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SWR 1000 — AN ADVANCED BOILING WATER REACTOR WITH PASSIVE SAFETY FEATURES

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Abstract

The SWR 1000, an advanced BWR, is being developed by Siemens under contract from Germany's electric utilities and with the support of European partners. The project is currently in the basic design phase to be concluded in mid-1999 with the release of a site-independent safety report and costing analysis. The development goals for the project encompass competitive costs, use of passive safety systems to further reduce probabilities of occurrence of severe accidents, assured control of accidents so no emergency response actions for evacuation of the local population are needed, simplification of plant systems based on operator experience, and planning and design based on German codes, standards and specifications put forward by the Franco-German Reactor Safety Commission for future nuclear power plants equipped with PWRs, as well as IAEA specifications and the European Utility Requirements. These goals led to a plant concept with a low power density core, with large water inventories stored above the core inside the reactor pressure vessel, in the pressure suppression pool, and in other locations. All accident situations arising from power operation can be controlled by passive safety features without rise in core temperature and with a grace period of more than three days. In addition, postulated core melt is controlled by passive equipment. All new passive systems have been successfully tested for function and performance using large-scale components in experimental testing facilities at PSI in Switzerland and at the Jülich Research Centre in Germany. In addition to improvements of the safety systems, the plant's operating systems have been simplified based on operating experience. The design's safety concept, simplified operating systems and 48 months construction time yield favourable plant construction costs. The level of concept maturity required to begin offering the SWR 1000 on the power generation market is anticipated to be reached, as planned in the year 2000.

1 INTRODUCTION

The SWR 1000, an advanced boiling water reactor concept, is being developed by Siemens under contract from and in close with Germany's electric utilities and with the support of European partners in Finland (TVO), the Netherlands (KEMA), Switzerland (PSI) and Italy (ENEL). This development project is currently in its Basic Design Phase, which will be concluded in mid-1999 with the release of a site-independent safety report and costing analysis of projected erection costs.

In parallel with the design phase, an experimental testing program is being conducted at Siemens' own testing facilities and at other German and European research centres to provide verification of the function and effectiveness of the SWR 1000's passive safety systems.

2 NUCLEAR STEAM SUPPLY SYSTEM

The nuclear steam supply system is located in the reactor building and is surrounded by a steel-reinforced concrete containment equipped with an inside liner. Table 1 presents the key technical data for the SWR 1000 in comparison with those of a traditional 1300 MW BWR plant.

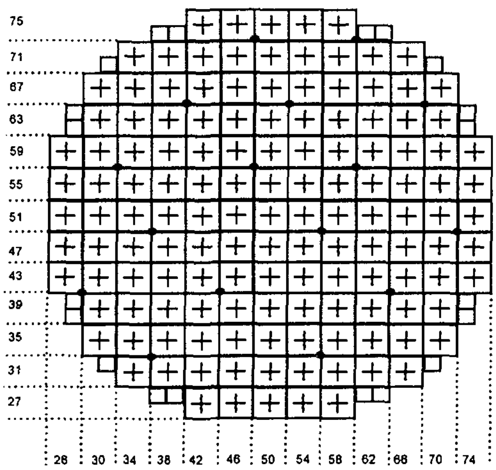
2.1 Reactor Core and Fuel Assemblies

The SWR 1000 core (Figure 1) represents an evolutionary further development of previous standard BWR core designs. While no changes have been made to the basic structure of the BWR

Table 1: Key technical data of SWR 1000 compared to an advanced 1300 MW BWR plant

Data		SWR 1000	1300 MW BWR*
Overall plant			
- thermal output	MW	2778	3840
- gross electric output	MW	1013	1428
- net electric output	MW	977	1373
- net efficiency	%	35.2	35.7
Reactor core			
- No. of fuel assemblies	-	568 (13x13)	784 (10x10)
- Total uranium weight	t	121	138,1
- Active height of core	m	2.80	3.71
- Average power density	kW/l	47	56.8
- Average discharge burnup	GWd/t	65	50
- Average enrichment	wt.%	5.45	3.63
- Core throughput	kg/s	12000	14300
Reactor pressure vessel			
- Inside height	m	22.55	22.35
- Inside diameter	m	7.0	6.62
- Design pressure	bar	88	87.3
- No. of recirculation pumps	-	6	8
Turbine			
- Number	-	1	1
- Speed	1/min	3000	1500
- No. of HP/LP casings	-	1/3	1/2
Containment			
- Inside diameter	m	32.0	29
- Inside height	m	28.7	32.5
- Design pressure (abs.)	bar	7.5	5.3
- Drywell volume + gas volume of core flooding pool	m^3	5700	8200
- Water volume of pressure suppression pool	m^3	2900	3100
- Gas volume of pressure suppression pool	m^3	5500	6000
- Water volume of core flooding pool	m^3	3100	-
Plant design life	years	60	40
Plant construction period	months	48	60

* Siemens Gundremmingen Nuclear Power Station, Unit B+C



Number of fuel assemblies:	568
Number of control rods:	137
Control rod pitch:	387 mm
Core diameter:	5500 mm
Local power range monitor assemblies:	16

FIG. 1: Arrangement of SWR 1000 Reactor Core

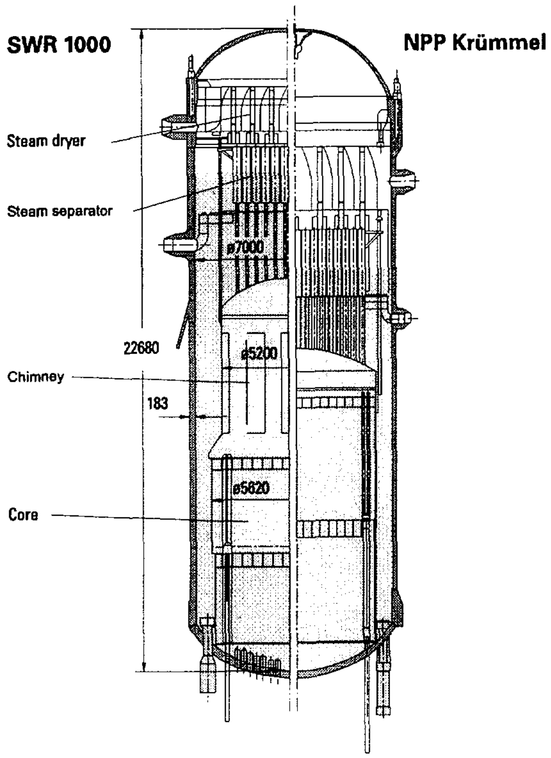


FIG. 2: Reactor Pressure Vessel

core design, certain modifications have been introduced. These adaptations include reducing the active height of the core and increasing the size of the fuel assemblies.

By reducing the active core height, the core can be positioned lower down inside the RPV. As a result, there is a greater water inventory available inside the RPV above the core, which facilitates accident control.

The aforementioned modification of the fuel assemblies consisted of enlarging the existing ATRIUM™10 fuel assembly design (10x10-9Q) to a 13x13-25Q (ATRIUM™13 fuel assembly) rod configuration. Fuel rod diameter and pitch, on the other hand, remain unchanged from the ATRIUM™10 fuel assembly. As a result of this new design, there are fewer fuel assemblies in the core, which reduces handling times during refueling. Reducing the number of fuel assemblies also lowers the number of control rods required, and hence the number of control rod drives as well. The number of in-core instrumentation assemblies and power distribution detectors can also be reduced.

The average power density of the core has been reduced from 56,8 to 47 kW/l. This reduction, together with the advanced fuel assembly design, ensures good plant behavior during transients.

Flexible operating cycles are planned for the SWR 1000. For example, the core can be operated in annual cycles or in cycles lasting anywhere from 1 to 2 years. The desired mean discharge burnup is 65 GWd/t.

All of these core design modifications contribute to the economic efficiency of SWR 1000 operation.

2.2 Reactor Pressure Vessel and Internals

The reactor pressure vessel (RPV) (see Figure 2) encloses the reactor core and the RPV internals. Its main dimensions are comparable to those of the RPV in a Siemens 1300 MW BWR plant (see Table 1), which means that the SWR 1000 RPV is of larger volume in relation to actual core power. As a result, and due to the low positioning of the core inside the RPV, core uncovery is prevented in the event of automatic depressurization, even without coolant makeup during pressure drop.

