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BWR 90 & BWR 90+ — TWO ADVANCED BWR DESIGN GENERATIONS FROM ABB

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Abstract

ABB has two evolutionary advanced light water reactors available today - the BWR 90 boiling water reactor and the System 80+ pressurised water reactor. The BWR 90 is based on the design, construction, commissioning and operation of the BWR 75 plants. The operation experience of the six plants of this advanced design has been very good. The average annual energy availability is above 90%, and total power generation costs have been low. When developing the BWR 90 specific changes were introduced to a reference design, to adapt to technological progress, new safety requirements and to achieve cost savings. The thermal power rating of BWR 90 is 3800 MWth (providing a nominal 1374 MWe net), slightly higher than that of the reference plant. ABB Atom has taken advantage of margins gained using a new generation of its SVEA fuel to attain this power rating without major design modifications. The BWR 90 design was completed and offered to the TVO utility in Finland in 1991, as one of the contenders for the fifth Finnish nuclear power plant project. Hence, the design is available today for deployment in new plant projects. Utility views were incorporated through co-operation with the Finnish utility TVO, owner and operator of the two Olkiluoto plants of BWR 75 design. A review against the European Utility Requirement (EUR) set of requirements has been performed, since the design, in 1997, was selected by the EUR Steering Committee to be the first BWR to be evaluated against the EUR documents. The review work was completed in 1998. It will be the subject of an *"EUR Volume 3 Subset for BWR 90"* document. ABB is continuing its BWR development work with an "evolutionary" design called BWR 90+, which aims at developing the BWR as a competitive option for the anticipated revival of the market for new nuclear plants beyond the turn of the century, as well as feeding ideas and inputs to the continuous modernisation efforts at operating plants. The development is performed by ABB Atom together with TVO. Swedish BWR operators have also joined the project.

1. INTRODUCTION

Today, ABB has a modern BWR design, the BWR 90, that has already been offered commercially. This design was selected by the European Utility Requirements (EUR) group to be reviewed for compliance with its set of requirements. ABB is continuing its BWR development work, however, with focus on the 21st century, on a new design called BWR 90+ that offers reduced costs and significant safety improvements. The work aims at providing an economical alternative based on evolutionary development of the earlier advanced BWR design. The design goal is a 1500 MWe plant that can be built in less than 1500 days.

A second purpose of the development activities is to provide input to improvements and modernisation of earlier generations of nuclear power plants.

2. DEVELOPMENT BASED ON SUCCESSFUL OPERATION EXPERIENCE

ABB Atom has a long tradition of plant and system development activities related to nuclear power plants. Its first BWR unit, Oskarshamn 1 nuclear power plant in Sweden was taken into operation in 1972, - developed and built without reliance on licenses. This design incorporated a number of advanced features such as a pre-stressed concrete containment, fine-motion control rods and a passive isolation condenser. Subsequent plants were designed much along the same lines as Oskarshamn 1, with step-wise improvements.

A major step forward came with the advanced BWR 75 design, which is characterised by use of internal recirculation pumps, fine-motion control rod drives, four independent and physically separated trains of engineered safety systems, and a pre-stressed slip-formed containment. Six nuclear power plants of this design are in operation in Sweden and Finland. The accumulated successful operation experience of these plants amounts to almost 100 reactor-years, and demonstrates the capability of being operated at high energy

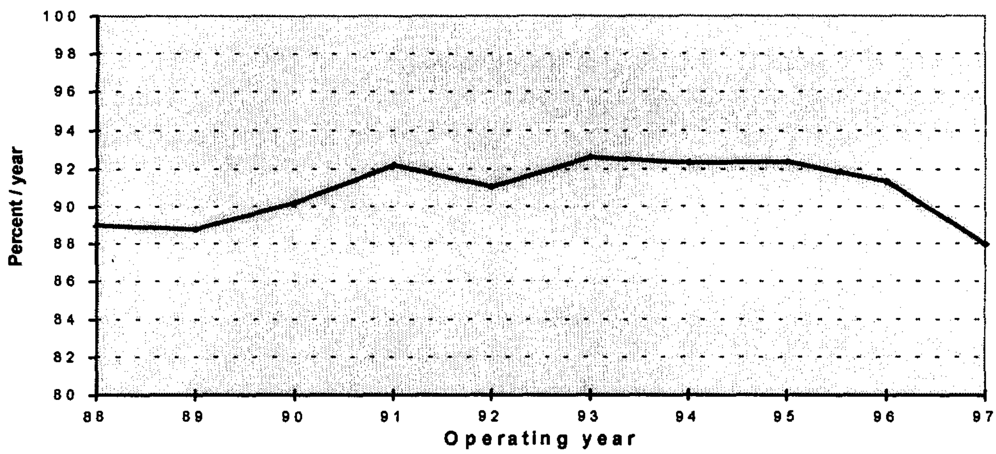

FIG. 1. Annual energy availability factors for the BWR 75 plants.

availability factors (figure 1). The total electricity generation costs have been low, as demonstrated by the published production costs for the Forsmark 1, 2, and 3 plants during the last decade (figure 2).

3. THE BWR 90 DESIGN FOR THE 1990s

The most recent BWR design of ABB, the BWR 90, was offered commercially to Finland in 1991, as one of the contenders for the fifth nuclear power plant project in Finland.

