are considered systematically, but retained only in cases where they offer a real benefit to the optimization of the overall construction schedule without introducing a technical and financial burden due to advanced detailed design, procurement or prefabrication. This approach enables the site preparation schedule to be optimized, delays investment costs with regard to start of operation, and so offers financial savings.

For instance, modules are implemented for the civil works associated with the reactor building (e.g. containment liner & dome), pool structure for vertical walls in Reactor & Fuel buildings, control room, as they are on the critical path.

Maximization of piping and support prefabrication. Piping and support prefabrication is maximized in order to minimize installation man-hours and especially welding and controls at installation locations; this measure also results in an even better quality of the piping spools at lower cost.

MAJOR COMPONENT MANUFACTURING

AREVA NP's Chalon/Saint-Marcel and Jeumont plants have over thirty years of experience in the manufacture of heavy nuclear components. This has resulted in considerable experience in optimization of the production time of heavy nuclear components. The construction of the EPR™ reactor benefits from this unique manufacturing capability and expertise.

COMMISSIONING TESTS

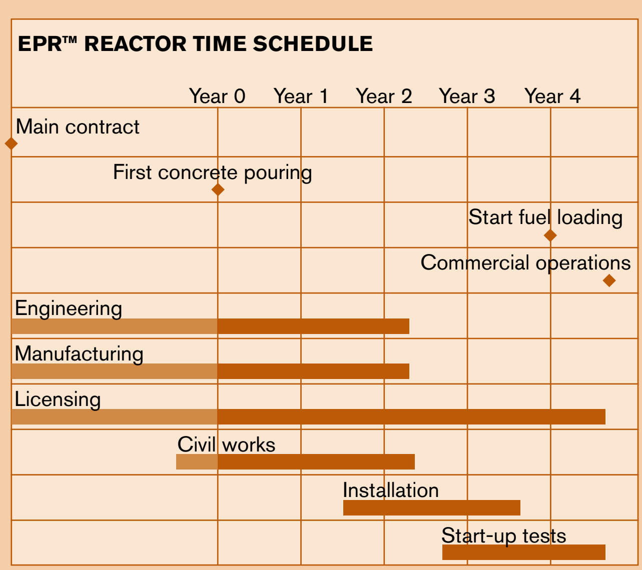
As with the interfaces between civil and construction works, the interfaces between construction and testing have been carefully reviewed and optimized. For instance, teams responsible for the commissioning tests are also involved in the finishing operations, flushing, and system conformance checks, so that these activities are only carried out once.

Instrumentation & Control factory acceptance tests are carried out on a single test platform with all cabinets interconnected, which ensures a shorter on-site test period together with improved overall quality.

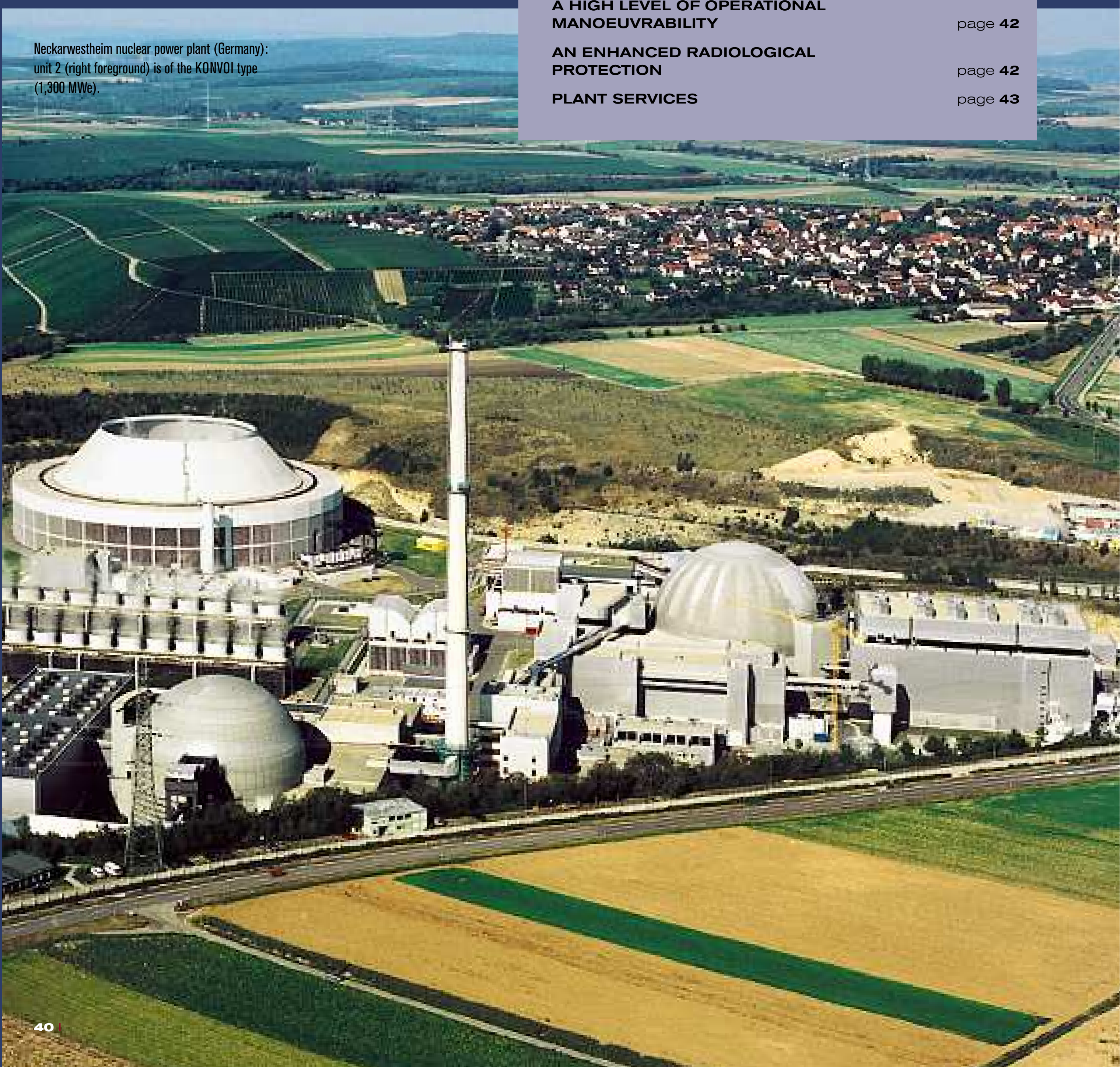
The benefits drawn from the unique experience feedback gained by AREVA NP in previous projects, and systematic optimisation of construction and testing activities and their interfaces, results in an optimal technical and economical construction schedule for EPR™ reactor implementation. This experience and that from current EPR™ reactor projects, gives confidence that the planned EPR™ reactor time schedule is realistic.

