B.18 "Topical Report on Boric Acid Corrosion (BAC)," by Robin L. Jones and John Hickling

Understanding of BAC prior to the 2002 Davis Besse Incident

Corrosion of carbon and low-alloy steel (C&LAS) components by leaking borated water has posed significant maintenance problems for many PWR plants[1]. Two incidents illustrate the potential importance of this problem. In 1980, leakage from the gaskets of two reactor coolant pumps at one plant resulted in severe corrosion to seven coolant pump flange studs. The diameter of the worst-case stud was reduced from its original 3.5 inches (89 mm) to 1.0-1.5 inches (25-38 mm). This represents a reduction to less than 20% of the original stud cross-sectional area. In 1986, leakage from a valve body-to-bonnet gasket at another plant resulted in corrosion that extended two-thirds of the way through the wall thickness of a low-alloy steel nozzle in the main coolant piping system.

Subsequent to these and other significant events, the NRC issued Generic Letter 88-05,[1] requiring operators of PWR-type power plants to develop and implement a plan to ensure that there is an extremely low probability of abnormal leakage, rapidly propagating failure, or gross rupture as a result of boric acid corrosion (BAC) of primary coolant loop components.

EPRI efforts to provide assistance to utilities in addressing the requirements of NRC GL 88-05 and BAC issues in general have centered around the *Boric Acid Corrosion Guidebook,* originally published in 1995 and updated in 2001,[2] which summarized the extent of the BAC problem as recognized at the respective times, as well as compiling and assessing data from previously performed BAC test programs.

Background

Borated water is used in the primary systems of PWR plants to control reactivity during normal plant operation and refueling and under potential accident conditions. This is accomplished by adding boric acid to the primary side water. In some cases, boric acid is also injected into the secondary side of PWR plants at low concentrations to reduce the potential for corrosion of Alloy 600 steam generator tubing at crevice locations.

In general, there is little concern with general corrosion inside the primary and secondary systems since the concentrations of boric acid and oxygen in these systems are low, and corrosion rates are typically less than 0.001 inches per year (in/yr) (0.025 mm/yr). Although C&LAS are not normally exposed directly to PWR primary water, the use of high-alloy materials in contact with the coolant is for reasons of chemistry (including radiation protection) and cleanliness, rather than the avoidance of C&LAS corrosion. In fact, LAS is sometimes exposed as a result of a "half-nozzle" repair to component penetrations and this has been deemed acceptable by the U.S. regulator from a corrosion standpoint.[3]

Exceptions to this generally good experience for materials in intended direct contact with PWR operating media include 1) stress corrosion cracking of some stainless steel pipes containing stagnant, high-concentration boric acid solutions, 2) cracking of stainless steel cladding in some components that leads to galvanically driven stress corrosion cracking (SCC) of the low-alloy steel base materials, and 3) primary water stress corrosion cracking of Alloy 600 nozzle penetrations and welds (considered in a separate topical report).

If borated water leaks from primary and secondary systems through gasketed joints, valve packing, mechanical seals, etc., significant corrosion problems can develop. Specifically, the water can become oxygenated and the boric acid can concentrate as the water boils off or evaporates. These factors can increase the corrosion rate of exposed carbon steel to several inches per year.

The reported plant incidents prior to 2002 ranged in severity from minor corrosion of parts, which can be accepted without evaluation or repair, to major incidents involving plant shutdowns and significant loss of material on major components (see Fig. B.18.1).

