Economical opportunities on advanced conventional island design for the European pressurized water reactor (EPR) based on Konvoi design

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Abstract. design of the European Pressurized Water Reactor (EPR) has been finalized by the end of 1998. In parallel with these efforts, the German utilities group contracted the Siemens AG Power generation Group (KWU) to develop an advanced and optimized conventional island for the EPR. The main objectives for improving the conventional island design were determined on the basis of experience of the Konvoi series plants and advanced fossil plants. This paper describes the innovations introduced to the conventional island and presents the reasons for the resultant cost reductions.

1. SUMMARY

German and French designers agreed in 1989 to jointly develop a standardized nuclear island for the European Pressurized Water Reactor (EPR).The basic design supported by German and French utilities and safety authorities was started 1995 and was finalized by the end of 1998. In parallel with these efforts, the German utilities group contracted the Siemens AG Power Generation Group (KWU) to develop an advanced and optimized conventional island for the EPR.

The main objective of the EPR design, i.e. to be able to compete economically with other nuclear power plant designs and fossil-fueled power plants and at the same time to increase nuclear safety, has been achieved. The results of these optimization efforts on the conventional island side can be summarized in the following points:

- The entire development and implementation process, i.e. from plant design work all the way through to plant service and maintenance, was reviewed and improved without any restricting operational or maintenance aspects;
- The efficiency of the steam, condensate and feedwater cycle, including the steam turbine and heat sink, was increased by introducing, among other design changes, the new 3DS/ 3DV blade design;
- The plant's electrical generating capacity was increased without any need of additional or new special tools or equipment;
- Common general European codes and related national codes and standards were applied to the designing, sizing, approval and documentation of all conventional island components;
- Only specialized personnel with global turn-key know-how was involved.

The performance figures of the improved design demonstrate the following:

- The EPR is economically competitive with modern fossil-fueled power plants,
- The EPR is much less dependent on fuel cycle costs than fossil-fueled power plants,
- One EPR saves some 10 million tons of CO_2 emissions per year compared with a hard-coal-fired power plant.

The result is a nuclear power plant with a gross electrical generating capacity of 1850 MW (for a site equipped with cooling tower), a gross efficiency rate of 37.8 % and a net efficiency of 35.9 %.

2. INTRODUCTION

2.1. Technical objectives of the EPR

In February 1995 Electricité de France and a group of German utilities (including PreussenElektra AG, Bayernwerk AG, RWE Energie AG, Badenwerk AG, Energie-Versorgung Schwaben AG, Isar-Amperwerke AG, Kernkraftwerke Lippe-Ems GmbH, Kernkraftwerk Stade GmbH and Neckar-werke Stuttgart), Framatome, Siemens AG Power Generation Group (KWU) and Framatome's and Siemens' joint venture company Nuclear Power International (NPI) signed a contract to develop the basic design of the nuclear island.

The result is the European Pressurized Water Reactor (EPR) with an evolutionary nuclear reactor design derived from the German Konvoi series and the French N4 series.

The main technical objectives of the European Pressurized Water Reactor project are

- To be able to compete economically with other nuclear power plant designs as well as hard-coal-fired power plants;
- To provide satisfactory performance characteristics, such as a generating capacity of about 1850 MWe, a plant service lifetime of 60 years for non-replaceable components, an average availability over the plant's lifetime of > 90 %, an average duration of scheduled refueling outages of ≤ 19 days per year and average inadvertent unavailability of < 5 days per year, as well as other objectives specific to the nuclear island;
- To fulfill German and French public power grid requirements;
- To increase safety by reducing the risk of accidents and mitigating the consequences of severe accidents by implementing accident control design features;
- To be licensable in Germany and France;
- To achieve a plant construction period of 57 months beginning with first concrete for the foundation raft.

2.2. Additional technical objectives of the conventional island

In the same year the German utilities involved contracted Siemens to develop an optimized conventional island design for the EPR in line with the same main technical objectives defined within the scope of the Franco-German cooperation agreement.

The following technical objectives for the conventional island were given highest priority with regard to improve efficiency, reliability and economy of the EPR plant:

- Excellent plant operational behavior and a design which allows flexible, unrestricted maintenance, i.e. as good as or better than the Konvoi series design;
- Mean forced outage time per year for the turbine-generator-set much smaller than 40 h per year;
- Risk-free manufacturing of components based on existing technology and proven design principles and, as far as possible, without need for additional or new special tools and equipment;
- Transportability of heavy components by railway using existing transport trolleys, e.g. for the generator and transformers;

As reference engineering and know-how
- the advanced design of Siemens' Konvoi series plants, with its excellent operational behavior and economy,
- publicly available data on the designs developed by other turbine generator set suppliers, and
- the experience gained from advanced fossil-fueled power plants

were agreed upon as bases for the optimization work.

The study conducted by Siemens is based on a river site with cooling tower, and was carried out in accordance with the standard site conditions for the nuclear island. All optimization measures described below are transferable to an EPR plant with direct cooling. Under Section 3 below, the main data for an EPR with direct cooling are compared to an EPR equipped with cooling tower.

3. MAIN RESULTS OF THE INNOVATIVE CONVENTIONAL ISLAND

The essential objectives for improving the conventional island with respect to lowering capital investment and power-generation costs were determined on the basis of the experience gained from the design, construction, erection, operation and maintenance of the Konvoi series plants and advanced fossil-fueled power plants.

These essential objectives are the following:

- Increased plant output;
- Increased turbine and steam, condensate and feedwater cycle efficiency and availability;
- Optimized and simplified mechanical and electrical systems and functions taking into consideration the high level of equipment quality;
- Applied common, general European codes to all conventional island components without reducing equipment and system reliability and availability;
- As far as reasonable, use of proven design principles, existing technology and familiar manufacturing procedures.Provision of physical separation of conventional island and nuclear island functions;
- Reduction of the enclosed volume of buildings without restricting erection, service or maintenance work;
- Simplification of instrumentation & control and mechanical systems without restricting operation by implementing advanced instrumentation & control systems;
- Same type of operational I & C as applied for the nuclear island.

The innovations introduced to the conventional island in comparison to the Konvoi series design are described in the following subsections.

3.1. Steam, condensate and feedwater cycle

The general architecture of the steam, condensate and feedwater cycle for the EPR is shown in Fig. 1, including one double-flow high-pressure turbine section, three double-flow low-pressure turbine sections, seven extraction stages, four feedwater pumps and one spray-type feedwater buffer tank.