Indicative planning and overall time-scale

The overall construction schedule of a unit in the series depends largely on site conditions, industrial organisation and policies, and local working conditions. Therefore figures quoted for a specific project cannot usually be extended to others.



PLANT OPERATION, MAINTENANCE & SERVICES



Neckarwestheim nuclear power plant (Germany): unit 2 (right foreground) is of the KONVOI type (1,300 MWe).

PLANT OPERATION, MAINTENANCE & SERVICES

Plant operators worldwide are trying hard to increase plant availability and to reduce maintenance costs. The EPR™ systems and components have been designed from the beginning to help them achieve these goals through efficient refueling outages and simplified inspection and maintenance.

AN AVAILABILITY DESIGN TARGET ABOVE 92%

The EPR™ reactor is designed to exceed an availability rate of 92%. This is made possible by long cycles, short-scheduled outages for fuel loading/unloading and in-service inspections and maintenance, and also through reduced downtimes attributable to unscheduled outages.

The quadruple redundancy of the safety systems allows a part of the preventive maintenance operations to be performed while the reactor is at power.

Moreover, the reactor building is designed to keep some areas accessible, under standard safety and radiation protection conditions, while the reactor is at power. This enables the outage and maintenance operations to be prepared and demobilized with no loss of availability. This possibility of access with the reactor on line also facilitates field services which could be needed outside scheduled outage periods. Based on experience feedback, easier access to the components of the reactor allow simple and rapid performance of inspection and maintenance work.

Chooz B1, France (N4, 1,500 MWe): removal of the hydraulic section of a reactor coolant pump for maintenance.

Access to the reactor building during power operation allows to start preventive maintenance and outage preparation up to seven days before reactor shutdown and to continue their demobilization up to three days after reactor restart.

The duration of the plant shutdown phase is reduced by a time gain for reactor coolant system cooldown, depressurization and vessel head opening. Similarly the length of the restart phase is reduced as well and benefits from the reduction in the time needed to run the beginning-of-cycle core physics tests (gain supplied by the "aeroball" in-core instrumentation system). Durations of about 70 and 90 hours are respectively scheduled for the shutdown and restart phases. For the fuel loading/unloading operations, a time period below 100 hours is scheduled.

➡ **Typical outage duration: the duration of a regular outage for preventive maintenance and refueling is reduced to 16 days. Duration of an outage for refueling only does not exceed 11 days. Decennial outages for main equipment in-service inspection, turbine overhaul and containment pressure test are planned to last 40 days.**

The EPR™ reactor is designed to:

- ➡ **maximize plant availability and manoeuvrability,**
- ➡ **ease operation and maintenance and reduce their costs,**
- ➡ **enhance radiological protection of the personnel,**
- ➡ **protect the environment and contribute to a sustainable development.**

A HIGH LEVEL OF OPERATIONAL MANOEUVRABILITY

In terms of operation, the EPR™ reactor is designed to offer the utilities a high level of manoeuvrability. It has the capacity to be permanently operated at any power level between 25 and 100% of its nominal power in a fully automatic way, with the primary and secondary frequency controls in operation.

The EPR™ reactor capability regarding manoeuvrability is a particularly well adapted response to scheduled and unscheduled power grid demands for load variations, managing of grid perturbations or mitigation of grid failures.