The core shroud, as well as the top upper and lower core grid, mainly serves to align the core, control rods and core instrumentation and to guide core flow. Steam separators and steam dryers are installed in the RPV to separate the steam-water mixture leaving the core. A chimney is located between the core and the steam separators.

All RPV internals are designed to allow removal and replacement as needed.

The RPV is supported against the building via a frame mounted around the RPV top half. The RPV internals, such as the core shroud, upper and lower core grid, steam separators and steam dryers, for example, are essentially based on the proven technology used in Siemens 1300 MW BWR design.

2.3 Reactor Coolant Pumps

The reactor coolant pumps provide flow of coolant through the core. Comparative studies of natural and forced coolant circulation in the RPV have shown that it is advantageous to retain the forced circulation flow provided by internal reactor coolant pumps in the SWR 1000 design owing to the benefits gained in terms of fuel utilization and load cycling capability. The design calls for six reactor coolant pumps.

Unlike the previous standard pump design used in German BWR plants, a wet-rotor pump is planned for the SWR 1000, which requires neither mechanical seal nor oil supply. This design offers certain operational advantages, and has been proven in the Swedish and Finnish BWR plants from ABB Atom.

2.4 Control Rod Drives

The SWR 1000 retains the control rod drive design proven by operating experience at existing BWR plants. However, plans call for the long drive components (hydraulic drive unit and threaded spindle) in future to be installed and removed from above through the RPV. Only the electric motor drive unit and the seal housing will be installed and removed from the control rod drive compartment below the RPV as before. This modification enables the required withdrawal height in the control rod drive compartment - and hence the building height - to be reduced by the equivalent of the drive length.

2.5 Fuel Assembly Handling and Storage

There is no significant difference from a function point of view between the equipment and plant structures used for refuelling, storage of new and spent fuel assemblies and handling of reactor components in the SWR 1000 and those equipment and plant structures found in standard BWR nuclear power plants.

2.5.1 Store for New Fuel Assemblies

New fuel assemblies are stored in the new fuel store specially provided for this purpose, which is located adjacent to the spent fuel pool. The new fuel assemblies are placed in dry storage in racks that can accommodate some 270 fuel assemblies.

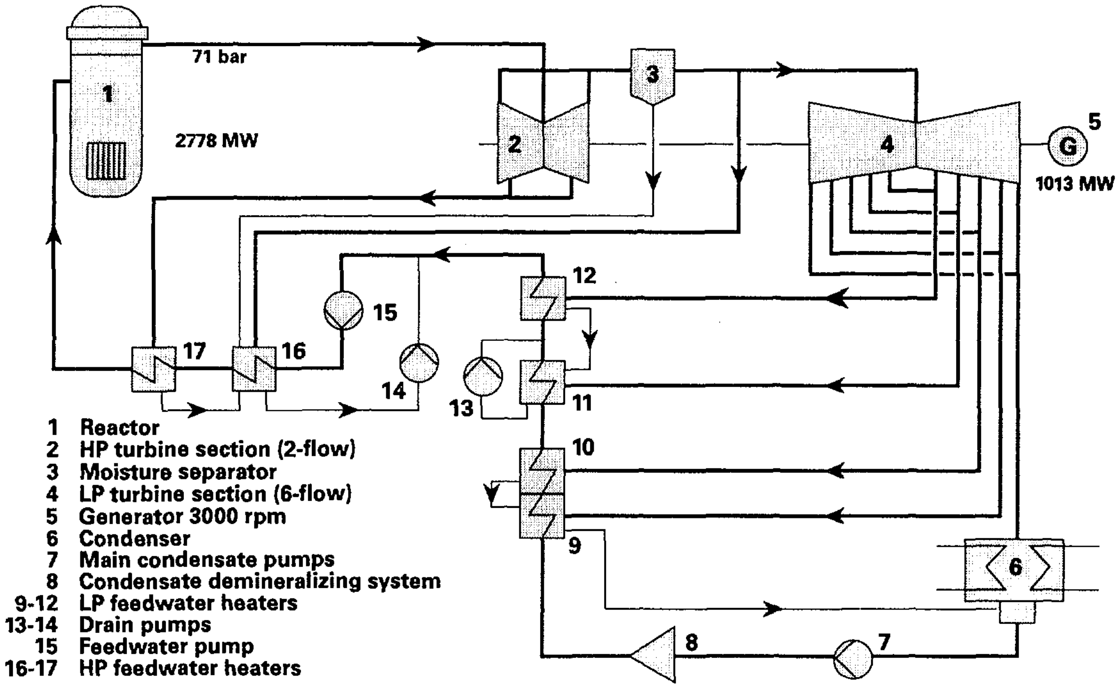


FIG. 3: Steam, Condensate and Feedwater Cycle

2.5.2 Spent Fuel Pool

Spent fuel assemblies are stored in the water-filled fuel pool located in the reactor building on an extension of the axis of the dryer-separator storage pool and reactor well. The pool water ensures residual heat removal and provides shielding.

Owing to their reduced length, the fuel assemblies are stored in two layers in high-density storage racks with inserted boron channels to maintain subcriticality. Racks for storage of control rods and RPV internals (such as in-core instrumentation assemblies, neutron sources, etc.) are provided in addition to the fuel assembly storage racks. Total storage capacity allows accommodation of some 1400 fuel assemblies and approximately 170 control rods.

3 STEAM, CONDENSATE AND FEEDWATER CYCLE

Like the boiling water reactors in operation today, the SWR 1000 operates according to the direct-cycle principle (Figure 3), i.e. the live steam generated in the RPV passes directly to the double-flow high-pressure (HP) section of the steam turbine via three (instead of the previous four) main steam lines fitted with combined stop and control valves. After undergoing partial expansion in the HP turbine section, the steam is passed through a moisture separator to the three double-flow low-pressure (LP) sections of the turbine. Reheating upstream of the low-pressure turbine sections - a feature of previous designs - is eliminated in the SWR 1000 as, thanks to continuous development in the turbine sector (including in particular dewatering capabilities in the individual turbine stages), the increase in efficiency achieved today by reheating is insignificant. This translates into savings in investment and maintenance costs.

The condensate is removed from the condensers of the three LP turbine sections and returned to the RPV at a temperature of 210 °C via a single-train (as opposed to the previous double-train) feed

Pos.		Number
1	Wetwell	1
2	Condensation pipe	16
3	Spring loaded pilot valve	8
4	S&R valve	6
5	Scram system	2
6	Core flooding pool	4
7	Emergency condenser	4
8	Passive pressure puls transmitter	3 x 4
9	Pilot valve	8
10	Core flooding system	4
11	Dryer-separator storage pool	1
12	Containment cooling condenser	4
13	Passive outflow reducer	4

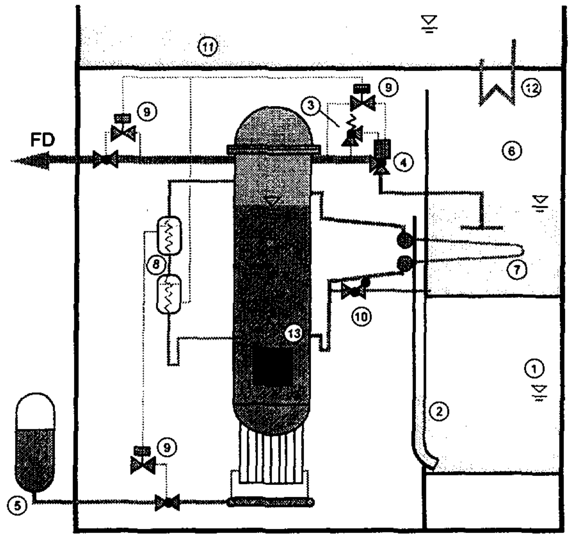


FIG. 4: Passive Shutdown, Core Flooding and Residual Heat Removal Systems

heating system comprising a condensate demineralizing system, LP feedwater heater, HP feedwater heater and two pump units. The LP feedwater heater units 1 and 2 are designed in a duplex arrangement and installed horizontally in the condenser neck. Two combined pump units will be used for the condensate and feedwater pumps, comprising motor, condensate pump as re-entry pump and feedwater pump. In the event of loss of one pump unit, the other unit delivers 75% of rated flow. Feedwater injection is via two feedwater lines (four in previous BWR designs) connected to the RPV. In the SWR 1000, the feedwater tank is eliminated and replaced by a surface feedwater heater. This concept is supported by the excellent operating experience gained from existing BWR plants.

