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NUCLEAR REGULATORY COMMISSION
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PDR

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MEMORANDUM FOR: Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

FROM: Lawrence C. Shao, Director
Division of Engineering
Office of Nuclear Regulatory Research

SUBJECT: INTERIM PLUGGING CRITERIA FOR TROJAN NUCLEAR PLANT

The Division of Engineering has provided a discussion of the key technical aspects of the rationale used to support steam generator tube interim plugging criteria (IPC) for the Trojan nuclear plant and to provide independent conclusions on the viability of IPC for one fuel cycle. The IPC apply only to the specific case of outer diameter stress corrosion cracking (ODSCC) and intergranular attack (IGA) at tube support plate (TSP) intersections in the steam generators. The technical rationale presented in the enclosure are based on data and analyses available from NRC research, Trojan plant operating experience, and the technical literature. The enclosure also reflects staff technical experience and opinions. The Office of Nuclear Reactor Regulation (NRR) has been consulted on technical details regarding IPC during the preparation of this document. The report endeavors to maintain a distinction between staff opinion and published data.

Based on the discussion presented in the enclosure, the Division of Engineering concludes that continued operation of the Trojan plant for one fuel cycle is justified. This justification is based on:

(1) Examination of steam generator tubes removed from service at the Trojan plant which has revealed cracks that are generally confined to the tube support plate intersections.

(2) Burst test results from cracked tubes removed from service at the Trojan plant which showed burst pressures well in excess of main steam line break (MSLB) pressure.

(3) Stress corrosion crack growth rate results which indicate that incremental growth of the cracks to a critical length beyond the tube support plate during one fuel cycle is unlikely.

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(4) The probability of a main steam line break, the key initiating event for a steam generator tube rupture is very low for one fuel cycle.

Lawrence C. Shao, Director
Division of Engineering
Office of Nuclear Regulatory Research

Enclosure: As stated

cc: J. Taylor
J. Sniezek
T. Speis
J. Heltemes
W. Minners
T. Murley
F. Miraglia
W. Russell
J. Richardson
J. Strosnider
L. Kokajko
J. Fouchard

ENCLOSURE

Discussion of Technical Rationale for Steam Generator Tube Interim Plugging Criteria (IPC) at The Trojan Nuclear Plant

The purpose of this report is to provide a discussion of the key technical aspects of the rationale used to support steam generator tube interim plugging criteria (IPC) for the Trojan nuclear plant and to provide independent conclusions on the viability of IPC for one fuel cycle. The IPC apply only to the specific case of outer diameter stress corrosion cracking (ODSCC) and intergranular attack (IGA) at tube support plate (TSP) intersections in the steam generators. The technical rationale presented in this report are based on data and analyses available from NRC research, Trojan plant operating experience, and the technical literature. The report also reflects staff technical experience and opinions. The Office of Nuclear Reactor Regulation (NRR) has been consulted on technical details regarding IPC during the preparation of this document. The report endeavors to maintain a distinction between staff opinion and published data.

The rationale presented in this report are based on technical considerations which we believe are adequate to justify IPC for one fuel cycle. Subsequent operation with IPC would require additional review after completion of one cycle and would require consideration of additional information developed at that time. Longer term technical considerations, such as reliability and sensitivity of NDE techniques for steam generator tube inspection, are the subjects of on-going and new NRC research which is being coordinated with NRR as part of an overall steam generator tube alternate plugging criteria (APC) action plan.

(1) Background: Steam generator tube structural integrity guidance provided in Regulatory Guide 1.121 has generally translated into a 40% through-wall "plugging limit" for flaws in steam generator tubes as part of the plant technical specifications. However, evidence from pulled steam generator tubes at several plants has revealed numerous short cracks at TSP intersections which are greater than 40% through-wall and yet can withstand pressures in excess of three times operating as required by Regulatory Guide 1.121. It has therefore been argued by the industry that the 40% plugging limit is conservative, at least for the case of short axial ODSCC/IGA confined to TSP intersections. Burst testing of cracked tubes removed from service at the Trojan plant has resulted in burst pressures of at least a factor of two in excess of main steam line break (MSLB) pressure, even for through-wall cracks.[1] NRC research results on tubes with machined and chemically-induced flaws support the contention that the tubes retain significant structural integrity even for up to through-wall cracks, provided that the cracks are short. From this research "short" can be defined as less than 0.5 inches, which is the length of a near through-wall crack needed to burst for 7/8-inch diameter, 0.050 inch wall thickness tubing under MSLB differential pressure[2] (see Figure 1). The burst pressure is defined as the pressure required to penetrate the tube wall. Tube burst then, can result in either small or large leakage. Tube burst results when the differential pressure acts from the primary side. Tube rupture relates to a significant opening under burst

pressure with a consequent increase in leak rate and potential ductile crack advance. Burst failure is differentiated from collapse failure where the differential pressure acts from the secondary side.

