

UK ABWR

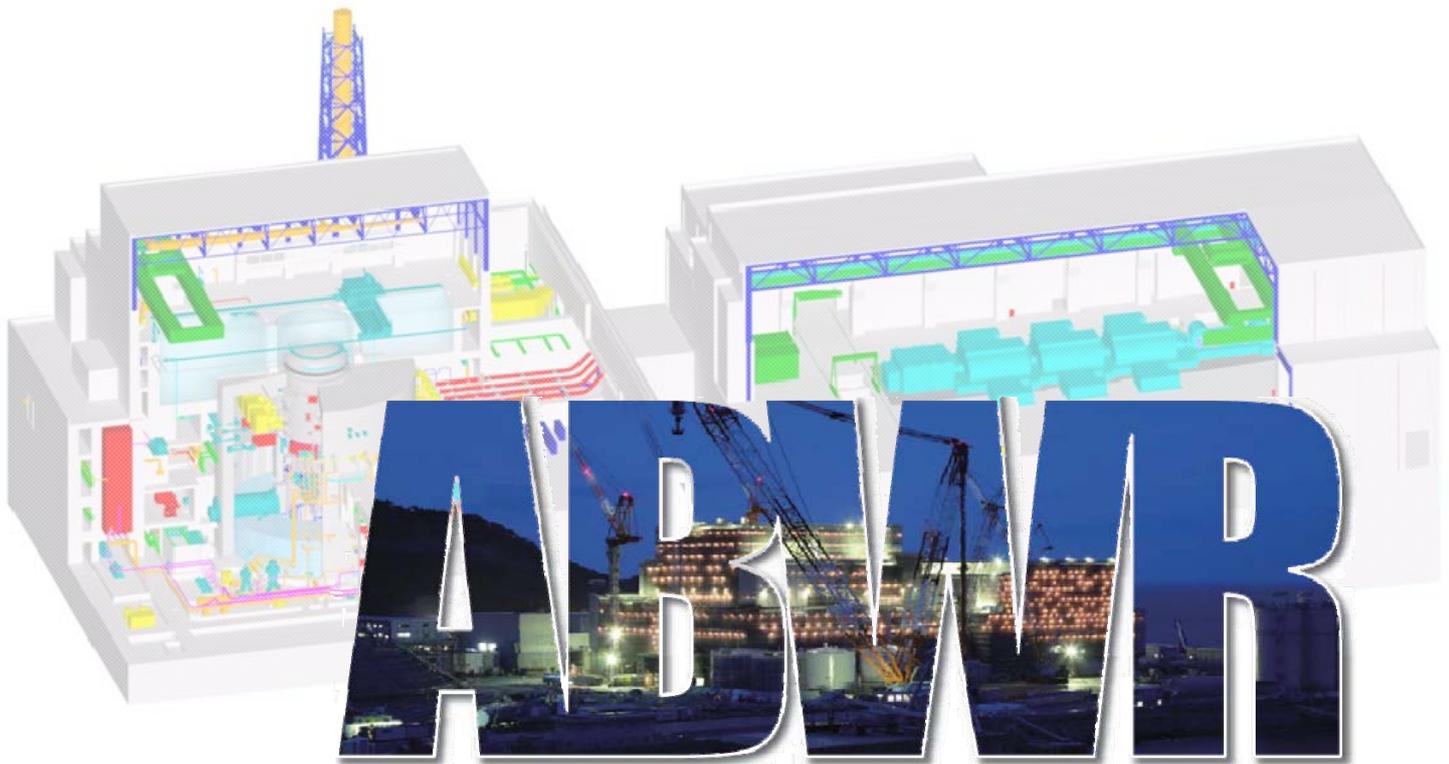
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UK ABWR Generic Design Assessment

Preliminary Safety Report on Reactor Chemistry



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1. INTRODUCTION

This document describes chemistry management in UK ABWR. Chemistry management in UK ABWR is similar to that in previous BWRs, including J ABWR. In this chapter, the purpose of chemistry management is described. Chapter 2 describes the most important chemistry control related to the primary cooling water system and other auxiliary system chemistry controls are described from chapter 3 through to chapter 6. Chapter 7 summarizes the claims for UK ABWR chemistry control.

1.1 Purpose of Chemistry Management in BWR

The purpose of chemistry management during the plant life cycle is summarized in Table 1.1. In the construction phase, chemistry management is conducted to maintain structural material integrity by reducing material corrosion and to eliminate potentially harmful chemical species during plant operation. Corrosion reduction in this phase is also important to reduce dose rate and radioactive waste after the start of operation.

In the pre-operation phase, it is also important in maintaining structural material integrity. When countermeasures to reduce Co deposition on structural material such as alkaline pre-filming are planned, pre-treatment of structural material becomes one of the purposes of chemistry control.

During normal operation, there are five main reasons for chemistry management, which are:

- to maintain fuel integrity,
- to maintain structural material integrity, to reduce dose rate,
- to minimize radioactive waste and
- to minimize radioactivity release to the environment.

Accomplishing one of the above may give rise to an adverse effect on the other, such as an increased rate of hydrogen injection which reduces stress corrosion cracking (SCC) potential but increases N-16 dose rate in the turbine system. It is crucial that chemistry management in the operational phase is optimized considering all of these aspects.

Though no criticality control is necessary during normal operation through the use of chemistry, establishment of sub-criticality becomes an important part of chemistry management in case of abnormal or accident conditions. Suppression of radioactivity release to the environment also becomes an important consideration in the case of accidents.

In the decommissioning phase, reduction of dose rate, minimization of secondary radioactive waste and minimization of radioactivity release to the environment become the main reasons for chemistry management.

In this report, chemistry management during normal operation is described and further information will be included in the PCSR later in GDA.

Table 1.1 Purpose of chemistry management in plant life cycle

Phase	Purpose of chemistry management
Construction	<ul style="list-style-type: none">• To maintain structural material integrity• Elimination of potentially harmful species for plant operation
Pre-operation	<ul style="list-style-type: none">• To maintain structural material integrity• Pre-treatment of structural material (if planned)
Normal operation	<ul style="list-style-type: none">• To maintain fuel integrity• To maintain structural material integrity• To reduce dose rate• To minimize radioactive waste• To minimize radioactivity release to the environment
Abnormal condition	<ul style="list-style-type: none">• To establish subcritical conditions• To suppress radioactivity release to the environment
Decommissioning	<ul style="list-style-type: none">• Dose rate reduction by decontamination• To minimize secondary radioactive waste• To minimize radioactivity release to the environment

2. PRIMARY COOLING WATER SYSTEM

2.1 Outline of Chemistry Control in BWR and its Evolution

This section provides an introduction to materials and reactor chemistry background for BWRs with respect to materials selection, component design and fabrication, coolant quality and control, radiation exposure, and fuel and water chemistry interactions. These aspects have broad impacts and interfaces throughout the entire plant; however, this section focuses on impacts and evolution related to piping, reactor internals, and fuel.

Some of the ABWR plant interfaces with respect to reactor chemistry are shown in Figure 2.1. The purpose of this figure is to emphasize that Reactor Chemistry interfaces with the majority of UK ABWR plant systems. Key examples of interfaces are shown on this figure – but these are not all inclusive. Multiple additional interfaces exist for instance, the Suppression Pool Cleanup System, Reactor Internal Pump (RIP) & Fine Motion Control Rod Drive mechanism (FMCRD) purge flow, NI & TI/BOP piping and heat exchangers, and so forth.

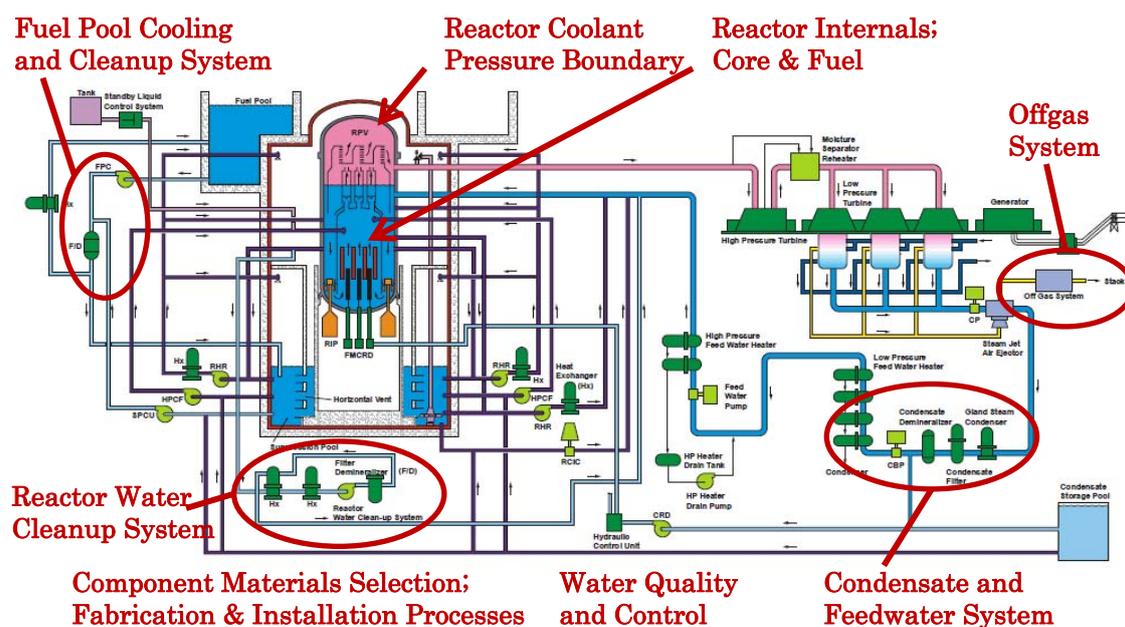


Figure 2.1 Examples of ABWR Systems Interfaces with the Discipline of Reactor Chemistry

For the early BWRs, reactor chemistry seemed straight forward enough, for example, keeping the reactor cooling water as pure as possible. BWR water chemistry specifications were primarily introduced to control conductivity and chloride levels to prevent the occurrence of transgranular stress corrosion cracking (TGSCC). This seemingly fundamental approach did not recognize some of the issues dealt with today, such as intergranular stress corrosion cracking (IGSCC), in part because early testing did not fully reveal the severity of the oxidizing nature of the BWR environment or the long incubation period for IGSCC initiation and subsequent growth in weld or furnace sensitized stainless steel. The high tensile

residual stresses that could be produced by welding and grinding which contributed to IGSCC for earlier BWRs, were not well understood either.

Since the recognition of IGSCC in BWR structural materials, a number of remedies have been qualified that address the materials, tensile stress and environmental aspects of this phenomenon. While this is not the only issue that has captured attention in the discipline of reactor chemistry, it has been one issue requiring considerable attention to address. This section, therefore, describes background and mitigation strategies to address stress corrosion cracking and dose rate reduction, before providing broader discussion on other issues such as reactor water chemistry.

