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Title ANO-1 Pressurizer Nozzle Level Tap LBB Assessment

PREPARED BY:	REVIEWED BY:
Name K.E. Moore	Name C.A. Ouellette
Signature K.E. Moore Date 12/29/90	Signature C.A. Ouellette Date 12/29/90

Technical Manager Statement: Initials [signature]

Reviewer is Independent.

Remarks:

1.0 PURPOSE

The purpose of this document is to evaluate the potential for Leak-Before-Break in the remaining ANO-1 pressurizer instrument nozzles (level taps).

2.0 BACKGROUND

One of the ANO-1 pressurizer level taps located in the vapor space has been subjected to NDE following discovery of a small leak. An axially oriented crack about 0.4 inch long has been detected in the nozzle bore within 0.2 inch and 0.6 inch of the end of the nozzle.

All seven of these nozzles were fabricated from the same heat of SB 166, Alloy 600; Allegheny Ludlum Steel Corp. Heat No. 26471. This material has a yield strength of 47.5 ksi and a carbon concentration of 0.069 w/o.

The barstock was hot rolled and annealed; the annealing temperature has not been determined.

The preliminary review of manufacturing records indicates the nozzles were installed prior to stress relief. The stress relief heat treatment is believed to have been 10 hr at 1100-1150°F.

Four of these nozzles are located below the normal liquid level; the other 3 are in the vapor space.

The cracking mechanism is strongly suspected to be pure water stress corrosion cracking (PWSCC). PWSCC refers to intergranular stress corrosion cracking (IGSCC) in the primary water environment of PWRs. The laboratory demonstration of PWSCC in Inconel 600 was first reported by Coriou almost 30 years ago. The studies of PWSCC in Inconel 600 have been well documented. However, the mechanism for PWSCC in Inconel 600 is still not well understood. In PWRs, PWSCC of Inconel 600 was first reported in steam generator tubing. Laboratory and service experience indicates SCC can be hastened at elevated temperatures. This is believed to be the

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reason the majority of the PWR nozzle failures have occurred in pressurizers. The evidence also suggests certain (possibly all) product forms of Alloy 600 are susceptible in pressurizer applications. Residual and applied stresses in some instances are sufficient to initiate SCC.

3.0 SERVICE EXPERIENCE

There have been numerous failures of Alloy 600 pressurizer nozzles and heater sleeves in the U.S. and in Europe. These occurrences have been well documented; one of the most recent updates is contained in a study performed for the B&W Owners Group[1]. The following is a summary of these occurrences:

1. Southern California Edison detected a small pressure boundary leak on February 27, 1986, in a 3/4-inch diameter pressurizer level instrument nozzle at San Onofre Unit 3. A PT inspection of the leak revealed an axial crack that extended from the end of the nozzle inside the pressurizer for a length of 5/8-inch outward through the pressure boundary. The cracked nozzle was removed for metallurgical analysis, and the failure mechanism was identified as PWSCC; axial, intergranular cracks were observed. The failure has been attributed to an unfavorable material heat treat condition and to environmental conditions, including an operating temperature greater than 650°F. This nozzle was replaced. In January 1987, Southern California Edison decided to replace additional nozzles: two upper nozzles in the vapor space that were from the same susceptible heat of material. Florida Power & Light has also replaced pressurizer instrument nozzles at St. Lucie Unit 2 (See 3. below); these were manufactured from the same heat of material used at San Onofre Unit 3.

2. In April, 1987, Arkansas Power & Light discovered leakage from two pressurizer heaters and sleeves at Arkansas Nuclear One, Unit 2. A heater sheath had ruptured, allowing the insulation to swell as a result of the absorbed coolant. This caused the sheath to press against the nearby heater sleeve, which cracked under exposure to the coolant and the resulting increase in stress. Subsequent failure analyses of the heater sheaths indicated that PWSCC had occurred and that the material used to fabricate the heater sleeves had characteristics (nonuniform carbide distribution and very little intergranular carbide precipitation) that would indicate susceptibility to SCC; axial cracks were observed. In addition, these heaters were manufactured by swaging the Alloy 600 tubing onto the heater elements without a final anneal. Thus, the surface was cold

[1] C. A. Ouellette and S. Fyfitch, "Alloy 600 Susceptibility: Scoping Study of Components at Crystal River 3," BWNS Document 51-1201160-00, November 29, 1990.

worked and relatively high residual stresses were imparted to the material. All heaters were replaced, while the sleeves were restored and welds repaired. Boric acid damage below the pressurizer was also repaired.