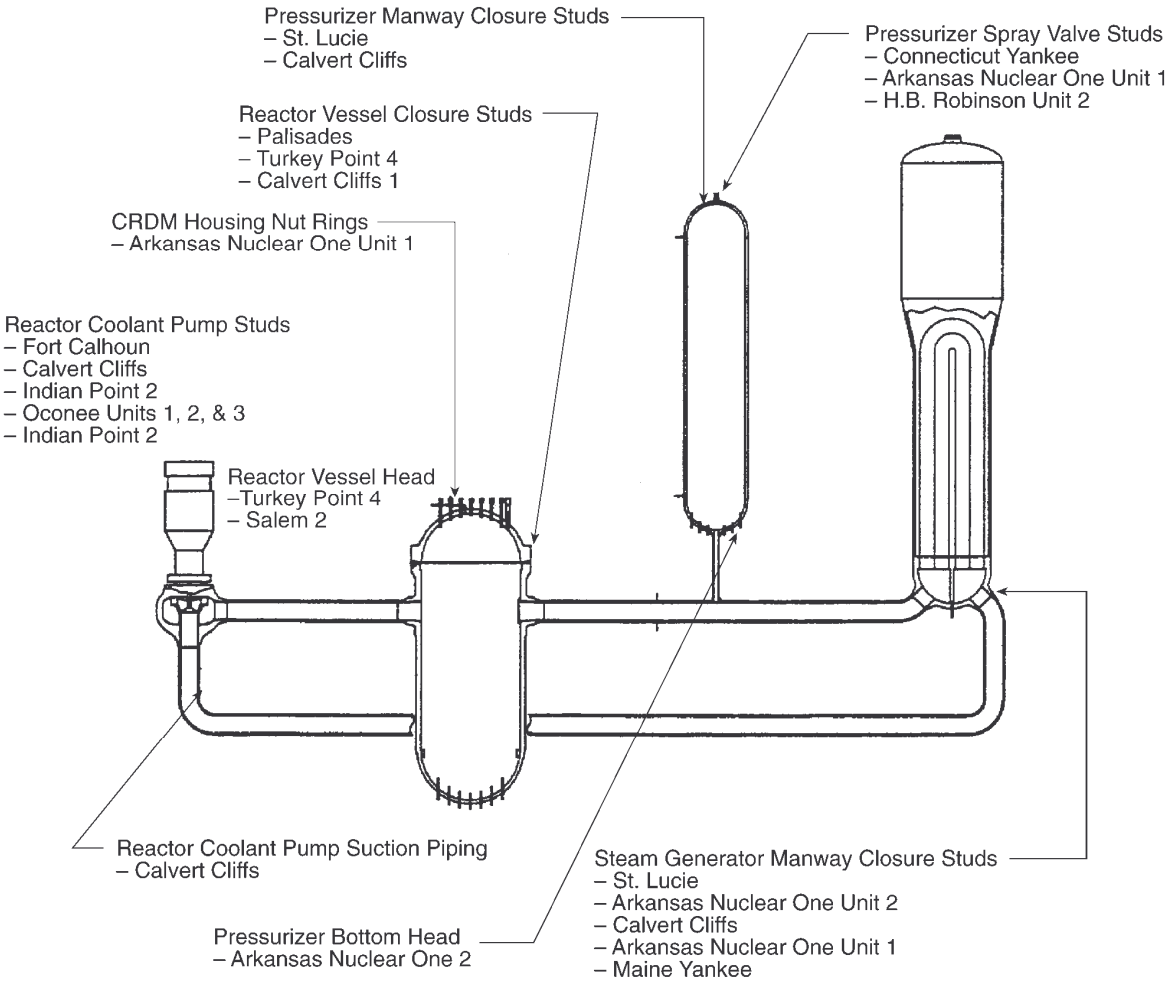


Figure B.18.1 Locations of boric acid corrosion experienced in primary loop[2] *Used by Permission of EPRI.*

Reference 1 required that utilities develop and implement programs to identify leaks and take corrective action to prevent recurrence. All plants have developed programs that respond to this generic letter. Fig. B.18.2 gives some information on the identified sources of leakage.

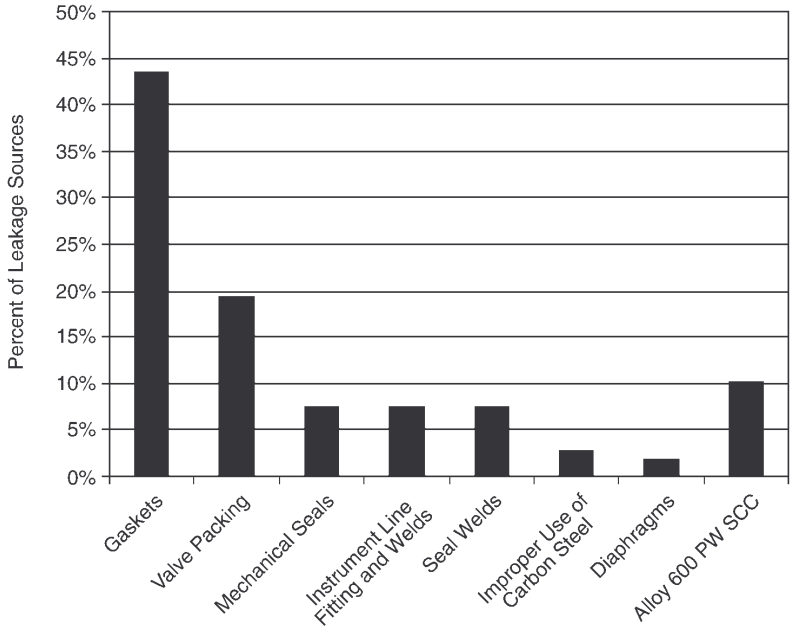


Figure B.18.2 Distribution of reported leakage incidents (US prior to 2002) by source[2]
Used by Permission of EPRI

Main type of boric acid corrosion observed

Overall, the mode of corrosion of greatest concern due to leakage of borated water is uniform corrosion, often referred to by plant engineers as "wastage," of C&LAS. Boric acid in water can result in an aggressive environment that uniformly attacks the surface of the metal. Although boric acid is considered a "weak" acid when compared to acids such as hydrochloric or nitric acid, boric acid in water will still increase the concentration of hydrogen ions (H) and lead to a drop in pH. In reality, the process of surface attack is further accelerated by what amounts to miniature galvanic cells, whereby small areas of the metal surface behave cathodically or anodically due to slight changes in the alloy composition (for example, higher chromium or nickel in steel), surface imperfections or defects, or surface strain. In addition, the corrosion product itself may be cathodic to the surrounding base metal. The anodic/cathodic areas on the metal surface can shift with time, resulting in an essentially uniform rate of attack over the entire metal surface. One of the reasons that the rate of attack of the unprotected, exposed steel can be so great is that the exposed area of the cathodic surfaces often exceeds that of the anodic material.

Surfaces which are corroded generally often exhibit some increase in texture as a result of small differences in the rate at which different areas of the surface are attacked. It is sometimes difficult to detect general corrosion of a surface because there is no clear reference point for assessing the amount of material loss, particularly if the rust is continually solubilized by, or entrained into, the fluid stream.

General corrosion is usually the easiest form of corrosion to predict using experimental data. However, as with all modes of corrosion, the rate can be affected significantly by factors that were not included in the experiments used as the basis for the predictions. Some of these factors are discussed in the following paragraphs.

Effect of Impurities on General Corrosion

When impurities are present in the metal, they may act as the source of local anodes/cathodes and thus accelerate corrosion. If impurities are present in the corrosive medium, they can have a variety of effects on the corrosion rate. Impurities may act to increase the conductivity of the aqueous solution, thereby often increasing corrosion rates, and can also cause increased corrosion rates by affecting or destroying the protective layer of hematite (rust) or other metal oxide that builds up on the exposed surface of the metal, helping to protect it from further damage. In other cases, impurities in the fluid stream can actually help retard corrosion by acting as inhibitors. In any event, the effect of impurities is generally complex and non-linear and must be determined through experiments designed to simulate the actual metal/environment combination.