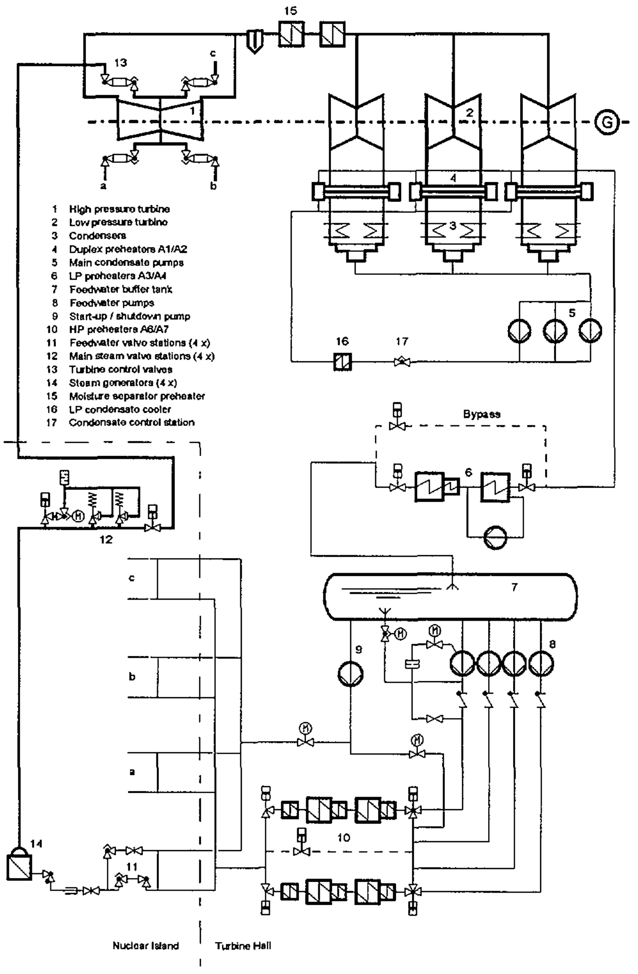


FIG. 1. Steam, condensate and feedwater cycle.

The major improvements to the steam, condensate and feedwater cycle over the Konvoi series design can be divided into the following two categories:

- *Innovations which have a direct impact on lowering investment costs*

  These innovations comprise simplifications or reductions of systems or equipment which have no direct effect on plant availability or the application of systems and equipment which have an acceptably low failure rate.

  These modifications were based entirely on the operational experience of the utilities and the designer, and resulted for example in no reduction in the number of main condensate pumps, with three 50-% capacity units, and the main feedwater pumps, which are configured as four 33-% capacity units instead of in a 3 x 50 % arrangement.

The following are examples of such innovations:

- Reduced number of low-pressure main condensate trains;
- A smaller feedwater (buffer) tank;
- Integration of cooler function into preheaters;
- Modified warmup procedure for the steam, condensate and feedwater cycle which has ultimately led to the elimination of an entire building, i.e. the auxiliary steam supply system building;
- Elimination of the condensate polishing system based on the good experience gained with steam, condensate and feedwater cycle chemistry together with improvement in material composition and component design.

- *Innovations which increase electrical power output and ultimately decrease specific power-generation costs*

  A decrease in power-generation costs can only be achieved if any additional costs for equipment are lower than the gain in additional electrical power output.

  Examples of such process improvements are:

  - higher main steam pressure,
  - higher final feedwater temperature,
  - optimized feedwater (buffer) tank pressure,
  - optimized number of steam turbine extraction stages,
  - two-stage reheating in a vertical design as used in the Konvoi series design,
  - optimized preheater efficiency,
  - higher turbine efficiency together with an optimized heat sink (see details below).

  The gain in electrical generating capacity in comparison with the Konvoi plants amounts to approximately 67 MW. This gain can be broken down as follows:

  - 50 % of this increase or more is due to design improvements to the steam, condensate and feedwater cycle, while
  - up to 50 % of this increase can be traced to improvements to the high- and low-pressure turbine sections, including the new blade design.

  Some of these improvements have already been backfitted at Isar 2 Nuclear Power Station (one of the Konvoi series).

3.2. Steam turbine-generator set including heat sink

3.2.1. Steam turbine

Basis for the steam turbine plant is the proven, highly reliable product installed in the Konvoi series plants. In light of the experience gained from state-of-the-art turbines used at today's fossil-fueled power plants, certain modifications were introduced to achieve higher efficiency.

The main design features of the EPR Siemens steam turbine are as follows:

- 1 double-flow high-pressure turbine section and 3 double-flow low-pressure turbine sections;
- 2 instead of 4 inlet and outlet nozzles in the high-pressure turbine sections;
- High-pressure turbine section upper casing equipped with only one nozzle;
- Use of blades shaped using 3D design techniques for the high- and low-pressure turbine sections (see details below);
- Combined main steam control and stop valves arranged below the turbine floor instead of above the high-pressure turbine section;
- Electrohydraulic valve actuators with external high pressure control fluid supply (compact actuators were not used for reason of costs);
- Low-pressure turbine section outer casing directly welded to the condenser shell, which rests directly on the foundation without springs;
- Support for the low-pressure turbine section inner casing rests directly on the turbine foundation deck and not in the outer casing;
- With the exception of the final-stage moving blade rows, the low-pressure turbine section blades are designed with shrouds;
- Intercept butterfly valves are not required according to German VGB rules and international (IEC) requirements.

3.2.2. Steam turbine blading

Turbine blade design has a major influence on the quality of energy transfer. In earlier years, it was only possible to use cylindrical blades of uniform profile. Design improvements were made to these cylindrical blades time and time again. Increasing understanding of turbine processes and improved manufacturing machinery made possible improvements in efficiency.

Today, powerful computers make it possible to resolve the system of differential equations in greater detail using some 80 free parameters limited by approximately 300 constraints such as material characteristics as well as design, fabrication and erection requirements. Such methods provide better understanding of ideal blade shape. On the basis of this new technology it has become feasible to develop blade shapes optimized in three dimensions in which profile, twist and slope change over the entire length of the blade.

This approach permits better adaptation to the complex radial flow distribution and to the specific steam conditions between stationary and moving blades, and helps to reduce secondary losses at the root and tip of the blades. The resulting product has been dubbed a 3DS blade.

There remained further potential for improvement in terms of adapting blade geometry to the specific flow and steam conditions in the various turbine stages. The distribution of the pressure decay per stage over the stationary and moving blades - the so-called mean reaction - was more or less uniform.

Now, Siemens is the first blade manufacturer to succeed in adapting the blade shape for each stage separately. Called 3DV blades, these designs eliminate the classic distinction between impulse (with a reaction of about 0 %) and reaction turbines (which have a reaction of 50 %).

Figure 2. shows the new rotating blades with three-dimensional shapes (3DS and 3DV) in comparison with cylindrical blades.