2.1.1 Materials and Stress Corrosion Cracking

IGSCC and Irradiation Assisted Stress Corrosion Cracking (IASCC) are not unique to the BWR; PWRs have also needed to address SCC issues, although the mechanisms and remedies have some differences. Historically, instances of SCC occurred in the BWR as summarized in Table 2.1.

Table 2.1 Evolution of SCC in the BWR (Ref 1)

Table with 2 columns: SCC Type and Time Period. Rows include Stainless Steel Fuel Cladding IGSCC (Late '50s/Early '60s), IGSCC of Furnace Sensitized Type 304 During Operation (Late '60s), IGSCC of Welded Small Diameter Stainless Steel Piping (Mid '70s), IGSCC of Large Diameter 304 Piping (Late '70s), IGSCC of Alloy X750 Jet Pump Beam (Late '70s), IGSCC of Alloy 182/600 in Nozzles (Late '70s), Occurrence of IGSCC of BWR Internals (Late '70s), Crevice-induced Cracking of Type 304L/316L ('80s), and Localized Cold Work Initiates IGSCC in Resistant Material ('80s).

Some previous IGSCC concerns in BWRs were resolved by replacing the affected materials with more IGSCC-resistant materials or by performing repairs. However, because such repairs can be expensive, mitigation strategies were adopted to reduce the probability of SCC and escalating repair costs. One primary mitigation strategy was to focus on water chemistry practices to protect components and mitigate SCC. This grew out of an observation that oxidizing species in high purity coolant (i.e., oxygen and hydrogen peroxide), as well as anionic species that contribute to coolant conductivity, were correlated with the incidence of IGSCC cracking as well as the rate of progression of any initiated cracks.

For a new plant such as ABWR, additional options exist to improve SCC mitigation. Examples of these options include:

- Design to avoid crevices and eliminate or minimize welds (e.g., one piece forged and machined top guide, simplified core plate design)
• Selection of materials that resist IGSCC in low and high fluence (IASCC) locations (e.g., low carbon Type 316NG austenitic stainless steel, Alloy 600M with niobium stabilization)
• Improved fabrication processes (e.g., controls on welding, cold work, solution annealing)

Since the recognition of IGSCC in BWR structural materials, a number of remedies have been qualified

that address the three key contributing aspects of this phenomena: materials (selection and fabrication processes), tensile stress and environmental factors. Examples of this multi-faceted technology approach to SCC are provided in Figure 2.2. Figure 2.3 shows the time frame for the evolution of mitigating strategies in the three aspects described above. Environmental mitigation such as Hydrogen Water Chemistry (HWC) or HWC + Noble Metal Chemical Addition (NMCA) are effective in suppressing the crack growth rate. Mitigation of crack initiation is achieved by material and manufacturing process improvement and stress improvement.

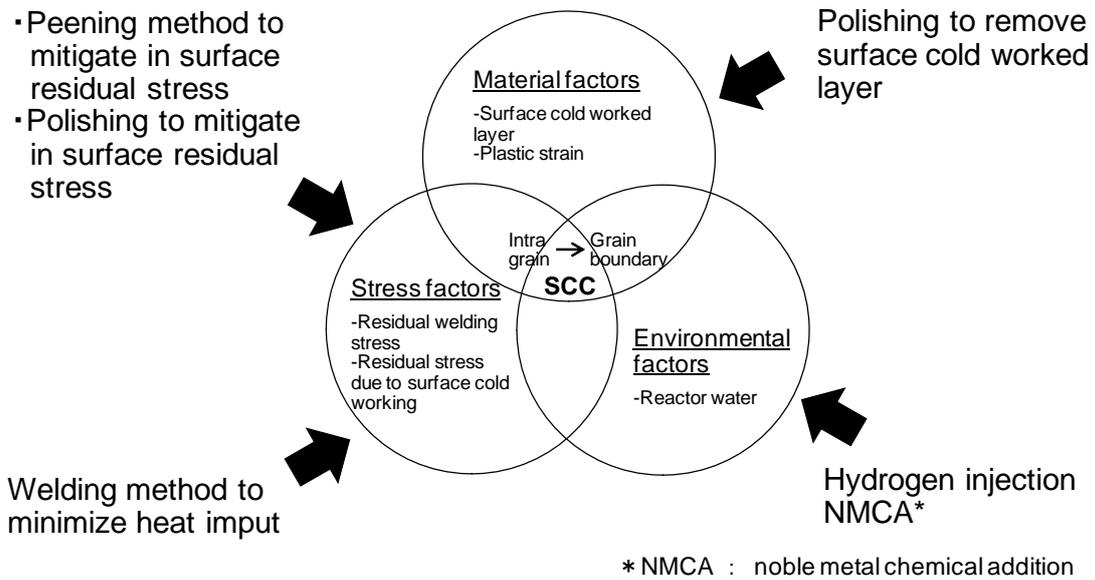


Figure 2.2 Multi-Technology Approach to SCC Mitigation Considering Contributing Factors

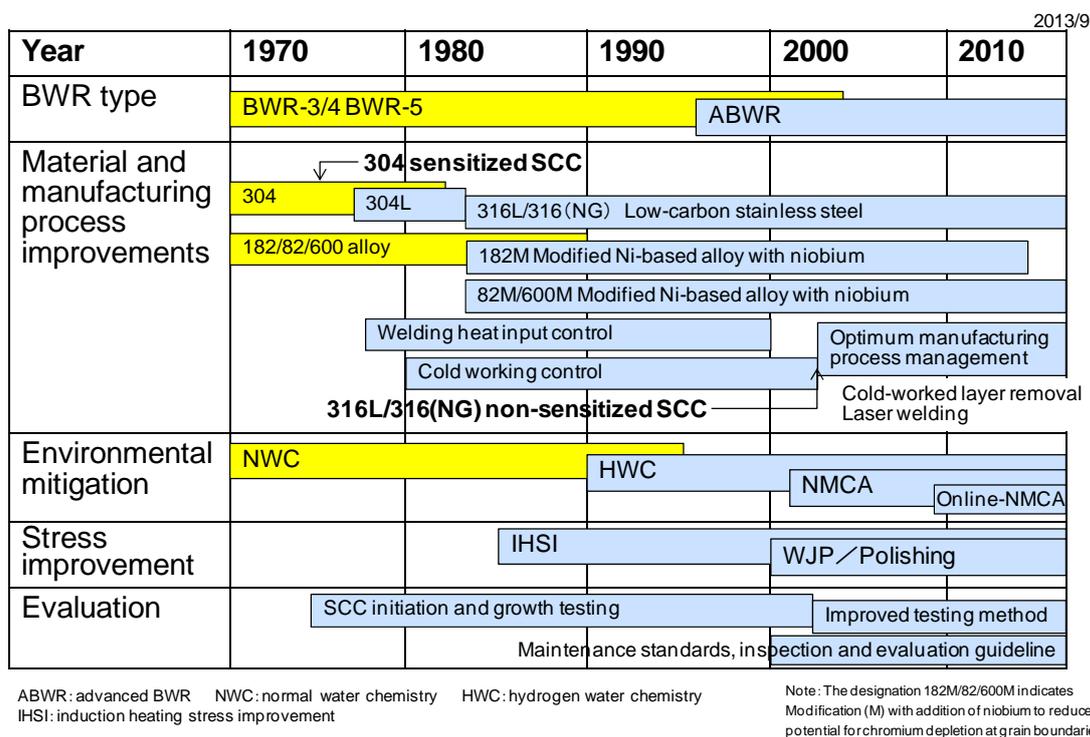


Figure 2.3 Time Frame of SCC Mitigation Considering Contributing Factors

2.1.2 Dose Rate Reduction

The first generation of BWR was designed based on the experiences of fossil power plants. The main material of the balance of plant system was carbon steel with a Stellite overlay used for the turbine blades. A large amount of iron crud was produced and significant amounts of Co were released into the condensate water. Though condensate purification system was used to remove impurities from the condensate water, condensate demineralization was not enough to prevent all these corrosion products from flowing into the Reactor Pressure Vessel (RPV). Most of these corrosion products were deposited on the fuel cladding surface and activated by neutrons during operation. Some activated corrosion products were released into the reactor water and circulated through the primary cooling system. They deposited on the surface of the piping and components such as the Reactor Recirculation System (RRS) piping and valves, which resulted in high dose rates.

In order to reduce dose rates of the primary system, the cause of dose rate increase was studied. This identified that Co-60 and Mn-54 were the main contributors to dose rate. (Ref 2) The first countermeasure was to reduce the source term. Corrosion resistant steel was used for the condenser and heater drain system in the following generation of BWRs. Dual condensate purification systems were applied to remove iron crud almost completely with hollow fiber filters or pleated filters. Oxygen injection was also applied to all BWRs including back-fitting to older plants to reduce corrosion of carbon steel of the feed water piping, which also had a large effect in helping to reduce feed water iron crud concentration.

Co source reduction was also applied to the following generation of BWRs such as elimination of Stellite overlay from the turbine blades, low Co content feed water heater tubes and fuel spacers and replacement of Stellite from pins and rollers of control rods. As ABWR does not use jet pumps, Stellite use in ABWR is much less than previous BWRs.

However, too low an iron concentration caused high ionic Co-58 and Co-60 concentrations in the reactor water in the mid '80s (Ref 3). A Fe/Ni ratio control method was developed and applied to reduce radioactive Co concentrations in the reactor water.

On the other hand, the ultra-low iron concentration control concept was also proposed and applied to some Japanese BWRs. Although this method increases radioactive Co concentrations, high Ni concentration in the reactor water reduces Co deposition on stainless steel surfaces. Overall the dose rate of reactor recirculation piping in those BWRs remained low in the early operating cycles, but showed a rapid increase in dose rates after several cycles of operation (Ref 4). As UK ABWR has no reactor recirculation piping, an optimum iron concentration control in feed water is applied.

Another approach to reduce dose rate is the reduction of Co deposition rate on the piping and components surfaces. The effect of zinc in suppressing the buildup of Co-60 inside oxide films was first recognized by the observation that plants with high zinc concentrations in reactor water had less radiation dose rates from piping. Through experimental and field studies, it was found that amounts of soluble zinc in reactor water reduced Co-60 buildup in the corrosion films on piping and components by promoting the formation of a protective oxide film of spinel structure. Radiation dose rates are lowered since Zn is favored for incorporation into the oxide film relative to Co-60. While Natural Zinc Oxide (NZO) is effective in reducing radiation fields, activation of the Zn-64 (48% of NZO isotopic composition) to form Zn-65 contributes to radiation fields and low level wastes. Consequently, Depleted Zinc Oxide (DZO), that is, zinc depleted in Zn-64, is commonly used for zinc injection application. When DZO is coupled with both low iron input and cobalt alloy control, low shutdown dose rates can be obtained. Zinc injection is recommended to reduce dose rates when plants implement HWC with or without NMCA. (Ref 5)

A qualification program of zinc addition to reduce shutdown dose levels additionally indicated a positive effect of zinc on IGSCC susceptibility. Research showed low levels of zinc reduced crack propagation rates in Type 304 SS and Alloy 182 under reducing conditions, and high levels reduced crack growth rates even under oxidizing conditions. Beneficial effects of zinc on crack initiation and growth of Alloy 600 were also observed in PWR environments. Therefore, work was initiated to find a specification to optimize the zinc concentration and hydrogen injection rate that would minimize operating dose rates while providing IGSCC crack mitigation for the bottom region of the reactor vessel. (Refs 6 through 8) However, in the present day, zinc is used in BWRs which apply HWC and noble metal technology mainly for the reduction of piping dose rates.

