# DESIGNING FOR NUCLEAR POWER PLANT MAINTAINABILITY AND OPERABILITY

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## Abstract

Experience has shown that maintenance and operability aspects must be addressed in the design work. ABB Atom has since long an ambition of achieving optimised, overall plant designs, and efficient feedback of growing operating experience has stepwise eliminated shortcomings, and yielded better and better plant operating performances. The records of the plants of the latest design versions are very good; four units in Sweden have operated at an energy availability of 90.1%, and the two Olkiluoto units in Finland at a load factor of 92.7%, over the last decade. The occupational radiation exposures have also been at a low level. The possibilities for implementing "lessons learned" in existing plants are obviously limited by practical constraints. In Finland and Sweden, significant modernisations are still underway, however, involving replacement of mechanical equipment, and upgrading and backfitting of I&C systems on a large scale, in most of the plants. The BWR 90 design focuses on meeting requirements from utilities as well as new regulatory requirements, with a particular emphasis on the consequences of severe accidents; there shall be no large releases to the environment. Other design improvements involve: all-digital I&C systems and enhanced human factors engineering to improve work environment for operators, optimisation of buildings and containment to decrease construction time and costs, and selection of materials as well as maintenance and operating procedures to reduce radiation exposures even further. The BWR 90 design was offered to Finland in the early 1990s, but development work continues. It has been selected by a number of European utilities for assessing its conformance with the European Utility Requirements (EUR), aiming at a specific EUR Volume 3 for the BWR 90. Some characteristics of the ABB BWRs, with emphasis on features of importance for achieving improved economy and enhanced safety, are described below.

## 1. INTRODUCTION

The operating records of ABB BWR plants show high plant availability and power production reliability. A prerequisite for such achievements is a good basic design of the plant; not only with respect to systems performance and component reliability, but also a design which from the beginning has taken the needs for maintenance and service into consideration. Facilitated maintenance work normally yields shortened outage time for refuelling and maintenance, and generally, an improved quality of maintenance work - with better prospects for an undisturbed period of power production to follow.

Designing for low occupational radiation exposure doses for maintenance personnel is a natural part of the "ease of maintenance" design; experience clearly shows that a low radiation exposure is important with respect to proper maintenance activities. With respect to costs, it should be born in mind that a key lesson learned from the operating history of nuclear power plants is that the total life cycle cost is a much more important economic factor than the initial investment cost.

The operating utility quite obviously has a profound influence on the performance of a specific plant with respect to availability, power production reliability, occupational radiation exposure to plant personnel, etc. since the utility is managing the maintenance work as well as the operating procedures. But even a proficient utility will have difficulties in achieving high availability and reliability figures, if the plant design does not address this aspect properly.

A suitable plant design covers many different aspects - the design of the various systems, the choice of materials and components, their installation, radiation shielding, accessibility to components, transport routes, proper routing of ventilation air, general building arrangement, etc. The end result will always represent a compromise between a number of concerns, and co-operation with and continuous feedback from the operating utilities are of paramount importance for the development of new designs.

It is difficult to discuss "suitable plant design" aspects in a general way, and therefore, the BWR 90 and its reference plant, the Oskarshamn 3 plant (of BWR 75 design) in Sweden - in operation since 1985, are utilised for examples; measures taken to facilitate easy and proper maintenance are discussed with respect to different parts and systems of these plants.

## 2. THE BWR 75 AND BWR 90 DESIGNS

The BWR 75 design which was developed in the mid 1970s, represents an overall plant design, including the turbine plant and balance-of-plant systems, based on the experience gained from the design, construction, and operation of earlier ABB Atom plants, including turn-key deliveries. The need for improvement of structures, systems and components was evaluated by a special task force, putting emphasis on both operational, safety and maintenance aspects.

The BWR 75 design effort focused on providing a plant that would provide owner a good basis for a good operating economy with low radiation exposures to the crew and maintenance personnel, as well as low releases to the environment. The objective was to comply with the most stringent safety requirements while at the same time trying to avoid the tendency of some requirements to negatively impact the plant availability. Specific design objectives included:

[1] simplicity by avoiding complicated designs of systems and components;
[2] identification and elimination of weak points;
[3] design work bearing in mind the function of the plant as a whole, based on ABB Atom experience as reactor vendor and architect engineer, as well as turn-key supplier for complete plants, and observing that the split responsibility reported in a number of plants by other vendors had, beyond doubt, been a source for many interface problems and shortcomings; and
[4] maintainability and accessibility of systems and components addressed in parallel with the systems design work - a special group is regularly assigned to this task in ABB Atom development work.