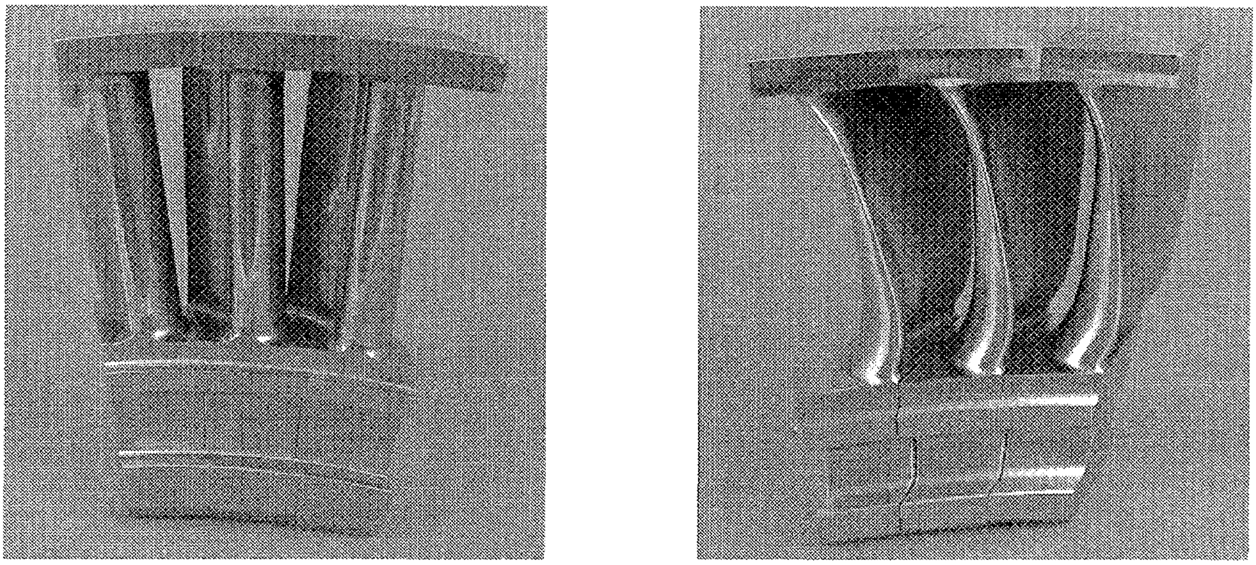


FIG. 2. Cylindrical blade *3DS/3DV blade*

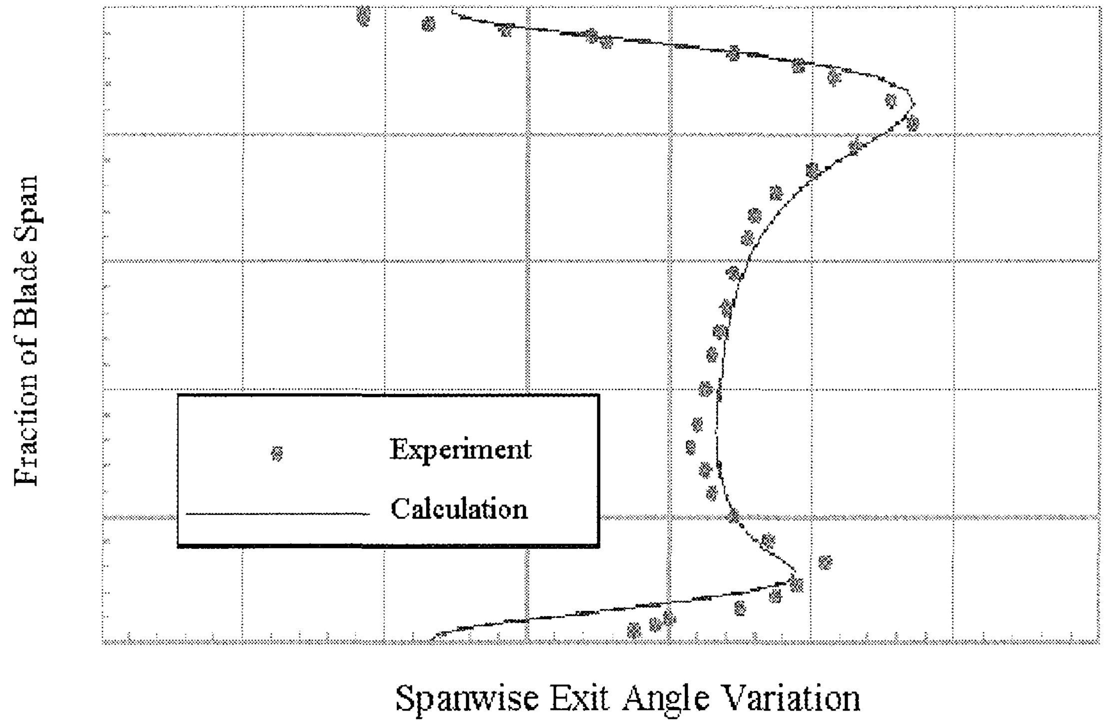


FIG. 3. Calculated and measured flow angles.

In comparison to cylindrical blades, these individual optimizations over the lengths of all the turbine blades and across the various stages result in a gain of 2 to 3 percentage points in efficiency in each turbine section and up to 1 percentage point in total for the overall plant.

At Siemens' manufacturing plant, improved computerization facilitates not only precise visualization of shape and strength analyses but also direct transfer of blade shapes to the fully automated fabrication cells. This results in lower blade failure rates, higher quality and lower cost.

The methods applied make possible quite accurate simulation of boundary and secondary flows in critical areas. Analytical results have been confirmed by numerous experimental measurements performed in wind tunnels and on test turbines.

The good agreement of calculated and measured flow angles for 3DV variable reaction blading is shown in Fig. 3.

3DV blades are shaped such that the thermodynamic energy of the steam is optimally converted into rotating shaft mechanical energy, with reduced secondary losses. These blades significantly improve steam turbine efficiency.

3.2.3. Generator

With the exception of the rotor cooling system, the EPR's generator system is based on the improved and highly reliable product used in the Konvoi series. The coolant for the rotor winding cooling system has been changed from water to hydrogen.

The main design features of the EPR generator are as follows:

- single-shaft turbine generator set
- 2056 MVA, power factor 0.9, 27 kV, 44 kA, 4-pole type
- hydrogen cooling system for rotor winding and stator core
- water cooling system for stator winding
- end shield bearings with integrated hydrogen sealing
- total weight: 899 Mg; total length: 22.4 m (including exciter set).

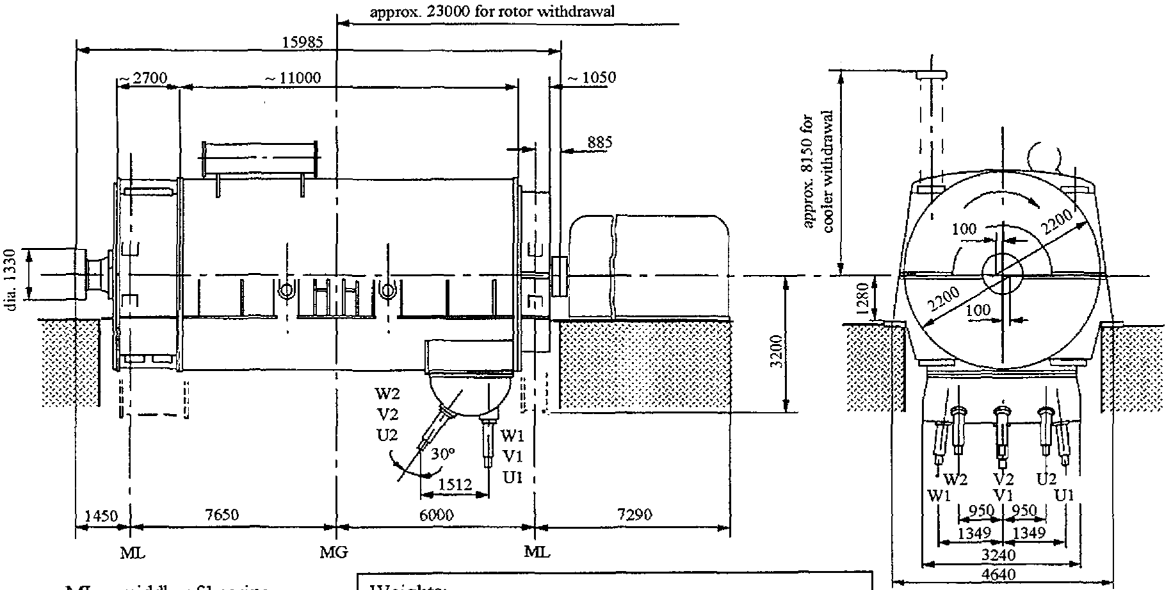
The design of this generator series, up to a power range of 2200 MVA with a power factor of 0.9, has produced an advanced product. It is still based on the identical design principles of proven generators with water- or gas-cooled rotor winding, and remains in compliance with the requirements defined by the International Electrotechnical Commission (IEC).