The BWR 90 design is based on the experience from design, construction, commissioning and operation of the BWR 75 plants in Finland and Sweden. Specific changes were introduced to an established reference design, that of the Forsmark 3 and Oskarshamn 3 units. Modifications were made to adapt to technological progress, new safety requirements and to achieve cost savings. An efficient feedback of operation experience was provided by a co-operation with the Finnish utility Teollisuuden Voima Oy (TVO) that operates the Olkiluoto 1 and 2 plants of BWR 75 design in Finland. The operating experience of these units has been very satisfactory; e.g., the average capacity factor over the last ten years is 93,2 %.

The design is characterised by the use of internal recirculation pumps, fine-motion control rod drives, and comprehensive physical separation of the four-train safety systems, basically in the same way as in its predecessor, the BWR 75. The thermal power rating of the base version is 3,800 MWth, somewhat higher than that of the reference plant, supplemented by a smaller unit of 3,300 MWth. The BWR 90 takes advantage of

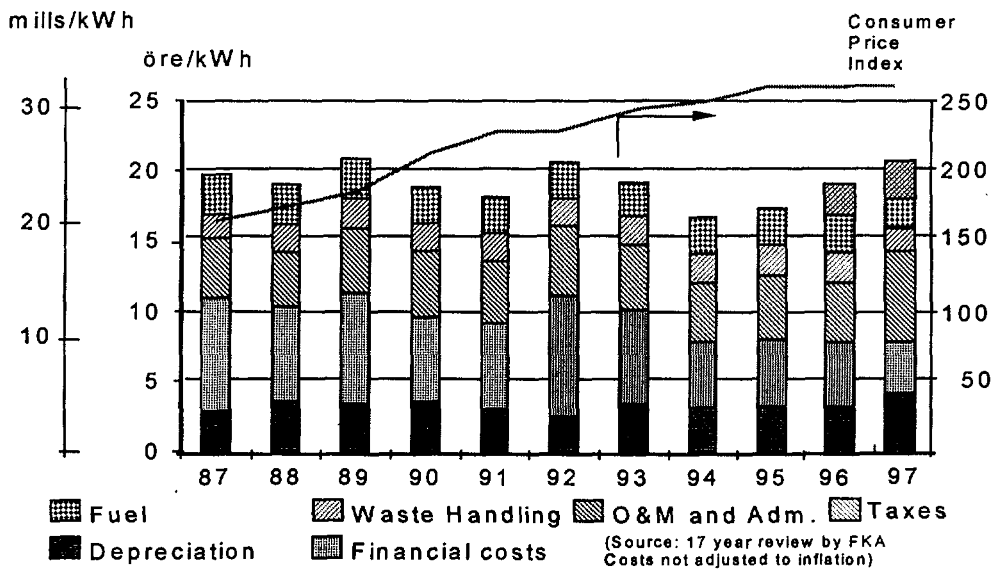

FIG. 2. Generation costs for the three BWR 75s at Forsmark.

margins gained by BWR fuel development results, e.g., the introduction of a fuel with four sub-assemblies of 5x5 fuel rod array, offering increased heat transfer capability and thereby permitting power increase.

In 1997, the Steering Committee of the European Utility Requirements (EUR) group, selected the BWR 90 design to be the first BWR design to be evaluated and reviewed for compliance with the EUR document. This work that is scheduled for completion by the end of 1998, has comprised a detailed assessment against the overall requirements - in Volumes 1 and 2 of the EUR document. The results will be incorporated into a "Volume 3 Subset for the BWR 90 design" document. As a matter of fact, the effort also serves to demonstrate the general applicability of the EUR document to BWR designs. The review has shown that BWR 90 meets most of the requirements; deviations mainly refer to technical details.

4. SOME BWR 90 HIGHLIGHTS

A main emphasis in the development work has been to maintain "proven design" features, unless changes would yield improvements and simplifications. In line with this philosophy, the reactor design has changed very little.

The core design is closely the same as in previous ABB BWRs. Advanced utilisation of burnable absorber material (Gd_2O_3) in the fuel made it possible to achieve good axial and radial power distribution with low peaking factors. The SVEA-100 fuel with its thinner fuel rods yielded an increased heat transfer surface and improved operating margins. For the BWR 90, the improved power peaking factors and the increased margins were taken into account to raise the power level of the reactor.

In other respects, the core design and arrangement are not changed. The control rod and control rod drives are of the well-proven ABB design with a grey-tipped solid steel blade cruciform rod; the neutron-absorbing material is filled into horizontal bores - boron carbide along the blade length and hafnium at the blade tip.

The steam separator units have been improved - and the steam dryers as well - in order to ensure low moisture content in the steam at the increased power output; the basic arrangement is just the same as in previous plants.

The reactor pressure vessel has been modified slightly. The cylindrical portion is made up of cylindrical forgings in the same way as in the Forsmark 3 and Oskarshamn 3 plants; this eliminates the longitudinal welds. The bottom portion is redesigned in such a way that large sections can be made by forging; the number of welds is reduced significantly. This reduction in number of welds is important for the plant operation since it reduces the amount of in-service inspection to be carried out during the refuelling outage.