The development of the BWR 90 design [1] started in 1986 as a review of "lessons learned" from projects with the previous plant design version, the BWR 75 in Finland and Sweden; in particular, from design and commissioning of the third units at the Forsmark and Oskarshamn nuclear power stations in Sweden. The development work was conducted in co-operation with the Finnish utility TVO (Teollisuuden Voima Oy), the operator of two BWR 75 plants, ensuring an efficient feedback of operating experience.

The basic design was developed by making specific changes to the design of the reference units, Forsmark 3 and Oskarshamn 3; a main emphasis in the development work was to maintain "proven design" features, unless changes would yield improvements and simplifications. This development approach follows the traditional ABB way of cautious step-by-step improvements rather than dramatic changes. The efficiency of this process is supported by the performance records of the operating plants; the annual "energy availability" for the four BWR 75 plants in Sweden, - the Forsmark 1, 2 and 3 and the Oskarshamn 3 units, - averages 90.1% over the last decade, and the two TVO units, the Olkiluoto I and II, are among the best performing nuclear power plants in the world; last year's capacity factors were 92.5 and 95.1%, respectively, and the average over the last ten years is 92.7%. Annual occupational radiation exposure figures are also low for the six units.

The basic design has been completed, and it was offered to Finland in October 1991, as one of the contenders for the fifth Finnish nuclear power plant project. The result is a plant with reduced building volumes, shortened construction time and decreased amounts of systems and components. Measures for simplified operation, testing and maintenance have been included, and the new design thus offers lowered costs and more simple operation.

The BWR 90 design is characterised by the use of internal recirculation pumps, fine motion control rod drives, and extensive redundancy and separation of safety systems in the same way as its predecessor, the BWR 75 design. For the BWR 90, modifications were made to adapt to technological progress, new safety requirements and to achieve cost savings.

There is one easily distinguishable departure from previous designs, however; the containment arrangement. In the new design, the piping connections between the drywell and the condensation pool in the wetwell are accomplished in a quite different way, and design measures to cope with a "degraded core" accident have been incorporated (by provision of a core catcher arrangement and filtered venting for the containment), in order to ensure that public and environment will be protected even in the event of a degraded core accident situation. This way the "remaining risk" for the public is reduced to an extremely low value.

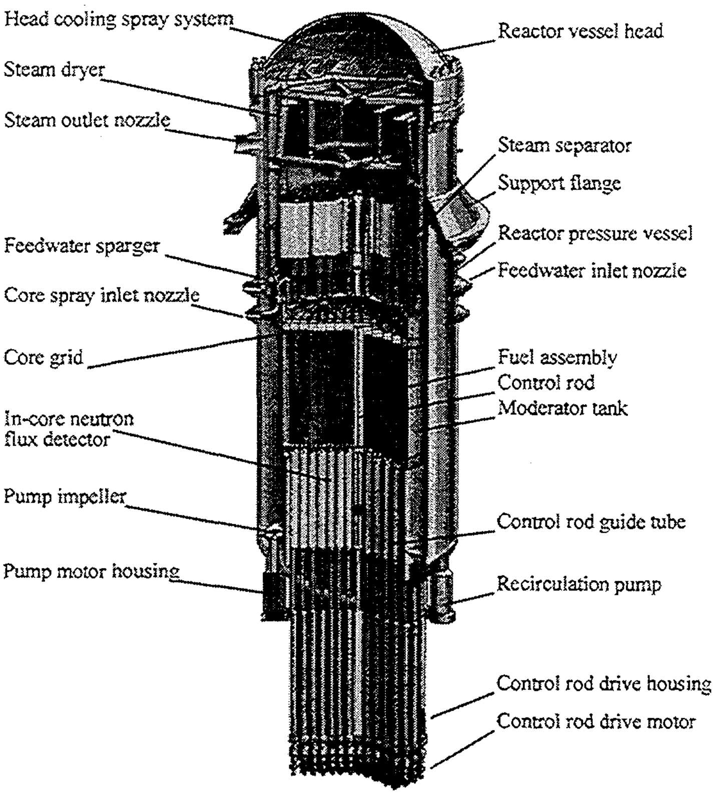


*FIG. 1. BWR 75 - Reactor pressure vessel and internals*

The thermal power rating of the base version is 3,800 $MW_{th}$, supplemented by a smaller version of 3,300 $MW_{th}$. The BWR 90 takes advantage of the margins that are gained by utilisation of a newer generation of ABB BWR fuel, which differs from earlier versions by the use of thinner fuel rods, yielding a significant increase in total fuel rod length and surface and a corresponding decrease in average heat rate and surface heat flux.

