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ABSTRACT

Intergranular stress corrosion cracking (IGSCC) is common in boiling water reactor (BWR) components. Corrosion problem is a serious matter that has overwhelmed the light water reactor (LWR) industry for many years. The conditions in which IGSCC takes place due to stress, a sharpened microstructure and an environment that will facilitate the cracking while injecting H₂ into the feed water system. Nuclear reactor made up of stainless steel facing serious Intergranular stress corrosion cracking due to the injection of hydrogen dosage into the nuclear reactor in the form of heavy water chemistry. Moderately large concentrations of H₂ may be essential in nuclear power plants to bring the ECP below the critical value of -230 mV (SHE) to ease Intergranular stress corrosion cracking, which in turn results in an increase of steam line dose rate and shutdown dose rate and hence heavy water chemistry is limited in the nuclear reactor plant. Hence this led to the development of the concept called noble metal chemical addition (NMCA) to control IGSCC even in the presence of H₂. This review gives the insights and development of NMCA on corrosion control in BWRs.

Keywords: Intergranular stress corrosion cracking, Boiling water reactor, Heavy water chemistry, Electrochemical Corrosion Potential, Noble metal chemical addition.

1. INTRODUCTION :

BWR is the second most familiar kind of electricity-generating nuclear reactor, pressurized water reactor (PWR) stands first [1]. Nuclear energy plays a very important role to provide the highest energy to the world. At the end of 2016, there were 450 nuclear power plants operating in 32 countries. These plants report for 17% of the world's electricity [2]. BWR has undergone many chemistry changes as a result of the need to control radiation fields and stress corrosion cracking of reactor internals. Some of the demanding chemistry changes include hydrogen addition, zinc addition, iron addition and noble metal chemical addition to many of the modern day operating BWRs [3]. Injection of Hydrogen to feed water structure in BWR is one of the current cases in alliance to water chemistry of primary systems in nuclear reactors [4, 5]. IGSCC of refining type SS 304 has been a most prominent problem in the recirculation piping of BWRs, but corrective methods developed over the past decade have greatly shortened the unscheduled downtime attributed to IGSCC form of corrosion [6].

Corrosion leftovers as one of the major issues in nuclear plant availability, finance, and safety. Several other sources of decline also take place. Most related incidents appeared in the stainless steel pipe, reactor internals and other components such as due to containment results in localized corrosion and in particular IGSCC in BWRs. Nuclear reactor operation in the USA faced powerful contraction due to IGSCC of recirculation system piping resulting in maximal loss of about 15% in 1984. Cracking of pipe in BWR results in a loss of more than 3 billion dollars in the USA from the detailed conclusion which crossed 1000 million [7]. To increase the performance of HWC in a BWR, noble metal treatment technique is introduced. It is helpful in the form of a noble metal spray coating or noble metal chemical addition. The efficient dosage of hydrogen requirement is less to achieve the IGSCC protection an identical degree of IGSCC that found under HWC alone and thus minimization of radiation levels in the planar is possible by the noble metal treatment technique. At present NMCA has been applied to more than dozen of BWRs and with a low level of HWC worldwide [8]. Results

also show a pleasing ECP drop in a BWR with a heavy noble metal coating and a low-level HWC [9]. Electrochemical corrosion potential is also called as rest potential or open circuit potential. It is represented by E_{corr} . ECP is the voltage differences between a metal dipped in a given environment and an appropriate standard reference electrode.