4.1 Reactor coolant system

The recirculation system is based on the use of internal glandless pumps driven by wet asynchronous motors, supplied with "variable frequency & variable voltage" power from individual frequency converters. This type of pump has been operating reliably in ABB BWR plants (for more than four million operating hours) since 1978. The internal pumps provide means for rapid and accurate power control and are advantageous for load following purposes; such internal pumps are now employed also by other BWR vendors, in the ABWR plants.

4.2 Safety systems

The engineered safety systems in BWR 90 are characterised by a consistent division into four redundant and physically separated subsystems. This concept was introduced in Olkiluoto 1 and 2 and further developed in Forsmark 3 and Oskarshamn 3, and has been reconfirmed as an optimal arrangement with respect to safety, layout and maintainability. For the emergency cooling systems, this implies that each of the four subsystems is located in its own bay, adjacent to the reactor containment and surrounded by thick concrete walls. The physical separation is maintained all the way to the ultimate heat sink. The individual compartments for safety-related subsystems and components constitute separate fire areas and fire cells.

The safety-related auxiliary electrical power supply equipment is in the same way divided into four independent and physically separated parts, and the reactor protection system operates on a 2-out-of-4 logic for signal transmission and actuation.

The four safety-related, standby power diesel generators with their auxiliary equipment are installed in two diesel buildings. They are located at opposite sides of the reactor building, which provides a high degree of physical protection. The diesel buildings house also pumps and heat exchangers for safety-related cooling systems, as well as safety-related auxiliary power supply and control equipment.

The capacities of the emergency core cooling systems suffice to provide water under all postulated pipe break conditions without any uncovery of the fuel. This statement is also valid assuming that only two of the four redundant subsystems are operable; the postulated loss-of-coolant conditions include a hypothetical 80 cm^2 leak at the bottom of the reactor vessel. In this context, it can be noted that the capacity of the low-pressure coolant injection pumps has been reduced for BWR 90, following comprehensive core cooling analyses. As a secondary effect, it has been possible to simplify the auxiliary power supply systems.

BWR 90 predominantly relies on active systems and components to realise safety functions; diversity is mainly found in the use of different process parameters and backup systems. Examples are the scram backup circuit of the reactor protection system, the use of diverse types of pilot valves for the pressure relief, and the filtered containment venting system for residual heat removal.

Another feature along this line is the traditional ABB BWR control rod drives system that incorporates diversified means of control rod actuation and insertion, by hydraulic pressure and by electrical motor. Together with a generous reactor pressure relief capacity, and combined with a capability of rapid recirculation flow rate reduction (by pump runback), it provides an efficient ATWS (Anticipated Transient Without Scram) countermeasure.

4.3 Reactor auxiliary systems

The main development objective related to the reactor auxiliary systems was to evaluate possible simplification of their design in order to achieve cost reductions and more straight-forward operation. An example on this approach is given by the reactor water cleanup system (RWCU). In previous plants, a portion of the full-power reactor coolant flow rate was continuously passed through the RWCU filters, and a forced flow mode (at a doubled flow rate) was initiated when needed. In the BWR 90, the RWCU operation is controlled by the reactor water chemistry conditions; during normal full power operation cleanup need is limited, and only a small flow of reactor water is passed through the RWCU. However, when measurements show a need, the RWCU is taken into operation at full capacity. This reduces heat losses, and therefore yields "cost reductions".

4.4 Containment and auxiliary buildings

The plant and buildings of the BWR 90 are laid out and designed to satisfy aspects of safety, maintenance and communication in a balanced way. The layout is strongly influenced by safety requirements, in particular the physical separation of safety-related equipment.

The general arrangement of the buildings (cf. Figure 3) is characterised by a division into a nuclear, safety-related part of the plant, containing the reactor building, the diesel buildings and the control building, and a more "conventional" part that is "separated" from the former by a wide communication area. The "conventional" part contains the turbo-generator and auxiliary systems of the plant. This arrangement is advantageous when building the plant as well as during plant operation, since the conventional part does not interfere with the nuclear part.

Compared with previous plants, building volumes have been substantially reduced, yielding a significant cost reduction. Nevertheless, BWR 90, like previous plants, is characterised by a fairly spacious layout. This facilitates access to components and is a key to low occupational exposure.

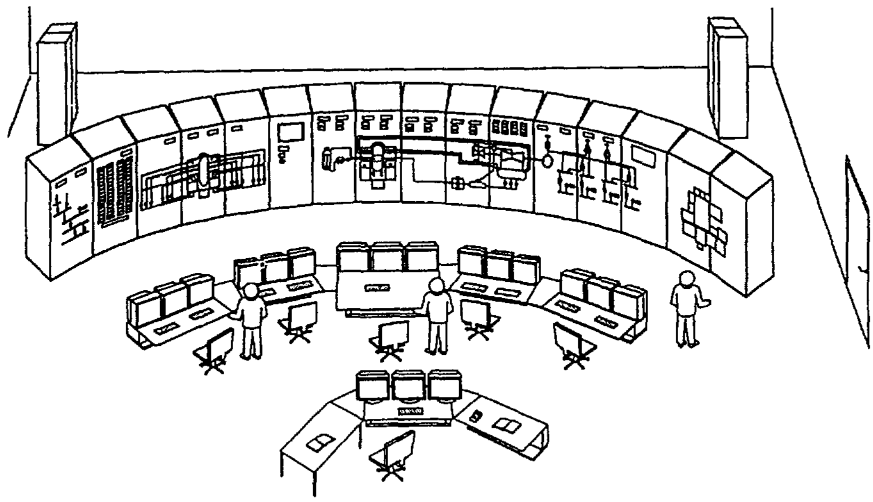

FIG. 4. BWR 90 Control Room Arrangement.