The turbine generator set consists of a single-shaft, saturated steam turbine coupled directly to a three-phase AC synchronous generator. The planned 3000 rpm design costs less and is smaller than a 1500 rpm unit, which also allows the turbine building to be of smaller dimensions.

4 PASSIVE AND ACTIVE ACCIDENT CONTROL SYSTEMS

4.1 Overview

The primary objective in developing the SWR 1000 is to enhance the quality of safety by introducing passive systems (Figure 4) for performing safety-related functions in the event of transients or accidents. Compared to the reactors of today, the technology employed in these systems is much simpler, operation of the equipment being independent of a power supply and activation by I & C systems.

Passive systems are characterized by the fact that they utilize the laws of nature (e.g. gravity, pressure differentials) to perform their designated safety functions and dispense with active components (e.g. electromotor driven valves and pumps).

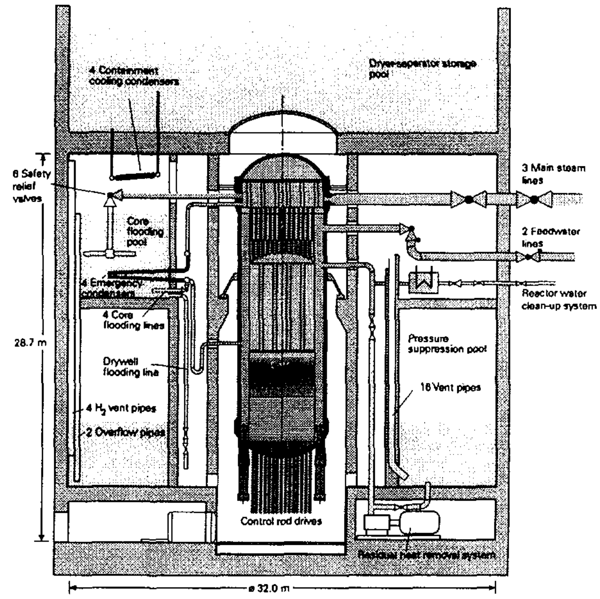


FIG. 5: Containment and Internals

4.2 Containment and Passive Safety Features

4.2.1 Containment

The primary function of the containment is to protect the environment against any release of radioactive materials or line-of-sight radiation under all accident conditions.

Like all other recent-generation BWR plants, a cylindrical containment made from steel-reinforced concrete equipped with an inner liner and pressure suppression system was selected (Figure 5). The containment is divided into a drywell and a pressure suppression pool, as required by the pressure suppression system.

The containment design pressure also takes account of the hydrogen release arising from a postulated 100% oxidation of the zirconium present in the RPV in the event of a core melt accident.

4.2.1.1 Drywell

In addition to the RPV and the three main steam lines and two feedwater lines, the following components are located in the drywell: four large hydraulically-linked core flooding pools, the emergency condensers and containment cooling condensers for passive heat removal, the flooding lines for passive flooding of the RPV and the passive pressure pulse transmitters for initiation of safety functions without the need for actuation by I&C systems. In addition, the drywell is equipped with two 100 % capacity recirculation air cooling systems. The high-pressure zone of the reactor water cleanup system (HP cooler and pressure-reducing station) and the lines of the residual heat removal system are also located inside the drywell. Thanks to the shorter control rod drives and a design which allows the long control rod drive components to be removed from above, the RPV can be positioned lower down inside the containment.

The main steam lines and feedwater lines connected to the RPV are each equipped with two isolation valves, one located inside and one outside the dedicated containment penetrations. Apart

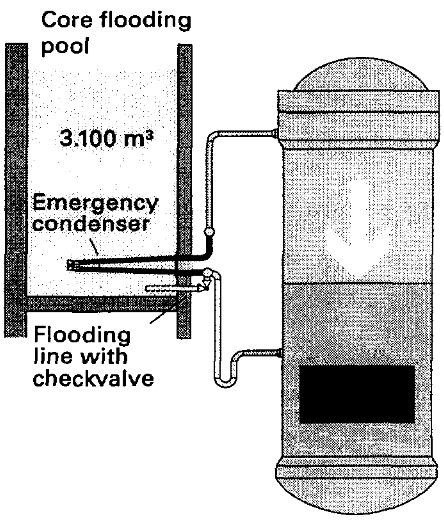


FIG. 6: Core Flooding by Gravity Flow

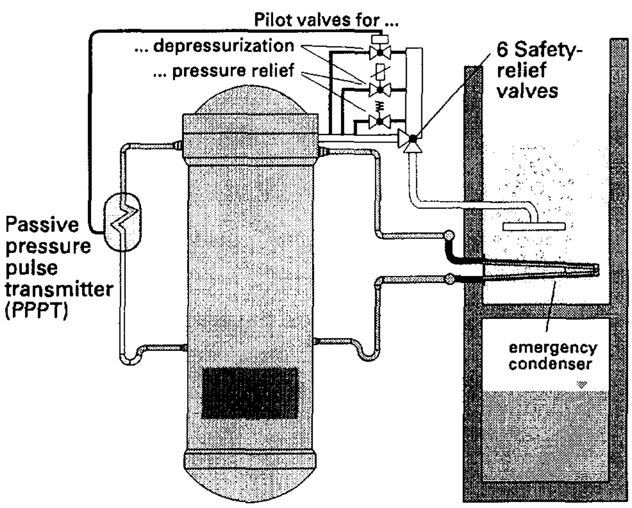


FIG. 7: RPV Safety Relief Valve System

from the main steam and feedwater lines, there is no high-energy piping conveying reactor water (with the exception of instrumentation lines) exiting the containment; the isolation valves of these remain open during operation.

The entire containment is inerted with nitrogen during normal operation to reliably prevent hydrogen-oxygen reactions which can result from a serious core melt accident, thereby ensuring fire protection during operation.

4.2.1.2 Pressure Suppression Pool

The pressure suppression pool performs the following tasks:

- acts as a heat sink in the event of accident conditions
- provides a water inventory for active RPV makeup via the LPCI-residual heat removal system.

As part of the pressure suppression system, the pressure suppression pool is located between the outer and inner cylinder below the core flooding pools and is one-third filled with water. The pressure suppression pool is connected to the drywell via vent pipes concrete-embedded into the inner cylinder.

4.2.1.3 Core Flooding Pools

The core flooding pools act as a heat sink for the emergency condensers and the safety relief valve system. In addition, owing to the pool elevation, the water in the core flooding pools is used for passive flooding of the reactor core following RPV depressurization in the event of a LOCA. In this function, spring check valves open the flooding lines automatically (Figure 6). Passive flooding serves as a diverse supplementary function to the active injection systems for core cooling.

In the event of a serious core melt accident, the water inventory in the core flooding pools is used for cooling the RPV from the outside.

4.2.1.4 Safety Relief Valve System

The tasks of the safety relief valve system are as follows:

- Protection of the reactor coolant pressure boundary against pressure in excess of allowable limits (pressure relief)
- Automatic depressurization of the RPV in the event that the RPV level falls below specified values or in the event of a pressure rise in the containment (LOCA in the containment)
- Short-term removal of excess steam in the event of turbine trip and load shedding
- Open position of valves under depressurized condition to prevent HP core melt path

The safety relief valve system is located inside the containment and consists of the safety relief valves and relief lines with steam quenchers, which are installed in the core flooding pool (Figure 7). This system is thus based largely on the previous, proven system concept used in German BWR plants to date.

4.2.1.5 Emergency Condensers

The emergency condensers function as completely passive devices for residual heat removal from the RPV to the core flooding pool. As a result, the need for HP injection systems is eliminated. The emergency condensers also function in part as a diverse means of depressurization to the safety relief valves down to a pressure which ensures active low pressure coolant injection.