## 3. THE REACTOR PRESSURE VESSEL AND ANCILLARIES

The central - and largest - component in a BWR reactor plant is the reactor pressure vessel (cf. FIG. 1) which contains the reactor core and a number of reactor internals. In a BWR, the steam is generated inside the reactor vessel, and since the recirculation pumps are incorporated into the reactor vessel of the BWR 75 and the BWR 90, the steam supply system has become very compact.

The BWR 75 was designed for "fast refuelling"; there are no external pipe connections to the reactor vessel head and it can therefore be removed directly when the flange bolts have been loosened (by means of "multi-stud-tensioner" equipment - an equipment that can handle a number of flange bolts [and nuts] simultaneously). The hold-down force on the reactor internals is provided by a spring beam arrangement on the underside of the head. The internals are stacked onto eachother without bolt connections, and they can be lifted out directly when the vessel head has been removed.

The compression force from the spring beams is small when the reactor is cold, but when heated to operating conditions, the stainless steel internals expand more than the pressure vessel made of low alloy steel. Then the spring forces become significantly higher and a very stable aggregate has been accomplished.

These features make the core available for refuelling, rapidly and smoothly, with little radiation exposure to the personnel. It can be noted that the pool above the containment dome (cf. Fig. 2) is filled with water during normal plant operation, serving as a radiation shield for the reactor service room. It may also be noted that short refuelling outages are normal practice at the BWR 75 plants, e.g., at the Olkiluoto plants which are shut down for two weeks one year and three the next in a two-year cycle.

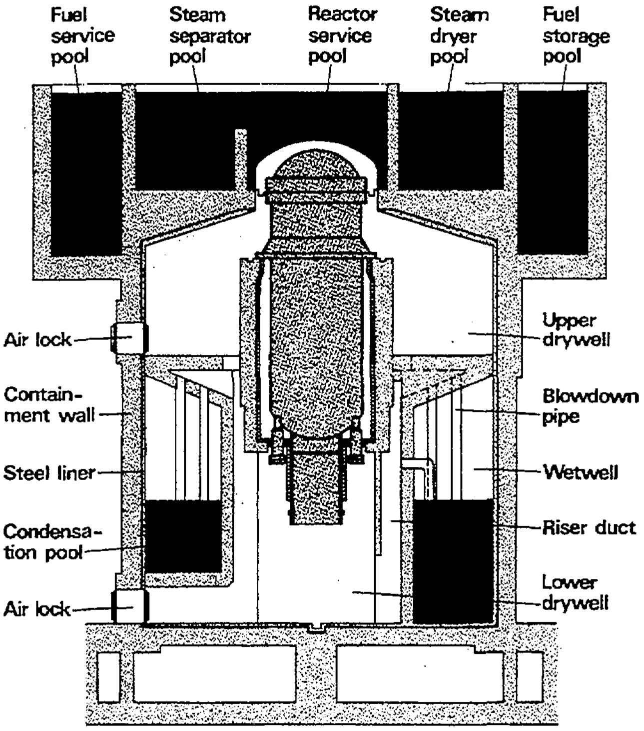


*FIG. 2. BWR 75 - Reactor containment arrangement*

The pump deck at the reactor vessel bottom and the cylindrical support of the moderator tank are welded to the vessel. All other internals, including feedwater spargers and control rod guide tubes, are easily removable. This makes the whole inside of the reactor vessel accessible for In-Service Inspection (ISI) of welds.