Effects of Oxygen and pH on General corrosion

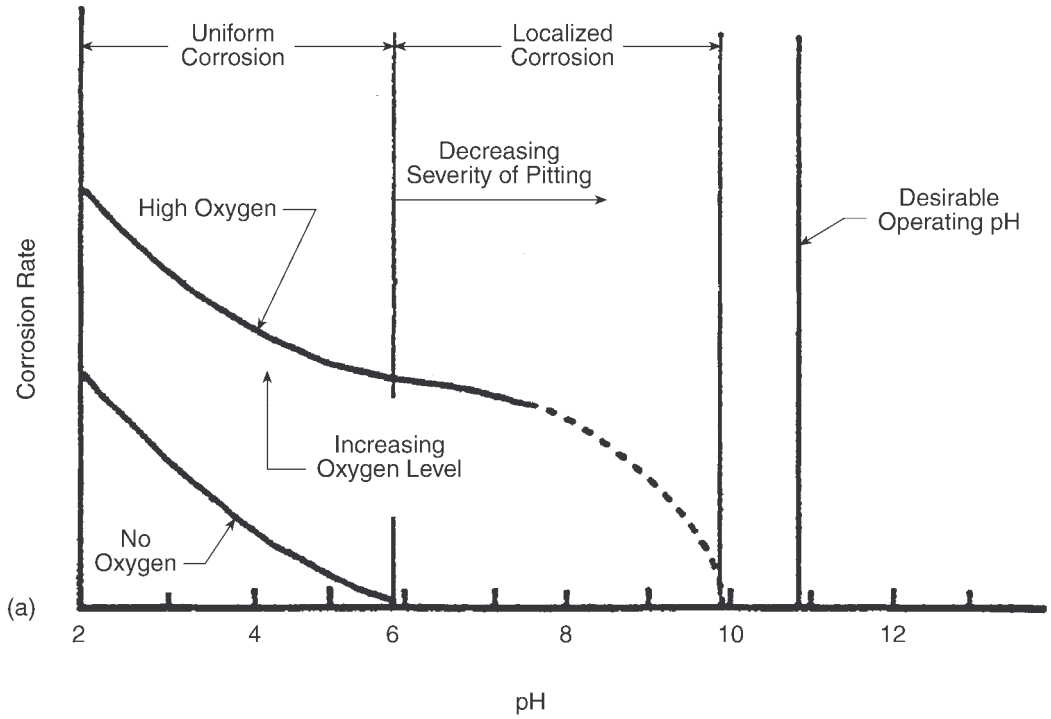
The corrosion of most steels which are soluble in acids depends on pH similar to the pattern shown in Figure B.18.3. In the middle pH range of 4 to 10, the corrosion rate is generally controlled by the rate of diffusion of oxygen to the surface and the insolubility of oxides in oxidizing systems, which increases with increasing electrochemical potential. At lower pH, the uniform corrosion rate increases owing to the progressive increase of oxide solubility in acidic solutions and the increased availability of hydrogen ions for reduction in the cathodic areas. At intermediate pH values, both the rate itself, and the extent to which corrosion becomes non-uniform, are still affected by the concentration of dissolved oxygen (the other main cathodic reactant).

Effect of Temperature on Wastage

In most cases of corrosion in acids, corrosion rates increase with increasing temperature and high enough temperatures also boil the water away, leaving more concentrated acid and thus even higher corrosion rates. However the concentration of dissolved oxygen in the water decreases with increasing temperature, so that the situation is more complex with a weak acid such as that resulting from leakage of primary water. Furthermore, as the temperature continues to increase, the water may be boiled off completely, leaving dry boric acid crystals that are not very corrosive at all.

Effect of Flow Velocity on Wastage

In many of the field reports, general corrosion is accelerated by the impingement of borated water, or steam with boric acid carryover, onto hot metal surfaces. This impingement has the dual effect of removing protective corrosion films from the surface of the metal and replenishing the corrodent with fresh, oxygenated acid. Both of these factors can markedly increase the corrosion rate.



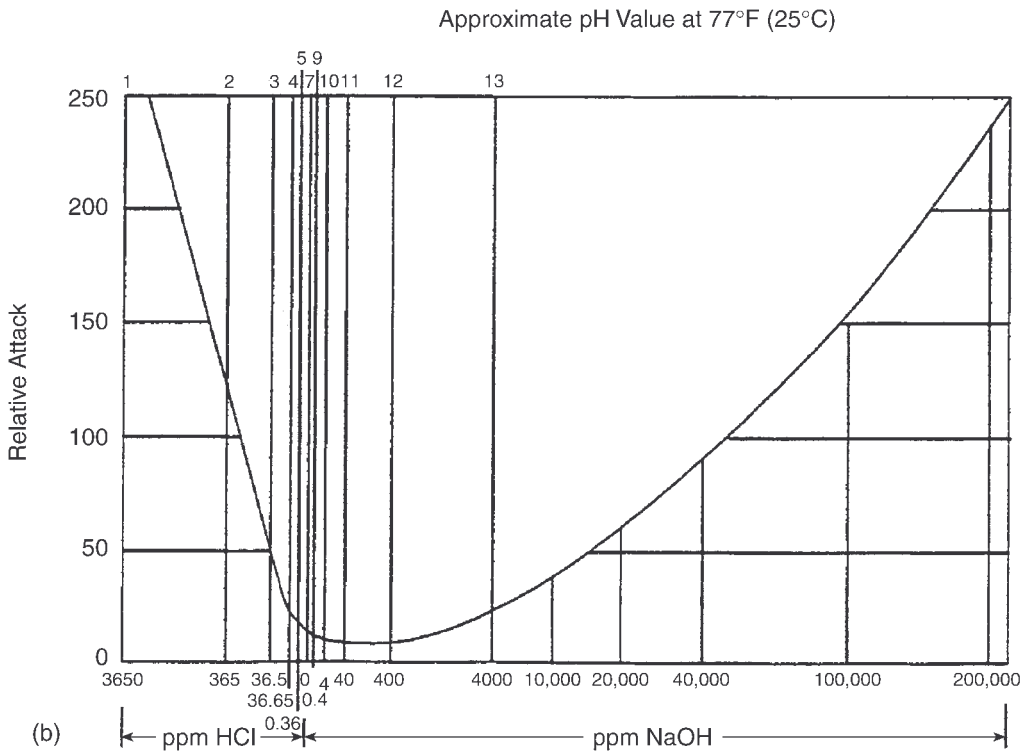


Figure B.18.3 Summary of oxygen and pH effects on general corrosion of iron[4] *Used by Permission of EPRI.*

Secondary Types of Boric Acid Corrosion

In addition to general corrosion (the predominant type of boric acid corrosion), there have been isolated reports of other types of corrosion, such as galvanic corrosion, crevice corrosion, pitting, intergranular attack, and stress corrosion cracking.