This advanced generator with gas-cooled rotor winding has the following advantages over an equivalent generator with water-cooled rotor winding:

- shorter total length
- less total weight
- fewer active components
- simplified cooling system
- simplified rotor bar fabrication
- simplified operation and maintenance work.

This advanced Siemens generator shown in Fig. 4 is not larger than the water-cooled generators installed in the Konvoi series, with an apparent power of 1640 MVA, and is consequently also transportable by road as well as by railway using an existing transport trolley. The weight of the heaviest generator component is still less than the maximum weight of 450 Mg allowed for railway transportation.

Siemens manufacturing facilities are already equipped with the machinery needed to fabricate this generator with hydrogen-cooled rotor winding, the world's largest generator of its kind.



ML = middle of bearing
MG = middle of generator

Weights:	
Rotor	249 Mg
Stator complete (incl. cooler, bearing, housing)	521 Mg
Transport weight, stator	434 Mg
Cooler	9 Mg
Exciter	75 Mg
Others	54 Mg
Total weight	899 Mg

FIG. 4. EPR generator.

3.2.4. Heat sink

Optimization of the heat sink, which can have significant effect on generator output, auxiliary power load, component costs and plant layout, is one of the essential steps towards achieving high efficiency while keeping an eye on high plant economy. Site conditions for a cooling tower or direct cooling system, interface requirements to the nuclear island and fuel-cycle costs must be considered in addition to overall plant requirements.

The major input data for optimization work are the following:

- Air and cooling water temperatures for a site equipped with cooling tower, or the given temperature rise and circulating water temperature for a direct-cooling system,
- Electrical power output,
- Operating time per year at full-load power operation,
- Heat consumption,
- Fuel-cycle cost,
- Cost of specific plant systems and components taking into consideration plant layout constraints,
- Anticipated investment cost of the overall plant,
- Annuity.

The optimized design aspects which lower power-generation costs are:

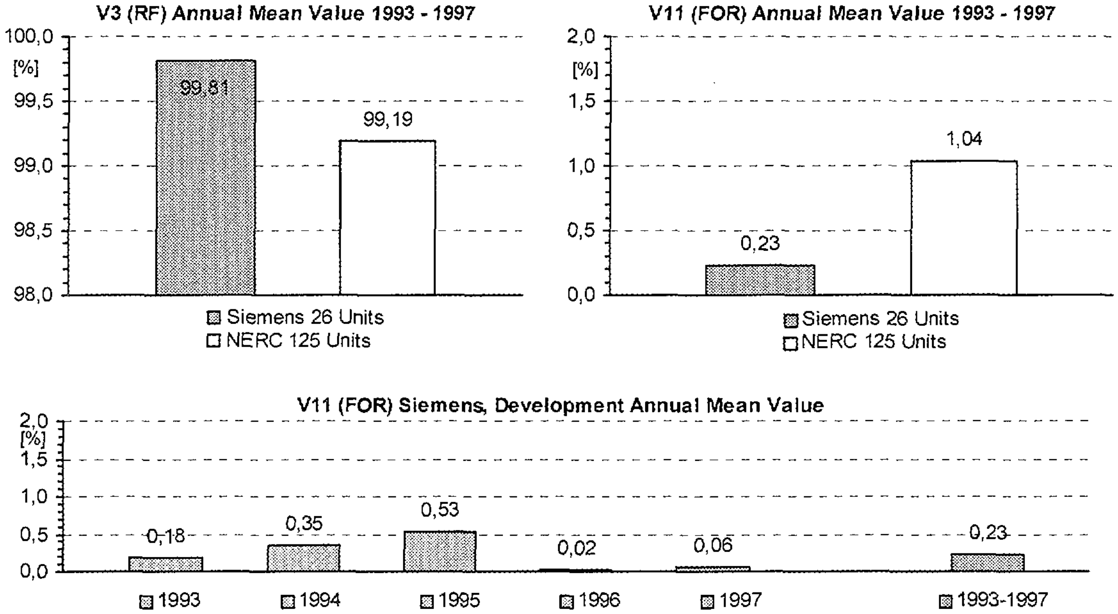
- Condenser pressure and length,
- Circulating water flow rate and velocity,
- Design of the cooling tower and circulating water structures.

One example of the EPR's optimized heat sink is the lower circulating water flow rate required, which is about 15 % less than flow at the Konvoi series plant Isar 2.

Furthermore, a significant additional increase in generating capacity, higher efficiency and lower power-generation costs can be achieved in cases in which site conditions allow direct cooling of exhaust steam rather than requiring a closed cooling system. A gain of 20 MW is realistically feasible given a cooling water temperature of between 12 and 16°C.

3.2.5. *Availability*

In Fig. 5 values of availability of Siemens turbine-generator-units are compared with values of NERC units (North American Electric Reliability Council).



$$V3\ [RF] = \frac{\text{Period Hours} - \text{Forced Outage Hours}}{\text{Period Hours}} \times 100\ \%$$

$$V11\ [FOR] = \frac{\text{Forced Outage Hours}}{\text{Operating Hours} + \text{Forced Outage Hours}} \times 100\ \%$$

FIG. 5. Turbine-generator, availability.

The upper left diagram shows the availability based on period hours (= 8760 h/a) and the upper right diagram the forced outage rates based on operating hours. Evaluated years (1993 to 1997) are detailed in the next diagram.

