

Current Materials Issues in U.S. Nuclear Power Plants

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Abstract: *Materials issues are not new at U.S. nuclear power stations. The industry has mounted largely successful campaigns to mitigate or repair defects in both PWRs and BWRs. However, recent materials issues have challenged the approach to managing Alloy 600 and related alloys in the reactor coolant system. The current unified effort to create a new strategy for managing materials issues is outlined.*

Introduction

Since the early 1970s, the worldwide nuclear industry has been coping with various materials issues in the components of the primary systems of both pressurized water reactors (PWRs) and boiling water reactors (BWRs). This paper reviews the programs developed to cope with the various forms of defects in the primary system components and their internal structures.

PWR Materials Issues Background

Steam generators of PWRs exhibited early degradation which manifested itself in wastage, tube denting and stress corrosion cracking. Materials research data available to the industry gave limited insights and there was limited

information available on the actual nature of the defects. Preliminary conclusions attributed the degradation to condenser in-leakage and ineffective secondary chemistry control. At that time, the prevalent form of chemistry control for recirculating steam generator PWRs was phosphate chemistry.

The industry, through ad hoc meetings and information sharing forums, recognized that mutual efforts and collaborative research efforts were required to obtain the information necessary to adequately manage the materials issue related to steam generator tubing. In 1977, the PWR owners created the Steam Generators Owners' Group (SGOG) and gained participation from PWR owners in Europe and Japan. A five-year program

was developed to gain data on mechanisms which created tube defects and means to detect and repair these defects. Early work identified that the defects resulted from a complex interaction of systems and disciplines including mechanical design and properties, thermal-hydraulic design and operation, water chemistry, metallurgy and plant operation. That initial program led to guidelines in the areas of water chemistry, inspection, repair (tube plugging) and replacement.

The industry followed up the five-year SGOG program with SGOG II in 1983 to deal with the continuing emerging challenges. Steam generator replacements were underway at Surry and Turkey Point where thermally treated Alloy 600 tubes were used, replacing the mill annealed Alloy 600 tubes used in the original steam generators. In 1987, the SGOG transitioned to the Steam Generator Reliability Project under the auspices of the Electric Power Research Institute (EPRI). Inspection and repair techniques continued to improve and the thresholds of detectability increased. However, circumferential cracking joined the more prevalent axial cracking and steam generator replacement projects increased in number. Alloy 690 emerged as the preferred tubing material for replacement steam generators (RSG). However, by and large, the various steam generator programs have been successful in managing the defect populations in steam generators with Alloy 600 tubing, until tube plugging reached the point where derating, or the prospect of derating, created an economic justification for replacement.

BWR Material Issues Background

Materials issues were slower to emerge in BWRs but by the early 1980s were threatening operations. Problems with intergranular stress corrosion cracking (IGSCC) in BWR reactor recirculation system piping required the development of new inspection and assessment techniques, mitigation measures, repair strategies and replacement projects. In this case the original material was Type 304 stainless steel. Replacement material was typically Type 316N stainless steel.

In the early 1990s, cracking in BWR shrouds and other reactor internal components caused the industry to consider the need for a new management strategy. The BWR Vessels Internal Project (BWRVIP) was the result. Initially formed under the aegis of the BWR Owners' Group, this project transitioned to EPRI sponsorship in the late 1990s. BWRVIP has been successful in providing the industry guidelines to successfully manage BWR reactor vessel internals. These guidelines include: assessment of susceptibility and risk; inspection guidelines and development of non-destructive examination (NDE) techniques; mitigation options such as hydrogen water chemistry, noble metal chemical addition and stress distribution improvement techniques; repair techniques and replacement strategies.

Industry –sponsored Projects

The industry–sponsored projects of the last 25 years have been largely successful in addressing the significant materials issues which have emerged by following a proven successful formula.