Galvanic Corrosion

A practical example of such a condition in an aerated, borated water environment in a PWR plant would be a weld between a low-alloy steel pipe and a stainless steel pipe. The stainless steel is the more noble material, and the low-alloy steel is the more active material. Field experience and laboratory test results both indicate that a galvanic couple between carbon steel and stainless steel can accelerate the local corrosion rate in the carbon steel, typically by about 1.5 times. Therefore, the galvanic effect for BAC can be significant, but is not usually overwhelming and will depend upon pH, boric acid concentration and dissolved oxygen level. It is not expected to be a major factor in deaerated primary water of nominal composition.[3]

Crevice Corrosion

Environmental conditions in a crevice can be significantly different than on adjacent bare metal surfaces. Under many conditions, the environment in the crevice can be more aggressive than outside the crevice, and accelerated local corrosion can take place. Typical crevice locations on the outside surfaces of PWR pressure boundary parts include bolts, washers, and gaskets. Crevice corrosion has not generally been reported to be a significant practical problem in borated water environments on the outside surfaces of PWR components. However, this may not always be the case if the part or component includes crevices.

Both galvanic and crevice effects can become significant in the case of C&LAS exposed to boric acid via a crack or other such defect in a stainless steel or nickel base cladding.

Pitting

Pitting has not generally been reported to be a significant problem in borated water environments on the outside surfaces of PWR components, probably because the conditions under which it might be expected (see Fig. B.18.3) involve higher pH values than would normally be expected for BAC and because boric acid is a buffer that does not support local acidification within an incipient pit.

Intergranular Corrosion

Intergranular corrosion is localized attack along the grain boundaries of a metal or alloy and is most common with stainless steels or nickel-base alloys that are generally resistant to BAC. There are no reports of intergranular corrosion being a significant contributing factor to problems associated with C&LAS corrosion due to leakage of borated water.

Stress Corrosion Cracking

Stress corrosion cracking in the presence of borated water leakage has been reported to be a problem only in the case of highly loaded steam generator manway studs that have been coated with lubricants containing sulfur and is not thought to be associated with boric acid itself. The most celebrated case occurred at Maine Yankee where 6 of 16 studs were found to have failed

after disassembly, and 5 more were found to be cracked. The stress corrosion cracking in this case was attributed to interaction between the leaking borated water, leak sealant, and sulfur-containing thread lubricant. This experience identified the need to minimize the use of sulfur-containing compounds around pressure boundary parts.

Summary of Corrosion Rates for Various Situations

Figure B.18.4 summarizes the results for all of the corrosion tests reported in reference 2 and points out the main areas of interest. Briefly summarizing the key points:

Corrosion rates for immersion in deaerated, dilute boric acid solutions are usually quite low regardless of temperature. Moderate corrosion rates, between 0.02 and 0.05 in/yr (0.5 and 1.3 mm/yr), have typically been measured[a] during immersion in deaerated, concentrated boric acid solutions.

For cases involving immersion in aerated borated water, corrosion rates are in the range of 0.001–0.01 in/yr (0.025–0.25 mm/yr) for low concentrations at room temperature and increase to a maximum of 1–10 in/yr (25–254 mm/yr) for high concentrations at 200–220°F (93–104°C).

The main problem regarding borated water dripping on hot metal surfaces is that the solution can concentrate as the water boils off and the boiling can lower the local metal temperature to the boiling point (212–230°F [100–110°C]) of the concentrated boric acid solution, thus avoiding dry-out. Therefore, the typical situation is to have concentrated boric acid at around 212–220°F (100–104°C), which is the point of the maximum corrosion rate. However, if the metal surfaces are hot and the leakage rate sufficiently low, the water evaporates rapidly, leaving dry boric acid crystals that cause essentially no corrosion. Lower corrosion rates are expected when the surfaces onto which the borated water is dripping are below the boiling point of the borated water.

If borated steam impinges on hot metal surfaces, the corrosion rates can be very high as a result of the combination of high concentration, local metal temperatures near the boiling point of the borated water, and some mechanical effects due to the flow impingement. This condition can be highly damaging as evidenced by several cases involving rapid stud corrosion.

Laboratory results suggest that borated water leaking from a PWSCC-type crack should not cause corrosion deep in the annular clearance gap to the vessel shell since there is little oxygen at this location. However, tests with upward-pointing nozzles suggest that corrosion rates exceeding 1 in/yr (25 mm/yr) are possible. It is not yet clear if these test data are directly relevant to CRDM penetrations in the RPV head.

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[a] Note, however, that ongoing work referred to later in this topical paper appears to suggest that these values can be exceeded under certain circumstances.