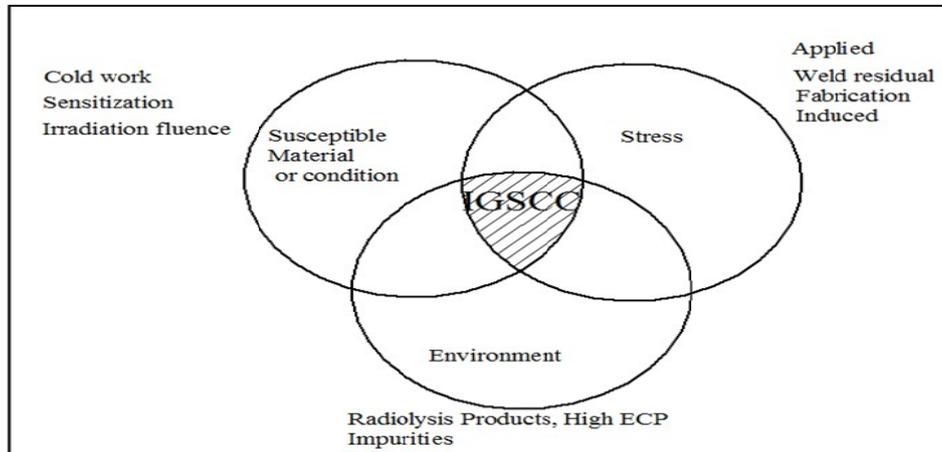


Fig. 1: The three conjoint factors necessary for producing IGSCC in BWRs (Klepfer et al., 1975 [1])

2. OBJECTIVE :

This review paper consists of collective information of Inter granular stress corrosion cracking taking place in Boiler water reactor which is used for the generation of electricity. Corrosion prevention was done by noble metal coating on stainless steel by reducing the dosage of hydrogen requirement in BWR. Large number of successful results was carried out to prevent IGSCC by noble metal coating and thereby decreasing the addition of hydrogen in water level (Feed water H_2 concentration) to 0.2 ppm to 0.3 ppm and in turn reduces the risks of steam line dosage rate in BWR.

3. BOILING WATER REACTOR :

Boiling Water Reactor (BWR) technology is well established in several parts of the world over the past few decades. BWR is the source of the second most familiar kind of electricity-generating nuclear reactor, pressurized water reactor stands first. At present they are 95 BWR's in the world. Most of them are owned by the USA, followed by Japan Most of them are operated, maintained and administered by the central government of the nation. In the earlier 1950s, Argonne National Laboratory and General Electric (GE) are the leading manufacturers of BWR. Presently BWR is developed by GE Hitachi Nuclear Energy, known for specializes in the design and construction [1]. Nuclear energy is a significant source of power worldwide. In the United States, commercial nuclear power plants provide approximately 20% of the consumed energy.

The main difference between BWR and PWR is, in BWR the reactor heats the water and turns directly into steam. The steam drives a steam turbine, which spins a generator to produce power. But in the case of PWR, the water in the reactor is pressurized so it doesn't boil. This heated water then passes through heat contacts called a steam generator. The heat from the steam than converts another loop of water to steam, which drives the turbine to produce power as shown in Figure 2 [1].

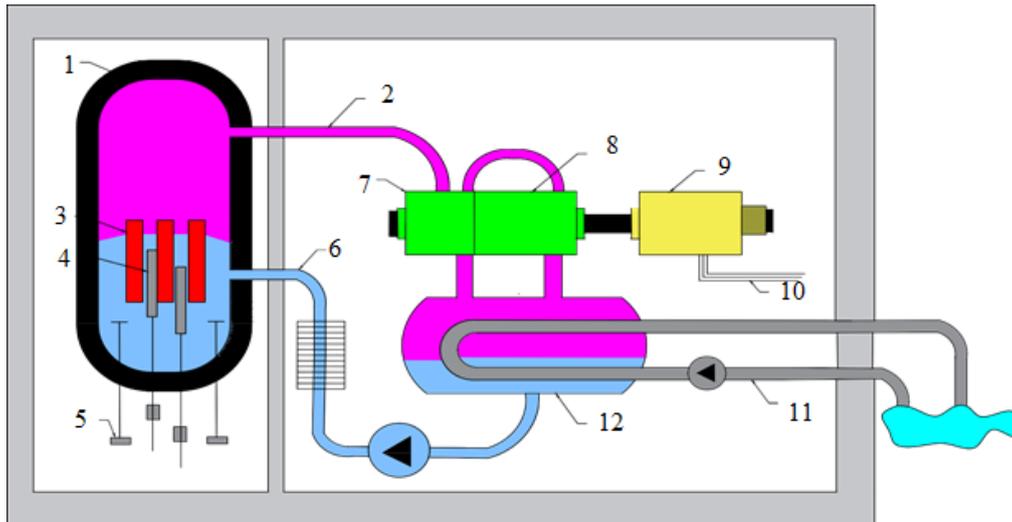


Fig.2 : Schematic diagram of a boiling water reactor (Reproduced from BWR Wikipedia).