The BWR 90 pressure-suppression containment consists of a cylindrical pre-stressed concrete structure with an embedded steel liner - as in all previous ABB BWR plants. The containment vessel, including the pressure-suppression system and other internal structural parts as well as the pools above the containment, forms a monolithic unit and is statically free from the surrounding reactor building.

At the time of the design review, regulatory developments indicated a need to strengthen the capability of the reactor containment to withstand the effects of a core melt accident. Today, such requirements are codified in several countries, e.g., Finland and Sweden. The essential features of the BWR 90 containment to achieve enhanced environmental safety including protection during a degraded core accident, are:

- The blow-down of steam to the suppression pool passes through vertical concrete pathways to horizontal openings between drywell and wetwell.
- The relief pipes from the safety/relief valves are drawn into the suppression pool via the lower drywell rather than penetrating the drywell-wetwell intermediate floor.
- A pool is provided at the bottom section of the lower drywell for the purpose of collecting and confining fuel melt debris. The pool is permanently filled with water to enhance passive safety.

In addition, the containment vessel can be vented to the stack through a filter system, installed in the reactor building, similar to the filtered venting systems installed at all nuclear power plants in Sweden. These arrangements improve the reliability of the pressure-suppression system and reduce the probability of containment leakage during a severe accident.

4.5 Electrical distribution and support systems

The electrical power systems for safety-related objects are strictly divided into four separated subdivisions - a principle that is implemented in the operating BWR 75 plants and maintained in the BWR 90.

For the ordinary power distribution, some simplifications have been introduced. In previous plant designs, voltage stability considerations, limiting the ratio between direct-starting motor loads and available short circuit power on each busbar, represented a design constraint. In the BWR 90, the ratings of some of the major plant loads have been reduced by design changes in process systems. The condensate and main feedwater pumps in the turbine plant have been provided with static power supply converters, which result in reduced inrush currents during pump startups, i.e., the requirements on available short circuit power on the busbar system are significantly reduced. Switchgear components, with higher short circuit ratings, are also now available, and consequently a significant simplification of the structure of the auxiliary power supply systems has been made possible.

Another visible feature is that the number of distribution voltage levels have been reduced. As an example, it can be noted that DC distributions at several voltage levels for power supply to control equipment has been replaced by power supply from the battery-backed AC distribution, using distributed AC/DC converters for the supply to the various types of equipment, when needed. These simplifications of the electric power systems will of course also have a significant influence on the amount of maintenance work; a substantial reduction is anticipated.

4.6 Instrumentation and control systems.

A key to modern process control and communication applied to the BWR 90 is the use of control and instrumentation systems based on micro-computers. Process communication with the control room is realised by means of distributed functional processors. These in turn interact via serial communication links with a number of object-oriented process interface units. Thus, the protection and control system configuration is characterised by decentralisation and the use of object-oriented intelligence. The arrangement satisfies the requirements of redundancy and physical separation. It includes intelligent self-monitoring of protective circuits.

The use of serial communication links guarantees interference-free performance and reduces cabling. Standardisation of the object-oriented circuits minimises maintenance and the necessary stock of spare parts. The arrangement will also tend to improve availability, since components can be replaced quickly and simply. An important aspect is that the software is also standardised to simple program functions. This makes it easy even for non-computer specialists to handle the systems, and it facilitates implementation of new micro-computer generations.

Video display units (VDUs), keyboards, and display maps are used consistently to facilitate the man-machine communication in the control room. The main control room (cf. Figure 4) contains several work positions, each equipped with three VDUs. Typically, one VDU will display a total view of the process in interest, another will provide a list of alarms, and a third VDU will display a diagram with sufficient detail to facilitate operator action. This arrangement is supplemented with a special overview panel, visible to all operators in the control room. The overview shows the main process in the form of a flow diagram and indicates the status (normal, disturbed or failed) of various plant functions by conventional instruments and computer-based displays.

The main computer has the task of collecting information from the process control systems, and it communicates with the distributed micro-computers via serial links. The main computer compiles information and generates reports, such as daily/weekly operation reports, reports of periodic testing, actual status reports, and disturbance reports. During normal plant operation, the main computer will present occurrences on a special VDU display located between the "overview" panel for the plant and that for the safety systems and functions.

Further information on the BWR 90 design is found in the IAEA Status report on Advanced Light Water Reactor Designs, IAEA-TECDOC-968 [6].

5. THE BWR 90+ DESIGN

ABB is continuing its BWR development with work on a new advanced design, the BWR 90+. The aim of the continued programme is to maintain and develop the BWR as a competitive option for a reviving market, primarily in Europe, beyond the turn of the century, as well as feeding ideas and inputs to the continuous modernisation efforts at operating plants. In essence, the programme is firmly based on evolutionary development of the company's previous, advanced BWR designs.