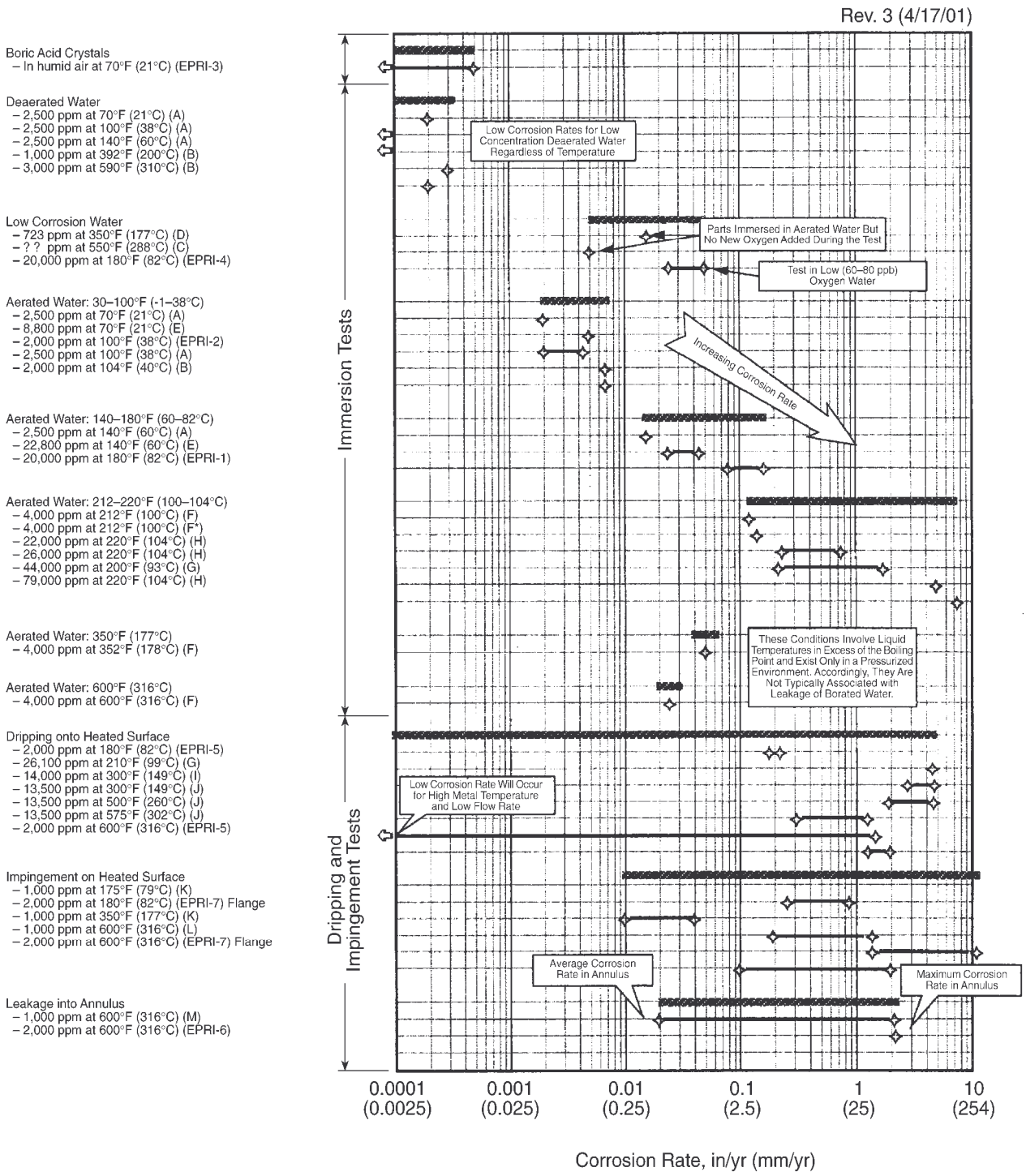

Figure B.18.4 Summary of corrosion tests on BAC of C&LAS prior to 2002[2] *Used by Permission of EPRI.*

BAC management programs at U.S. PWRs

The first level of protection against boric acid corrosion should be to prevent leaks from occurring in the first place. If there is no leakage, there will be no boric acid corrosion.

Detecting and preventing leakage

The requirements of the Code of Federal Regulation, the NRC, and the ASME Boiler and Pressure Vessel Code are remarkably similar as they apply to leakage from reactor coolant systems. The common themes in these requirements are:

- Closures should be designed to have a low risk of leakage.
- Closure designs and materials should be such that there is a low risk of rupture or abnormally high leakage.
- Closures should be fabricated and assembled to have a low risk of leakage.
- Inspection programs should be developed and implemented to find leakage and to determine other areas where the leakage could have flowed or accumulated.
- Corrective action should be implemented to correct situations where leakage has occurred.

The NRC is prepared to grant relief from the ASME Code requirements to remove insulation during the final VT-2 inspections of insulated flanges. However, several reasonable concessions have to be made to obtain the relief.

In most cases, the technical means for reducing leakage are not difficult. However, developing an effective program for reducing leakage risk from the many possible sources requires concerted effort by both plant management and staff. A major key to cost effective leakage reduction is to start with state-of-the-art procedures and materials that are capable of developing high-integrity joints and then train craft personnel to follow the procedures and identify adverse conditions.[5] EPRI sponsors a Fluid Sealing Technology Working Group where utilities meet on a regular basis to review the results of relevant research, discuss plant-specific leakage problems, obtain complementary information on current areas of research from sealing technology vendors, and establish priorities for further leakage reduction activities.

A more problematic source of leakage is through-wall cracks which can develop under certain circumstances in reactor components themselves. For example, there have been many reported cases of leakage of primary water from primary water stress corrosion cracks (PWSCC) in Alloy 600 nozzles attached to pressure boundary parts by partial penetration J-groove welds.[6,7] Another major source of leakage of primary coolant above the RPV has been transgranular SCC in stainless steel canopy welds.[8]

Preventing Degradation If Leaks Occur

The consequences of leakage in both joint fasteners themselves and adjacent components can often be reduced by replacing the carbon steel or low-alloy steel parts with more corrosion-resistant materials or diverting any leakage to areas where it will not cause damage (e.g., by installing protective shrouds).

The primary emphasis should always be on preventing leakage from occurring in the first place and then stopping leaks when they are found by retightening joints, injecting sealants, and other similar procedures. In some cases, however, it may be necessary to continue operating a plant with leakage and/or continuing degradation. A prime reason is that leakage may be discovered during plant operation, and it may be desirable to defer maintenance until the next scheduled refueling outage so that the repairs will not result in a power decrease or plant shutdown. In other cases, it may be desirable to defer repairs for problems discovered during a refueling outage due to a lack of parts, or for other reasons. In either case, a justification for continued operation (JCO) with the leakage and/or degradation must be prepared and Reference 2 describes a recommended methodology for this. The level of effort in developing the JCO will depend upon the criticality of the affected parts. Preparation of a JCO for operation with a small leaking valve in an isolable line requires significantly less effort than a JCO for continued operation with a leaking reactor coolant pump flange gasket.