1. Reactor pressure vessel.
2. Steam.
3. Nuclear fuel elements.
4. Control rods.
5. Recirculation pumps.
6. Feed water.
7. High pressure turbine.
8. Low pressure turbine.
9. Generator.
10. Connection to electricity grid.
11. Coolant.
12. Condenser.

4. RESULTS :

Noble metal chemical addition: The NMCA technology involves in injections of noble metal (Pt, Rh) compounds into the reactor water, which results in the deposition of particles of these metals on the surfaces in contact with this water. The claim can be performed at the close of a cycle during the cooling phase (classic NMCA) or during operation at full power and is then termed on-line NMCA or OLNCA (Online noble metal coating) for short [16]. The entire process is maintained during hot standby at a temperature in the range of 125 to 143°C under the conditions of the shutdown cooling system or under steaming mode. Is a catalytic method when noble metal particles of nano-meter size deposited on all wetted surfaces. Thus, when excess hydrogen is added into the reactor feed water, component surfaces have basically zero oxygen on the surfaces because of the rapid catalytic recombination of hydrogen and oxidants in the form peroxides (O_2 and H_2O_2). This process lowers the ECP of components to the desired HWC specification potential of < -230 mV(SHE) at low feedwater hydrogen concentrations, thereby largely eliminating one of the side effects of HWC, i.e. operating dose rate increases due to ^{16}N . Details of typical NMCA applications are described elsewhere [10, 11]. An example of an effective ECP reduction following NMCA is shown in Figure 3.

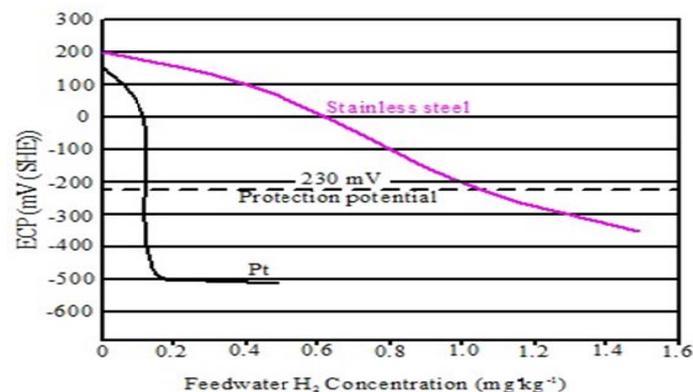


Fig. 3: Variation of corrosion potential of stainless steel as a function of feed water Hydrogen concentration.

Corrosion potential is the main major problem responsible for the IGSCC when exposure of materials of the reactor to the high temperature. Hydrogen addition can reduce the stress corrosion in LWRs. But in some cases of plants, corrosion in potential is high due to hydrogen addition into the core part is high. And hence more hydrogen addition is needed to reduce the potential of corrosion. But it noticed that extra dosage of hydrogen increases the ^{16}N turbine shine and ^{60}Co deposition, proceeded in some cases. A tactic involving noble-metal coatings on and alloying additions to engineering things theatrically improve the competence with which the corrosion potential is decreased as a purpose of hydrogen addition, such that very low corrosion potentials are obtained once a stoichiometric focus of hydrogen (versus oxygen) is achieved [15]. ECP measurements in BWR plants to mitigate IGSCC which are performed in BWR-3 and BWR-4. It is established that the ECP is reduced to $<-200\text{mV}$ (SHE) by 0.9 ppm H_2 concentration at feed water in BWR-3 and 1.1 ppm H_2 concentration at feed water in BWR-4, and that the ECP can be reduced to $<-200\text{mV}$ (SHE) by 0.3 ppm or less H_2 concentration after NMCA is applied [17].