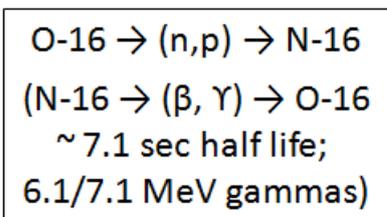
2.1.3 Reactor Water Chemistry

In the area of material selection, reactor internal structures' resistance to sensitization for UK ABWR is achieved by using a special Type 316NG (Nuclear Grade) steel. This alloy has carbon restricted to a maximum of 0.020% by weight to prevent sensitization and has specific fabrication and processing controls imposed to increase the resistance to crack initiation.

To add margin against IGSCC for nickel based alloys in UK ABWR, Alloy 600 and their weld metals have been modified with stabilizing additions of niobium to reduce the potential for chromium depletion. For wrought structures, UK ABWR employs a modified Alloy 600 (designated as 600M) which has a niobium content below 3% and low carbon. For weld metal, a modified Alloy 82 with high stabilizing ratios is used, leading to high IGSCC resistance.

As noted above, during the early years of the nuclear industry, common thinking was to use Normal Water Chemistry (NWC) by controlling impurities, e.g., Cl⁻, SO₄²⁻, (i.e., plant operation in highly purified water chemistry). However, as IGSCC issues arose (Table 2.1), laboratory tests indicated the beneficial effects of addition of hydrogen through HWC, to control IGSCC. Hydrogen additions to the reactor water that reduced Electrochemical Corrosion Potential (ECP) to less than -0.23 V (SHE) were found to be effective in suppressing stress corrosion cracking.

Unfortunately, a side effect of adding hydrogen to the reactor water is an increase in gamma radiation emission in the main steam to the turbine. The primary source of the radiation increase is from increased volatilization of nitrogen-16 under HWC conditions produced from neutron activation of oxygen-16:



Although the half-life of N-16 is very short and does not cause substantial radiation exposure for maintenance work during outages, gamma shine in the turbine building is increased during normal operation.

Another important adverse effect of HWC technology is the increase of piping dose rates which strongly affects the worker's occupational dose during plant outages. This phenomenon is caused by the buildup of radioactivity such as Co-60 inside the oxide film formed on the piping surface in the strongly reducing environment due to HWC application.

Both laboratory and in-plant crack growth rate data confirm the benefit of HWC in mitigating existing cracks. Therefore, numerous methods such as hydrazine injection (Ref 9) and titania injection (Ref 10) have been explored to decrease the ECP of nuclear reactor structural materials exposed to high temperature water below -0.23 V(SHE), while also reducing the amount of hydrogen addition in order to reduce gamma shine levels and suppressing the piping dose rate.

One promising method for the reduction in ECP and increase in main steam radiation is depicted in Figure 2.4. This is based on the adoption of noble metal technology combined with hydrogen injection (Note: the upper curve of In-Vessel ECP in Figure 2.4 shows the effect of HWC without considering other chemical injections, i.e., without Noble Metal injection, which is discussed below.) Through the adoption of noble metal technology, the radiation fields in the turbine building can be effectively reduced to the level observed in the NWC case, because the required hydrogen injection amount is suppressed to below the level at which the dose rate increase begins.

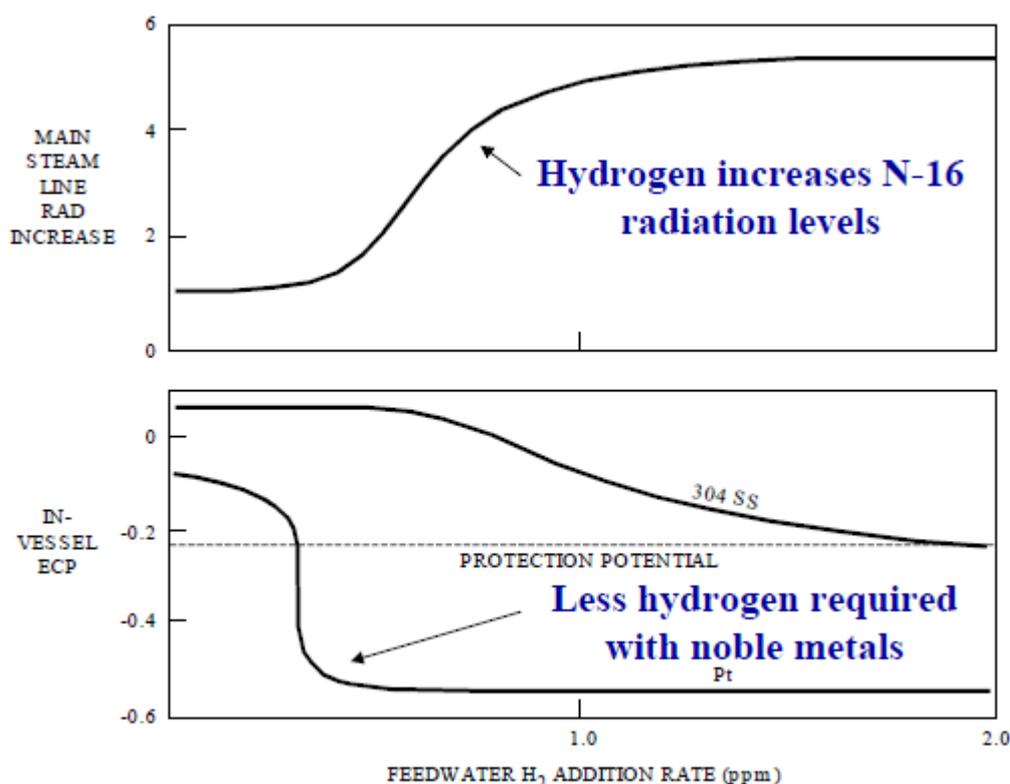


Figure 2.4 Changes in ECP and main steam line radiation increase as a function of feed water hydrogen addition rate and the application of NobleChem™ (Ref 11).

Noble Metal Chemical Addition (NMCA) is a technology introduced to control IGSCC using lower levels of hydrogen and thereby resulting in lower levels of gamma radiation. The effect of NMCA can be seen in the lower curve of In-Vessel ECP in Figure 2.4 where to maintain an ECP less than -0.23 V(SHE), hydrogen levels low enough to maintain gamma radiation levels in the turbine building close to those observed for NWC are achievable.

NMCA achieves a lowering of the ECP by injecting Platinum (Pt) and Rhodium (Rh) along with low levels of hydrogen addition. Typical NobleChem™ applications were performed just prior to an outage at a temperature of 116 to 143°C (240 to 290°F). All chemical species added are cleaned-up during application

and during outage, before the plant resumes its startup operation. More recently, NobleChem™ has been applied as On-Line NobleChem™ (OLNC) while the plant is in power operation at approximately 280°C (538°F). In addition, OLNC deposits noble metal inside cracks more efficiently because of their more open nature during plant operation. The advantage of NobleChem™ or OLNC is that they require very little hydrogen addition in to the feed water (0.15 to 0.35 ppm) to achieve low ECPs, (Ref 12). As is mentioned above, zinc injection techniques are normally applied in parallel with NobleChem™ or OLNC to suppress the radiation dose rate increase in piping.

It is clear that hydrogen, zinc and noble metal chemical additives protect the core and plant systems. Investigations have also been conducted to ensure there are no effects on fuel cladding surface crud deposition. For example, zinc deposits can form a tenacious, insoluble spinel form of zinc ferrite on the fuel cladding, and there has been concern with respect to spalling and corrosion from these crud deposits. Therefore, monitoring the effects of chemical additions has been a focus of recent fuel surveillance programs. However, no gross adverse effects of hydrogen, zinc and noble metal chemical additives on corrosion including SCC and crud deposition have been observed. No gross hydriding has been identified either, although detection methods are not capable of detecting minor hydriding. (Refs 13 through 15) In conclusion, reactor chemistry has played an important role in the existing BWR fleet to minimize the incidence and growth of IGSCC. It has also played an important role in minimizing plant radiation fields. This has been achieved while maintaining fuel integrity by minimizing cladding corrosion.

2.2 Outline of the System and Functions of UK ABWR

Figure 2.5 shows the outline of the primary cooling water system of UK ABWR. UK ABWR adopts a direct cycle, in which steam is produced by the boiling of the reactor coolant in the reactor core and the steam directly drives a turbine to generate electricity.

In the primary cooling water system, the reactor coolant is circulated by reactor internal pumps and is turned into high pressure and high temperature steam in the reactor core. Generated steam is fed to the turbine, passing through the separator and the dryer within the RPV. The steam flows into the condenser after driving the turbine. In the condenser, the steam is condensed by the cooling water system. Condensate water is returned to the reactor through the feed water heaters and the feed water pumps.