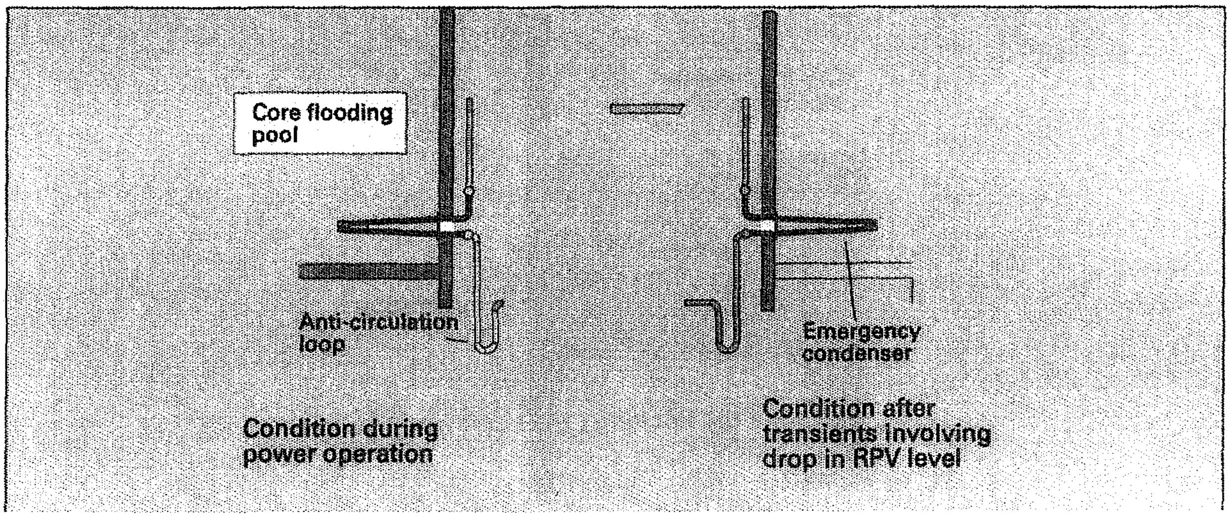


FIG. 8: Emergency Condenser

The emergency condenser system (Figure 8) consists of four separated sub-systems. Each emergency condenser system consists of a steam line leading from an RPV nozzle, and a condensate return line back to the RPV, which is equipped with a siphon. The emergency condensers are connected to the RPV with no isolating element, and are activated only by a drop in the RPV level. The emergency condenser is not in operation during plant operation, as the heat exchanger tubes are filled with cold condensate owing to their location in relation to the normal RPV level, such that heat transfer is not possible. The heat exchanger tubes only fill up with steam (which condenses) after the water level in the reactor falls. The condensate returns to the RPV by gravity flow.

These components were successfully tested at the emergency condenser test facility at Germany's Jülich Research Center using large-scale components, thereby verifying their functional capability and capacity.

4.2.1.6 Containment Cooling Condensers

The containment cooling condensers (CCCs) are designed to remove residual heat passively from the containment to the dryer-separator storage pool located above the containment inside the reactor building following loss of the active residual heat removal systems. The CCCs are actuated by rising temperatures in the containment at increasing steam partial pressure.

The system (Figure 9) consists of four CCCs. The condenser is connected to the dryer-separator storage pool outside the containment via a feed line and a discharge line. The feed line and discharge line and the condenser tubes are filled with water from the dryer-separator storage pool. As the system functions entirely passively, no switching operations are necessary for startup.

In addition to the heat exchangers with feed and discharge lines, the system also includes four H_2 vent pipes lines. The H_2 vent pipe intake is positioned above the heat exchanger and its discharge end is at a submerged position in the pressure suppression pool (Figure 5). They are submerged at a lesser depth than the vent pipes.

The function of these new components was successfully verified at the PANDA test facility at the Paul Scherrer Institute in Würenlingen (Switzerland) using large-scale components.

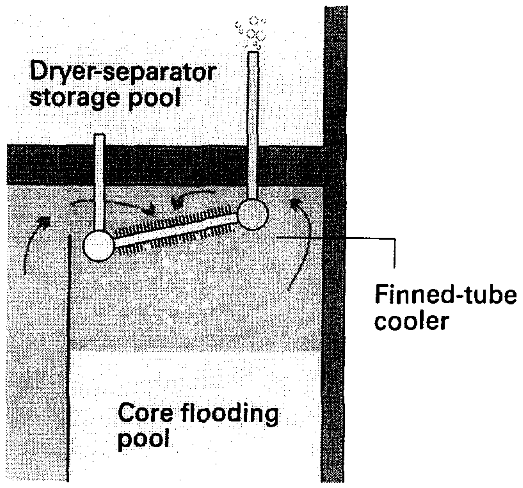


FIG. 9: Containment Cooling Condenser

4.2.1.7 Passive Pressure Pulse Transmitter

Passive pressure pulse transmitters (PPPTs) are installed in the SWR 1000 as new, passive switching devices for safety-related switching operatings. The PPPTs, which function without need of electric power supply, external media or actuation via I&C signals, serve to initiate reactor scram, containment isolation of main steam lines, and automatic depressurization of the RPV using system-fluid-actuated valves and valves with stored actuation energy. The PPPTs only commence functioning given a drop in the RPV level.

The PPPT (Figure 10) consists of a small heat exchanger, which is connected to the reactor via a non-isolatable pipe. At normal fill level in the reactor, the primary side of the heat exchanger is filled with water such that no heat transfer takes place. When the reactor fill level drops, however, the primary side is emptied and fills with steam, which condenses. The water stored on the secondary side

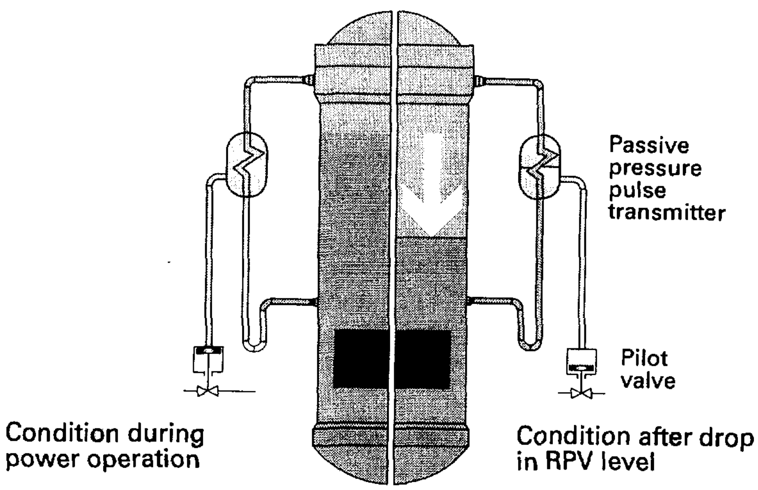


FIG. 10: Passive Pressure Pulse Transmitter

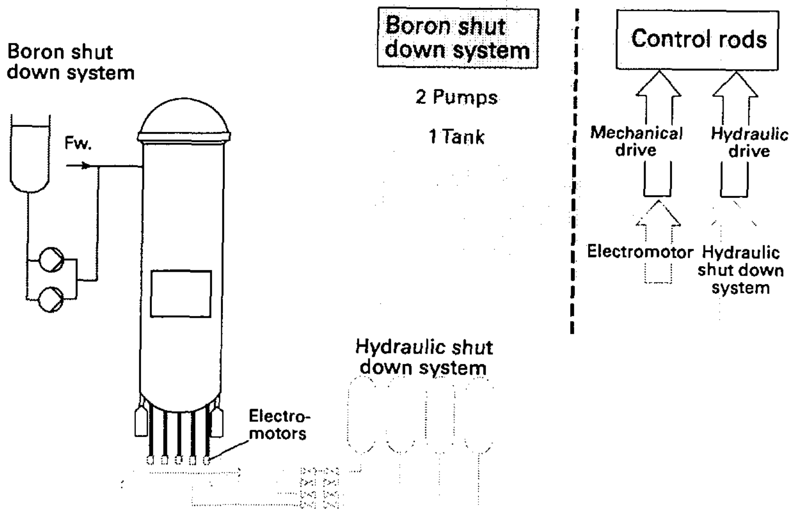


FIG. 11: Shutdown Systems

is thereby heated and partially evaporates, leading to a rapid pressure rise. The pressure rise triggers the safety functions automatically and passively via diaphragm pilot valves.

These devices function entirely independently, and therefore on a diverse basis to the safety I&C equipment. Their integration into the plant's systems engineering is planned (two 2-out-of-2 configuration) such that spurious actuation of a PPPT does not lead to initiation of actions, but also such that loss of a PPPT cannot prevent initiation.

As a new device, the functional capability of the PPPT was tested in the emergency condenser test facility at Germany's Jülich Research Center.