Based on the arguments presented previously and supporting analyses, the industry has proposed an alternative to the traditional 40% depth-based guidance, the so-called alternate plugging criteria (APC), for steam generator tubes. The APC are based on correlations between the voltage amplitude recorded during eddy current tube inspections with a bobbin coil and subsequent measurements of the tube burst pressures and leak rates. The APC are also currently restricted to ODSCC at TSP intersections. A modified version of steam generator tube APC has been accepted by NRR for several licensees. These criteria have been termed interim plugging cri eria (IPC).

(2) Trojan Service Experience: Examination of steam generator tubes removed from service at the Trojan plant has revealed cracks which were generally confined to the TSP intersections. Evidence from the Trojan pulled tube examinations[1] has shown that the outer diameter (OD) lengths of the cracks ranged almost up to the TSP thickness. Subsequent evaluation has revealed that 2 of the 21 TSP intersections examined had cracks which extended beyond the TSP thickness; these cracks extended 0.025 and 0.110 inches beyond the TSP.

(3) Steam Generator Tube Burst Test Results: Burst test results on tubes removed from the Trojan steam generators showed no leakage under normal operating or MSLB pressures.[1] When pressurized to failure, the burst pressures measured for the tubes were in excess of the MSLB pressure by at least a factor of two. NRC research results from burst tests of tubes with machined, chemically-induced and service-produced defects have also provided a significant body of data on tube integrity. Equations which have been fitted to the burst test data for electric discharge machined (EDM) slots in steam generator tubes have shown that 0.5 inches would be the length of through-wall crack that would be expected to burst at MSLB pressures for 7/8-inch diameter, 0.050 inch wall thickness tubing[2] (see Figure 1). The equation for the through-wall EDM slot represents an extrapolation from data measured on up to 90% through-wall slots. NRC research has shown that the empirical equation developed from EDM slots provides a realistic estimate of remaining margin to failure for tubes with stress corrosion cracks.[3] An empirical equation fitted to data from burst tests of uniformly thinned steam generator tubes has also been developed.[2] This equation is contrasted with the EDM equation in Figure 1. It can be seen that the two equations are of similar form but that the uniform thinning equation provides more conservative estimates of tube burst pressures for flaw depths greater than a/t of 0.8, where a = flaw depth and t = tube wall thickness. Use of either equation to bound degradation up to a/t of 0.8 should yield similar results in terms of burst pressure. However, the EDM equation provides a more accurate representation of stress corrosion cracking and should be used for flaw depths greater than a/t = 0.8.

(4) Stress Corrosion Crack Growth Rate: Growth of the ODSCC tube cracks at the Trojan TSP intersections is not expected to be significant during one fuel cycle. For purposes of this report, significant can be defined as a through-

wall crack extending on the order of 0.5 inches beyond the TSP intersection. As described previously in (2), the Trojan cracks were generally confined to the TSP thickness; hence, growth beyond the TSP on the order of 0.5 inches would be required for these cracks to be considered critical from a MSLB pressure standpoint. Upper bound laboratory ODSCC growth rate data[4] indicate that crack growth of this magnitude would not be expected to occur during one fuel cycle. While a through-thickness, full TSP length crack would be expected to fail at MSLB pressure, the opening or rupture would be constrained by the tube support plate. True rupture for the portion outside of the TSP would be expected to occur at MSLB pressure only if the crack had grown on the order of 0.5 inches beyond the TSP intersection. Further, little or no movement of the TSP which could potentially "uncover" the cracks is predicted to occur for the MSLB condition.

(5) Probability of Main Steam Line Break: The probability of a MSLB, the key initiating event for a steam generator tube rupture, is very low. The MSLB would cause approximately a 2600 psi pressure differential across the steam generator tubes. A MSLB has never occurred in a U.S. nuclear plant. Quoting from reference 5, "Under the Evaluation and Improvement of NDE for Inservice Inspection of Light Water Reactors Program sponsored by the NRC, a team of experts estimated the median frequency of a MSLB to be 1.7×10^{-4} per reactor year for a volume of 50 gallons per minute. This extrapolates to a frequency estimate of 6.8×10^{-4} per reactor year for a four loop plant such as Trojan.

(6) Summary and Conclusions: Based on a review of Trojan steam generator tube operating experience, on destructive examinations of tubes removed from the Trojan plant, stress corrosion crack growth rates and expert opinion concerning MSLB frequency, it is concluded that operation of the Trojan plant with steam generator tube IPC for one fuel cycle does not constitute a significant threat to public health and safety. Subsequent operation with IPC would require additional review after completion of one cycle and would include consideration of information developed at that time. In summary, the above conclusion is based on:

(1) Examination of steam generator tubes removed from service at the Trojan plant which has revealed cracks that are generally confined to the tube support plate intersections.

(2) Burst test results from cracked tubes removed from service at the Trojan plant which showed burst pressures well in excess of main steam line break (MSLB) pressure.

(3) Stress corrosion crack growth rate results indicate that incremental growth of the cracks to a critical length beyond the tube support plate during one fuel cycle is unlikely.