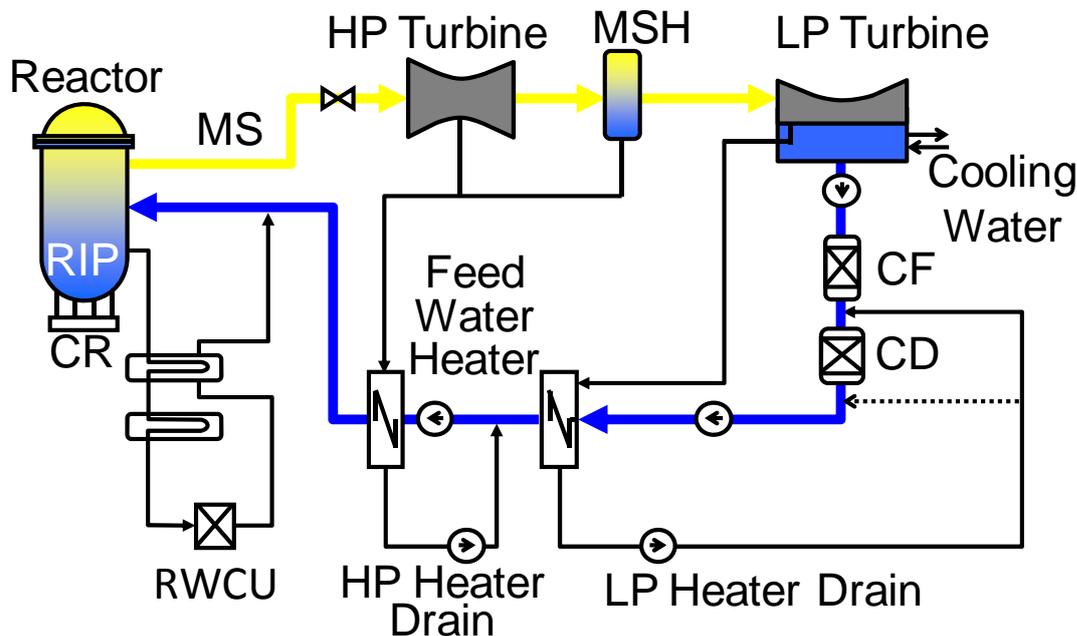


Figure 2.5 Outline of the primary cooling water system

2.3 Water Chemistry Management

2.3.1 Purpose

As described in Section 2.2, reactor coolant contacts with many kinds of materials which constitute the reactor system: these are stainless steel, nickel based alloy and low alloy steel in the reactor pressure vessel, zirconium based alloys of fuel, and carbon steel and cobalt based alloys in the BOP system. At the same instant, the reactor coolant covers a wide temperature range from room temperature to almost 300 °C. The purpose of water chemistry management is to manage these conditions appropriately and to maintain long-term plant safety. In particular, the main purposes are summarized as the following four items:

- ① Maintain structural material integrity
- ② Maintain fuel integrity
- ③ Reduce radiation exposure
- ④ Reduce radioactive waste generation

Here, it is noted that the purpose of minimizing radioactivity release to the environment, which is listed on Table 1.1, is related to the off-gas system.

2.3.2 Methods to Control Water Chemistry

(i) Operational state

- ① Maintain structural material integrity

General corrosion rates in high-temperature pure water have been elucidated for the constituent materials, which are used in the primary cooling water system. The thickness of the constituent materials is designed

taking into account such a corrosion margin. From the viewpoint of structural material integrity, the concentration of impurities which cause corrosion should be controlled. To prevent the incorporation of impurities, condensate filters and condensate demineralizers are installed.

On the other hand, the amount of general corrosion product, referred to as crud, is controlled in the feed water and condensate system as input of too much crud into the core region may create harmful effects for fuel structural material integrity by accumulating on the fuel cladding and thereby decreasing thermal conductivity. Since general corrosion correlates with Flow Accelerated Corrosion (FAC), the prevention of both crud formation and FAC of carbon steel in the feed water and condensate system depends on the same countermeasures. It is known that a concentration of dissolved oxygen of more than 15 ppb can suppress both phenomena. Taking into consideration the above fact, the dissolved oxygen in the feed water and condensate system should be controlled greater than 15 ppb.

SCC is one of the main failure causes of components, made of stainless steel and nickel based alloys in BWRs. Figure 2.6 shows the factors leading to SCC occurrence. SCC occurs in the overlap area of the three factors. The concentration of chloride ions, sulfate ions and oxidizing species such as dissolved oxygen and hydrogen peroxide are controlled by operating a controlled water chemistry regime. Filter demineralizers are installed in the reactor water cleanup system to reduce the concentration of chloride ions and sulfate ions. The conductivity of reactor coolant at the inlet and outlet of filter demineralizer is monitored to confirm the performance of the filter demineralizer.

In order to remedy the oxidizing environment of reactor water, many BWRs have adopted the NMCA plus low-concentration hydrogen injection in recent years to reduce the concentration of oxidizing species such as dissolved oxygen and hydrogen peroxide.

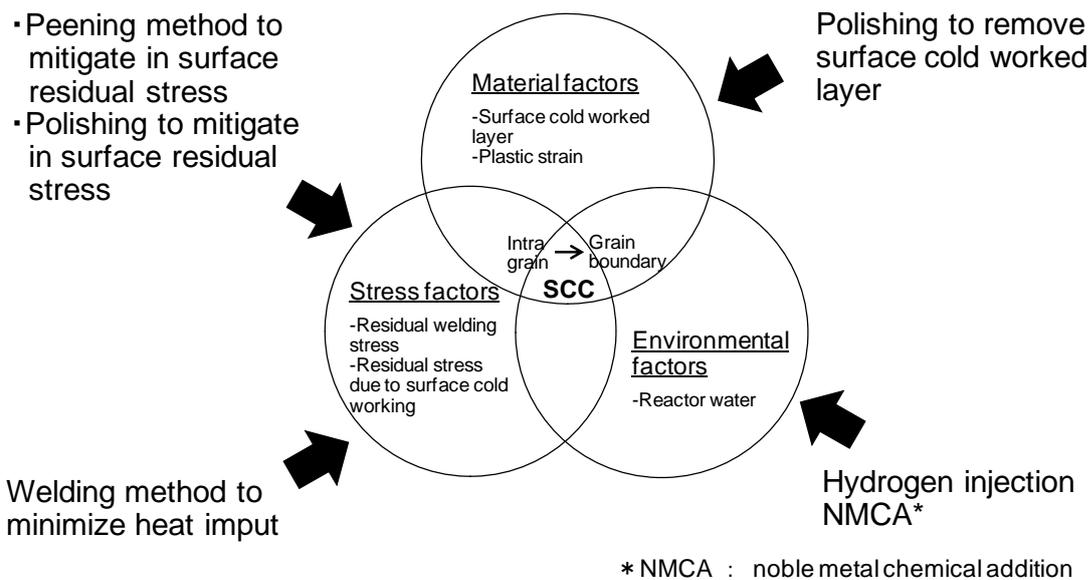


Figure 2.6 Main cause of SCC of stainless steel and countermeasures

② Maintain fuel integrity

Fuel failures in existing BWRs are mainly categorized by the following four causes:

- (a) Debris (Grid to Rod Fretting)
- (b) Crud / Corrosion
- (c) Duty Related
- (d) Fabrication Related

Crud / Corrosion are primarily related to water chemistry. There are two types of corrosion for zircalloy-2 (Zry-2) used in BWRs. One is uniform corrosion and another is nodular corrosion. Uniform corrosion, which is the basis of the corrosion mechanism seen in zirconium based alloys, occurs by the oxidation reaction between zircalloy and reactor coolant. Once the oxide film is formed, corrosion proceeds by the diffusion of oxygen ions to the base metal surface. Nodular corrosion is characteristic of BWRs and the lenticular oxide is locally formed whose size is from a few micrometers to a few millimeters. Dissolved oxygen concentration is also considered to be concerned with nodular corrosion. To maintain fuel integrity, the concentration of dissolved oxygen as well as of ions such as chloride are controlled.

Except for general and nodular corrosion, Crud Induced Localised Corrosion (CILC) caused by deposition of corrosion products on fuel surfaces was first observed in US BWR plant in 1979. Localised deposition of the corrosion products such as copper ions on the fuel cladding was found to accelerate CILC. To prevent CILC, the concentration of copper ions in the feed water system should be controlled. In UK ABWR, copper alloy is not applied for the feed water heater and the heat exchanger tube of the condenser to reduce the concentration of copper ions in the feed water system. Titanium tube is applied for the heat exchanger tube of the condenser. As a result, no generation source of copper exists in the UK ABWR primary cooling water system.

An European BWR had experienced Enhanced Spacer Shadow Corrosion (ESSC). Zircaloy in contact with inconel spacers had experienced severe corrosion damage. This is considered to be one of galvanic corrosion between zircaloy and inconel under specific water chemistry. Low corrosion resistivity of the cladding material was considered to have affected the ESSC, because another inconel spacer fuel cladding with higher corrosion resistivity had no corrosion acceleration.

③ Reduce the radiation exposure

Radiation exposure is expressed by the following equation:

$$\text{Person-Sv} = \Sigma(\text{Dose rate} \times \text{Number of workers} \times \text{Working time})$$

Here, dose rate is proportional to the amount of radioactivity which is determined by the balance of the deposition rate and decay of radioactivity. The deposition rate is calculated by the product of radioactive inventory concentration in the reactor water and the deposition rate coefficient of radioactivity on the oxide film of structural materials.

Cobalt-60, Co-58, Mn-54 and Cr-51 are the main contributors for dose rate in UK ABWR. Low cobalt content stainless steel and nickel based alloys are applied to reduce cobalt generation. Alternative materials of Stellite (cobalt based alloy) are also applied.

The source of Mn-54 is predominantly iron crud. To reduce iron crud generation, low alloy steel is applied for the piping in the extraction steam system and feed water heater drain system. Another corrosion resistant steel, which is another kind of low alloy steel, is applied to the condenser for the same reason. Furthermore, the input of iron crud into the reactor is reduced by the installation of pleated filters in the condensate purification system. From the viewpoint of water chemistry, Zn injection is applied to reduce occupational radiation dose. Zn injection can reduce the deposition coefficient of Co-60 and Co-58 inside the oxide film because Zn ions are incorporated into the oxide film of stainless steel more easily than cobalt ion. Zn is injected continuously from the feed water system. For Zn injection, Zn-64 depleted Zn oxide is used because Zn-64 is activated to radioactive Zn-65. Zn-64 is removed by isotope separation in advance.

④ Reduce radioactive waste generation

Radioactive waste generation is positively correlated with the radioactive inventory in the primary cooling water system. Therefore, radioactive waste generation can be reduced by introducing countermeasures for the reduction in generation of Co-60, Co-58, Mn-54 and Cr-51. Co-60 is the main nuclide in terms of activity, hence it is necessary to reduce its generation. In particular, the use of low cobalt content materials and alternate materials of Stellite are effective in reducing radioactive cobalt generation. The use of low alloy steel including corrosion resistant steel is effective in reducing the radioactive source of iron crud.

(ii) Startup state

① Maintain the structural material integrity

Before startup, the concentration of dissolved oxygen in the coolant is saturated because the primary system is exposed to air. There is a period during which the transfer efficiency of oxygen into the main steam is low because steam generation during start up is lower than that during operation. High oxygen concentrations may be experienced during startup, which is undesirable for SCC prevention. To prevent SCC, deaeration is conducted and the dissolved oxygen concentration is controlled above a coolant temperature of 100 °C.

② Maintain the fuel integrity

The concentration of dissolved oxygen in the coolant affects the fuel integrity because the presence of high concentrations of oxygen accelerates the corrosion of fuel cladding. Deaeration described above is also effective in maintaining the fuel integrity.

③ Reduce radiation exposure

The crud generated during the outage in the condensate system and feed water system is fed into the reactor at startup state, which results in increase in the radioactive corrosion products. Before startup, the feed water and condensate system water is purified by re-circulation through the condensate filter to remove crud which is generated during the outage.