3. Four instrumentation nozzles at the top of the pressurizer were replaced (with Alloy 600 material believed to be more resistant to PWSCC) at St. Lucie Unit 2 during a refueling outage in October, 1987. Although extensive metallurgical examination was not performed, two of the nozzles were observed to have axial cracks. These nozzles were fabricated from the same material used for the SONGS-3 nozzles (see 1. above), which had a high yield strength and susceptible microstructure; therefore, PWSCC was suspected. Time-to-failure estimates were calculated for six remaining Alloy 600 nozzles; these nozzles were left in the system until completion of that current operating cycle, after which it was decided to leave the nozzles in service.

4. In a refueling outage at Shearon Harris in July, 1988, two of three steam generators were observed to have boric acid deposits on the lower channel heads. The channel head drain pipes were examined through eddy current testing, and were found to have throughwall, axial cracks up to 1.5 inches long. Residual stresses obtained through a rolling operation (unique to Shearon Harris) were concluded to have made the pipes susceptible to PWSCC. The drain pipes were repaired by cutting each pipe at the outer surface, then a coupling (which issued to connect two pipes) was welded to Inconel cladding, which had been applied to the outer surface of the steam generator head penetration area. The two sections of the drain pipe, inside and outside the steam generator, were then reconnected.

5. During a refueling shutdown at Baltimore Gas & Electric Company's (BG&E) Calvert Cliffs Unit 2, it was discovered on May 4, 1989, that boric acid deposits had accumulated around 20 of the 120 penetrations where the heater sleeves enter the bottom of the pressurizer. These same 20 heater sleeves were identified by PT indications as failed. Failure analyses performed on two sleeves removed from the pressurizer indicate that PWSCC had occurred in the base material. The cracks were axial and confined to a region within 2 inches of the top end of the heater sleeve (at the I.D. of the pressurizer shell). None of these cracks extended across the wall or HAZ. Again, the heat of material used for fabricating these heater sleeves was concluded to be susceptible to SCC due to its microstructure and initially high yield strength. Also, it is known that the failed heater sleeves were reamed during installation which induced residual stresses in the material. The cracks occurred in the reamed area. All 120 sleeves were replaced with heat treated Alloy 690 sleeves. Some of the sleeves in Unit 1 (which were made of the same heat of material as Unit 2 sleeves) were inspected for similar cracks, but none were observed; it was determined that

although the Unit 2 sleeves were reamed before welding, those at Unit 1 were reamed after the welding process, and to a lesser degree than the Unit 2 sleeves. Thus, the sleeves at Unit 1 were concluded to possess a lower degrees of susceptibility to SCC.

6. BG&E also detected cracking in a leaking level tap at Calvert Cliffs Unit 2 using liquid penetrant and eddy current techniques. The cracking in a vapor space level tap was axial and in the same general location as found at SONGS-3 and St. Lucie-2. Axial cracks were detected in 4, 5, and 9 o'clock orientations. The yield strength of the nozzle heat was 36 ksi; in this case, its susceptibility was attributed to stresses and material conditions caused by the rework (repair welding) required on this nozzle.

7. A number of pressurizer instrumentation nozzles have been reported to have failed at two PWRs in Europe. It has been reported that a susceptible material was used and that the nozzle surfaces were cold worked (in a rolling process); these two conditions were determined to have caused the SCC. The cracks were located in the rolled area and predominantly axially oriented. However, some circumferenital cracking was also observed. This was attributed to the rolling operation. Long term plans include the replacement of all Alloy 600 pressurizer penetrations with components made from stainless steel.

4.0 EVALUATION

The information presented above is evidence that failure of Alloy 600 components due to PWSCC occurs as a result of the propagation of axial cracks; no such failures have been attributed to circumferential crack propagation. At the ANO-1 pressurizer nozzle, this axial-crack mechanism is believed to have occurred, resulting in the throughwall crack which initiated at the ID of the nozzle and which was confined within the pressurizer shell-to-nozzle penetration. Should PWSCC occur in the other nozzles, all prior experience and the ANO-1 nozzle crack information demonstrate that the cracking will be axially oriented. Thus, given the inherent toughness of Alloy 600 and the location of the nozzle within the shell (confined), a leak-before-break mode of failure would result from the axial crack propagation which is characteristic to PWSCC failure.

Each of the failures described above has been attributed to presumably unique material and/or installation characteristics. Similar findings may be revealed as the failure investigation proceeds on the ANO-1 cracked nozzle.