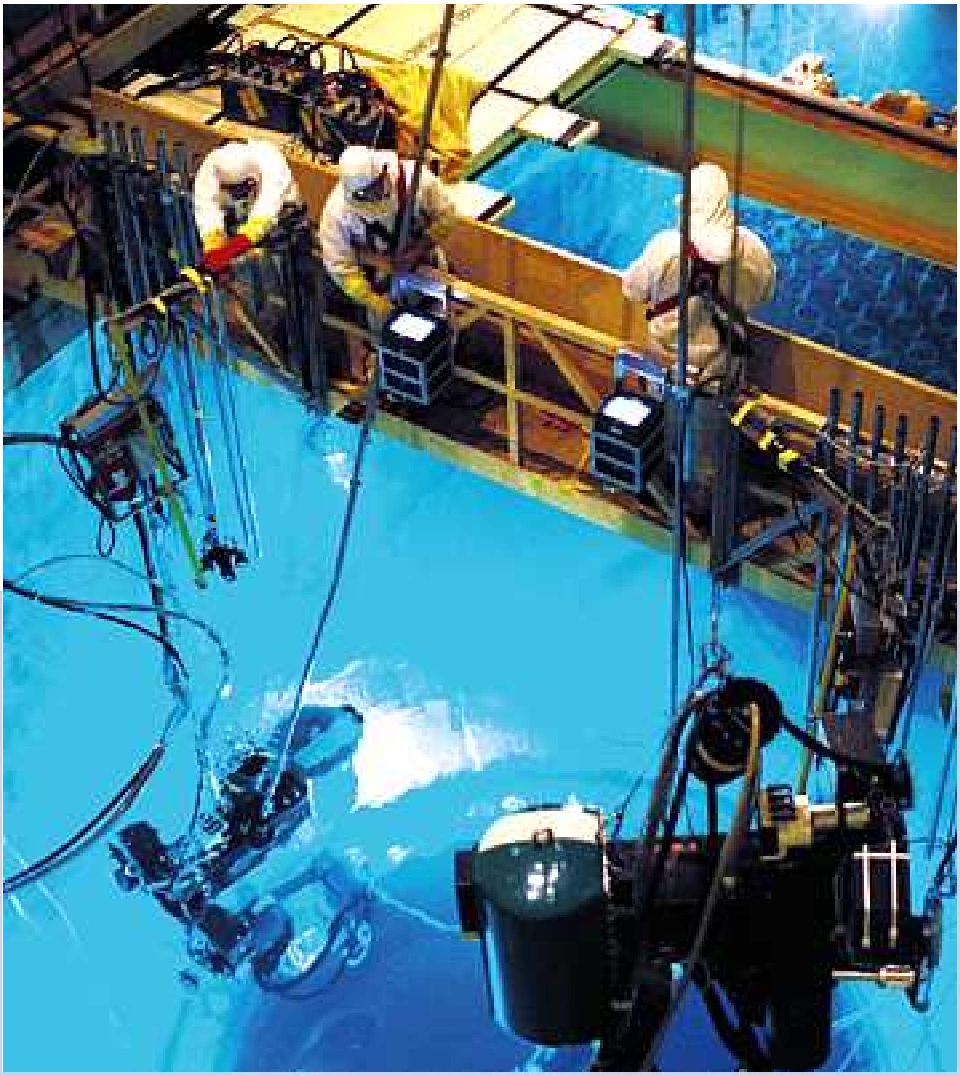
AN ENHANCED RADIOLOGICAL PROTECTION

Allowance for operating constraints and for the human factor, with the aim of improving worker radiation protection and limiting radioactive releases, together with radwaste quantity and activity, was a set objective as soon as EPR™ design got underway. For this purpose, the designers drew heavily upon the experience feedback from the operation of the French and German nuclear power plant fleets.

Accordingly, major progress has been made, particularly in the following areas:

- the choice of materials, for example the optimization of the quantity and location of the Cobalt-containing materials and liners, in order to obtain a gain on the Cobalt 60 "source term",
- the choices regarding the design and layout of the components and systems liable to convey radioactivity, taking into account the various plant operating states,
- the optimization of the radiation shielding thicknesses in response to forecast reactor maintenance during outages or in service.

Thanks to these significant advances and to shorter outages, collective doses less than 0.4 Man.Sievert per reactor/year can be expected for operation and maintenance staff (to date, for the major nuclear power plant fleets of OECD countries like France, Germany, the United States and Japan, the average collective dose observed is about 1 Man.Sievert per reactor/year).



In-service inspection machine for ultrasonic testing of reactor pressure vessels.

PLANT SERVICES

Optimization of plant processes and implementation of innovative maintenance technologies and concepts are also significant contributors to the achieving of operators' cost and availability objectives. In this area, AREVA NP supplies the most comprehensive range of nuclear services and technologies in the world.