The mean forced outage time in hours per year for the complete turbine-generator sets of Siemens and NERC-unites are as follows:

		period	1988 – 1992	1993 – 1997
☐ Siemens	unit	hours	25	17
	turbine / generator	hours	13 / 12	10 / 7
☐ NERC	unit	hours	70	71
	turbine / generator	hours	39 / 31	33 / 38

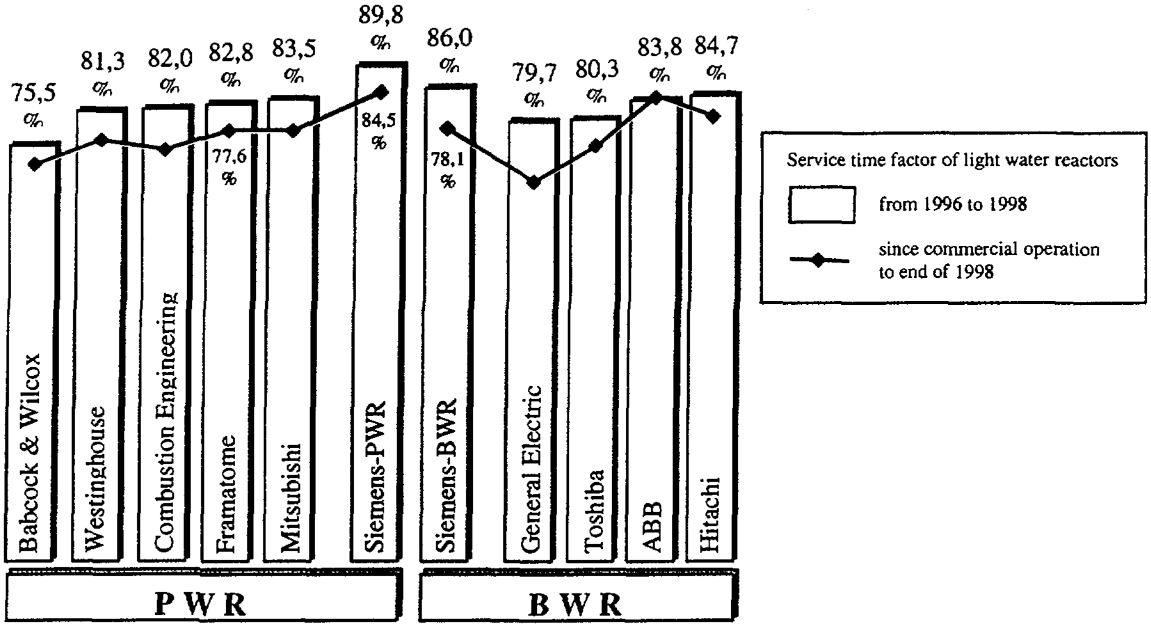


FIG .6. Service time factor of light water reactors (total plants).

Since Siemens did not change general design principles of the turbine and generator for the advanced and optimized conventional island for the EPR these really excellent values of Siemens units can be expected without any doubt also for the EPR plant. Beyond it, the availability of the total plant (NI and CI) also indicates quality just as economy. Fig. 6 shows the availability of Siemens plants (NI and CI) against international competitors.

Of course, the figures show an improvement of availability since commercial operation for pressurized water reactors (PWR) and boiling water reactor (BWR) of all suppliers, but Siemens plants fill the first places.

The higher availability of Siemens plants from 1996 to 1998 (at least 6.3 % for PWR and 1.3 % for BWR) and also since commercial operation demonstrates their quality and at the same time their economy of operation.

3.3. Electrical system

The main structure of the electrical system for the conventional island is similar to that of the Konvoi series, and follows the 4-train redundancy requirement specified for the nuclear island.

Fig. 7 shows the architecture of the electrical system of the conventional island.
The power plant is connected to two off-site power grid systems: one main grid connection for power transmission and normal plant startup and shutdown, and one independent auxiliary grid connection for plant shutdown in the event of simultaneous loss of the main grid connection and main generator.

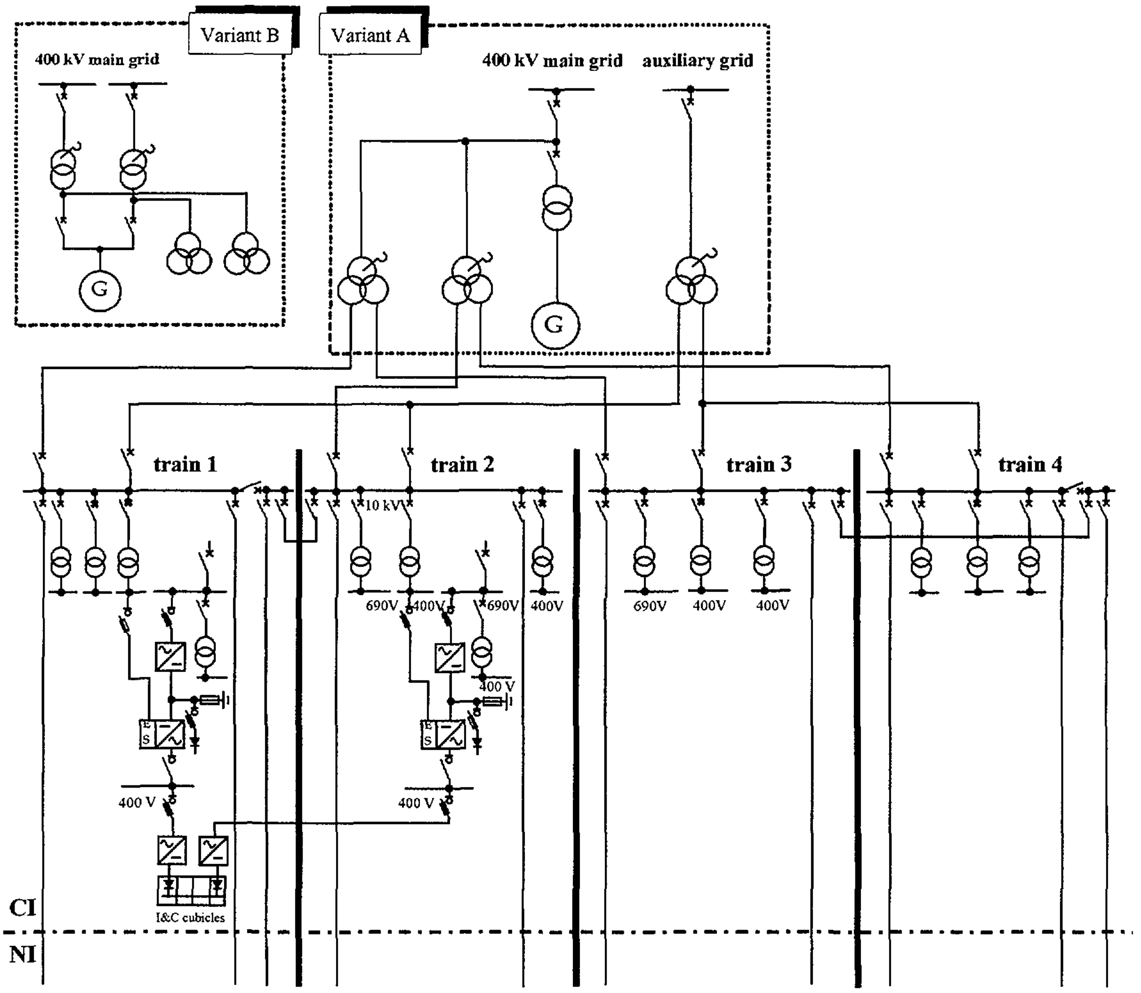


FIG. 7. Single line diagram of the conventional island.

Additionally, some consumers of the conventional island are connected to the emergency power supply of the nuclear island for investment protection (such as the turbine) and for discharge reduction of the batteries in case of loss of the above mentioned two offsite power grid systems.