Condition monitoring

A key factor in a successful boric acid corrosion management program is sound condition monitoring. This includes both equipment condition assessment and leakage detection. Information on equipment condition can lead to improvements that can reduce the potential for leakage. For example, potentially detrimental effects of smooth flanges, gouged flanges, out-of-flat flanges, misalignment, damaged valve stems, damaged or corroded bolts, etc., can be rectified and, thereby, reduce the potential for leakage. Similarly, low levels of plant leakage and a good leakage detection system can improve the ability to detect leaks early enough to take corrective action before more drastic measures are required. Enhanced monitoring for leakage may be advisable under certain circumstances and various systems are now available for this purpose.[9]

Ongoing BAC activities following the 2002 Davis Besse incident

Background

Between November 2000 and April 2001, leaks were discovered from reactor vessel top head penetrations at Arkansas Nuclear One-1 and Oconee 1,2: and 3. The leaks were discovered by visual inspections of the heads, which showed small amounts of boric acid crystal deposits ("popcorn" – see Fig. B.18.5) that were determined to have come from the annulus between the nozzles and the vessel head. The CRDM nozzle leaks were traced to predominantly axial PWSCC cracks in the Alloy 600 material of the head penetrations.

In August 2001, the NRC issued Bulletin 2001-01 requesting that PWR licensees provide information related to the structural integrity of the RPV head penetration nozzles, including the extent of nozzle leakage and cracking found. In response to this NRC bulletin, PWR licensees performed bare metal visual inspections of the RPV head looking for boric acid deposits adjacent to RPV head penetrations. An extensive safety analysis was also carried out to demonstrate that structural integrity was maintained, even with leaking CRDM penetrations.[10] The extent and way in which head penetrations of PWR vessels are inspected to detect boric acid leakage have also now been refined and details of current practices are contained in Reference 11.[11]

Figure B.18.5 Typical appearance of boric acid deposits (without wastage) at a leaking Alloy 600 CRDM penetration in a RPV head. *Used by Permission of EPRI*

In March 2002, in conjunction with an earlier inspection regime, the Davis-Besse (D-B) plant discovered evidence of significant wastage of the low alloy steel head contiguous to CRDM nozzle #3 (see Figs. B.18.6 & 7) and much less substantial wastage adjacent to other CRDM nozzles. The extent of the corrosion at nozzle #3 was completely unanticipated given the results of previous head inspections there and at other plants which had shown small volumes of leakage from a few nozzles, but little evidence of corrosion of the low-alloy steel head.

Figure B.18.6 Cavity in RPV head at D-B after removal of CRDM nozzle #3

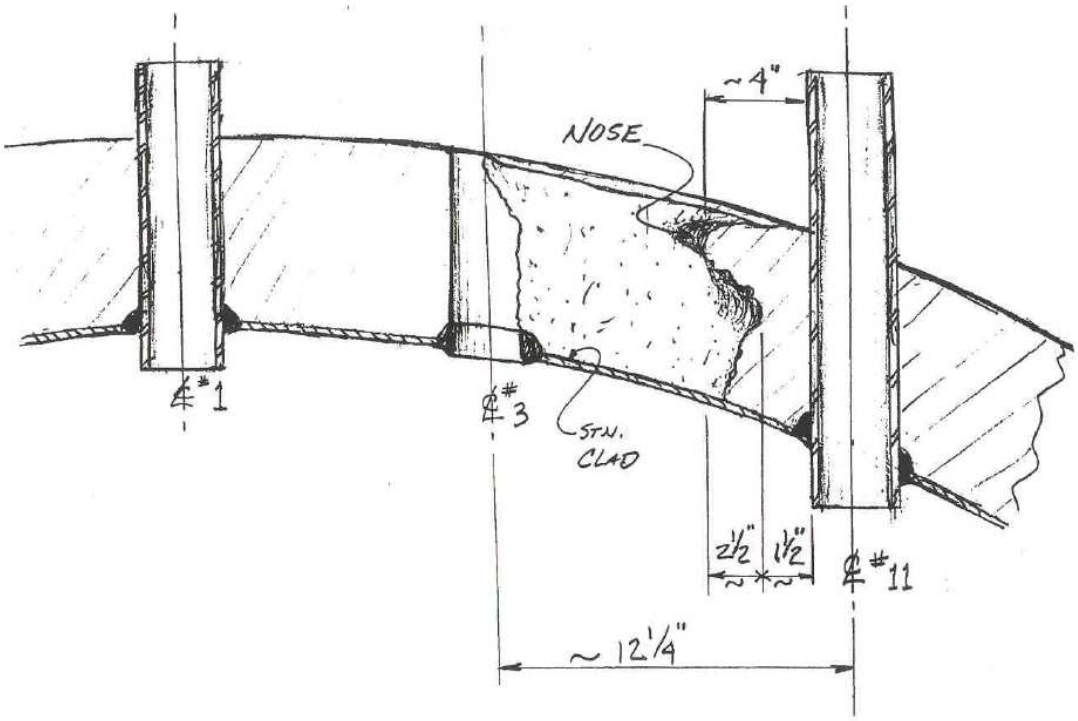

Figure B.18.7 Sketch of D-B RPV head degradation between nozzles 3 and 11

In response to the findings at D-B, the NRC issued Bulletin 2002-01 focusing on the integrity of the reactor coolant pressure boundary including the reactor pressure vessel head and the extent to which inspections have been undertaken to identify corrosion of the RPV head.

Analysis carried out to understand the severe BAC in the D-B RPV head

Reference 2 is a relatively comprehensive source document with regard to managing boric acid corrosion issues at PWR stations. Care is needed, however, in interpreting its content with regard to the way in which PWR primary coolant might attack the LAS of the vessel head if it leaks from a through-wall SCC crack in an adjacent Alloy 600 penetration tube. At the point in time where a tight, highly-branched, intergranular crack in the Alloy 600 material (or interdendritic crack in the J-groove weld) first intersects the outer surface of the high-alloy material, the leakage rate will be extremely low, irrespective of the annulus geometry (i.e. interference fit or radial gap). Thus the pressure drop to saturated vapor pressure will occur within the stress corrosion crack itself and the environment immediately above the J-weld is likely to be hydrogenated, superheated steam. As the leakage rate into the annulus from SCC of the high-alloy material increases, boiling (and possible concentration) of primary water will occur within the annulus itself, i.e. external to the crack or cracks. The exact location of the boiling transition and the extent of concentration near the liquid/vapor interface will be a complex function of the crack and annulus geometries.