Thanks to its experience from designing and constructing over 100 nuclear power plants worldwide, its global network of maintenance and services centers with highly trained teams (more than 4,000 specialists mainly based in France, Germany and the USA) committed to excellence, AREVA NP provides a full range of inspection, repair and maintenance services for all types of nuclear power plants, based on the most advanced techniques available today. Its field of expertise covers the whole scope of customers' needs from unique one-of-a-kind assignments to the implementation of integrated service packages with a view to reducing outage duration. In addition, AREVA is introducing innovative partnership models featuring long-term performance-based contracts for services.

AREVA NP's offer of power plant services encompasses:

- in-service inspection and non destructive testing,
- outage services,
- asset management,
- life cycle management,
- predictive maintenance,
- supply of spare parts,
- off-site maintenance of components in "hot" workshops,
- fuel inspection, repair and management,
- services in the fields of instrumentation and diagnosis, I&C and electrical systems, chemistry,
- plant decommissioning and waste management,
- training of operating personnel,
- expert consultancy.

The "FROG" Owners Group (see page below) offers member electricity companies a cost-effective means for exchange of information and experience. FROG's members have access to broad operational and maintenance feedback. They also benefit from the results of study programs jointly decided to deal with issues of shared interest.

THE "FROG" OWNERS GROUP

The FROG (formely Framatome Owners Group) is dedicated to building strong and efficient teaming for mutual cooperation, assistance and sharing of its members' experience and expertise, to support the safe, reliable, cost-effective operation of its members' nuclear power units.

The FROG was set up in October 1991 by five utility companies that were either operating or building nuclear power plant units incorporating a Framatome nuclear steam supply system or nuclear island.

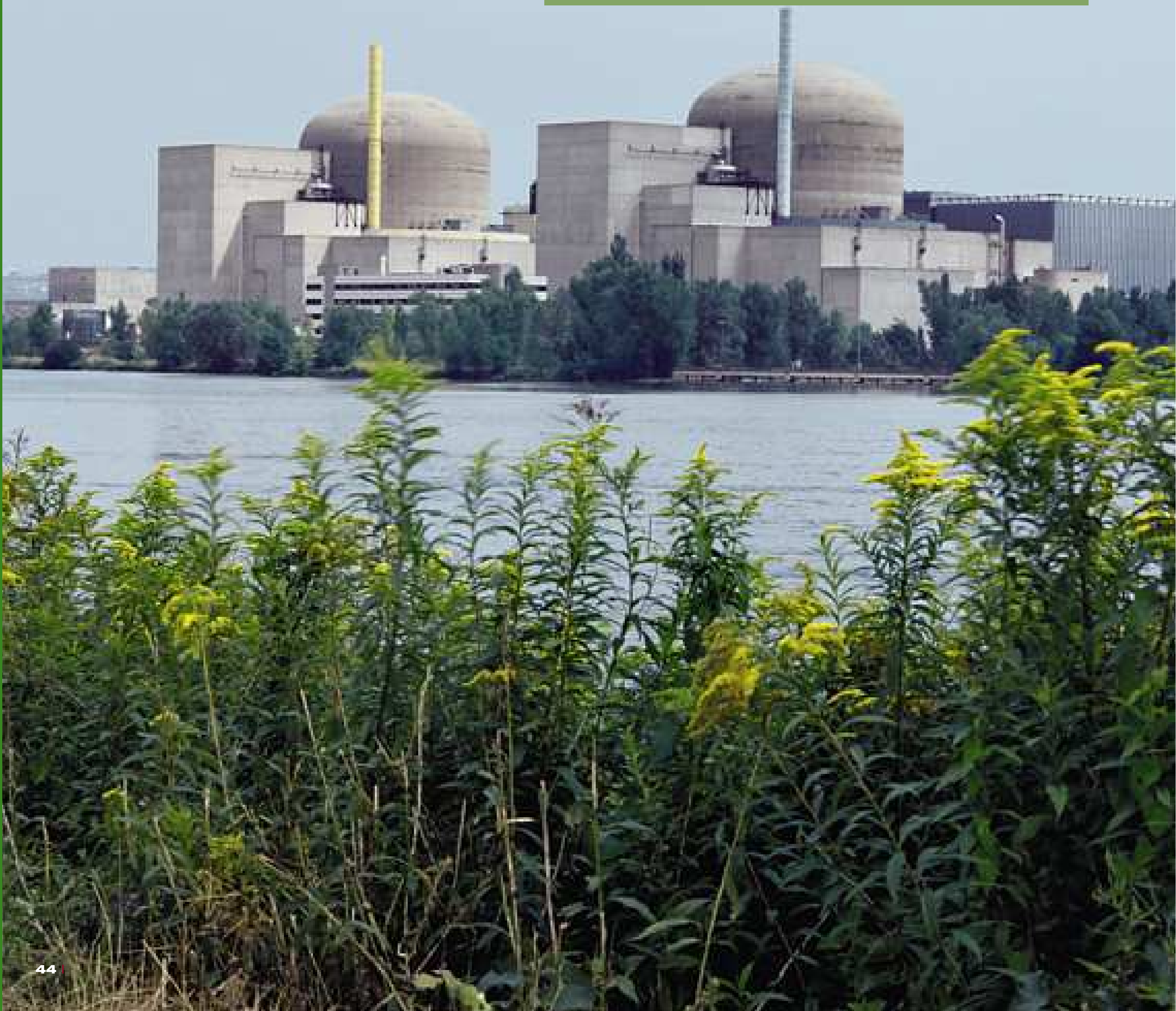
These utility companies are Electrabel from Belgium, Electricité de France, Eskom from the Republic of South Africa, GNPJVC from the People's Republic of China and KHNP from the Republic of Korea.