The results of optimization of the electrical system over the Konvoi series design can be divided into the following three categories:

- Modifications with interface to the public power grid,
- Modifications with interface to the power supply of the nuclear island,
- Modifications which lower investment costs.

All of these modifications fulfill both French and German requirements despite the differences in general grid structures such as load concentration, power transmission distance, load flow, network node for power control and safety rules & regulations, as well as requirements governing power supply of the nuclear island via the auxiliary or standby transformers.

The following are examples of improvements to the electrical system:

- Three 400-kV single-phase main transformers with build-on air/oil coolers instead of two 3-phase transformers with separate water/oil coolers;
- Indoor 400-kV generator circuit breakers instead of 27-kV units;
- Two 400-kV/10-kV 3-phase auxiliary transformer and one 400-kV (or 220-kV or 110-kV) standby transformer;
- Physical separation of conventional island switchgear from the nuclear island;
- Dry-type low-voltage transformers;
- Intelligent switchgear and intelligent drive actuators, including bus systems;
- 230V AC power supply for instrumentation & control equipment.

These modifications bring the following benefits:

- Easier manufacturing and transportation of main transformers by railway or road,
- Simpler erection and removal of main transformers,
- No cooling water system connection required for main transformers,
- Simplified generator leads,
- Identical auxiliary and standby transformers,
- Shorter cable runs from auxiliary transformers to the switchgear and loads,
- Less cabling between I&C cabinets and switchgear,
- Continuous monitoring of equipment,
- No DC switchgear.

These improvements lower investment costs, ultimately decrease power-generation costs and have no adverse effect on plant availability.

3.4. Instrumentation and control (I & C)

In order to improve the economy of the overall plant, the instrumentation & control (I&C) systems, too, required optimization, taking into consideration requirements governing the nuclear island as well as operational & safety plant behavior and performance.

First, the architecture of the operational I & C of the nuclear and conventional islands was harmonized with a view of achieving a homogeneous man-machine interface. The cost reduction potential of the conventional island was determined and evaluated. The optimizations identified for implementation were closely matched to nuclear island requirements.

Figure 8 presents an overview of the operational and the safety I & C systems for the entire plant (NI and CI). Process variables are monitored by the operational and safety instrumentation. Many of the measured values generated by the safety I & C are also used for normal operation.

The introduced main improvements of the conventional I & C systems based on a homogeneous architecture are:

- Comprehensive use of a fiberoptic network;
- Use of standardized instrumentation, branch connections and automation systems;
- Standardized blackbox controls and interfaces;

- Use of field bus systems together with intelligent switchgear and actuators;
- Direct supply of 230V AC power to I&C equipment cabinets using integrated 230V AC/24V DC converters and, as far as reasonable for specific equipment, without power conversion;
- Optimization of equipment arrangements.

These improvements result in unproblematic signal transmission over long distances, inherent resistance to electromagnetic interference, provisions for physical separation, fewer I & C equipment cabinets and branch connections, less cabling and auxiliary power requirements as well as simpler design, assembly, erection, commissioning, maintenance and documentation. Consequently, equipment costs are lower.

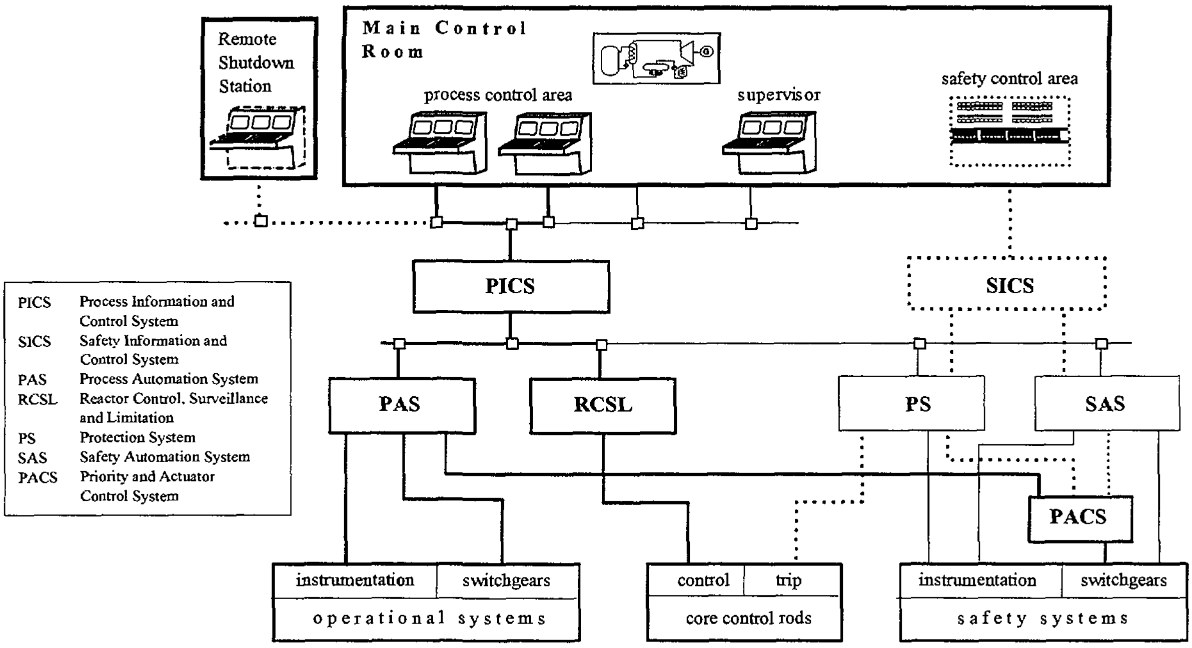


FIG. 8. Architecture of I & C systems.

3.5. Components specifications

The manufacturing and quality specifications defined for the Konvoi series covered the conventional and nuclear islands. These specifications stipulate requirements for design, sizing, materials, manufacturing and the preparation of pre-approval documents as well as for documentation of nuclear island and conventional island components. The philosophy behind this concept was to achieve a compact and homogeneous quality code for the complete nuclear power plant.

With this concept in place, however, it was very difficult for foreign suppliers and sub-suppliers to gain access to the German nuclear power market due to the specific quality certificates required. Furthermore, the small group of suppliers qualified to these requirements enjoyed a virtual monopoly and took advantage of this situation.

In future, only common, general European codes and the related national codes and standards will be applied to the EPR conventional island components. This ensures an equivalent quality of components fabricated in all member nations of the European Union.

The advantages of this new concept include the following:

- All European manufacturers will have a fair chance in competition since all national requirements for design, sizing, approval and documentation will be based on common European codes;
- All European manufacturers are familiar with the national codes applicable in their respective countries;
- Manufacturers need not implement any special, additional quality management program;
- The manufacturers' qualifications and product quality of the European suppliers will be comparable since qualification procedures, like the training of skilled workers and experts, are comparable;
- Costs will be as low as those for fossil-fueled power plants.

These advantages produce benefits in the procurement of components which meet high quality management requirements, resulting in lower investment costs and ultimately lower power-generation costs.

3.6. Plant layout

3.6.1. Site plan of the EPR with cooling tower (Single-Unit Arrangement)

The turbine building is arranged in axial line with the reactor and safeguard buildings. On one side of the turbine building, the circulating water system is arranged at a right-angle to the turbine building, while the conventional island switchgear building and auxiliary buildings (workshop, office and entrance buildings) are located on the other side.