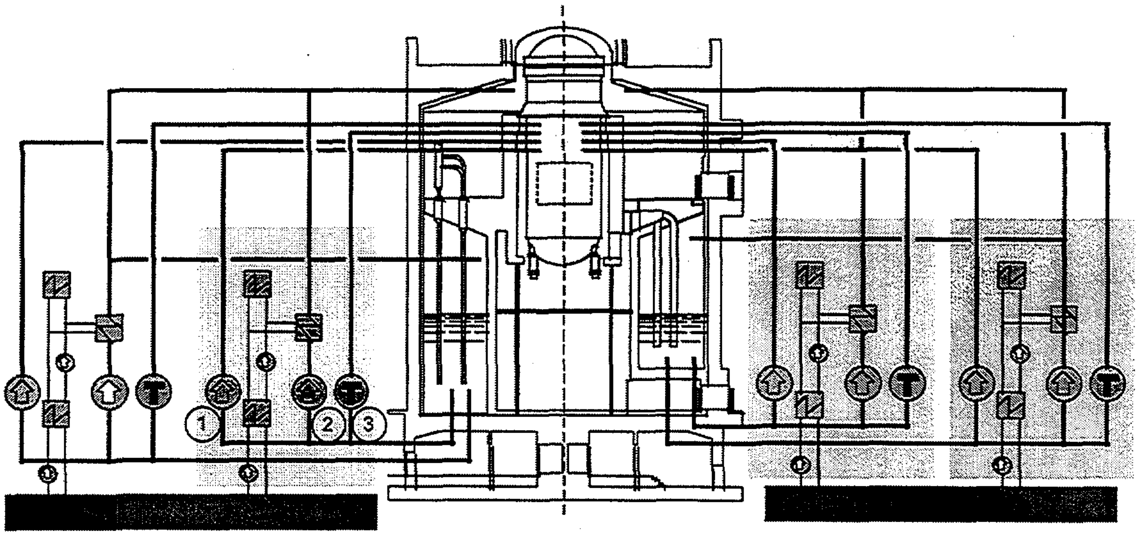
The reactor vessel bottom of the BWR 75 was modified compared with previous designs in order to reduce number of welds; in the BWR 90 the number of welds have been further reduced. This decreases the amount of ISI work that is required during a refuelling outage, i.e., it shortens the outage time with respect to inspections and reduces the associated radiation exposure.

The internal recirculation pumps have the impellers located inside the reactor vessel with the wet motors in housings on the outside, welded to the reactor vessel bottom. In order to enable dismantling the pumps have a split shaft design. The pump impeller shaft extends through the hollow motor shaft, to which it is fixed by a bolt connection at the bottom.

If a dismantling of the motor is needed, the thrust bearing of the motor unit is lowered slightly and the impeller will provide a first step seal against the reactor water. A secondary, inflatable seal is located above the motor; after activating this seal, the motor housing can be drained of water. Then the motor can be lowered by means of an hydraulic tool, and brought out to a service station outside the containment, for service. If the impeller has to be taken out for inspection, the motor housing is blinded and refilled with water. The secondary seal is depressurised, and the impeller can then be lifted upwards through the reactor downcomer by means of a tool operated from a service platform in the reactor service room.

These dismantlings can be performed without draining the reactor vessel, but it has to be depressurized. During plant operation, a purge flow of clean water is supplied to the pump shaft. The purge water flows up around the pump shaft to the reactor, preventing intrusion of reactor water and deposition of crud and other reactor impurities in the motor housing: This is an important feature for keeping the radiation exposure to the maintenance personnel low.

An important advantage of the internal pumps with wet motors is the elimination of the shaft seals; another the elimination of external recirculation loop piping. The piping calls for In-Service Inspection of welds which increases the work load close to radioactive sources and often implies extra critical path working time during maintenance periods. The radiation level at the service floor for the internal pumps has proven to be very low - about 1-2 mrem/h (10-20 μSv/h) - and the motor itself has negligible radiation level as a result of the closed motor water volume and the purge water flow. Replacement of a motor with a spare unit takes less than 24 hours and will not interfere with the critical path. The overhaul of the motor unit can be performed at a suitable time.



1: Low Pressure Coolant Injection
2: Containment Vessel Spray System
3: Auxiliary Feedwater System

*FIG. 3. Emergency core cooling systems*

The internal pumps and their static "variable frequency-variable voltage" power supplies are advantageous with respect to operability; they permit rapid load following and power changes and with a suitable overcapacity in recirculation flow rate enable improving fuel cycle costs by "spectral shift" operation towards the end of the operating cycle. The built-in overcapacity and the arrangement of the core inlet plenum serve another purpose, making it possible to continue power operation - at up to 100% power, if one of the pumps should fail; a positive feature for ensuring operability even though pumps and power supplies have proven to be very reliable.