4.3 Reactor Shutdown Systems

Diverse systems are available for shutdown of the reactor (Figure 11). These include the control rods, with their diverse drive systems (electric motor drive for operational shutdown processes, and hydraulic drive for reactor scram). The hydraulic drives are supplied by a scram system. The SWR 1000 is equipped with a boron shutdown system, which functions as a diverse means of reactor shutdown with respect to the control rods and is completely independent of control rod operation and effect.

The concept of the scram system is based largely on the collector tank concept implemented in German BWR plants, whereby the energy required for fast control rod insertion by hydraulic means has to date been stored in tanks under nitrogen pressure. With regard to scram tank pressure medium, a change from nitrogen to steam pressure is currently being investigated. In the latter case, the water-filled tanks used for supplying the hydraulic medium are under a permanent steam pressure blanket generated by electric heating of the top water area. This modification would enable reduction of the tank size and design pressure, and prevent nitrogen from entering the RPV in the event of malfunction of the tank isolation valve.

The planned boron shutdown system is also based on the known concept implemented in all BWR plants: the quantity of pentaborate solution required for hot and cold sub-criticality is stored in an open tank and conveyed to the RPV upon challenge by means of high-pressure pumps. The recirculating pumps of the reactor water cleanup system are used as the high-pressure pumps.

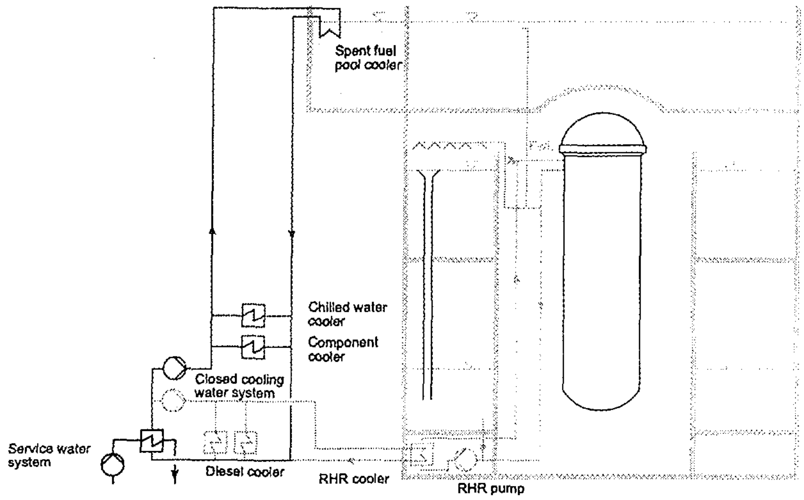


FIG. 12: Active Core Flooding and Residual Heat Removal Systems

4.4 Containment Isolation of Main Steam Lines

The main steam lines are equipped with isolation valves positioned inside and outside the containment at the containment penetrations. The system-fluid-actuated valves are of diverse design, the valve inside the containment being of quick-closing gate-type design, while the external valve is a quick-closing angle valve. Containment isolation is initiated, as in existing BWR plants, via safety I&C systems. In addition, however, a further passive actuation is planned for the SWR 1000, via diaphragm pilot valves arranged in parallel, actuated by PPPT.

4.5 Active Core Flooding and Residual Heat Removal Systems

Due to the additional passive residual heat removal systems, the SWR 1000 concept will include only two active low-pressure core flooding and residual heat removal systems, which are comparable to the systems in existing BWR plants in terms of their range of tasks (Figure 12).

These systems perform the following tasks, as in plants of earlier design:

- Reactor cooling during operational shutdown and in the shutdown condition
- Water transfer operations prior to and subsequent to refuelling
- Operational heat removal from the core flooding pool and pressure suppression pool water
- Heat removal from the containment in the event of loss of the main heat sink by cooling the pressure suppression pool and core flooding pool water
- Low-pressure feed of coolant to the RPV and simultaneous heat removal in the event of loss-of-coolant accidents.

The systems are actuated via safety I&C systems, and system-associated electrical loads are connected to the emergency power supply system.

High-pressure injection systems for the RPV are no longer required in the SWR 1000 design thanks to installation of the emergency condensers.

4.6 Systems for Control of Severe Core Melt Accidents

Loss of all active and passive injection functions and all emergency condensers is assumed for the postulated severe core melt accident. To control this serious accident scenario the following additional safety systems are planned for the SWR 1000 and the plant is designed to withstand the consequences of the accident:

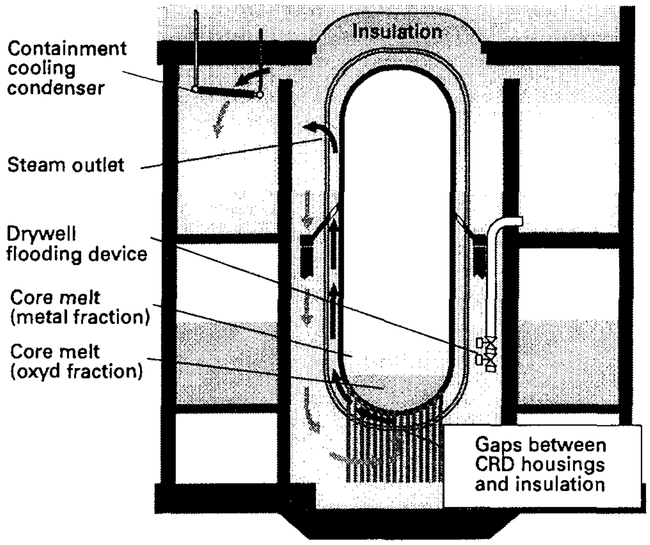


FIG. 13 Cooling of RPV Exterior in the Event of Core Melt

Core melt at high pressure is ruled out by the design of the depressurization system. The core melt is retained in the RPV at low pressure owing to cooling of the RPV exterior. A flooding system is installed for this purpose which feeds into the lower area of the drywell from the gravity core flooding pool (Figure 13). The flooding system is permanently isolated and activated upon challenge. The steam arising from cooling of the RPV from the outside is condensed at the CCCs, which transfer the heat from the containment to the water of the dryer-separator storage pool. Refilling of the dryer-separator storage pool, which only becomes necessary several days after the onset of accident conditions, enables virtually unlimited heat removal.

The containment design is based on the pressure buildup due to the hydrogen arising from a 100 % zirconium-water reaction involving the zirconium inventory present in the core. Hydrogen release always occurs via the drywell, and hydrogen is also partly flushed into the pressure suppression pool depending on the given pressure conditions (cf. Section 4.4.2.4). Any further pressure buildup due to chemical reactions of the hydrogen is not possible, as the containment is inerted with nitrogen.

Long-term pressure relief in the containment after the onset of accident conditions is effected via the off-gas venting system already installed in all current BWR plants, with catalytic hydrogen recombination and the connected holdup system.

5 OTHER REACTOR AUXILIARY SYSTEMS

5.1 Fuel Pool Cooling System

Two redundant cooler units, each consisting of four heat exchangers operating in parallel, are installed in the fuel pool in the SWR 1000 (Figure 12). The fuel pool water is cooled by natural convection. Redundancy is ensured by connecting the cooler units to the redundant closed cooling water systems that are backed up by emergency power supply. The coolers are arranged on the fuel pool wall in such a manner that defined water flows are obtained.

5.1.1 Reactor Water and Fuel Pool Cleanup System

In the SWR 1000, unlike in previous BWR plants, the low-pressure concept is applied (standard practice in pressurized water reactor plants) for reactor water cleanup system. In the SWR 1000

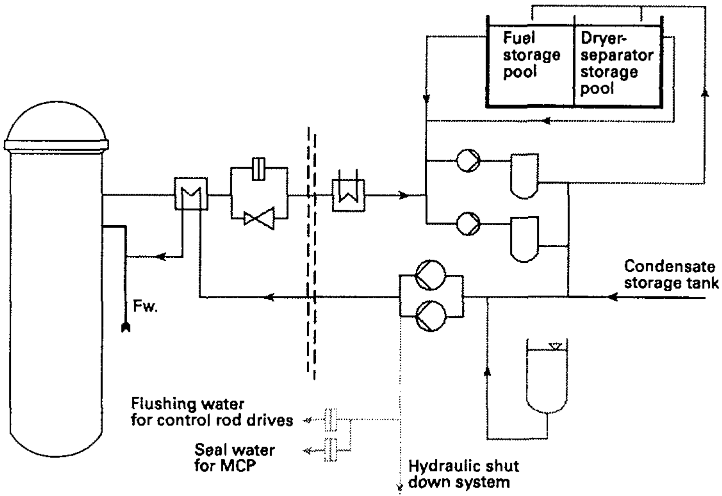


FIG. 14: Reactor Water and Fuel Pool Cleanup System

application, a regenerative heat exchanger and a pressure reducing station are arranged inside the containment, while a further cooler and the powdered resin precoat filter are located outside the containment (Figure 14). The cleaned water is conveyed back into the containment by means of two recirculating pumps and fed into the RPV via the regenerative heat exchangers. The two recirculating pumps also convey the control rod drive flushing water and the reactor coolant pump sealing water. In addition, they are used for the boron shutdown system and as booster pumps for filling the scram tanks. In comparison to high-pressure cleanup, this effective combination of tasks compensates for the disadvantage in energy terms of low-pressure cleanup with pressure reduction and high-pressure pumps.