In considering the composition of the liquid formed with regard to its propensity to initiate OD SCC of the CRDM penetration, the MRP Expert Panel on PWSCC considered that it would most likely to be buffered to a pH close to that of normal PWR primary water [12] as a result of precipitation of various boron compounds (including iron metaborate arising from corrosion of the LAS). It was agreed that back diffusion of oxygen into the crevice environment could be disregarded for a number of reasons (steam counterflow, hydrogen concentration, etc.), even without taking into account the gettering effect of corrosion at the LAS crevice wall. This scenario would appear to describe the situation at most leaking CRDM nozzles (including those at D-B apart from #3), where little or no wastage corrosion of the RPV head material has been observed.

To account for the development of the cavity found at D-B adjacent to leaking nozzle #3, a large number of potential BAC mechanisms (and their complex interaction over time) have been postulated,[13] as illustrated by the preliminary analysis shown in Figs. B.18.8 and 9.

The initial industry model ("top-down" corrosion – see Appendix C of Reference 14[14]) concentrated on the formation of a pool of highly concentrated boric acid on the top of the RPV head adjacent to nozzle #3 due to the ready supply of boric acid (from pre-existing deposits on the head) and local cooling of the metal so as to maintain an acidic pool of aerated liquid, despite the high temperature of the rest of the head. Independent thermohydraulic analyses confirmed that such a scenario is indeed viable, once the leakage rate of primary water through a cracked nozzle is sufficiently high, although some of the assumptions made in the calculations (e.g. with regard to the effective cross-sectional area of the PWSCC cracks in the nozzle material) require experimental verification. However, it was considered likely that flow and impingement effects adjacent to the liquid exiting the SCC cracks might also be involved. Furthermore, a possible role of LAS corrosion in "molten" boric acid within the deposits was recognized.

PRELIMINARY		Extent of Wastage			
		Initial Tight Annulus	Enlarged Annulus	Small Cavity	Large Cavity
Rough Progression of Mechanisms	Low-Oxygen Boric Acid Corrosion Conc. Boric Acid Corrosion but $DO_2 \approx$ 0-10 ppb	Low rates	Low rates	Low rates	Low rates
	Dry BA or Boric Oxide Crystal Corrosion Corrosion in Contact with Dry Crystals and Humidity	Low rates	Low rates	Low rates	Low rates
	Steam Cutting Single-Phase Erosion	Yes for high leak rates	Less likely than for tight	Less likely than for tight	Large flow area
	Flow Accelerated Corrosion (FAC) Low-Oxygen Dissolution through Surface Oxides	Possible if liquid velocities high enough	Possible if liquid velocities high enough	Possible if liquid velocities high enough	Oxygen stabilizes films
	Impingement / Flashing-Induced Erosion Droplet and Particle Impact Opposite Crack Outlet	Possible if droplets right size and momentum	Possible if droplets right size and momentum	Possible if droplets right size and momentum	Possible if droplets right size and momentum
	Crevice Corrosion Liquid Ionic Path from Top Head Surface	Possible if liquid at mouth	Possible if liquid at mouth	Possible if liquid at mouth	No crevice geometry
	Galvanic Corrosion Corrosion Driven by EMF Between Dissimilar Metals	Possible if liquid at mouth	Possible if liquid at mouth	Possible if liquid at mouth	No crevice geometry
	"Molten" Boric Acid Corrosion Corrosion in Pure or Nearly Pure Melted BA Crystals	Possible on top head surface	Possible on top head surface	Possible	Possible
	Boric Acid Corrosion (BAC) with Oxygen Concentrated Boric Acid Solution with Oxygen	No oxygen in crevice	Unlikely	Possibly	1-5 inches per year

Figure B.18.8 Preliminary analysis of possible BAC mechanisms to cause D-B cavity[13]