The main reasons for this arrangement are the following:

- Safety requirements specified for the nuclear island buildings and associated equipment;
- Economic flow of fluid and energy between the buildings and equipment;
- Economic arrangement of circulating water system and power grid connection;
- Economic requirements governing civil construction, component erection and plant operation.

Modification of circulating water piping and channels for a plant site with direct cooling (river or seaside) or for a twin-unit arrangement can be easily implemented.

Fig. 9 shows the overall arrangement of a single-unit EPR for a site with cooling tower.

3.6.2. Turbine building

The layout of the conventional island building has been totally rearranged due to the results of optimization of systems, components and equipment.

The main requirements governing this rearrangement are the following:

- Reduction of enclosed volume of buildings;
- Adaptation of layout to accommodate optimized mechanical and electrical systems;
- No changes shall be made to the vertical arrangement of the moisture separators;

- Improvement of the service area for the combined main steam control and stop valves and the high-pressure turbine section;
- No reduction of area provided to perform maintenance work, e.g. for the steam turbine and pumps;
- Provision of physical separation of nuclear and conventional island electrical and I&C systems;
- Rearrangement of areas for laboratories, workshops and stores;
- Reduction of required number of operating personnel.

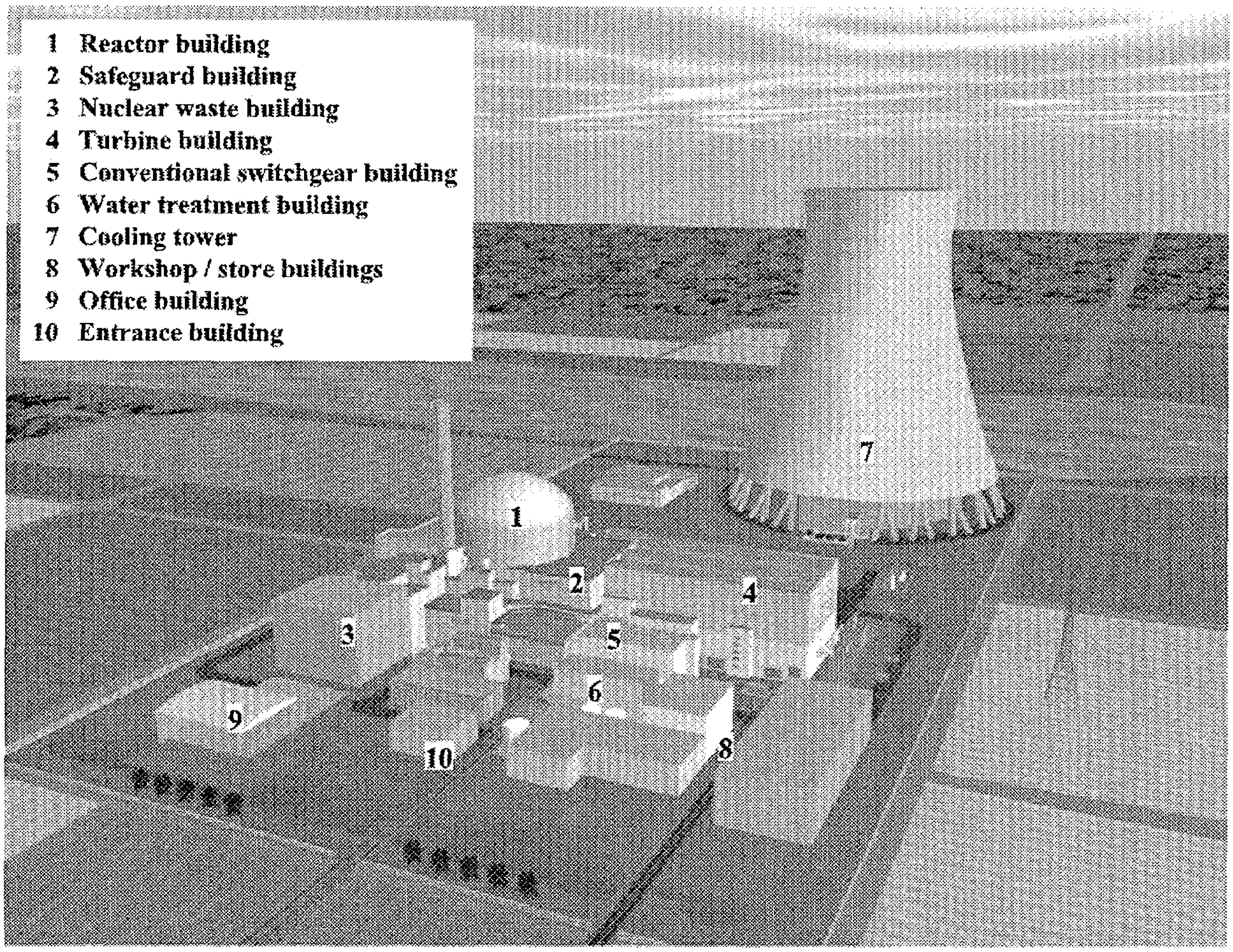


FIG. 9. 3D-arrangement of the EPR-plant.

Optimization work of the turbine building for the EPR with 1850 MW, viewed against previous layouts of nuclear power plants rated at around 1400 to 1500 MWe, reduced enclosed building volume by some 10 % compared to the Konvoi series and by some 50 % compared to competitor vendors. Areas for service and maintenance work were not reduced, thus ensuring short erection and maintenance times.