The advantage of this concept lies in the fact that the filters, with their large number of connections, and the low-pressure cooler can be positioned outside the containment, and the number of containment penetrations can thus be significantly reduced. In addition, the filters, now located in the reactor building, can also be used for cleanup of the fuel pool water and the water in the dryer-separator storage pool.

6 ELECTRICAL AND INSTRUMENTATION & CONTROL SYSTEMS CONCEPT

6.1 Electrical Systems

The passive safety systems are capable of controlling all postulated accidents during power operation. This enables redundancy of active safety systems to be limited to two 100%-capacity trains. As a result, electric power supply to the plant itself (both the auxiliary and emergency power supply grids) are designed on a two-train basis.

6.1.1 Connection to Public Grid

The structure of the electric power supply system is shown in Figure 15. The generator feeds into the public grid via a generator transformer and the main grid connection. The power required for the auxiliary power system is tapped off between the generator and the generator transformer and fed to the 10 kV switchgear via two auxiliary power transformers.

The 10 kV auxiliary power busbars, in addition to being connected to the auxiliary power transformers, are connected to the grid via a backup grid transformer and a backup grid connection. In the event of unit failure, or loss of the main grid connection, power supply for auxiliary power can be guaranteed by switchover to the backup grid connection.

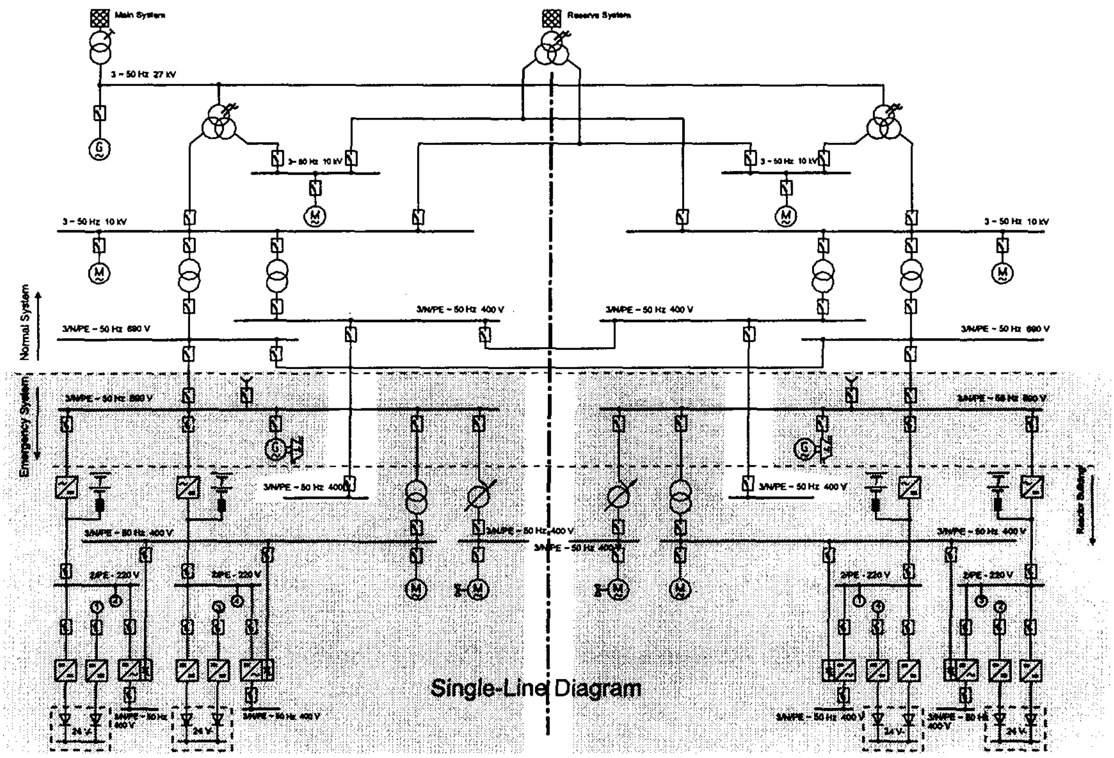


FIG. 15: Electric Power Supply Systems (Single Line Diagram)

6.1.2 Plant Auxiliary Power Grid

In view of the different power levels of the various loads connected to the plant auxiliary power grid, three voltage levels are made available.

For reasons of maintaining voltage stability, only electrical loads with a capacity of < 1 MW are connected to the 10 kV busbars to which the emergency power supply trains are connected. Electrical loads with a higher capacity are connected to the second 10 kV busbar in each train.

One 690 V emergency power supply busbar per train is supplied from the 690 V busbar of the auxiliary power supply grid.

6.1.3 Emergency Power Supply Grid

All electrical loads that have to remain in operation or come on-line in the event of loss of the auxiliary power supply grid are supplied by the emergency power supply grid.

In the event of loss of the auxiliary power supply grid, an emergency diesel generator takes over independent power supply of all connected electrical loads. Electrical loads for which a period without power is allowable during run-up of the emergency diesel generator are connected to the three-phase distributors (690 V and downstream 400 V distribution) of the emergency power supply grid.

A separate busbar is provided for each train for power supply to valve actuators. This busbar is connected to the 690 V busbar via a regulating transformer. This ensures that the valve actuators can be operated reliably and without wear or damage even in the event of major voltage dips in the auxiliary power system.

6.1.4 Uninterruptible Power Supply

Electrical loads that must remain in operation on an uninterruptible basis or have to be connected immediately in the event of loss of the auxiliary power supply grid are connected to the

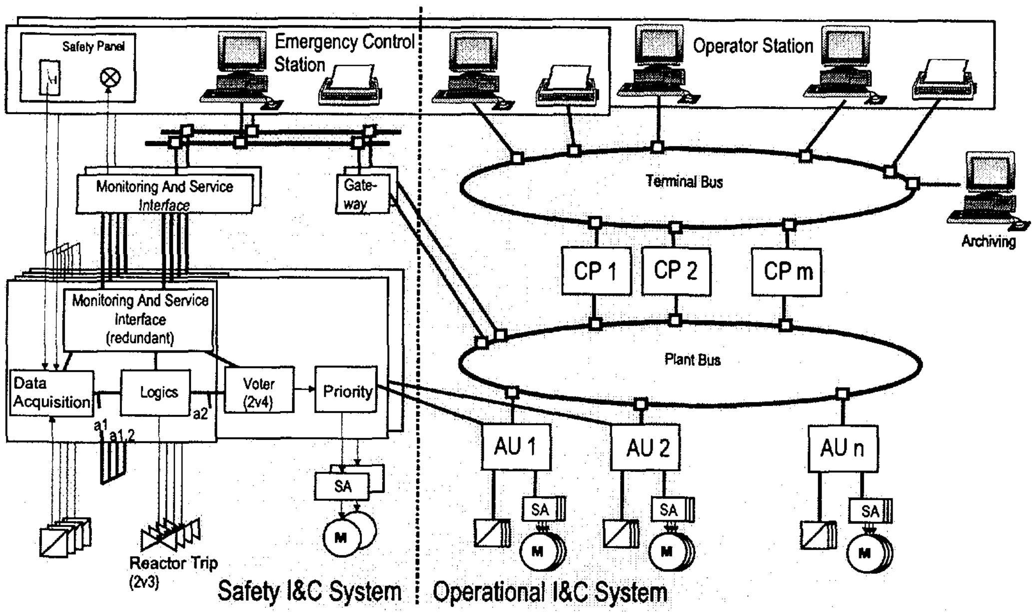


FIG. 16: Instrumentation & Control Concept

uninterruptible power supply. These loads are supplied with power either by the 220 V DC system or via the downstream inverter and the 400 V distributor connected to it, or supplied directly via local uninterruptible power supply systems.