④ Reduce radioactive waste generation

The crud generated during the outage in the condensate system and feed water system is fed into the reactor during startup, which results in an increase of radioactive corrosion products. These radioactive corrosion products are purified by the filter-demineralizer of the Reactor Water Cleanup system (RWCU) after startup. It results in the potential increase of radioactive waste. The purification of the condensate and feed water prior to startup operation contributes to the reduction of the waste through the suppression of radioactivity in reactor water.

(iii) Shutdown state**① Reduce radiation exposure**

Radioactive crud concentration in the reactor coolant spikes during the decreasing pressure and temperature phases of shutdown. Crud may be deposited in stagnant areas, which results in the formation of radioactive 'hot spots'. ABWR minimizes the formation of radioactive hot spots during the shutdown due to the design and elimination of areas of stagnant flow or crevices.

The concentration of radioactive species increases due to the decrease of corrosion product deposition on the fuel surface in the shutdown state. Radioactive species are incorporated into the hydroxide on residual heat removal (RHR) system piping, which is used for reactor cooling during the shutdown state. As a result, the dose rate of RHR piping increases. The degree of incorporation into the hydroxide is mainly dependent on the in-service temperature. To reduce the incorporation of radioactive ion into the RHR piping, in-service temperature is controlled.

② Reduce radioactive waste generation

During the shutdown state, radioactive crud release spikes and is removed by the filter-demineralizer in RWCU system, which results in an increase of radioactive waste generation. Minimizing the formation of radioactive hot spots during shutdown is also effective in reducing radioactive waste generation.

③ Maintain structural material integrity

During shutdown, the concentration of dissolved oxygen in the reactor water is kept low before vacuum break because the generation of oxidizing species by radiolysis decreases. As a result, the environment of the reactor water is not susceptible to SCC during shutdown.

④ Maintain fuel integrity

If a small amount of leakage exists in the fuel, additional emission of iodine from the fuel occurs with depressurization of the reactor pressure vessel during shutdown which is usually removed by the demineralization system. Iodine concentration in the reactor coolant is monitored after the start of power reduction.

(iv) Outage**① Maintain structural material integrity**

Water in the piping of the feed water and condensate system is drained and the system dried during the outage to reduce the corrosion of structural materials if the outage period is extended. If drainage and/or dry conditions are difficult to conduct, the system is filled with demineralized water. Before startup, the feed water and condensate system is purified by re-circulation through the condensate filter to remove crud which is generated during the outage.

② Maintain fuel integrity

Crud generation reduction during outages is also effective in maintaining fuel integrity during operation by reducing the amount of crud entering the reactor water via the feed water system.

③ Reduce radiation exposure

RWCU and FPC purification systems are used during the outage (except for ISI and their maintenance periods), which results in a reduction in radiation exposure, in order to maintain low radioactive nuclide concentrations in the reactor water, separator-dryer pool water, reactor well water and spent fuel pool water, which are connected as one pool. Reducing the radiation exposure during outages is also described in Section 3.2.4.

④ Reduce radioactive waste generation

The condensate demineralizer is isolated before vacuum break of the condenser and is stored in demineralized water to prevent degradation of the resin.

2.3.3 Operating Experiences**(i) Oxygen injection**

Figure 2.7 shows conductivity, iron concentration and dissolved oxygen concentration of feed water line with oxygen injection. The oxygen injection point is usually set at the outlet of the condensate demineralizer (CD) and the concentration of dissolved oxygen ranges from 20 to 30 ppb in feed water with oxygen injection. The concentration of iron crud and conductivity decreases with oxygen injection,

which indicates that corrosion of carbon steel is reduced.

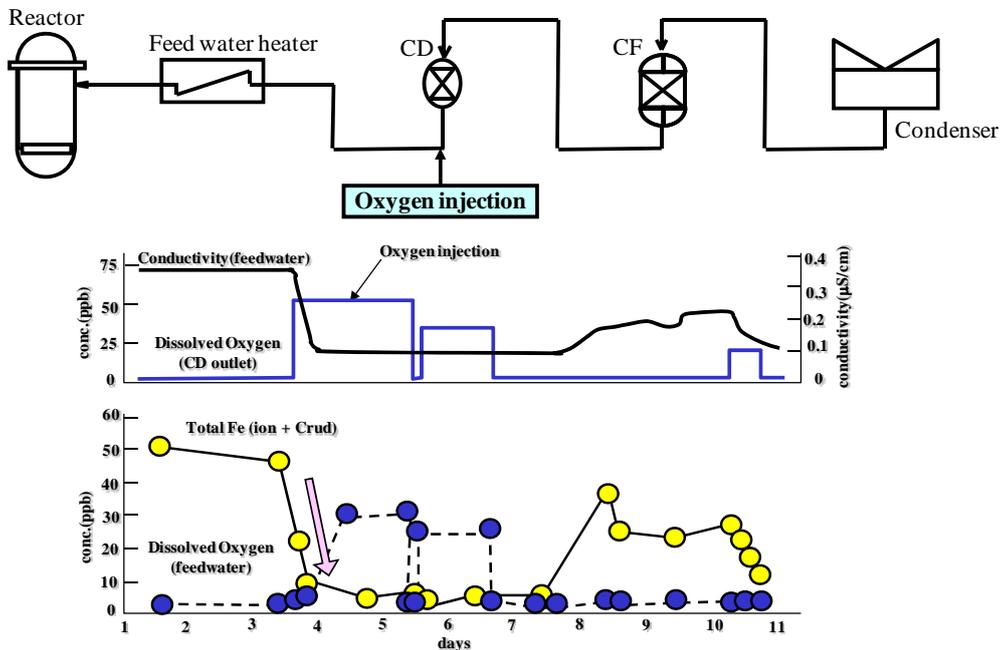


Figure 2.7 Conductivity, iron concentration and dissolved oxygen concentration of feed water line with oxygen injection (Ref 16)

(ii) Environmental discharge and dose rate reduction

From the viewpoint of water chemistry, there has been a long history of maintaining structural material integrity and the suppression of occupational radiation dose. In the development of both technologies, it is well known that the two fields are closely interrelated with each other. In the initial stage of HWC application, dose rate increases in recirculation piping (note that the UK ABWR design has eliminated recirculation piping through the use of reactor internal pumps) have been experienced. It has been clarified that this increase of dose rate was caused by the formation of oxide films which could easily incorporate radioactivity such as cobalt-60 under the reducing environment by the presence of hydrogen. This phenomenon also occurs in the presence of noble metal. In order to remedy this, the injection of Zn was found to be effective for the reduction of dose rates. Most BWRs which apply HWC and NMCA therefore normally adopt Zn injection.

The injection of noble metal and Zn is controlled to prevent adverse effects on fuel integrity following the experience of several plants which experienced spallation of oxide film when too much noble metal and/or Zn was applied.

(iii) Radioactivity concentration in reactor water

As was shown in section 2.3.2, the dose rate of components in the reactor system is proportional to the

concentration of radioactivity in reactor water. Therefore, the reduction of radioactivity is an important point for dose rate reduction. In the initial stages of BWR development, radioactivity associated with crud was high as high levels of crud were input from the feed water system. Due to this reason, the high radiation dose rate spots in the primary system were created by accumulation of crud with radioactivity resulting in the increase in occupational radiation dose.

However after the application of the countermeasures described in this section and the use of pleated filter , the crud induced radioactivity was dramatically reduced. Instead, the soluble ion concentration dominated the radioactivity level and the deposition of radioactivity inside the oxide film affected the dose rate of the components. The radioactivity concentration tends to increase when the iron crud input is quite limited (below 0.1 ppb in feed water line). This mechanism can be explained by considering the stabilization mechanism of radioactivity on the fuel cladding surface. Radioactivity is incorporated in the form of spinel oxides on the fuel surface resulting in the decrease of the concentration in reactor water if sufficient amount of oxides/(crud) is present. For this reason, the input of iron crud is controlled to suppress the radioactivity concentration.

2.4 Water Chemistry Regime

The water chemistry regime for UK ABWR must be selected from the view point of optimization of plant safety. When one chemistry parameter is optimized for one purpose, it may have a negative effect on another variable. For example, HWC is effective in mitigating SCC, while high hydrogen injection results in high N-16 dose rates in the turbine system. In order to satisfy the four criteria mentioned in 2.3.1 simultaneously, not only water chemistry control methods, but also material selection is important for optimization.

Currently operating ABWR plants adopt NWC. No hydrogen injection, no Pt injection, and no Zn injection are applied for NWC. In NWC plants, neutral, pure water is maintained. Iron concentration control in feedwater and oxygen injection into feedwater are applied as water chemistry control methods in these plants. However, dissolved oxygen and hydrogen peroxide concentrations of these plants are higher than 100 ppb in the reactor water originated by water radiolysis in the core, which creates a corrosive environment to the structural materials. Though UK ABWR is made of SCC proof materials and adopts stress relief measures, residual SCC potential for the 60 years plant life is reduced through the use of HWC and platinum injection.

Hydrogen injection is a method to reduce dissolved oxygen and hydrogen peroxide concentrations in reactor water as described in 2.1.3. HWC effects on the plant depend upon the hydrogen injection rate. Lower injection rates result in less mitigation effect on SCC and less side effects on the plant. Higher concentrations in feed water will be necessary to obtain enough SCC mitigation effect, which will cause higher dose rates around the turbine system during operation and higher radiation exposure to plant personnel.

Noble metal chemical addition was developed to reduce N-16 side effect of HWC. This combination of water chemistry enables a high SCC mitigation effect with little N-16 dose rate increase. However, it is predicted that this water chemistry increases the carbon steel piping dose rates such as RWCU and high temperature areas of RHR piping. Though there are some methods for dose rate reduction of carbon steel (CS) in NWC conditions, there are none in HWC with or without NMCA conditions.

Zn injection is the only effective dose rate reduction method under a reducing environment. However, it has little reduction effect for CS. Material changes to RWCU piping from the existing ABWR can be considered. This combination resolves the dose rate problem of RWCU piping. However the SCC potential of this piping arises due to the material change from CS to stainless steel. A considerable SCC potential decrease and a significant crack growth rate reduction for reactor internals and parts of the pressure boundary of RPV are expected, while a small SCC potential increase for RPV external stainless steel piping, additional dissimilar welding and the potential increase of RWCU piping length inside the PCV due to larger thermal expansion rate are predicted. However, RWCU piping of stainless steel is widely used in the US and no SCC for RWCU piping of stainless steel was reported so far. Approximately 4 times higher dose rate is predicted for CS under reducing conditions compared to the NWC conditions and is not tolerable for inspection and maintenance during the outage. The combination of hydrogen, platinum and zinc injection for UK ABWR water chemistry control with the RWCU piping of stainless steel is a very strong candidate. So in addition to high water purity and optimum iron concentration control, HWC, Pt and Zn injections are assumed to be as base water chemistry conditions for UK ABWR. The chemistry regime for UK ABWR including the option of material change of the RWCU piping will be finalized after detailed evaluation in SCC mitigation, radwaste, structural integrity and dose rate.