Later on, Ringhals AB from Sweden (in June 1997), LANPC, owner of the Ling Ao plant in China (in October 2000), British Energy owner of Sizewell B in the United Kingdom (in October 2002) joined the FROG as members. In 2003, GNPJVC and LANPC merged operation of their plants in one company DNMC.

The Owners group provides a forum for its members to share their experiences in all domains of nuclear power plant operation, enabling a cost-effective exchange of information to identify and solve common issues or problems.

Several working groups and technical committees are actively dealing with specific technical and management issues. Among them, a specific Steam Generator Technical Committee, has been formed by utilities having steam generators served by AREVA NP. Committee participants are the FROG members plus the companies NSP and AmerenUE from the USA, NOK from Switzerland and NEK from Slovenia.

ENVIRONMENTAL IMPACT



Saint-Alban nuclear power plant, France (1,300 MWe x 2).

ENVIRONMENTAL IMPACT

Ensuring that the impact of a nuclear unit on the environment is minimal requires complementary actions by the reactor vendor, the operator, the safety authorities and various other organizations. The vendor's contribution to minimizing the environmental impact is set out below.

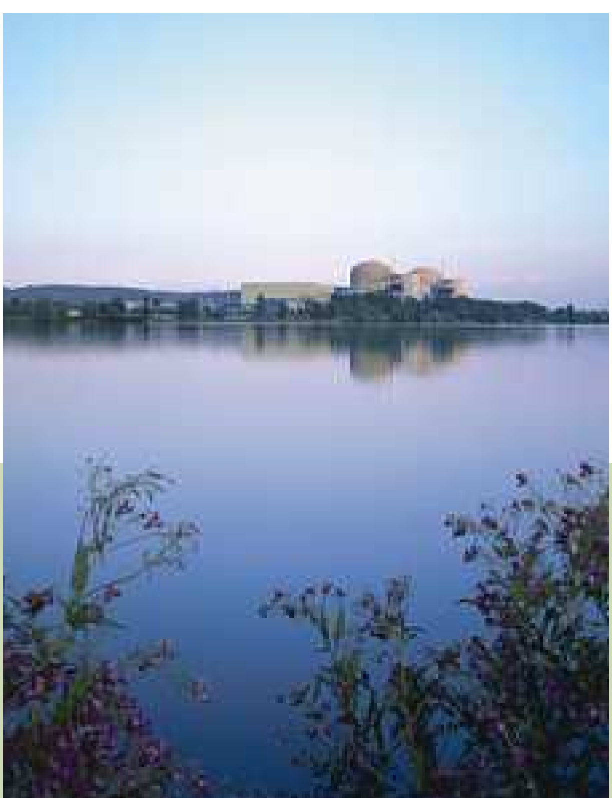
DESIGN

As already stated in the section on "EPR™ safety systems", the reactor has been designed to avoid the occurrence of incidents and accidents and to reduce their consequences for the plant and the environment if they were to occur.

The improved thermodynamic efficiency of the plant ensures that its cooling water requirements are minimized.

The high performance core of the EPR™ reactor (see section on the reactor core) gives the operator increased flexibility in the utilization of nuclear fuel to generate power. Depending on the fuel management strategy adopted and on the relevant point of comparison, the savings on uranium consumption per unit of energy produced can reach 7 to 15%, giving a corresponding reduction in the quantities of high-level waste.

Processes have been optimized to reduce quantities of radioactive and chemical waste through the use of the best tried and tested methods available at an acceptable cost.



Saint-Alban nuclear power plant, France (1,300 MWe x 2).

CONSTRUCTION

During the building phase, activities such as clearance of the site, excavation, drilling, concrete production and start-up tests have a potential impact on the environment. Therefore the marine and terrestrial environments, freshwater, air, climate, landscape and the noise level must be kept under close scrutiny in order to minimize possible consequences.

OPERATIONS

The impact of operations on the environment translates into the gaseous and liquid releases, and solid wastes produced. The evolutionary character of the EPR™ design makes it possible to draw benefit from lessons learned from many years of operation of earlier generation reactors, meaning that whenever possible, releases and waste are reduced and, when this is not possible, the extent and impact of such releases can be accurately predicted.

Gaseous radioactive waste from an EPR™ reactor arises from:
- the ventilation of the nuclear buildings;
- the degassing of radioactive fluids.

Depending on its origin, the gaseous radioactive waste is:
- either filtered[1] and released into the atmosphere via the discharge stack. This is generally the case for gaseous waste coming from ventilation circuits;
- or retained in the treatment system to reduce the level of radioactivity and then filtered and released into the atmosphere via the discharge stack. This is the case for gases released by the degassing of primary cooling water.