The 220 V DC systems are supplied with power via rectifiers by the 690 V emergency power supply distributors on an individual train basis, whereby two DC systems are provided for each train. Each 220 V DC system has a battery and a charging rectifier.

6.1.5 Power Supply to Instrumentation & Control Systems

The instrumentation and control (I&C) systems are supplied with power at a constant voltage of $\pm$ 24 V by the 220 V DC systems via DC/DC converters. The power is supplied on a double diode-decoupled basis by one 220-V DC system of the dedicated train and one 220 V DC system of the second independent train.

Power is supplied to the monitoring systems and the computers at the master control console in the main control room and in the emergency control station via inverters or uninterruptible power supply systems.

6.2 Instrumentation & Control Systems

Thanks to improvements in the quality of safety in the SWR 1000, achieved through the introduction of additional passive systems to perform safety functions in the event of transients and accidents, the I&C concept can be considerably simplified in comparison with current BWR plants, as the passive safety systems function independently of electrical power supply and without actuation by I&C systems.

The digital I&C concept planned for the SWR 1000 is made up of the following subsystems (Figure 16):

- Operational I&C system
- Safety I&C system
- Process information system (PRISCA)

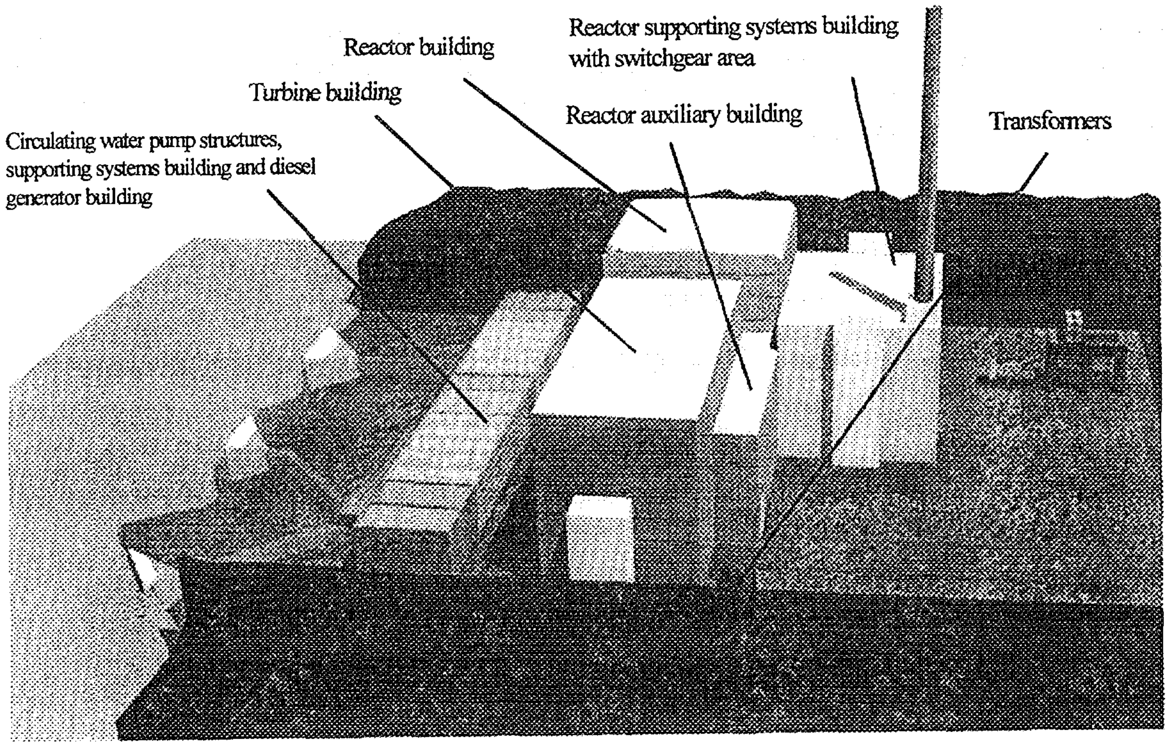


FIG. 17: Plant Site Layout

Operational I&C encompasses all systems required for process control in normal operation (i.e. during power operation and in the shutdown condition), such as:

- The process control system, including the operator station and emergency control station
- Automatic controls including protective devices and sensors in the plant
- Bus systems.

The task of the safety I&C system is to process and monitor key process variables important to reactor safety and environmental protection in order to detect accident conditions and to automatically initiate safety-related countermeasures in supplement to the passive switching actions in order to maintain reactor condition within safe limits. Safety I&C initiates no actions during normal undisturbed operation, but takes priority over all operational I&C system actions when required.

The computer-aided process information system provides a global information source. Intelligent information processing and compression enables it to display process conditions and process sequences with a high information content for safety-related and operational tasks.

The alarm and information system of the safety system first and foremost informs the operating staff of the status and condition of the safety system, and is used for service purposes.

The different I&C subsystems are connected via a common, redundant plant bus.

All accident conditions are detected by the safety I&C system, which initiates operation of the active safety equipment. If these safety systems fail, the passive safety equipment begins operating and brings the reactor to a safe condition.

As the passive safety features alone are capable of controlling all postulated accidents during power operation, the safety I&C system can also be limited to a redundancy of two 100%-capacity trains. Two 100 %-capacity I&C trains are therefore configured, the train allocation of which is maintained by I&C, process engineering and power supply systems. The process variables to be monitored are recorded by means of four measuring transducers. Further processing of measuring signals, limit value formation, formation and selection of actuation signals, and logic gating to form trip signals are all performed by means of a digital system. The trip signals directly actuate a process component or component group.

7 CIVIL STRUCTURES

7.1 General Arrangement of Buildings

The buildings are arranged in three complexes, thereby allowing simultaneous construction of all structures (Figure 17).

In terms of building arrangement, a distinction is made between site-dependent buildings such as the circulating/cooling water supply systems and ancillary systems building, and site-independent unit buildings, such as the following:

- Reactor building, including containment
- Turbine building
- Reactor auxiliary building
- Reactor supporting systems building, with switchgear area
- Diesel generator building
- Off-gas vent stack