The main objectives of the project focus on anticipated utility needs in the 21st century; the new design should offer reliable power generation at reduced construction and operation costs and incorporate significant safety improvements. The on-going review of the BWR 90 against the EUR is of importance for the BWR 90+ development work, and observed findings are specifically addressed in the design.

The development work is conducted in co-operation with TVO, which feeds adequate operation experiences into the project and performs analyses of different design alternatives regarding safety aspects, including mitigation of severe accidents. Swedish BWR operators have also recently joined the project with focus on getting ideas and inputs for modernisation and improvement works at their existing nuclear power plants.

TVO started a large modernisation programme for its Olkiluoto plants in 1994, including safety improvements and power upratings. The involvement in the present BWR 90+ development work is part of the utility's long-term strategy. They consider it necessary to keep informed about development trends, and to be prepared for construction of a new unit by the turn of the century, to be able to meet the increased demand for electricity generating capacity in Finland. TVO has also initiated an environmental study for a new nuclear power plant unit at the Olkiluoto site.

5.1 Design and performance goals

Economic competitivity is of paramount importance for a new nuclear power plant design. The BWR 90+ design work aims at developing a plant with: - reduced investment cost, - short construction time, - high energy availability, - short refuelling outages, - low operation and maintenance costs, - low fuel cycle cost, as well as - low waste management and decommissioning costs.

With respect to flexibility and reliability the governing design guideline is: "Proven system design and components are to be adopted to ensure reliable electricity production, and moderate development steps are introduced only when bringing improvements." As a result, most of the fundamental design features from the previous designs with respect to the energy production capability and reliability will be incorporated also in the BWR 90+ design.

Some specific design and performance goals of the BWR 90+ development project are:

(a) Plant nominal power output; 1500 MWe
(b) Construction time; less than 1500 days
(c) Energy availability; higher than 90 %
(d) Refuelling outage; 15-20 days/year.

An increased plant size will generally yield a reduction in the cost per unit of produced energy. Therefore, the plant size has been increased from 1350 MWe for the BWR 90 design to 1500 MWe for the BWR 90+ design. Results from the fuel development, e.g. the SVEA Optima, are fully incorporated in the design.

Interest during construction represents a large portion of the cost for a new nuclear power plant, and a shortened construction time will thus be cost effective. In earlier projects, ABB used a number of methods to reduce construction times. As an example, in the Oskarshamn 3 project the containment liner with associated reinforcement arrangement was built as a very large module in parallel with the erection of the basement structure. The module was then slid into the basement and placed in the correct position.

The BWR 90+ containment design and the reactor service room layout allow extensive use of slipforming and modular construction methods. The reactor building and the auxiliary buildings will be built with an extensive use of prefabrication. The use of new construction methods has been considered in the layout. As a result, the construction time, from pouring of first concrete to start demonstration run, has been estimated to be less than 1500 days.

A high energy availability will contribute significantly to a low energy production cost. The BWR 90+ design incorporates the important design features from the BWR 75 plants that have demonstrated an excellent operating record; over the last decade, corresponding to 60 reactor-years of operation, they have reached an average annual energy availability above 90 %. Therefore, the BWR 90+ plant is expected to attain similar results, and meet the EUR requirement of 87 % over 40 years of operation. Besides, an efficient feedback of operating experience from TVO, and the Swedish utilities, should bring improvements regarding operation and maintenance aspects.

TVO has demonstrated the feasibility of very short refuelling outages, down to ten days, in the 710 MWe Olkiluoto 1 and 2 nuclear power plants. For the larger 1500 MWe BWR 90+ design, refuelling outages in the order of 15-20 days are seen as a realistic target.

5.2 New evolution and safety requirements

The BWR 90+ design builds firmly on proven design, but considers and adopts new developments including new technology, digitised control equipment, and passive features and functions, as well as features that yield improved severe accident mitigation. The design principles are based on generally established international codes and standards. In addition, specific attention is paid to the requirements of STUK, the regulatory body of Finland. The EUR documents and the EPRI URD[1] are also considered.

The safety requirements applied in the design lead to use of redundancy and diversification in addition to physical separation to ensure independence. The diversification includes use of passive systems. The design follows the "defence-in-depth" principles, aiming at ensuring:

(1) low frequency of disturbances;
(2) that disturbances are controlled and do not develop into more severe events;
(3) that accidents are mitigated and do not develop into a core melt accident; and
(4) that the effects on the surroundings of a core melt accident remain acceptable.

The most recent edition of the STUK guides[2] addresses the need for a very high safety level and calls for improved severe accident mitigation, and limited accident consequences. Some examples are:

(a) The plant shall be designed so that no release of radioactivity will occur during the first period after a severe accident, even if all easily oxidising materials in the reactor core react with water.
(b) The design should include a containment venting system, but containment venting shall not be the primary way to reduce a containment overpressure in a severe accident situation.
(c) The relief valves shall be activated only temporarily (for brief discharges) during an anticipated transient to control the reactor pressure.
(d) The plant shall be designed to prevent release of radioactive matter in case of a possible accident, including a LOCA, during shutdown conditions, e.g., resulting from human errors during refuelling.
(e) Provisions shall be made to ensure decay heat removal in the event of loss of the ultimate heat sink normally used.