This approach requires the affected industry group to:

- Develop consistent approaches to the issues
- Combine resources to perform focused and comprehensive research to:
 - understand the synergistic effects of materials and their environments, such as chemistry, radiation and pressure
 - consider variations in plant operation among plants to achieve a better understanding of the sensitivity of plant conditions on material degradation
 - combine industry data so that trending and correlating degradation will lead to prediction of degradation progression
 - create contingency plans to minimize the impact on scheduled maintenance outages
- Provide opportunities for continuous improvement through feedback and lessons learned as products and techniques are deployed through the industry
- Allow for the development of uniform regulatory strategies that optimize regulatory interaction and implements a consistent regulatory process which
 - provides increased certainty in the regulatory process and
 - coordinates regulatory review resources

The structure of SGMP and BWRVIP led to the creation of program guideline documents which were adopted by all PWR owners in the case of SGMP and all BWR owners for BWRVIP. This in turn led to the possibility of generic program guideline acceptance by the

NRC regulatory staff. BWRVIP initiated this effort in 1996 and has since received a series of safety evaluation reports from NRC staff on its guidelines. SGMP and NRC staff have been reviewing SGMP guidelines since 1998 and have reached substantial but not yet complete agreement. In the case of the SGMP, the Nuclear Energy Institute served as the regulatory focal point for interface with NRC staff.

In 1998 for steam generators and 2001 for BWR internals, industry requested the Institute for Nuclear Power Operations (INPO) to conduct assessments of program effectiveness. These reviews have served to provide consistent measures of program performance and allowed for sharing of best practices among the utilities in their respective programs.

Emerging Materials Challenges

By the late 1990s, the materials challenges to both PWRs and BWRs seemed to be amenable to programmatic approaches and control in the areas of steam generators and BWR internals. The PWR Materials Reliability Project (MRP) was formed in 1998 to address known issues with baffle former bolts, fatigue in certain primary loop piping connections, and general Alloy 600 and reactor vessel internals issues. MRP had not been formed long enough to develop the holistic approach of SGMP and BWRVIP so that the events described below became emerging issues.

Starting in late 2000, three discrete events defined a turning point for materials issues in PWRs.

Hot Leg Safe End Cracking

In early 2001, South Carolina Electric & Gas discovered leakage in the dissimilar metal weld between the reactor pressure vessel hot leg nozzle and the reactor coolant loop piping at its V.C. Summer station (Figure 1). The self-revealing defect had not been discovered by programmatic in-service inspection techniques. Units in Germany and Sweden have observed reactor coolant loop to nozzle cracking in the same time frame as Summer.

The defects were found in the double-V joints at the buttered safe end between the RPV nozzle and the loop piping. The material was Inconel-based weld material 82/182. Extensive weld repair during the original fabrication resulted in high residual stresses. Combined with a susceptible material in the form of Inconel and the temperature-chemistry environment favorable for primary water stress corrosion cracking (PWSCC), the defects formed. This configuration is considered difficult to interpret through ultrasonic examination techniques due to the difference in material acoustic properties. We note that the Performance Demonstration Initiative, an industry group dedicated to enhancing the techniques associated with non-destructive inspections, is working on an improved method for this type of weld examination.

MRP to date has formulated an industry-wide approach to butt weld PWSCC which includes:

- the development of susceptibility and risk schemes
- generic inspection plans

- improved inspection techniques included phased array ultrasonic testing
- development of mitigation strategies such as mechanical stress improvement
- repair techniques, such as weld overlays
- completion of safety assessments
- initiation of research on corrosion rates on dissimilar metal weld materials

Reactor Vessel Head Penetration Cracking

Also in the fall of 2000, Duke Power discovered boric acid residue on the reactor vessel head of Oconee Unit 1 (Figure 2.) Subsequent investigations revealed axial cracking associated with the control rod drive penetrations tube to head weld. Other units, for example, Crystal River Unit 3 and TMI Unit 1, exhibited cracks and attendant boric acid leaks. Finally, in March 2002, First Energy discovered significant wastage of the reactor vessel head base metal as a result of boric acid leakage also associated with axial cracking of control rod drive penetration tube to head welds. The wastage reduced pressure retaining metal thickness to an average of 0.25 in and localized yielding was observed. Most recently, cracking was observed at North Anna Unit 2. Attempts at repair had been made during the previous refueling outage at this unit.

RPV head penetration cracking had been observed by the French leading to a head replacement campaign for their 3-loop units. Work in the U.S. in the mid-1990s had discounted this issue as not impacting safety.

The practices in use at the time of RPV head fabrication resulted in high residual stresses in susceptible material. These practices included shrink fitting and J-groove attachment welds. In addition the J-groove weld was performed using susceptible materials (Type 82/182). The combination led to the initiation of PWSCC cracking. Complicating this design was the code acceptance of the use of visual examination of the J-groove welds, which was not sufficiently invasive to identify cracking before the onset of leakage.