4.1 Noble Metal Applications in BWR

Methods to ease SCC and IGSCC in susceptible reactor apparatuses can be divided into two main categories, depending on whether they take place outside or inside the reactor system. The following are the requirements formulated to mitigate the corrosion when noble metal coating is applied to the reactor components [18].

- Gives good adherent and durable coating,
- Deposition is more even on all components,
- Hydrogen embrittlement is avoided,
- There is no negative impact on the operation procedure of the reactor,
- No introduction of harmful ions and adverse effect on fuel elements,
- No increase in ^{16}N volatility and steam line dosage rate,
- The shutdown dose rate decreases because there will no accumulation of Cobalt-60 in the recirculation piping,

5. IGSCC IN AUSTENITIC STAINLESS STEEL :

The occurrence of SCC is imaginary because SCC is an intensively threatening form of corrosion taking place in a nuclear power plant. SCC is frequently checked along the grain boundaries (Intergranular) or through the grains (trans-granular). SCC is commonly noticed in the presence of either hydrogen inactive region or oxygen intrapassive region in the high-temperature water system [12]. Some of the factors such as chloride, bromide, and sulfide are detrimental anions and also when a metal or alloy is subjected to tensile stress in a corrosive environment medium leads to SCC. If the stress level is more, the chemical combativeness of the solution does not need to be so high to result in SCC, but if the environment is highly corrosive than low values of stress can result in SCC and this

commonly leads to leakage of entire reactor finally. The conditions necessary to promote Intergranular stress corrosion cracking (IGSCC) include

1. A susceptible material microstructure.
2. Sufficiently corrosive environment.
3. The presence of tensile stresses [13].

BWR pipe cracking was first observed in small diameter (< 25 cm) recirculation lines nearly 30 years ago, but did not become a significant concern until 1974 [14]. A few years later, cracking was also detected in the more critical large diameter (> 60 cm) recirculation systems. The problem of restoration of these cracking lines was greatly more challenging and valuable. IGSCC is one of the serious issues in the lightweight reactor in the name of corrosion, as a result of this wide range of elementary and useful investigation were carried out to develop a systematic knowledge of IGSCC development and, more importantly, detect corrective movements to progress the performance of previous components and new remedial measures to certify cracking resistance for new piping systems. For the most part, these research activities were highly successful [14]. IGSCC features also depend on nature (external or internal) of the stress application. For SCC tests, cracks mainly propagate perpendicularly to the tensile direction Figure 4.

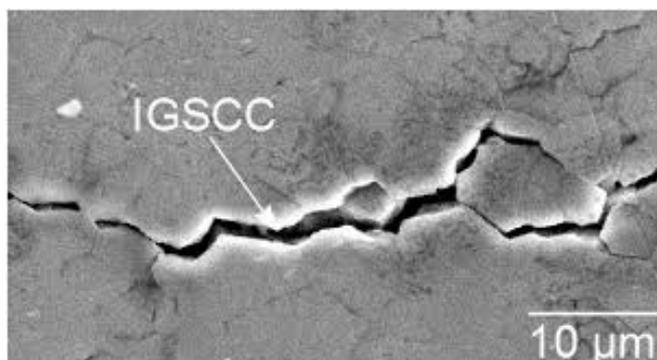


Fig. 4: SEM image taken after the corrosion test (M. Dhondt et al., 2015)

6. CONCLUSION :

The rate of corrosion is one of the major issues in nuclear power plant and hence it results in severe damage and replacement of the pipes and reactors vessels. Noble metals addition plays a vital role in corrosion control and minimizes the hydrogen dosing in requirements which results in decreases in the radiation effect inside the nuclear power reactor. Hence, a decrease in the IGSCC observed over from past 12 years by adopting proper remedies. The corrosion of stainless steel piping in nuclear power plants due to IGSCC is probably the best understood environmental cracking process and which leads to knowing the basics of considerate general IGSCC development. The concentration of H_2 into the feed water system increases the steam line radiation levels. The lesser the H_2 injection rates the lower the radiation levels. Plating the primary system internals with noble metals allows lower H_2 injection rates without impacting the operation procedure of the nuclear reactor plant.

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