(4) The probability of a main steam line break, the key initiating event for a steam generator tube rupture is very low for one fuel cycle.

References

1 - "Trojan Nuclear Plant Steam Generator Tube Repair Criteria for Indications at Tube Support Plates, " Westinghouse Energy Systems, WCAP-13129, Revision 1, December, 1991, WESTINGHOUSE PROPRIETARY CLASS2.

2 - NUREG/CR-0718, Steam Generator Tube Integrity Program, Phase I Report, USNRC, September, 1979.

3 - NUREG CR/2336, Steam Generator Tube Integrity Program, Phase II Final Report, USNRC, August, 1988.

4 - NUREG CR/5117, Steam Generator Tube Integrity/Steam Generator Group Project, Final Project Summary Report, USNRC. May, 1989.

5 - Memorandum, C.J. Heltemes to F.P. Gillespie, GI-163, Multiple Steam Generator Tube Leakage, September 28, 1992.

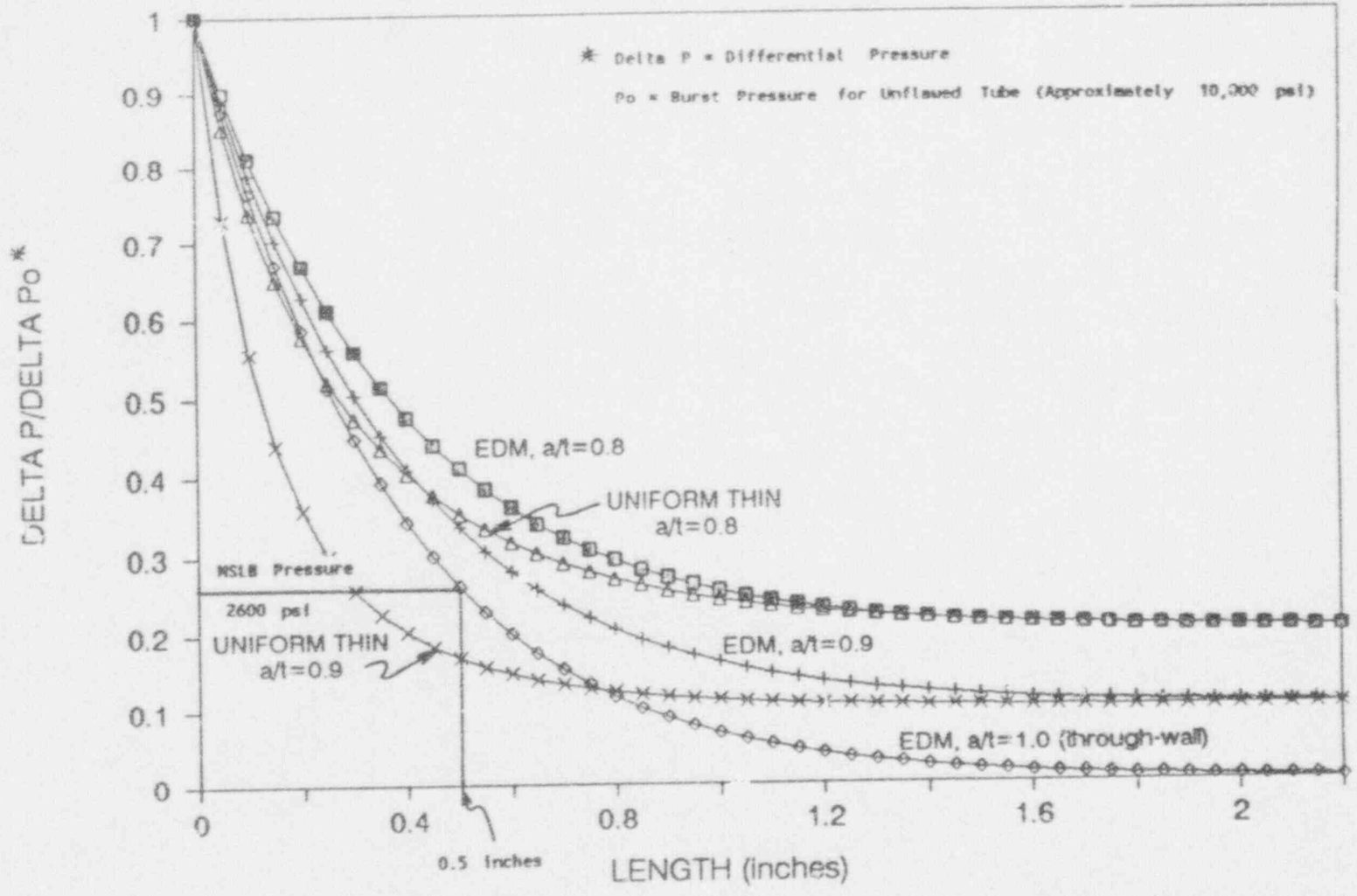

Figure 1 - Burst Pressure Parameter Curves for EDM Slot and Uniform Thinning Specimens