2.5 Claim for Primary Cooling Water System

Main claims for primary cooling water system are as follows.

- The chemistry regime for UK ABWR maintains the integrity of the fuel and structures in the reactor pressure vessel and reactor coolant system boundary.
- Radiation source term is minimized so far as is reasonably practicable by the combination of material selection and optimum water chemistry control to reduce operational radiation exposure.

3. SPENT FUEL POOL SYSTEM

3.1 Outline of the System and Functions

Figure 3.1 illustrates the schematic diagram of the spent fuel pool (SFP) system. The pool itself is made of reinforced concrete with stainless steel lining and a sufficient amount of coolant is maintained to keep the fuel cool under anticipated conditions. The fuel is arranged in racks of borated stainless steel immersed in the pool. In this system, coolant is re-circulated for purification and cooling. RHR can be aligned in parallel with the SFP cooling system in such cases where all spent fuel is removed to the SFP, creating a higher heat load.

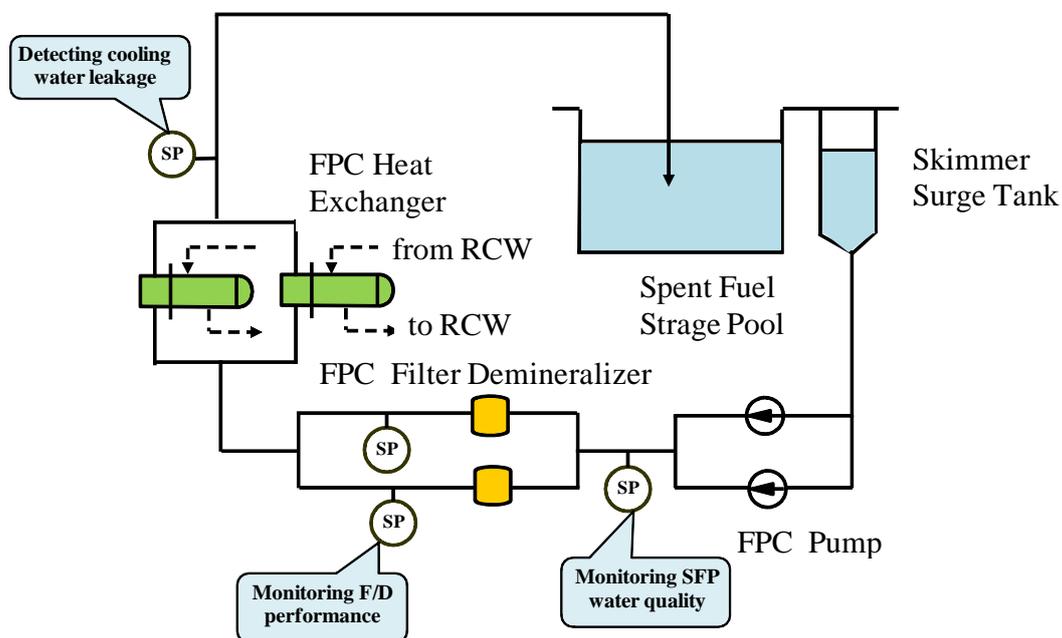


Figure 3.1 Schematic Diagram of Spent Fuel Pool

SP: Sampling point, RCW: Reactor building cooling water, FPC: Fuel pool cooling

3.2 Water Chemistry Management

3.2.1 Purpose

The purposes of water chemistry management of the SFP are primarily to maintain the fuel integrity in the storage pool, including the integrity of the storage rack and pool itself and to suppress the radioactivity level in the pool. For this purpose, coolant is purified and its temperature is controlled during normal operation. Coolant purification has two purposes: one is to protect the fuel, fuel rack and pool structure materials from corrosion and the other is to maintain the clarity of coolant for viewing the fuel assembly under water. At the same time, the radioactivity emanating from spent fuel is removed by the purification system.

Considering the coolant water of the SFP during the outage is mixed with the reactor water during refueling, the water chemistry of the SFP is required to be the same as or better than the reactor water chemistry in the reactor shut-down stage. Clarity of coolant is required especially during refueling.

3.2.2 Methods to Control Water Chemistry

As can be seen in Figure 3.1, two loops of filter demineralizer (F/D) for coolant purification and radioactivity removal and two loops of heat exchanger for temperature control are provided in UK ABWR.

3.2.3 Measurement and Operation Method

In the recirculation loop of the SFP, several sampling points depicted in Figure 3.1 are set to monitor the water quality of the coolant.

Sampling Points are located at the inlet and outlet of the F/D to enable monitoring of F/D performance. For the purpose of detecting the leakage from heat-exchanger, one sampling point is set downstream of a heat-exchanger.

3.2.4 Operating Experiences

In the initial stages of BWR development, a large amount of activated crud was dispersed inside the pool during refueling causing higher radiation fields on the operating floor. However, in recent years, because of the suppression of corrosion products from the feed water line, the problem of elevated radiation levels during refueling has been dramatically improved.

The water chemistry of SFP in actual operation is sufficiently controlled such that no failure caused by water chemistry related damage has been experienced.

3.3 Claims for Spent Fuel Pool System

- The chemistry of the spent fuel pool contributes to maintaining the integrity of the fuel and spent fuel pool structures and liner during refueling, normal operations and storage.
- The chemistry regime of the spent fuel pool ensures that occupational radiation exposure (ORE) is kept ALARP.

4. COMPONENT COOLING WATER SYSTEM

4.1 Outline of the System and Functions

The auxiliary component cooling systems consist of multiple, independent systems, which are classified by usage and supply area.

Figure 4.1 shows the reactor building cooling water (RCW) system as an example. The system, comprises the closed loop in which coolant is re-circulated to remove heat emanating from equipment in the component room. The re-circulated coolant releases the heat ultimately to sea water through the heat exchanger. In the system, a chemical addition tank is installed for injecting anti-corrosion chemicals into the coolant. Coolant is added to the system by supplying makeup water (MUW) to the surge tank.

As a constituent material, carbon steel is used for the piping and materials with low thermal resistance are applied to the heat exchanger tubes.

It should be noted that detailed design of the component cooling water system (including material selection and heat exchanger type) is ongoing, and the final design will be presented during the forthcoming steps of the GDA process.

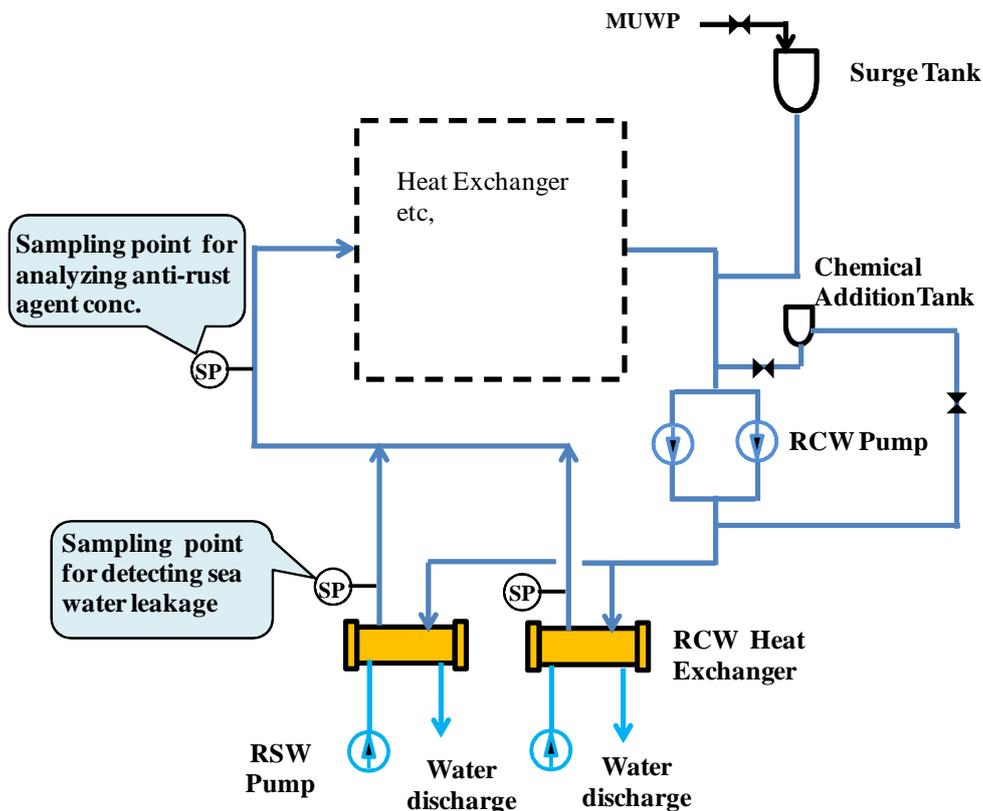


Figure 4.1 Schematic Diagram of Component Cooling System (ex.RCW)

SP: Sampling point, RCW: Reactor building cooling water,
MUWP: Makeup Water Purified System

4.2 Water Chemistry Management

4.2.1 Purpose

The purpose of water chemistry management is to prevent the equipment and piping of the system from corrosion damage, which could result in the decrease of equipment performance such as stable coolant supply and heat exchange efficiency.

4.2.2 Methods to Control Water Chemistry

Suppression of material corrosion in the system is achieved by adding anti-corrosion chemicals. Sodium nitrite is the most favorable chemical to be used for this purpose, as demonstrated through operational experience. Nitrite is known to reduce corrosion of carbon steel. Though nitrite may be oxidized by the presence of micro-organisms, this concern can be avoided by managing water chemistry so as not to contaminate the loop with micro-organisms in the closed system. The targeted nitrite concentration is more than 200 ppm as can be seen in Figure 4.2.

In the case of a system in which copper containing materials are used, chemicals of the nitrite family which contain the anti-corrosion chemicals for copper containing materials shall be applied. In this case, water chemistry is controlled to maintain the low solubility of copper oxides in order to measure the concentration level of anti-corrosion chemicals for the copper family. In actual management, pH of coolant is maintained to ensure that a low solubility of copper oxides can be established (Figure 4.3). pH can be adjusted to the proper value by adding sodium hydroxide via the chemical addition tank.

In case the nitrite concentration decreases, anti-corrosion chemicals can be replenished. If nitric acid concentration is increased, the coolant can be blown down and the loop re-filled with demineralized water.