In an ABB Atom BWR, the fine motion nut and screw control rod drives are hanging under the reactor vessel bottom. The control rod drives are, in similarity to the arrangement at the recirculation pumps, supplied with a purge flow of clean water in order to minimise contamination. When a control rod drive is to be serviced, it is disconnected and lowered down to the bottom of the lower drywell under the reactor, brought out of the containment and to a special service station. The time needed and the total dose burden for this work are so low that remotely operated or automatic tools have not been considered justified to develop.

Wet motor pumps, without shaft seals, are used also for the reactor shutdown cooling system, reducing significantly inspection and maintenance needs; on the other hand, maintenance can be carried out rapidly and efficiently, using a special servicing equipment, when maintenance is needed.

## 4. SAFETY SYSTEMS ARRANGEMENT

In the BWR 75, the 2 x 100 % safety system configuration used earlier was replaced by a 4 x 50 % arrangement; i.e., the safety systems are generally divided into four separate subsystems, each with a 50 % capacity with respect to the design basis event (cf. FIG. 3). A strict physical separation of the four subsystems of each safety system was also included in the design. In this way, an enhanced redundancy and subsystem independence were ensured. The BWR 75 concept was re-assessed during the BWR 90 design review - and compared with alternative concepts. It was concluded that the 4 x 50 % represented an optimal solution from the view point of safety, availability, maintenance and cost; hence, it was maintained also in the BWR 90 design.

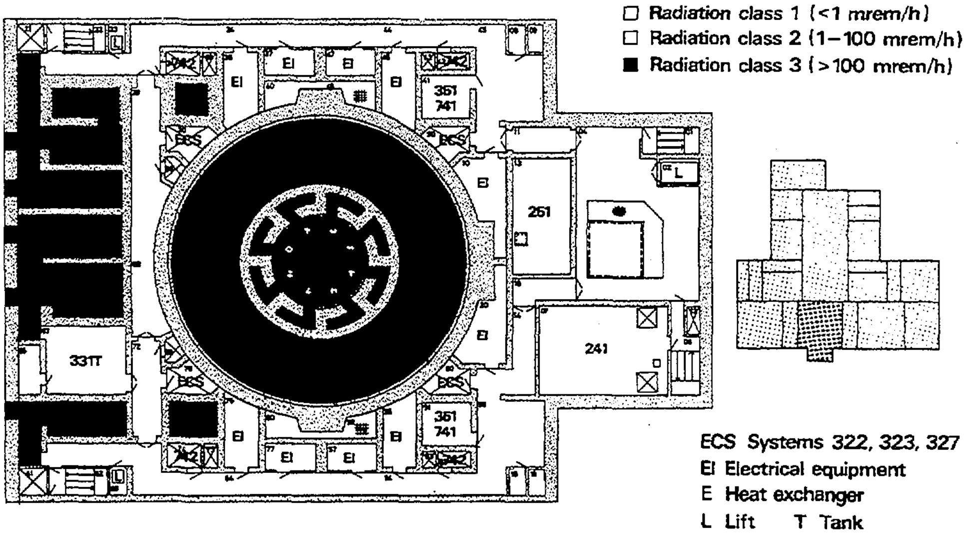


*FIG. 4. BWR 75 - Reactor building installation and radiation classification, Level +13.3m*

With respect to plant maintainability, the 4 x 50 % arrangement represents a significant improvement, since sufficient system capability/capacity will remain even if:

[1] one subsystem is taken out of service for repair or maintenance; and

[2] another subsystem fails upon request; the single failure criterion.

As a consequence, testing and preventive maintenance may be carried out during plant operation - on one subsystem at a time. This gives the plant management flexibility in planning the maintenance activities in the most efficient way; the work load during the annual refuelling and maintenance outage can be significantly reduced.

Another advantage relates to "permitted repair time". If a failure is detected in a 4 x 50 % safety system during normal plant operation, ample time is available for repair. As an example, the Technical Specifications for the Forsmark 3/ Oskarshamn 3 BWR 75 units permit a delay of up to one month for making the repair, without restrictions in plant operation. This means that the repair work can be carried out at a suitable time.

## 5. LAYOUT AND INSTALLATIONS

The requirements on physical separation of the subdivisions of safety systems have strongly affected the layout and installation of components in the plant buildings. The design goal of high maintainability and low radiation exposure has also had considerable influence.

In order to attain high maintainability the equipment has been installed in such a way that it is easily accessible for the maintenance personnel. Adequate communication routes have been provided throughout the plant - both for personnel and for transports of equipment. Space for performing hands-on operations, and for radiation shielding around components, is also important.