In all circumstances, gaseous releases are controlled and monitored at the stack in order to check that these discharges do not have a noticeable impact on the terrestrial environment.

(1) Filtration allows retention of more than 99% of aerosols and iodines and their conversion into solid waste.

A concern having a bearing on the whole life cycle of the plant.

Protection of the public and of the environment requires optimization at each step of the EPR™ life cycle of:

- ➡ **design;**
- ➡ **construction;**
- ➡ **operation;**
- ➡ **dismantling and decommissioning.**

Liquid radioactive waste is placed in two categories depending on its origin:

- waste from the primary system, which contains activation products (cobalt, manganese, tritium, carbon-14, etc.) minor quantities of dissolved fission gases (xenon, iodine, etc.), fission products (caesium, etc.), and also chemical substances such as boric acid and lithium hydroxide. The chemical substances can be recycled;
- waste from the systems connected to the primary system, which makes up the rest of the effluents. Among these, there are:
  – effluents which are radioactive and free from chemical pollution,
  – radioactive and chemically charged effluents, effluents with a very low level of radioactivity collected by the floor drains(2).

After being systematically collected, this waste is treated to retain most of its radioactivity. It is then channelled to storage tanks where it undergoes both radioactive and chemical testing before being disposed of.

Solid radioactive waste

Reduction in the volume of solid radioactive waste to lessen the unit's impact on the environment was one of the objectives adopted at the design stage.

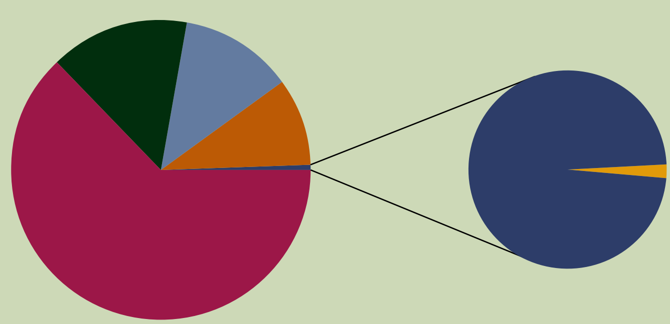
Spent fuel is removed for either reprocessing or storage and residual waste created is packaged, to ensure that radioactive matter is confined, in glass representing once conditioned 5 m^3 per year of high activity long-lived(3) waste and in concrete packages representing once conditioned 4 m^3 per year of long-lived intermediate level waste.

The production of operating waste is limited to 80 m^3 per year per unit thanks to the materials chosen to build the reactor and, the zoning(4) of premises after start-up to reduce the possible contamination of conventional equipment by radioactive material. Short-lived low level waste, a by-product of the operating process, is sorted, treated and stored in the EPR™ unit's Radioactive Waste Processing Building so as to reduce the volume of waste as much as possible (compaction) and to ensure the radioactive material is confined through suitable packing.


Sand sampling in the Cotentin peninsula (Flamanville and La Hague area).

(2) The floor drains constitute a network of underground pipes which collect material leaks, water from drainage operations, and water used to wash the floors.
(3) Lifetime of a radioactive substance depends on its radioactive half-life period, which is the time after which its activity has reduced by a half because of the natural decrease of the radioactive source.
(4) Separation of zones presenting contamination risks from other zones by means of doors, chambers, etc.

Typical distribution of annual dose to population from all sources



- 63% radon, soil and terrestrial materials
- 15% medical
- 12% background radiation (sun and Milky Way)
- 9.5% human body
- 0.49% miscellaneous artificial sources
- 0.01% nuclear power plants

Chemical waste

Operating a nuclear power station also involves the discharge of liquid chemical waste and gaseous emissions. These wastes are processed, tested and monitored to ensure that their discharge is in compliance with authorized limits.

Conventional waste

Conventional waste produced during the operating stage is also subjected to a strict management procedure so as to reduce its volume. It is sorted and stored in an adapted temporary location on the site.

Waste produced during the construction phase is treated in the same manner as during the operating phase, in a temporary location specifically created on the building site. The materials extracted during the earth-moving works, excavated material and rocks, are reused as much as possible on the site as fill and in the making of concrete after crushing.

DECOMMISSIONING

On the basis of the experience feedback resulting from dismantling operations performed in various countries on first generation nuclear power plants, the EPR™ unit's design includes various measures which:

- minimize the volume of radioactive structures,
- reduce the potential hazard of the waste, for instance with the material choice minimizing hazardous substances,
- lower the irradiation level of components submitted to fuel radiation,
- restrict the spread of contamination and favor systems decontamination, for example with the implementation of a radiological zoning,
- facilitate the access of personnel and machines and the evacuation of waste, for instance with the implementation of suitable areas and openings,
- ensure the gathering of building and operating data needed to prepare dismantling correctly.

These measures facilitate the dismantling of the reactor to a level equivalent to IAEA Level 3 (return of site to common industrial use), limit the radiation doses of the corresponding operations and limit the quantity and activity of the nuclear waste produced.