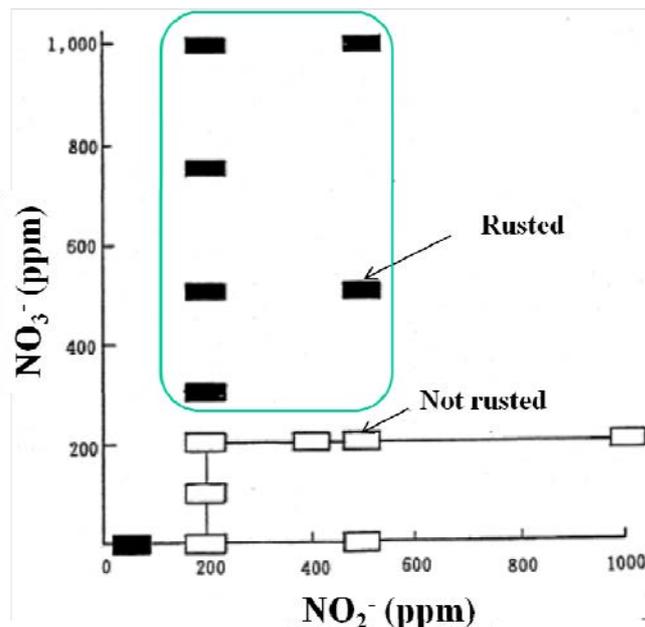


Figure 4.2 Effective range of nitrite as an anti-corrosion reagent under co-existing nitrate

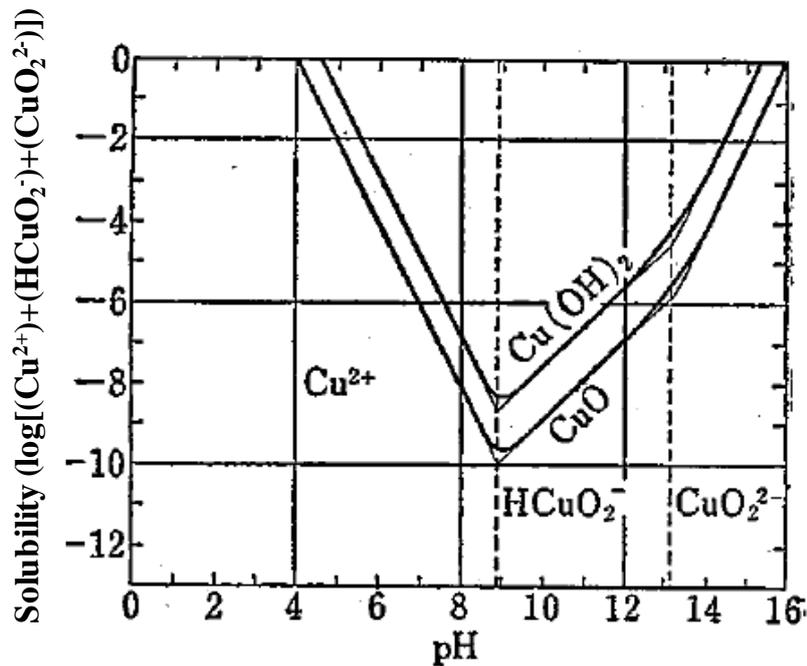


Figure 4.3 Solubility of CuO and Cu(OH)₂ (Ref 17)

4.2.3 Measurement and Operation Method

In the system, water sampling equipment is installed for monitoring water chemistry. Sampling equipment for measuring the concentration of anti-corrosion chemicals is installed at the main stream line at which the coolant is re-circulated. Furthermore, in order to detect the leakage from each heat exchanger, sampling points are installed at the outlet of each heat exchanger.

4.2.4 Operational Experiences

Detailed operational experiences of the component cooling water system are presented during the forthcoming steps of the GDA process.

4.3 Claim for Component Cooling Water System

- The chemistry of component cooling water minimizes the corrosion of its system materials to maintain their integrity and heat transfer function

5. SUPPRESSION POOL SYSTEM

5.1 Outline of the System and Function

The Suppression Pool (SP) is a large pool located at the bottom of the Pressure Containment Vessel (PCV) and has the function to suppress over pressure by condensing steam released from the reactor into the drywell in the case of a Loss Of Coolant Accident (LOCA). Other main functions of the pool are:

- (1) coolant source during RHR system surveillance operation,
- (2) coolant source for filling the reactor well during outage,
- (3) containment of iodine species in case of large scale fuel failure after LOCA,
- (4) coolant source during LOCA.

As is shown in Figure 5.1, coolant from the pool is supplied through the RHR system and Suppression Pool Cooling (SPC) system and can be purified by using the demineralizer of the FPC system. The suppression pool is lined internally with stainless steel.

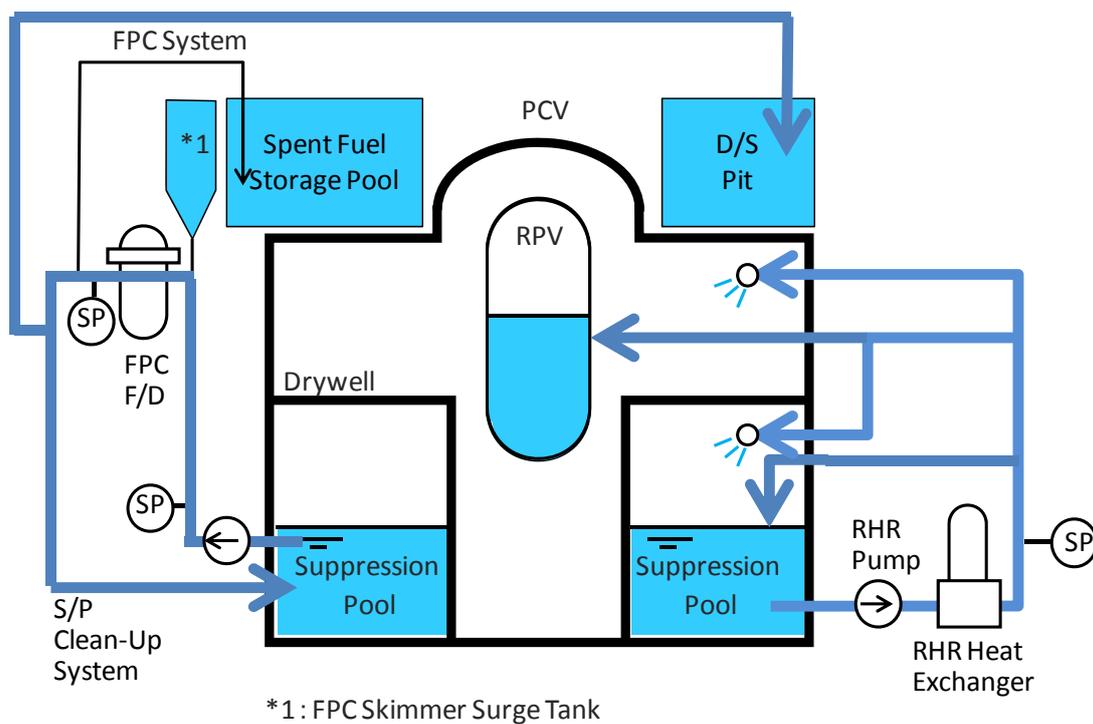


Figure 5.1 Schematic Diagram of Suppression Pool and related systems

SP: Sampling point, RHR: Residual Heat Removal System, FPC: Fuel Pool Cooling and Clean-Up System, RPV: Reactor Pressure Vessel, PCV: Pressure Containment Vessel

5.2 Water Chemistry Management

5.2.1 Purpose

The purpose of water chemistry management for the SP is described as follows:

- (1) effective suppression of volatilization of iodine species by containing the species in the coolant

during LOCA,

- (2) supply of pure water into reactor vessel during outages.

5.2.2 Methods to Control Water Chemistry

For suppression of iodine release outside of the PCV during a LOCA event, pH control of the suppression pool coolant is an important issue, because with a higher coolant pH, more iodine species formed as fission products are distributed in the liquid phase, as is illustrated in Figure 5.2. Since, from the viewpoint of safety analysis, the gas-liquid distribution coefficient of suppression pool coolant should be maintained to be more than 100, pH of the coolant should be managed so that it is greater than 5.5. As the coolant of BWR is demineralized water and the suppression pool is open to the air, the pH of the suppression pool water is normally around 5.3 due to the dissolution of carbon dioxides. Considering the situation that the iodine concentration in the liquid phase during a hypothetical accident is expected to be around 1.2 mg/ml, if pH is greater than 5.5 the iodine partition coefficient can be greater than the targeted value 100 with sufficient margin. If pH of the coolant is below the value, replacement or purification of the coolant by using the demineralization system of the suppression pool can be carried out. Furthermore, when the coolant is used for filling the reactor well during outages, the coolant can be demineralized to a quality similar to the spent fuel pool coolant by using the demineralizing system of the suppression pool.

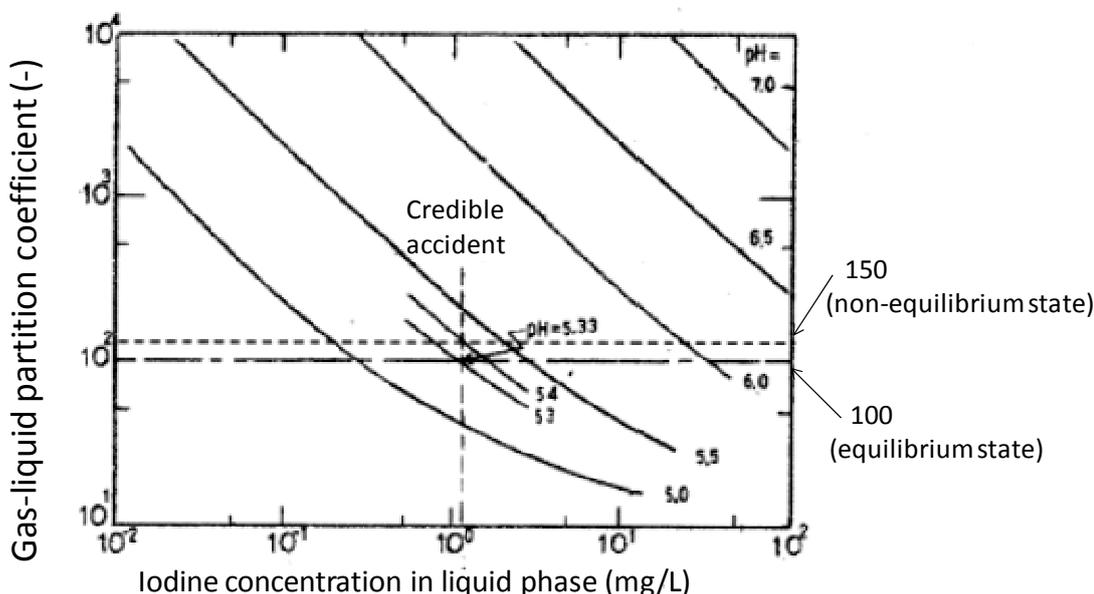


Figure 5.2 Relationship between partition coefficient and pH (Ref 18)

5.2.3 Measurement and Operation Method

Continuous surveillance of suppression pool coolant is not required because there is no inflow of coolant during normal plant operation. As coolant of the suppression pool is used as a water source for the RHR system during its surveillance operation, the coolant is sampled during the surveillance using the sampling

equipment of the RHR system in order to confirm that water chemistry meets the required value.