In order to meet these demands, a number of changes are introduced in the BWR 90+ design, compared with previous designs, including an improved containment design, introduction of passive systems and ECCS modifications. Design measures to cope with a "degraded core" accident have been incorporated in the containment design by provision of a core catcher arrangement and filtered venting for the containment.

The systematic division of the engineered safety systems into four independent and physically separated sub-systems (trains) in the predecessor yields benefits with respect to both safety and maintenance. Two-out-of-four trains provide the safety function that is required, and therefore maintenance may be performed during operation of the plant.

The control and instrumentation systems will be based on digital programmable equipment – with a computer-based control room, where the man-machine communication builds on video display units, keyboards and large display overviews.

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[1] EPRI URD – Utility Requirements Document of Electric Power Research Institute, USA.

[2] Guide YVL 1.0 – Safety Criteria for Design of Nuclear Power Plants.

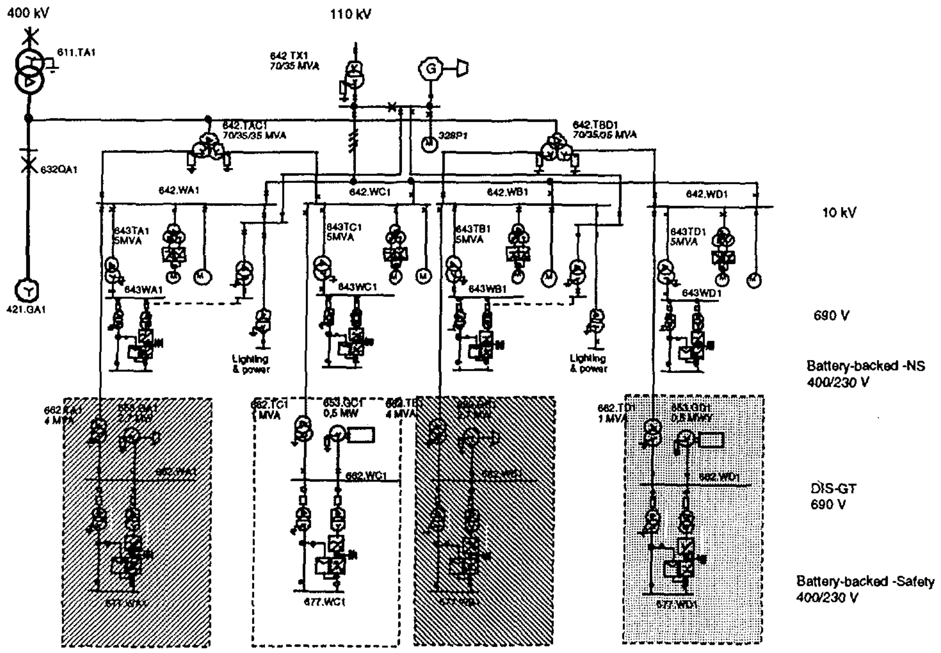

FIG. 5 BWR 90+ - Single line diagram

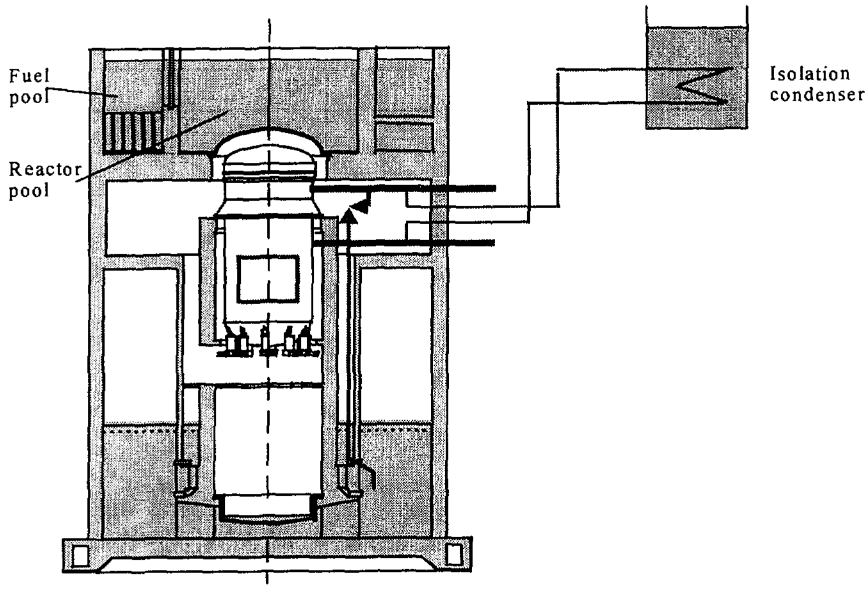

FIG. 6. Primary containment arrangement

The emergency power supply system (cf. Figure 5) is diversified by use of diesel generators and gas turbine driven generators. The number of distribution voltage levels has been reduced. All distributions are by AC, and local AC/DC converters are used where needed. The simplifications introduced will reduce maintenance work considerably and less space and cables are needed.

5.3 Improved containment design

The primary containment (cf. Figure 6) is characterised by robust design principles. During normal operation, the containment is inerted by nitrogen gas, thereby eliminating the risk of fires during operation and the risk for hydrogen explosions in case of postulated core melt accidents.