IMPACT ON PUBLIC HEALTH

The impact of liquid and gaseous radioactive waste discharges on public health cannot be measured directly. Radionuclides introduced into the environment by the operation of a nuclear unit cannot be discerned by practical means. Thus, the impact on public health must be assessed theoretically by estimating the effective dose received by a hypothetical group of people, known as the reference group. This group is considered as the group which would be subject to the maximum effects of the gaseous and liquid waste if members remained permanently in residence and only consumed local produce, and seafood fished at the waste outlets.

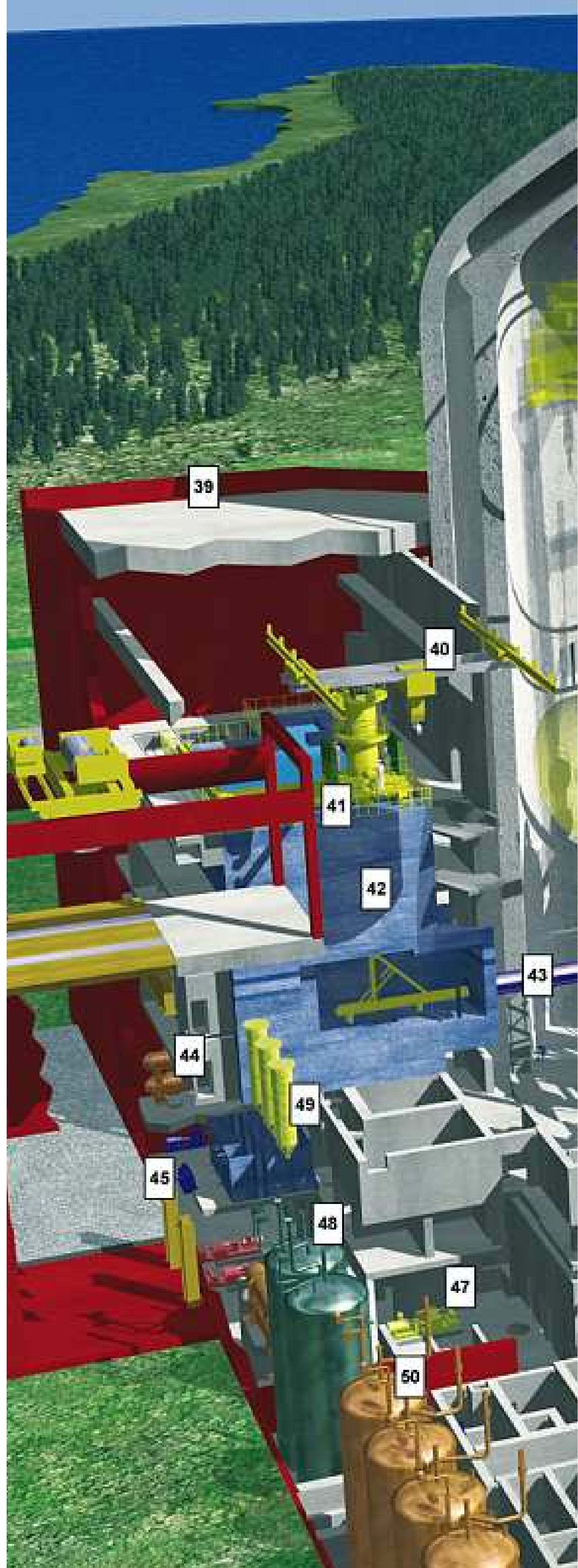
For the maximum gaseous and liquid radioactive waste emissions from the entire site, calculating the impact on health, for each inhabitant in the reference group, produces an annual effective dose amounting to a few tens of microsieverts.