5.2.4 Operational Experiences

Water chemistry of the suppression pool coolant can be measured during surveillance tests of RHR. The pH at the beginning of the operating cycle just after the outage tends to be lowered to about 6 due to the effect of carbonic acid which is formed by dissolution of carbon dioxide in air during the outage. However, the pH gradually approaches the neutral state during operation, because carbonic acid is released from the coolant through the process of PCV air purging with nitrogen gas. The carbon steel wall of the SP of previous BWRs was coated, so there have been some experiences of the water quality decreasing due to the dissolution of impurities from the painted film after re-painting of the SP wall. In the case of UK ABWR, because stainless steel lining is used instead of painting, there has been no phenomenon experienced as in the existing BWRs.

5.3 Claim for Suppression Pool System

- Suppression pool chemistry reduces the release of radioisotopes from the Reinforced Concrete Containment Vessel (RCCV) so far as is reasonably practicable during accident scenarios.

6. STANDBY LIQUID CONTROL SYSTEM

6.1 Outline of the System and Functions

The Standby Liquid Control System (SLC) is an emergency system designed to safely bring the reactor from full power operation to sub criticality by a continuous injection of a sodium pentaborate solution in a situation where the control rods (CRs) do not insert in the event of an ATWS (Anticipated Transient Without Scram).

Boron concentration and volume in the SLC is maintained to achieve cold subcriticality in the event of an ATWS.

In the event of an ATWS, sodium pentaborate solution is injected into the reactor from the SLC storage tank by activating the SLC pump.

Figure 6.1 shows an overview of the SLC. The SLC consists of a storage tank (SLC storage tank), two SLC injection pumps (SLC pumps), and the necessary piping, valves, instrumentation and controllers.

Detailed information regarding the SLC will be shown in the SLC Basis of Safety Case.

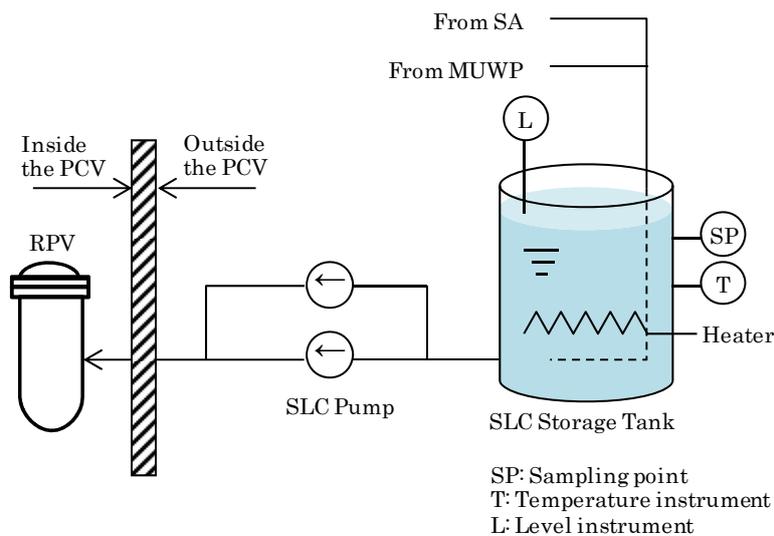


Figure 6.1 Outline of Standby Liquid Control System

6.2 Water Chemistry Management

6.2.1 Purpose

The purpose of water chemistry management of the SLC is to maintain sufficient sodium pentaborate solution to reach cold sub criticality of the reactor in the event of an ATWS.

6.2.2 Methods to Control Water Chemistry

Sodium pentaborate solution is made from sodium pentaborate and pure water supplied from the Makeup Water Purified System in the SLC Storage Tank.

Concentration and volume of the sodium pentaborate solution in the SLC Storage Tank is always maintained within an adequate range to achieve cold sub criticality in the event of an ATWS.

6.2.3 Measurement and Operation Method

Crystalline sodium pentaborate is loaded through a hatch provided on the SLC storage tank and demineralized water is supplied from the Makeup Water Purified System. The solution in the SLC storage tank is mixed by clean air from the Station Service Air System supplied to a sparger installed at a lower point in the SLC storage tank.

A sampling point is provided in the SLC storage tank to measure the boron concentration to verify the boron quantity inside.

A temperature and a liquid level of a solution in the tank are indicated in a local panel and the liquid level is also indicated in the main control room. High or low temperature, or high or low liquid level, initiates an alarm in the main control room.

6.2.4 System integrity and operability

System integrity and operability is maintained during the SLC is standby condition.

- The SLC is designed to be tested and inspected during commercial operation and reactor shutdown condition to demonstrate that components functions required for the system operation is available.
- The SLC Storage Tank and connected pipe works and valves are designed to prevent precipitation of sodium pentaborate that causes clogging.
- The SLC piping and components are designed to maintain their integrity for 60 years in consideration of maintenance and replacement.

6.2.5 Operating Experiences

The SLC has been adopted as a backup system to CR insertion in the BWR and the ABWR.

Though a mixture of borax and boric acid has been used as solute in the past, currently, sodium pentaborate is used instead due to availability and the reduction in size of the SLC storage achievable.

6.3 Claim for Standby Liquid Control System

- In the event of an ATWS, sufficient boron is supplied from the SLC to achieve cold sub criticality of the reactor.
- The design and chemistry of the SLC reduces corrosion within the SLC system so far as is reasonably practicable.

7. CLAIMS FOR REACTOR CHEMISTRY FOR UK ABWR

Claims related to Reactor Chemistry for UK ABWR are as follows.

- The chemistry regime for UK ABWR maintains the integrity of the fuel and structures in the reactor pressure vessel and reactor coolant system boundary.
- Radiation source term is minimized so far as is reasonably practicable by the combination of material selection and optimum water chemistry control to reduce operational radiation exposure.
- The chemistry of the spent fuel pool contributes to maintaining the integrity of the fuel and spent fuel pool structures and liner during refueling, normal operations and storage.
- The chemistry regime of the spent fuel pool ensures that occupational radiation exposure (ORE) is kept ALARP. .
- The chemistry of component cooling water minimizes the corrosion of its system materials to maintain their integrity and heat transfer function.
- Suppression pool chemistry reduces the release of radioisotopes from the RCCV so far as is reasonably practicable during accident scenarios.
- In the event of an ATWS, sufficient boron is supplied from the SLC to achieve cold sub criticality of the reactor.
- The design and chemistry of the SLC reduces corrosion within the SLC system so far as is reasonably practicable.

Claims related to other systems which are not described in this PSR and will be included within the PCSR.

8. REFERENCES

- 1 EPRI, BWR Water Chemistry Guidelines - 2000 Revision, Non proprietary version: BWRVIP-79 TR-103515-R2 Final Report, March 2000:
<http://pbadupws.nrc.gov/docs/ML0037/ML003722491.pdf>
- 2 K. Yamazaki, et. Al., "Analysis on the Primary System Radiation Control at Tsuruga Boiling Water Reactor Plant", J. Nucl. Technol., Vol. 52, pp. 7-21, January 1981
- 3 S. Uchida, et. Al., "BWR Plants with Low Shutdown Radiation Level", J. Nucl. Sci. Technol., Vol. 24, No. 8, pp. 1-8, August 1987
- 4 EPRI Technical Report 1003391, Assessment of Cost Effective Technologies to Reduce Radiation Fields, November 2005:
<http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=00000000001003391>
- 5 S. ITO, "Approach for reduction of radiation exposure at Tohoku Electric Power Co., Inc.", Presentation material of 2009 ISOE Asian ALARA Symposium, Aomori, Japan, September 2009:
<http://www.jnes.go.jp/isoe/english/alarasymposium/pdf/atc2009-2-3pp.ppt>
- 6 R.L. Cowan and E. Kiss, "Optimizing BWR Water Chemistry", Presented at the 6th International Symposium on Environmental Degradation of Materials in Nuclear Plants, San Diego, California, August 5, 1993.
- 7 P. Aldred, "Materials Qualification for GEZAP/GEZIP Treatments Applied to BWR Piping and Structural Alloys", GE Report NEDO-30962, Class 1, April 1985.
- 8 J.N. Esposito, et. al., "The Addition of Zinc to Primary Reactor Coolant for Enhanced PWSCC Resistance", Proceedings 5th Int'l Symposium on Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors, August 25-29, 1991, Monterey, CA, American Nuclear Society.
- 9 Y. Wada et al., "Hydrazine and Hydrogen Co-injection to Mitigate Stress Corrosion Cracking of Structural Materials in Boiling Water Reactors (IV): Reaction Mechanism and Plant Feasibility Analysis", J. Nucl. Sci. Technol., Vol. 44 [4], pp.607-622 (2007)
- 10 M. Okamura et al., "Corrosion Mitigation of BWR Structural Materials by the Photoelectric Method with TiO₂ – Laboratory Experiments of TiO₂ Effect on ECP Behavior and Materials Integrity", Proc. of the 12th Int. Conf. on Environmental Degradation of Materials in Nuclear Power Systems: Water Reactors (2005)
- 11 NUREG/CR-6923, BNL-NUREG-77111-2006, Expert Panel Report on Proactive Materials Degradation Assessment, Appendix B.10 (by Robin L. Jones, Peter L. Andresen, and Christopher Wood), BWR Water Chemistry: Effects on Materials Degradation and Industry Guide lines":
<http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6923/>
- 12 S. Hettiarachchi (GE Nuclear Energy), "BWR SCC Mitigation Experiences with Hydrogen Water Chemistry", Proceedings of the 12th International Conference on Environmental Degradation of Materials in Nuclear Power System – Water Reactors – 2005:
<http://iweb.tms.org/NM/environddegXII/0685.pdf>

- 13 IAEA NUCLEAR ENERGY SERIES No. NF-T-2.1, Review of Fuel Failures in Water Cooled Reactors, INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2010:
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1445_web.pdf
- 14 EPRI Technical Report 1008103, Assessment of Noble Metal Chemical Addition (NMCA) on Boiling Water Reactor (BWR) Coolant Chemistry and Product Transport on Fuel Surfaces, December, 2004:
<http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=00000000001008103>
- 15 EPRI Product Abstract, Technical Report 1022901, Assessment of Fuel-Cladding Performance in BWRs Operating in On-line NobleChem, 17-May-2011:
<http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=00000000001022901>
- 16 M. Izumiya et al., THE THERMAL AND NUCLEAR POWER, vol.27, No.5, pp.21 (1979). (In Japanese)
- 17 G. Ito, Corrosion Science and Engineering, pp.258 (1979). (In Japanese)
- 18 Atomic Energy Bureau, Science and Technology Agency, "Report of demonstration experiment evaluation committee on PCV spray effect", December 1981. (In Japanese)