The accessibility to various portions of the plant is to a great extent determined by the radiation from different components, but also by the amount of airborne radioactivity. In order to reduce the direct effects of the latter the ventilation systems will supply the clean intake air to the corridors (more or less uncontrolled access areas), from which the air will flow into the rooms with radioactive components. Areas in which the dose rate level will be below 0.3 mrem/h (3 μSv/h) and where there will be no risk of radioactive contamination, are defined as uncontrolled areas, while all other areas are controlled access areas.

The communication routes throughout the plant are separated in accordance with this, all the way from the entrance building which is the only normal personnel access to the plant. The main communication area between the reactor building and the turbine building is divided into two separate transport passages on two different floor levels, one controlled and one uncontrolled. The communication routes along the turbine building and to adjacent buildings are branched off from these main communication routes.

With respect to facilitating maintenance a number of ground rules and guidelines are applied in the design work on plant layout and equipment installation ( FIG. 4). The most important of these are:

[1] Non-radioactive systems and components are separated from pipes and components containing radioactive substances, except when absolutely necessary for the function of the radioactive systems

[2] In order to reduce maintenance doses, large radioactive components like filters, heat exchangers, pumps, tanks, etc. are either located in separate rooms or separated from each other by radiation shields.

[3] Each room containing radioactive system parts should have its own entrance from a corridor or communication area, where the radiation level is low; below 1 mrem/h (10 μSv/h), i.e., to a Class 1 area.

The corridors should also be arranged so that they can be used by the maintenance workers for preparing operations in the radioactive environment and for use during short breaks or waiting periods.

[4] Each radioactive component must be easily accessible and have a suitable working space for maintenance and In-Service Inspection. The component orientation must as much as possible facilitate maintenance.
Adequate space shall be provided for necessary handling equipment, and in some cases for temporary radiation shields.

From the point of view of radiology it is sometimes beneficial to remove the component and perform maintenance or repair in a better environment, e.g., in the active workshop. Therefore, it must be possible to remove and re-install the component rapidly.

[5] Valves in rooms with high radiation levels shall be remotely operated or have spindles to more accessible areas, in order to save doses to the operational and maintenance staff. For the same reason, other controls and checks, such as instrument readings, are as much as possible located in Class 1 areas.

[6] Radioactive pipes should have as short lengths as possible and be located at a distance from other components. This is important, because in many rooms the main portion of the radiation emanates from the pipes.

Accordingly, the radioactive systems in the reactor building are concentrated to the part that is closest to the turbine building. This arrangement results in short lengths of radioactive pipes since the main communication system which runs between these buildings, includes also a culvert for active pipes.

[1] Electrical components are to the extent practically possible located in separate rooms.

An important improvement with respect to accessibility for maintenance and service was introduced in the layout of the upper drywell of the BWR 75 containment; the major portion of the components (relief valves, isolation valves, etc.) are installed at the outer wall, in such a way that a transport space is available for all components.

## 6. MATERIALS SELECTION AND WATER CHEMISTRY

Proper materials selection is a key to the successful operation of a nuclear power plant. The best material is that which will be endurable, not crack, and not corrode significantly, i.e., that will suppress the need for maintenance and/or repair.

For purposes of maintainability it is essential to avoid elements which create radiation sources. Co 60 is the dominant gammaradiation source in primary system materials, and ABB Atom therefore early prescribed low cobalt contents in materials for reactor internals - less than 0.05 % (500 ppm) in stainless steels and less than 0.1 % (1,000 ppm) in Inconel.

The typical average annual occupational radiation exposure over the last ten years for the BWR 75 plants is 0.9 manSv (90 manrem), including some repairs and adjustments beyond normal maintenance and service, i.e., a rather low level compared with the experience from many other plants throughout the world confirming that the design measures incorporated in the BWR 75 design have been beneficial. There is a trend of increasing Co 60 contributions, however, and therefore further restrictions on cobalt contents have been found motivated.

There is also a strong ambition to further reduce the annual occupational radiation exposure, down to a target value of 0.5 manSv (50 manrem) for normal operation and maintenance. This makes the cobalt reduction efforts even more important. Cobalt-based alloys are always to be avoided. and a programme for Stellite replacement is ongoing. The 0.05 % (500 ppm) restriction on cobalt content is extended to include also components made in Inconel, the steam dryers, and the stainless steel cladding on the RPV inside. This value is also applied to smaller parts inside the RPV and to the preheaters/ coolers of the feedwater system. For ferritic steels in large-bore piping (D > DN 200) and casings of valves, apparatuses, and pumps the Co limitation has been set at an even lower value, 0.03 % (300 ppm). With respect to small parts and plant parts of austenitic steel and nickel alloys outside the RPV a higher cobalt content is allowed; the limit is here set at 0.2 % (2,000 ppm).