The industry has mobilized in response to these threats, and MRP is following the successful approaches of the SGMP and BWRVIP in the work described above.

The current actions include:

- initiation of EPRI task groups under the Materials Reliability Project to focus on the RPV and PWSCC issues
- development of RPV head susceptibility ranking based on time and temperature
- determination of specific RPV head inspections as frequencies
- assembly of an expert panel from industry and national laboratories to define growth rates used in RPV flaw evaluations
- development of flaw repair techniques by two primary vendors
- preparation of safety assessments to justify operations until inspections are performed
- promulgation of NRC GL 88-05 assessment guidance to ensure program elements appropriately assess leakage and removal of boric acid residue to minimize waste of carbon steel base metal

- ordering of replacement head by utilities whose RPV heads have high susceptibility to PWSCC.

Integrated Approach to Materials Issue Management

Yet the actions described above are not enough. The industry, both licensee and regulators, achieved success in steam generators and BWR internals by being proactive. In both examples, that involved taking a holistic view of the potential scope of the issues, establishing a structured approach, systematically examining both known and potential threats and then deploying inspection, evaluation, mitigation and repair techniques. While this approach has not eliminated progressive degradation in all cases, particularly in steam generators with mill-annealed Alloy 600 still in service, nevertheless it has reduced the number of surprises and allowed for successful contingency planning, or in the ultimate, sufficient planning for long-term component replacement.

The materials issues in PWRs, particularly the head wastage event at Davis-Besse have prompted industry leaders to call for an industry-wide assessment of materials challenges. This assessment, a combined project of the Nuclear Energy Institute and the Electric Power Research Institute is being conducted in the fall of 2002. In the first quarter of 2003, conclusions and recommended actions will be provided to the industry chief nuclear officers.

The comprehensive assessment of materials issues will review existing activities of programs being conducted by the SGMP, BWRVIP, MRP and the owners groups: BWOG, BWROG and

combined WOG/CEOG. In addition the materials interfaces of the Robust Fuels Project, the EPRI chemistry and corrosion control programs and the EPRI NDE center will be examined. The assessment is being performed by a group of industry technical experts familiar with the industry programs. The assessment will identify what aspects of the programs are working well and which are not, what improvements are needed, what activities are redundant, what gaps exist, and what best practices should be disseminated to other programs. The effectiveness of current organizational structures and efficiency of funding are also subjects for review.

The Task Force on Materials, to which the assessment group will report, will review the assessment and synthesize an action plan for industry. The recommended actions are expected to identify measures required to close identified gaps, and to identify emerging or likely future gaps that require actions now or in the immediate future. The ultimate goal is to provide an integrated approach to materials which will enable industry to proactively manage issues through targeted research and development, effective programs and industry-wide assessments.

Conclusion

Over the last 25 years, the industry in general has learned to manage the materials issues which have threatened plant operation. These recent events have attracted significant attention and required large-scale industry efforts to develop actions to inspect and mitigate. However, the past is prologue to the future. Having been challenged, the industry will once again learn how to

manage these new issues, putting strong programs in place for the future. With this asset management threat under control, the industry will then resume its path to strong safety and economic performance.