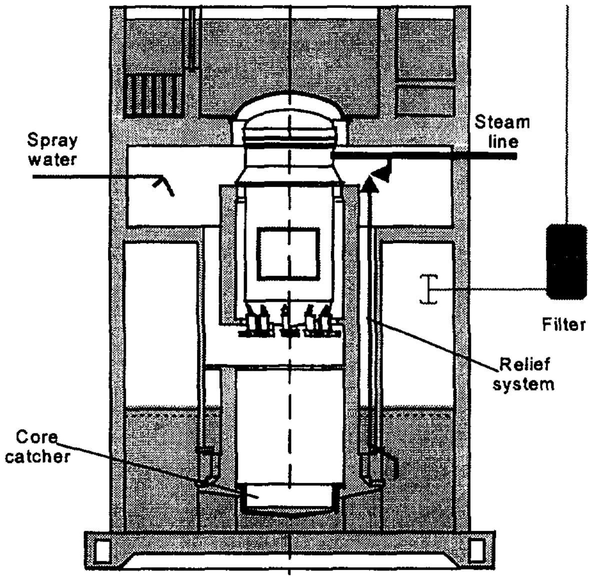

FIG. 7. Severe accident mitigation features.

TABLE 1. VOLUME COMPARISONS WITH PREVIOUS PLANT DESIGNS

	Power MW_{th}	Wetwell water volume m^3	Ratio DW/WW
BWR 90+	4250	6660	1,02
OL1/OL2	2500	2700	1,5
BWR 90	3800	3310	2,2
F3/O3	3300	3310	2,06

Except for vacuum breakers, all pipe connections between the drywell and wetwell have been eliminated. The number and size of the vacuum breakers have been reduced. The wetwell, including the partitioning floor, is provided with a leak-tight liner in stainless steel. This design minimises the potential for drywell - wetwell bypasses.

A dry core catcher (cf. Figure 7) is arranged beneath the reactor pressure vessel; its steel structure is submerged into the containment pool. In case of a severe accident, involving core melt and penetration of the reactor pressure vessel, the molten core will be collected in the core catcher, which will be cooled by the surrounding water. The containment structure is protected against the direct impacts of the molten material and does not serve as the primary barrier for a core melt. The containment proper will serve as an inherently passive system ensuring that no releases of radioactivity to the environment will occur during the first period after a severe accident with a molten core. The improved design implies a reduced risk for steam explosions, and a released molten core will be cooled in a passive way by the containment pool water. In addition, the core catcher arrangement eliminates the potential for major core-concrete interaction.

The wetwell gas compression chamber volume and the pool water volume have been increased compared with previous designs, as shown in Table 1. The improved design will accommodate the pressure build-up that may occur from hydrogen generation from all zirconium in the core for one day without activation of the cooling, overpressure protection, and support systems. Activation of active cooling systems, as well as spraying water into the drywell, will cool the containment structure, reduce the containment pressure and, in turn, prevent releases to the surrounding. The filtered venting system can be used to reduce the containment pressure in the long term without concerns for significant off-site consequences.

In the BWR 90+ design, there are no openings or pipe and cable penetrations from the lowest part of the drywell. The top of the core is located below the level of the upper drywell (or partitioning) floor. In the hypothetical case of a LOCA induced by human errors during plant shut-down and refuelling operations, the water volume in the pools above the reactor will suffice for filling the drywell volume to above the partitioning floor, and consequently, this design implies that the core will remain flooded without human action or safety system actuation.

Nuclear power plant containment structures can be characterised as pressure vessels. Logically, and in similarity with the code requirements for pressure relief equipment on other pressure vessels, the containments of all Nordic BWRs, as well as the BWR 90+ design, are equipped with pressure relief equipment. These consist of a safety rupture disk connected to the wetwell gas atmosphere and a parallel valve that can be opened manually. The drywell atmosphere will first be filtered through the containment pool water. In the longer term, the atmosphere from the wetwell can then be released via a filtered vent system. In addition, by sprinkling water to the drywell atmosphere the pressure can be reduced, the concrete structure cooled and activity can be transferred to the containment pool.

The improved containment design – with the pools on its top - is fully adapted to construction by means of slip-forming methods; the peripheral walls of the pools are made as integral parts of the containment wall structure. Combined with an extensive use of modular building technique, this reduces the construction time and costs.

The main features of the improved containment design are:

(a) Reduced construction time and costs.
(b) Minimised probability for drywell - wetwell bypass.
(c) Core remains covered by water if loss of coolant accident occurs during refuelling.
(d) Passive core melt retention and cooling inside containment; no releases within one day in the event of a core melt accident.
(e) Containment structure is protected against core melt impact by core catcher arrangement.
(f) A dry core catcher reduces the probability for steam explosions.
(g) Core concrete interaction is negligible.
(h) Increased volumes cope with pressure build-up from hydrogen generation at core melt accident.
(i) Nitrogen gas inertion allows cooling and pressure reduction by water spraying without risk for hydrogen explosions.
(j) Ultimate overpressure protection by filtered containment venting.