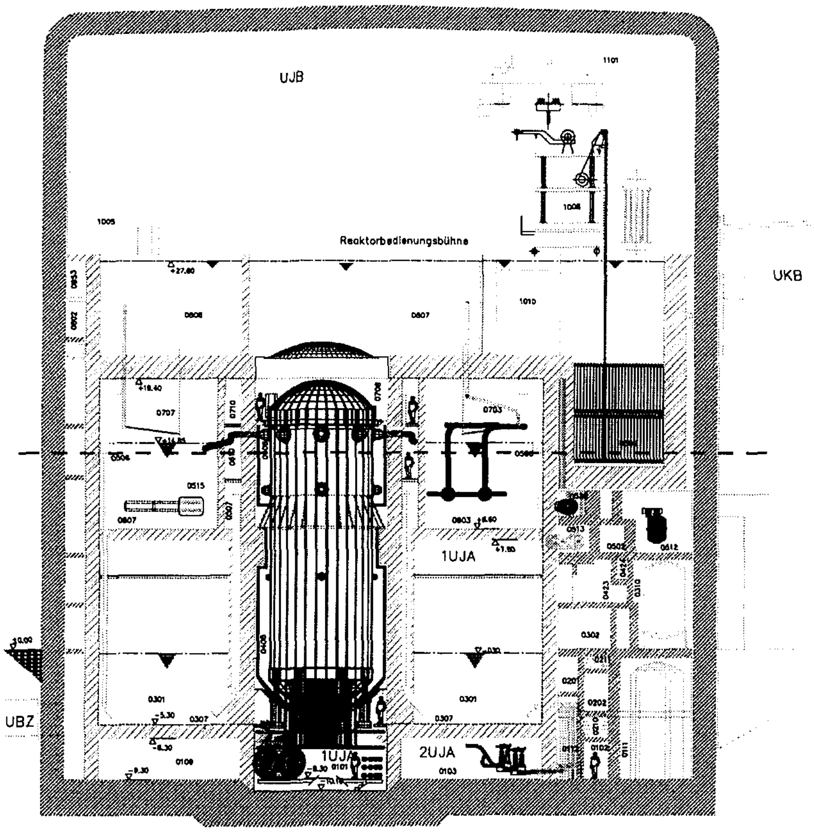


FIG. 18A: Reactor Building – vertical section

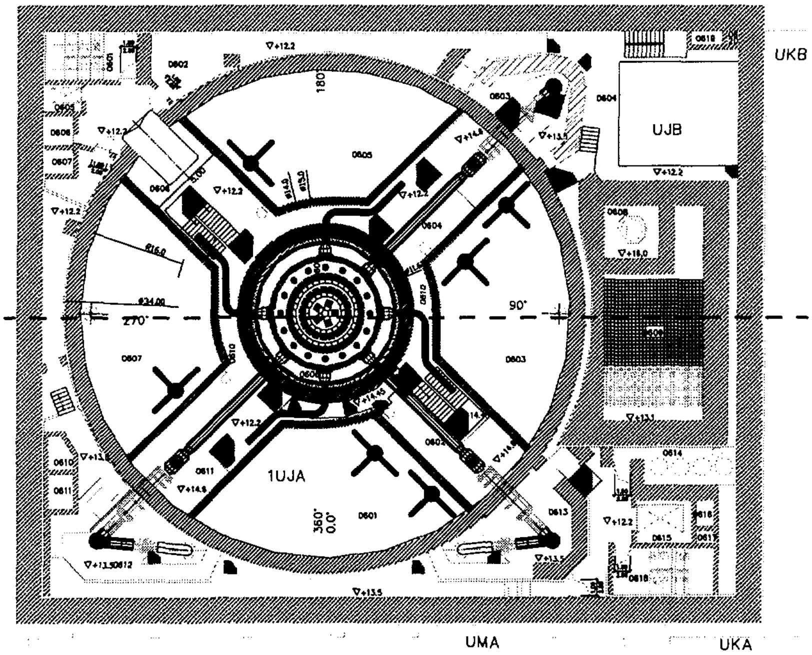


FIG. 18B: Reactor Building – horizontal section

The central unit comprises the reactor building and the turbine building, with partially integrated reactor auxiliary building. The reactor supporting systems building with the switchgear area and access to the controlled area are together connected to the central unit. Personnel entry and exit are exclusively via a stairwell, equipped with an elevator, which is centrally located in this building.

The circulating water pump house, the diesel generator building and the main conventional supporting systems are located at a distance from the unit buildings.

Piping and cables are routed either underground or in ducting structures.

7.2 Reactor Building

The reactor building (Figure 18A and B) houses the containment and the safety-related mechanical components, some of the electrical and I&C equipment, and the required power supply and protection systems. It provides protection against natural and external man-made hazards and ensures activity retention in the event of accidents.

The main systems and components located in the reactor building are the containment and its internals, the nuclear fuel storage and handling systems, the dryer-separator storage pool, the main steam and feedwater lines, the reactor water cleanup system, scram tanks, concentrate storage system and the heating, ventilation and air-conditioning systems, as well as the secured switchgear and the master control console.

The emergency control console is housed in the diesel generator building.

The structural concept is divided into three parts, as follows:

- Outer shell with penetration protection
- Inner structure, which is largely decoupled from the outer shell and the containment, and the
- Containment, whose structures, except for the base plate, are decoupled from the reactor building which encloses them.

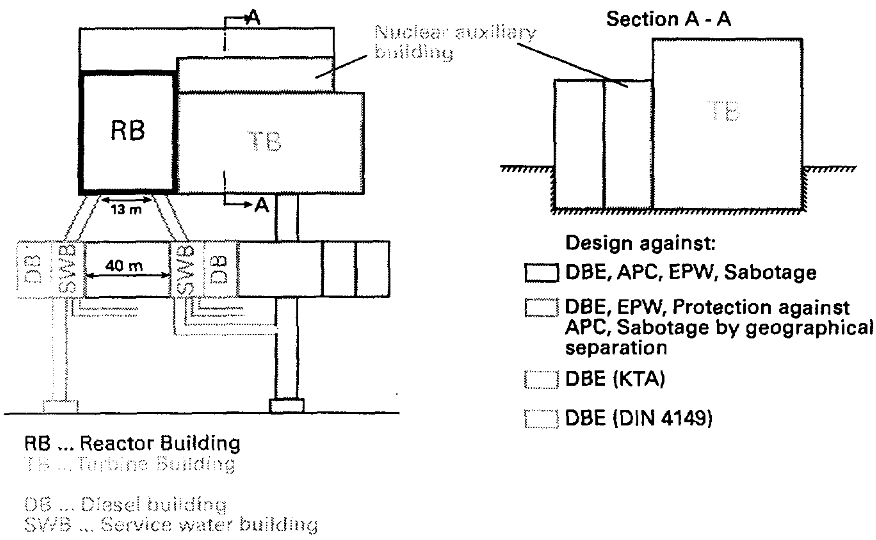


FIG. 19: Plant Protection Against Natural and External Man-Made Hazards

7.3 Other Buildings

7.3.1 Turbine Building

The turbine building contains mainly the systems and components of the steam, condensate and feedwater cycle, with condensate-feedwater pumps and feedwater heater as well as the turbine and generator. The feedwater heating system consists of a single train, and the feed heaters are arranged vertically in the immediate vicinity of the turbine.

The turbine building forms part of the controlled area of the plant.

7.3.2 Reactor Auxiliary Building

The reactor auxiliary building contains systems and components for the treatment and storage of radioactive wastewater, including the evaporator system, as well as the filters of the main condensate cleanup system and the unsecured part of the closed cooling water system.

The selected arrangement of the main condensate cleanup system and wastewater treatment and storage system ensures short piping connections with the system and equipment areas in the turbine building.

7.3.3 Reactor Supporting Systems Building

The reactor ancillary systems building contains the workshops and parts of the waste treatment and storage system, as well as the central access point to the controlled area. This building houses components of the following systems:

- Intake and exhaust air system
- Sanitary facilities, in particular the changing rooms and washroom facilities required for access to the controlled area
- Laboratory
- Hot workshop and decontamination facilities
- Reserved space for mobile concentrate treatment with a drum store for low-active waste

7.3.4 Switchgear Building

As a result of changes in the electrical and I&C equipment concept, the switchgear in the SWR 1000 also differ from the previous standard arrangement in BWR plants. The switchgear building no longer exists as an autonomous structure. Instead, the switchgear are housed in two common stories of the reactor building and reactor supporting systems building. In addition to being centrally installed in this switchgear area, operational switchgear is installed on a localized basis where possible and appropriate.

7.4 Plant Protection Against Natural and External Man-Made Hazards

The plant is designed to withstand all natural and external man-made hazards as required under German licensing procedures, including, for example, the design basis earthquake (DBE), aircraft crash (APC), explosion pressure wave (EPW) and industrial sabotage (see Figure 19). The reactor building is thereby designed as part of a comprehensive protection concept to accommodate the postulated loads, and the systems and components located inside it are designed, as a function of their classification, to withstand the shocks induced. To reduce consequential loads inside the building, the building floors are horizontally decoupled from the external walls.

Both the diesel generator building and the circulating water pump house for the residual heat removal systems are designed to withstand a design basis earthquake and the loads due to an explosion pressure wave. The principle of physical separation (> 40 m) is applied to protect against aircraft crash. The cooling water and cable ducts are routed underground at an appropriate depth and at the required intervals (> 13 m).

LIST OF ABBREVIATIONS

A summary list of abbreviations used in the text comprises:

ATWS	anticipated transients without scram
BWR	boiling water reactor
CCC	containment cooling condenser
CRD	control rod drive
EC	emergency condenser
EdF	Electricité de France
EPR	European Pressurized Water Reactor
FW	Feedwater
GPR	Groupe Permanent Chargé des Réacteurs Nucléaires
GRS	Gesellschaft für Reaktorsicherheit
HP	high-pressure
I&C	instrumentation and control
LOCA	loss-of-coolant-accident
LP	low-pressure
LPCI	low-pressure core injection
MSIV	main steam isolation valve
MSL	main steam line
NPI	Nuclear Power International
PPPT	passive pressure pulse transmitter
PSA	probabilistic safety analysis
PWR	pressurized water reactor
RHR	residual heat removal
RPV	reactor pressure vessel
RSK	(German) Reactor Safety Commission
UKB	Reactor supporting systems building
UBZ	Ducting structure (cable)
1UJA	Containment