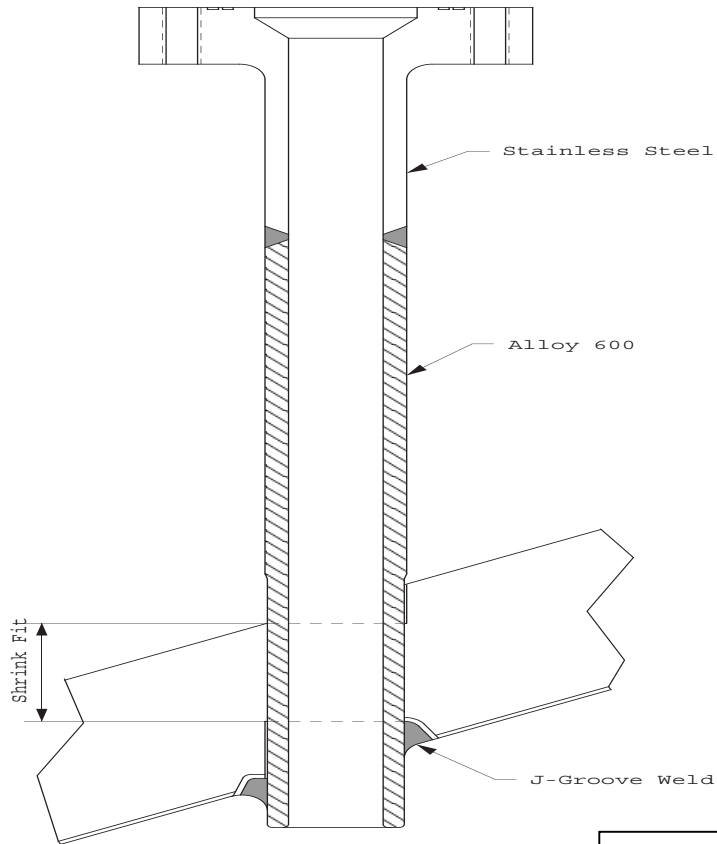
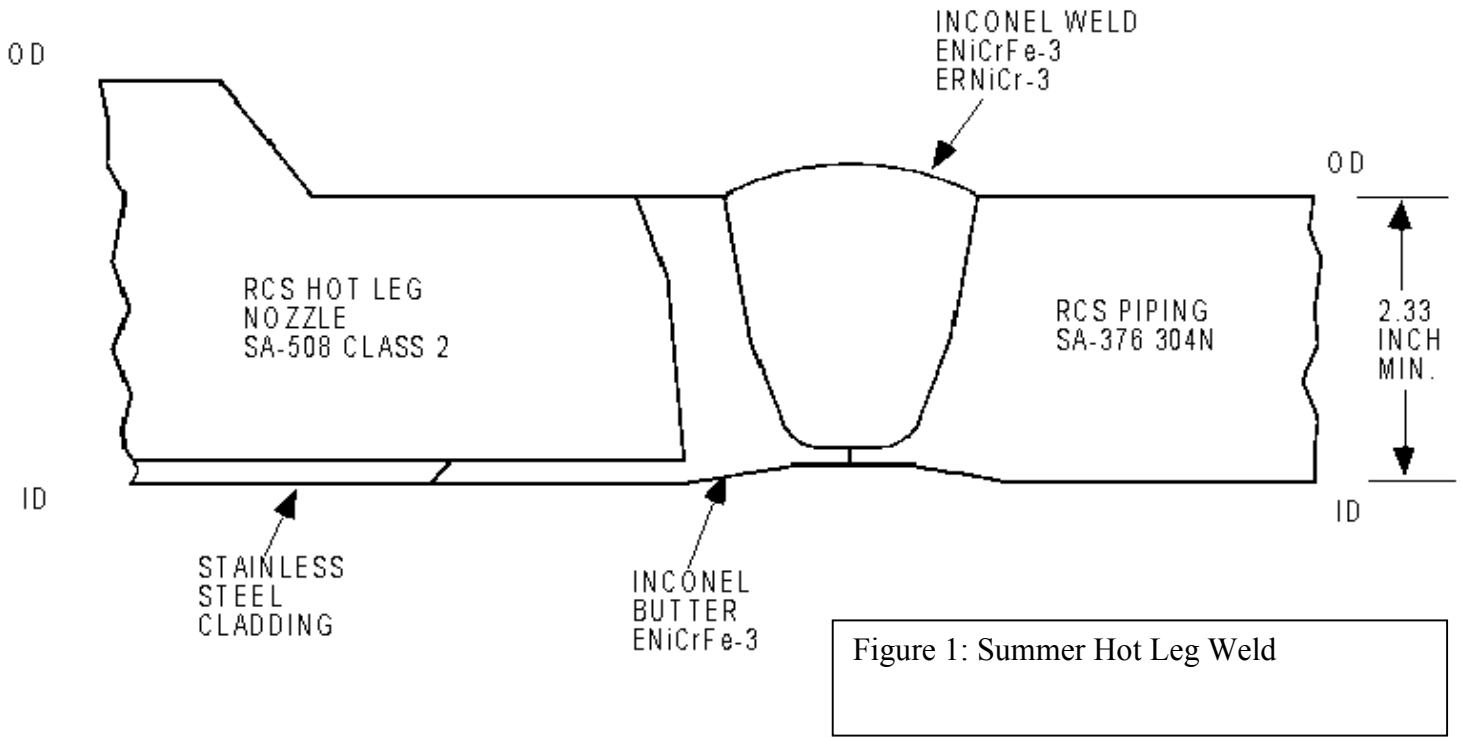


Figure 2: RPV Head Penetration