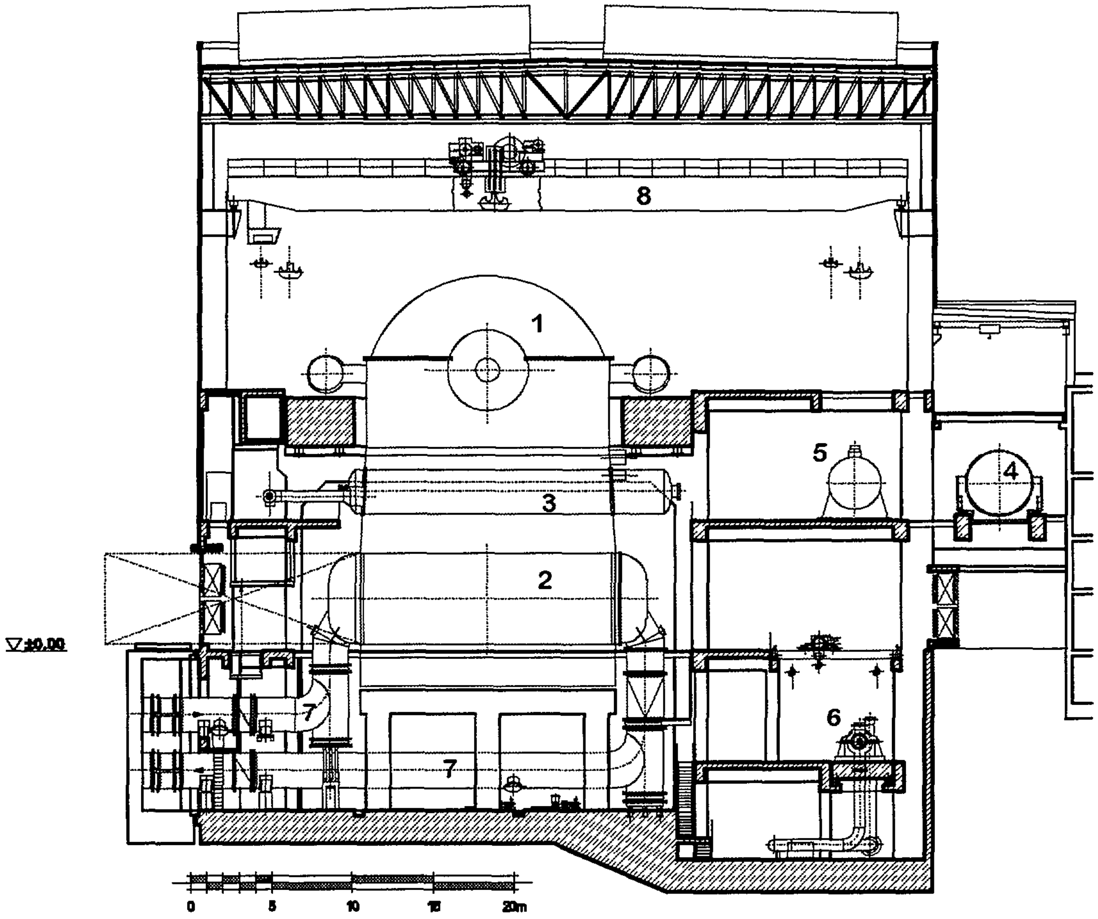
The following are examples of layout rearrangements introduced to the turbine building:

- Elimination of feedwater bay due to rearrangement of the feedwater pumps and optimized location of the feedwater buffer tank;
- Rearrangement of main steam stop and control valves;
- Rearrangement of building floor elevations;

- Rearrangement of preheaters;
- One instead of two high-pressure turbine section inlet and outlet lines;
- Simplification due to compact turbine auxiliary control and lubrication systems;
- No need for butterfly intercept valves.

This work involved an integrated team with good overall engineering knowledge of the civil works, systems and components, I&C and electrical equipment as well as know-how in the fields of civil construction, component erection, plant commissioning and inservice inspection and maintenance work.

Figure 10 shows a cross section of the turbine building.



1 LP Turbine
2 Condenser
3 Duplex Preheater
4 Feedwater Buffer Tank
5 LP Preheater
6 Feedwater Pump
7 Circulating Water Pipes
8 Steam Turbine Building Crane

FIG. 10. Cross section of turbine building (Turbine Generator Set).

4. MAIN DATA OF THE OPTIMIZED EPR PLANT AND THE REFERENCES DESIGNS FROM WHICH THE EPR IS DERIVED

4.1. Data on EPR nuclear island

Reactor power	4900 MW_{th}
Steam generator power	4925 MW_{th}

4.2. Optimized EPR conventional island

- **For an EPR equipped with cooling tower:**

Electrical power, gross	**1850 MW**
Gross efficiency ($P_{gross}/P_{Reactor}$)	**37.8 %**
Net efficiency ($P_{net}/P_{Reactor}$)	**35.9 %**
Auxiliary power	approx. 5 %
Steam turbine type	1 double-flow high-pressure turbine section 3 double-flow low-pressure turbine sections
Low-pressure exhaust area	6 x 20 m^2
Length of turbine generator set	approx. 60.5 m
Cooling system	natural-draft cooling tower
- temperature	18.2°C
Condenser pressure	0.060 bar
Generator apparent power	2056 MVA
- rotor cooling medium	hydrogen

- **For an EPR with direct cooling:**

Electrical power, gross	**1870 MW**
Gross efficiency ($P_{gross}/P_{Reactor}$)	**38.2 %**
Net efficiency ($P_{net}/P_{Reactor}$)	**36.3 %**
Auxiliary power	approx. 5 %
Low-pressure exhaust area	6 x 25 m^2
Length of turbine generator set	approx. 63.5 m
Cooling system	direct cooling
-temperature	12 to 16°C
Condenser pressure	0.049 bar

4.3. Current situation

Due to recent discussions between German and French utilities the reactor power for designing the EPR is intended to be limited to 4500 MW, although the application for a license of the first EPR unit in France will be made with 4250 MW. The expected electrical power is some

- 1630 MW for a site equipped with cooling tower, and
- 1645 MW for a sea site with direct cooling.

The presented design optimization and economy advantages are still valid.

4.4. Reference designs from which EPR is derived

	German Konvoi Series	French N4 Series
Steam generator power	3867 MW_{th}	4270 MW_{th}
Electrical power, gross	1440 MW	1520 MW
Steam turbine type	HP-LP/single-shaft	HP-IP-LP/single-shaft
Low-pressure exhaust area	6 x 20 m^2 (Isar 2)	6 x 20 m^2
Generator	1640 MVA	1710 MVA
- rotor cooling medium	water	hydrogen
Length of turbine generator set	approx. 65 m	approx. 69 m
Feedwater pump drive	electric motor (~ 20 MW)	steam turbine
Gross efficiency ($P_{gross}/P_{Reactor}$)	**37.4 %**	**35.8 %**
Start of operation	in 1988 (Isar 2)	in 1998 (Chooz)

5. ECONOMY AND PROSPECT

The capital investment required to construct the European Pressurized Water Reactor could be kept below that of a Konvoi series plant. Even increased economy will be achieved due to the higher output of the EPR.

The reasons behind such remarkable cost reductions can be summarized as follows:

- The entire development process chain, from design all the way to subsequent plant maintenance work, has been thoroughly reviewed;
- Plant efficiency has been increased mainly through technical innovations to the turbine and optimization of the steam, condensate and feedwater cycle together with the heat sink;
- Plant systems and components have been optimized;
- Common general European codes are to be applied to the conventional island together with related national codes and standards;
- Design efforts have made optimum use of specialized personnel with global turnkey know-how i.e., specialists with know-how of both conventional and nuclear island design;
- There has been only moderate price escalation in Germany and around the world over the last 10 years due to streamlining, competition and globalization of the world market.

The result of all these optimized innovations and improvements is an advanced and competitive conventional island which, at minimum, fulfills all the technical objectives of the nuclear island spelled out under Section 1 above. It is well matched to the EPR nuclear island, but also to the nuclear islands of other nuclear power plant supplier designs, as site-specific adaptations such as power range, power grid structure, cooling system, twin units, etc., can be easily implemented.

The calculated power-generation cost of the overall plant is competitive with that of fossil-fueled power plants, and the EPR is much less dependent on fuel-cycle cost fluctuations due to the lower impact of nuclear fuel on the determination of power-generation costs.

Finally, it should yet be mentioned that nuclear power plants do not generate any carbon dioxide emissions. This constitutes an important contribution towards reaching the CO_2 emissions targets set at world climate conferences. Compared with a hard-coal-fired power plant, an EPR can save some 10,000,000 tons CO_2 emissions per year.