A good water chemistry characterised by low concentrations of impurities is also essential to keep radiation exposures low. In the ABB Atom BWR the reactor water is purified in mixed-bed ion exchangers with radial flow. The normal cleanup flow rate is small and varies with the need for cleaning as determined by conductivity measurement. During plant shutdown and startup, the cleanup flow rate is normally increased to a maximum value, corresponding to 4 % of the feedwater flow rate at full reactor power. The filter system operates at 40-60 $^{o}$C.

The condensate flow from the condenser is purified in a pre-coat filter-demineralizer. This is preferable compared with the use of deep-bed ion exchangers since the main impurity in the condensate is particulate iron.

The conductivity is a good measure of water quality. In all ABB Atom BWR plants the conductivity of the reactor water is approximately 0.1 µS/cm (at 25 $^{o}$C) and about 0.06 µS/cm in the feedwater. The iron content of the water is of great importance for the radiation buildup, since the corrosion products of interest form compounds with iron oxides. In ABB Atom BWR plants the feedwater has an iron content of less than 0.5 ppb, typical of "low-radiation BWR plants".

## 7. CONTROL EQUIPMENT AND POWER SUPPLY SYSTEMS

Maintenance and operability aspects have also been taken into account in the design of the instrumentation and control and auxiliary power supply systems. I&C and power supply are integrated parts of the safety-related systems and have therefore been divided into four independent and separated parts. Literal application of the requirements on physical separation between redundant groups also in the control room may involve complications for the plant's operating personnel, and the goals of a high safety level implies risks of spurious plant trips; hence, great care must be taken to minimise the risk of unnecessary trips without jeopardising nuclear safety.

The design of the control equipment is governed by a Swedish safety requirement, in use since the early 1960s, that operator interventions shall not be needed within 30 minutes in the event of an accident with respect to ensuring nuclear safety. In addition, there are supplementary general design goals saying that a failure or malfunction of one component, or faulty calibration of a measuring channel should not cause a plant trip, and that the degree of automation for major process systems - with respect to keeping the plant in operation - should allow the operator some 10 minutes action time.

In addition to the measures intended to keep the plant in operation, there are also features aiming at reduced work load during maintenance and refuelling periods. Some specific features of the control equipment and power supply systems may illustrate these design efforts.

In the early plants, inputs to the reactor protection system (RPS) were taken from local limit switches, e.g., for temperature and pressure inside the containment. In the BWR 75, data are generated by transmitters located on instrumentation rooms outside the containment which means that less manhours are needed for work inside the containment for limit switch checking and calibration. The RPS input is generated by an electronic trip unit when the DC signal from the transmitter exceeds a set value; the calibration of the trip function is easily checked during plant operation by adding a voltage signal from a test generator and recording the trip function value.

Each of the parameters used for the RPS is supervised by four redundant measuring channels, and the process computer is routinely monitoring the proper function by comparing the signals of the four channels; a defective channel is detected rapidly and can then be disconnected and repaired at a convenient time. The RPS is built up with a "two-out-of-four" coincidence logic, and disconnecting one channel results in a transfer to "two-out-of-three" which is a fully acceptable situation from both safety and plant availability point of view. The RPS logic is built with electronic modules, without relays, which means that testing can be performed during operation, reducing the amount of work needed during the refuelling and maintenance periods.

In the BWR 90, it was decided that the control equipment for process communication, process monitoring and control, as well as for man-machine communication should largely be based on programmable equipment, including digital controllers for the major control systems. One of the advantages offered by this new control equipment is an improved communication with the operator; human factors engineering can be incorporated in the design activities. Another advantage is the possibilities for introduction of new control functions without "disturbing" the normal operation of the plant, and automatic test procedures for safety systems, etc. The new equipment is advantageous also in the longer term; when the "computers" become "obsolete" after some ten years, they can without too much impact on the plant be replaced by new generations, since most of the software can be maintained for the new equipment.