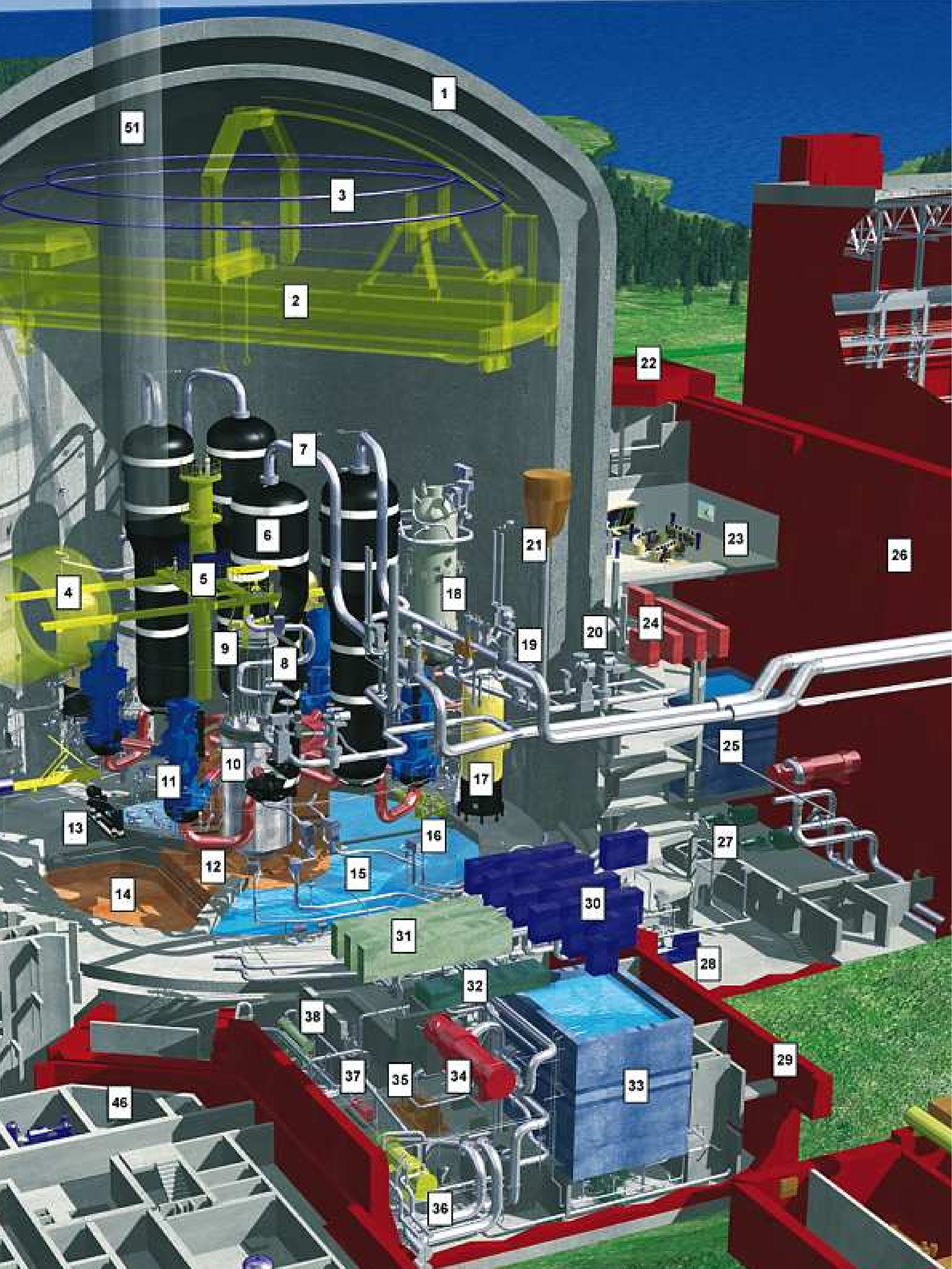
In reality the nuclear units have a lower activity discharge than the maximum activity defined by this theoretical method. Considering the radioactive waste produced by actual units, the impact on public health, for each member (whether adult or infant) of the reference group, produces an annual effective dose which is four to five times lower than the maximum values.

> EPR™ REACTOR

Key to power station cutaway

1 **Reactor building: inner and outer shell**
2 Polar crane
3 Containment heat removal system: sprinklers
4 Equipment hatch
5 Refuelling machine
6 Steam generator
7 Main steam lines
8 Main feedwater lines
9 Control rod drives
10 Reactor pressure vessel
11 Reactor coolant pump
12 Reactor coolant piping
13 CVCS heat exchanger
14 Corium spreading area
15 In-containment refuelling water storage tank
16 Residual heat removal system, heat exchanger
17 Safety injection accumulator tank
18 Pressuriser
19 Main steam isolation valves
20 Feedwater valves
21 Main steam safety and relief valve exhaust silencer
22 **Safeguard building division 2**
23 Main Control Room
24 Computer room
25 Emergency feedwater storage, division 2
26 **Safeguard building, division 3**
27 Emergency feedwater pump, division 3
28 Medium head safety injection pump, division 3
29 **Safeguard building, division 4**
30 Switchgear, division 4
31 I & C cabinets
32 Battery rooms, division 4
33 Emergency feedwater storage, division 4
34 CCWS heat exchanger, division 4
35 Low head safety injection pump, division 4
36 Component cooling water surge tank, division 4
37 Containment heat removal system pump, division 4
38 Containment heat removal system heat exchanger, division 4
39 **Fuel building**
40 Fuel building crane
41 Spent fuel pool bridge
42 Spent fuel pool and fuel transfer pool
43 Fuel transfer tube
44 Spent fuel pool cooler
45 Spent fuel pool cooling pump
46 **Nuclear auxiliary building**
47 CVCS pump
48 Boric acid tank
49 Delay bed
50 Coolant storage tank
51 Vent stack

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With its knowledge and expertise in these fields, the group has a leading role to play in meeting the world's energy needs.

Ranked first in the global nuclear power industry, AREVA's unique integrated offering covers every stage of the fuel cycle, reactor design and construction, and related services.
In addition, the group is developing a portfolio of operations in renewable energies. AREVA is also a world leader in electricity transmission and distribution and offers its customers a complete range of solutions for greater grid stability and energy efficiency.

Sustainable development is a core component of the group's industrial strategy. Its 75,000 employees work every day to make AREVA a responsible industrial player that is helping to supply ever cleaner, safer and more economical energy to the greatest number of people.

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