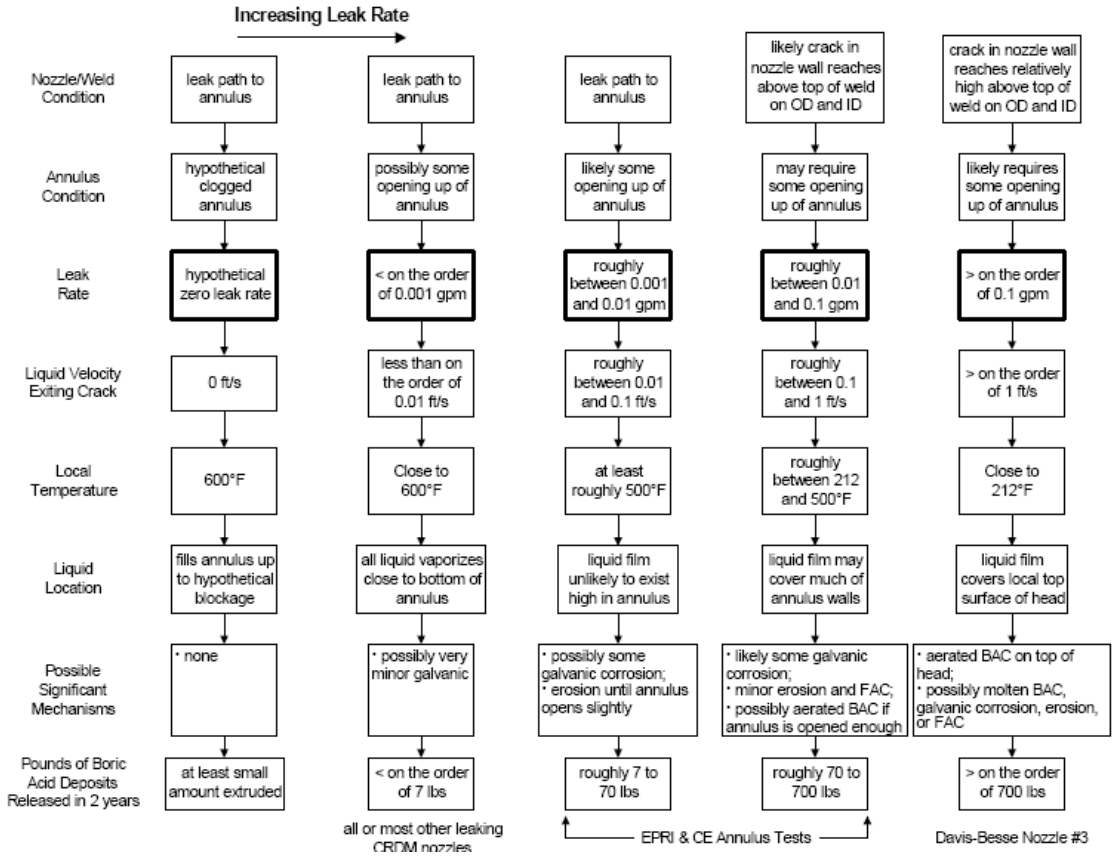

Figure B.18.9 Postulated progression of degradation with leak rate as main parameter[13]

Additional experimental work on BAC following the D-B incident

- Both the US PWR industry and NRC Research have initiated major programs on BAC since 2002, the results of which have yet to be fully reported.[b] The EPRI-managed program is structured to

    - improve understanding of the progression of boric acid wastage at RPV head penetrations,

    - identify the influence of plant specific parameters on wastage, and

    - support development of required inspection intervals for PWR plants with various penetration designs.

It consists of 4 main tasks, as shown schematically in Fig. B.18.10, culminating in an instrumented, full-scale RPV head penetration mock-up test (due to start in 2005):

Task 1: Corrosion tests in stagnant and low flowing (<0.005 gpm) primary water, simulating early stages of CRDM penetration degradation.[15]

Task 2: Corrosion tests in flowing primary water, with measurement of real time corrosion rate and ECP under laminar and impact flow.[16]

Task 3: Testing focused on a matrix of laboratory immersion corrosion, autoclave chemistry, and electrochemical polarization curve tests for concentrated boric acid and wetted molten boric acid environments.[15]

Task 4: Full-scale mockup tests for CRDM nozzles (planned examination of synergies considering the detailed results from Tasks 1, 2, and 3).

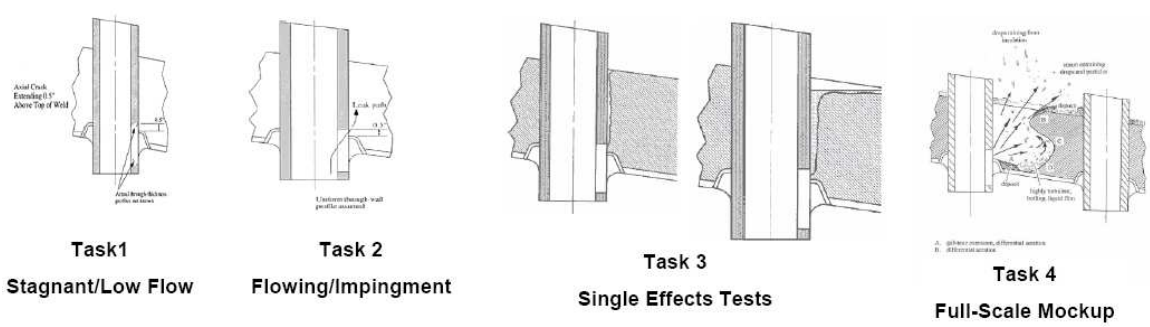

Figure B.18.10 Schematic of additional industry BAC testing program started in 2003

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[b] Since the initial preparation of this paper, the NRC research results have been reported in NUREG/CR-6875 "Boric Acid Corrosion of Light Water Reactor Pressure Vessel Materials," by J.H. Park, O.K. Chopra, K. Natesan, and W. J. Shack, July 2005.

At the time of writing (March 2005), some initial results from Task 3 have been publicly reported[17] with the following preliminary conclusions:

- Corrosion rates up to about 6 inches/yr were observed for the laboratory conditions tested.
- Corrosion was significantly slowed by the presence of lithium, with the effect being most apparent at high temperatures.
- Corrosion was greatest at intermediate temperatures and boric acid concentrations (50%, versus 1% or 90%).
- For high boric acid concentrations, no large reduction in corrosion rate due to deaeration was observed for the laboratory conditions tested
- pH measurements will be used to verify that this is due to low pH.
- Corrosion rates under deoxygenated conditions were about half to two-thirds of the rate under the corresponding oxygenated conditions.
- No significant acceleration was noted due to galvanic coupling or crevices.

The NRC experimental program at ANL has been completed and preliminary results, together with a survey of BAC plant experience and some analysis of the most likely scenario at D-B, are given in reference.[18] The authors conclude, "The galvanic difference between A533 Grade B steel, Alloy 600, and 308 stainless steel is not significant enough to consider galvanic corrosion as a strong contributor to the overall boric acid corrosion process." In addition, the NRC test program has found that the corrosion rate of A533 Grade B steel in contact with molten salts of the H-B-O system at 150°C to 170°C can be as great as that of A533 Grade B steel in contact with an aqueous, aerated solution of boric acid at temperatures near the boiling point, although the MRP test program suggests that this situation may not be applicable to operating plants.[17]

Finally, it should be mentioned that a full-scale destructive examination of the D-B RPV head cavity has now been carried out. These results were recently reported.[19]

Improvements to plant BAC management programs

Subsequent to the D-B incident, considerable attention has been paid to the way in which monitoring for BAC leakage is actually being carried out at operating plants [20] and revised "best practice" guidance is currently being put into effect within the industry.[21] The American Society of Mechanical Engineers (ASME) has also approved a 7/5/05 Code Case N-722 “Additional Examinations for PWR Pressure Retaining Welds in Class 1 Components Fabricated with Alloy 600/82/182 Materials.”

References for B.18

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