The introduction of programmable equipment is quite natural for a new plant design, but it is of interest also for operating plants; significant modernisation programmes are under way at the nuclear power plants in both Finland and Sweden. It may be noted that these programmes do not involve an "abrupt" change of all equipment on one occasion during a long plant shutdown, but are based on step-wise implementation during normal outages in accordance with a pre-determined plan - to achieve a desired final structure. The utilities note that the increased computing capacities enable more efficient and flexible operation and saves money, e.g., by reducing start-up times after outages by some hours, and the impact of the investment on the life-cycle-cost is small and may even be positive.

The division into four subsystems (mainly of the safety-related portions) means that loss of one sub-division will have only limited effects on plant operation. Maintenance work can therefore to a great extent be performed at a convenient time during normal plant operation. Examples on such maintenance work are checking and tightening bolted joints in busbar systems, checking relay protections, and testing of batteries.

With respect to the testing of batteries, it may be noted that a battery arrangement with two "50 %" halves, each provided with its own rectifier, was introduced in the Forsmark 3/Oskarshamn 3 plants. In this way, the batteries could be tested thoroughly during plant operation, including deep discharge tests, without affecting the plant operation. The only distinguishable effect is that the battery capacity, of the system and subdivision being tested, temporarily is reduced to about 50 %, from "2 hours" to "1 hour". The Forsmark 3 and Oskarshamn 3 plants have DC distributions at 110 V, 48 V and 24 V, i.e., the number of batteries and distributions is large and the above arrangement was well motivated.

In the BWR 90, there is distribution of battery-backed AC to local converters, instead of using central DC systems. The converters of the battery-backed AC system busbar systems are provided with automatic switching devices for supply from the diesel-backed AC system instead which permits testing and maintenance to be carried out also during plant operation. This simplification and the reduced number of batteries, as well as DC distributions, yield a considerable reduction in maintenance work.

## 8. OTHER SYSTEM FEATURES AND DESIGN MEASURES

The BWR 75 design includes a certain redundancy also for non-safety-related systems, but primarily not for maintainability reasons. Typical examples in the turbine plant are the condensate and feedwater pumps and the circulating water pumps, with 3x50 % or 4x33 % pumps operating together on a common piping system, and providing a functional redundancy with respect to the power operation impact of a malfunction of an active component. Similar arrangements are utilised for service systems of the reactor plant, e.g., the primary and secondary cooling water systems, but there are also cases where 2x100 % have been found most beneficial, e.g., for the shutdown cooling system of the reactor.

Anyhow, the main purpose of the functional redundancy in these systems is not to facilitate maintenance but to improve the functional reliability by making the power plant process less sensitive to component failures. The installed redundancy or over-capacity will involve an increase in the initial plant cost, but taking into account the potential gains in operational reliability, the effect on the total life-cycle cost will most likely be positive.

## 9. EUR EVALUATIONS OF THE BWR 90

Following the initiative of some of the utilities in the European Utility Requirements group, the BWR 90 has been selected to be one of the designs for which a detailed assessment against the requirements of Volumes 1 and 2 of the EUR document will be made. This activity is part of an effort to develop a Volume 3 for the EUR document with specific requirements for specific designs. The work was started up in the Spring of 1997, and is scheduled to be finished in 1998.

## 10. CONCLUSIONS

The operation experience of the BWR 75 plants has been very good. The average energy availability factor of the Swedish plants last year (refuelling outages included) was 90.1 %, including considerable load following and coast-down operation, yielding a recorded capacity factor of 85.8 %. Even more impressing are the capacity figures attained by the two units at Olkiluoto in Finland, - e.g., 92.5 % for Olkiluoto 1 and 95.1 % for Olkiluoto 2.

The high availability and capacity factors that have been attained, prove that the operability, reliability and flexibility of these plants are in the "top category" of operating plants; the Olkiluoto plants are ranked at the absolute top among the best performers of the world. At the same time, the recorded low occupational radiation exposures and the short annual refuelling outages show that the design measures that have been outlined above, have been beneficial for the plants "operability"; they have become easier to manage in an efficient way.

The BWR 90 design draws on the experience that has been gained from design, construction, commissioning and operation of BWR 75 plants. Based on this experience basis, design modifications and adjustments (or supplements) have been implemented in areas where design reviews indicated that significant improvements were within reach. In other areas, it was decided that a maintained proven design was the most appropriate and prudent approach.

The BWR 90 plant design incorporates a number of improvements with respect to operability and maintainability compared to the operating BWR 75 plants, and it has the capacity to equal and even surpass the excellent performance of the BWR 75 plants.

## REFERENCE

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