5.4 Decay heat removal and safety systems

The safety system configuration in the BWR 90+ design is characterised by a mixture of diversification, redundancy and separation and the use of passive systems. The four times 50 % approach introduced in the

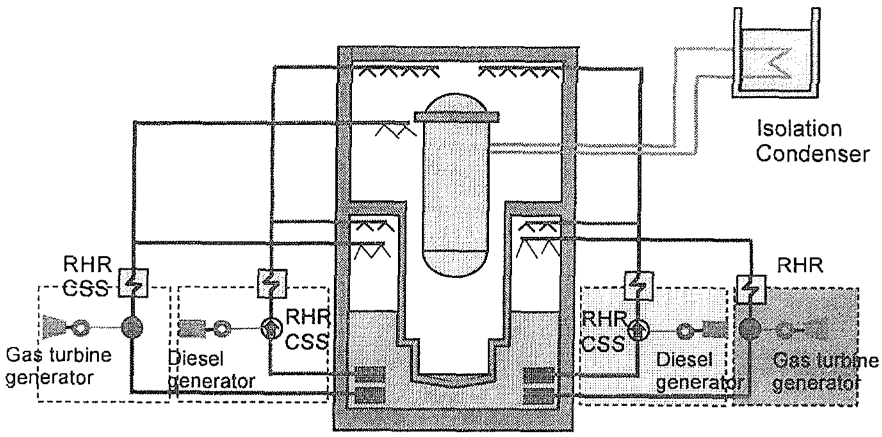

FIG. 8. Residual heat removal systems.

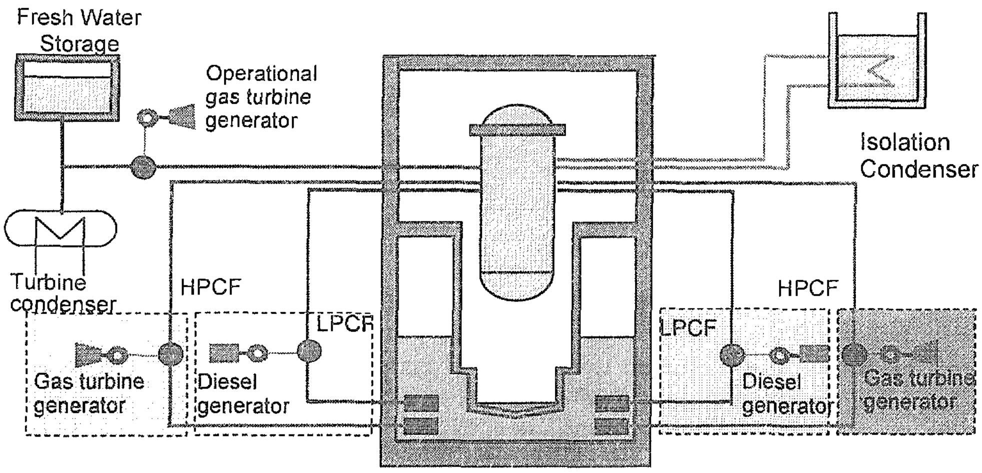

FIG. 9. Core coolant make-up systems.

Table 2. Comparison of main reactor data

		BWR 90	BWR 90+
Plant power output	MWe	1350	1500
Reactor power output	MWth	3800	4250
Cooling water temperature	°C	6	6
Number of recirculation pumps		8	12
Core coolant flow rate	kg/s	13900	17250
Fuel type		SVEA	SVEA Optima
Number of fuel assemblies		700	872
Average power per fuel assembly	MW	5,429	4,874
Volumetric power density	kW/l		54,9
Specific power density	kW/kgU_{IN}		28,5
Number of control rods		169	213
Number of scram groups		18	16
Number of safety/relief valves		18	16

BWR 75 design with independence and separation will in principle be kept. These principles have given cost savings in the field of operation and maintenance since they provide possibilities for inspection, testing and maintenance activities during normal operation. Probabilistic safety analyses, which are powerful tools for evaluating system configurations, show that the use of four identical components and subsystems has a certain disadvantage with respect to common-mode failures, however; a suitable diversification will yield favourable results with respect to the total reliability of the safety systems.

Therefore, a number of diversified components and system functions have been introduced, in line with the new safety requirements from the Finnish safety authority STUK, which demand diversity and provisions, in particular against loss of the final heat sink normally used, and that relief valves be actuated only temporarily. To this end, a passive heat removal system similar to the isolation condenser in the first ABB Atom NPP, Oskarshamn 1, will be incorporated in the design. The principles for the residual heat removal and coolant make-up systems are outlined in figures 8 and 9, respectively.

5.5 Comparison of main data

A brief summary of main reactor data for the BWR 90+ versus the BWR 90 is provided in Table 2.

6. CONCLUSIONS

ABB is convinced that there will be a reviving market for new nuclear power capacity in the near future. ABB is determined to be in a position to be able to compete for the new orders and therefore has continued its development efforts.

The BWR 90 design is available today for deployment in new plant projects and has been offered commercially. The design has, with a positive outcome, been subjected to a review by European utilities to evaluate how it compares with the requirements established by the EUR group.

The development of the BWR 90+ design is based on its 'forerunners' and can be referred to as a 'proven design', in line with power utilities' preferences. The 1500 MWe design incorporates considerations of new safety requirements, including severe accident impacts, and it will be marketed by the turn of the century.

The development work on the BWR 90+ design will also serve as input for modernisation, uprates and improvements of earlier generations of nuclear power plants.

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