UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

to 50-344

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12/4/92
Encl

12/7 Joe ... any comments today ... Gary Jerry

MEMORANDUM FOR: ERIC S. BECKJORD, DIRECTOR,
OFFICE OF NUCLEAR REGULATORY RESEARCH

FROM: LAWRENCE C. SHAO, DIRECTOR,
DIVISION OF ENGINEERING, RES

SUBJECT: RES POSITION ON STEAM GENERATOR TUBE INTEGRITY

The Division of Engineering has provided a discussion of the key aspects of the rationale used to support steam generator tube alternate plugging criteria (APC), and to provide independent conclusions on its viability as an interim (one fuel cycle) criterion. The interim APC applies 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 generator. The technical rationale presented in the enclosed report is based to the greatest extent possible on data and analyses available from our research and elsewhere in the rtechnical literature, but also represent staff technical experience and opinions. The report endeavors to maintain a clear distinction between staff opinion and published data.

Lawrence C. Shao, Director,
Division of Engineering Technology

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ADD: Lawrence Kokajko 13E16 Ltr. Encl. 1 1

Enclosure

Discussion of Technical Rationale for Interim (One Cycle) Alternate Plugging Criteria for Steam Generator Tubes

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The purpose of this report is to provide a discussion of the key technical aspects of the rationale used to support steam generator tube alternate plugging criteria (APC) and to provide independent conclusions on its viability as an interim (one fuel cycle) criterion. A chronology of events relative to this issue is provided as attachment 1. The interim APC applies 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 generator. The technical rationale presented in this report are based to the greatest extent possible on data and analyses available from NRC research and elsewhere in the technical literature but also represent staff technical experience and opinions. The report endeavors to maintain a clear 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 APC for one fuel cycle. Longer term technical considerations, such as reliability and sensitivity of NDE techniques for steam generator tube inspection, are the subjects of NRC research which is being coordinated with the Office of Nuclear Reactor Regulation (NRR) as part of an overall 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, eddy current inspection techniques routinely applied to detect and size cracks in steam generator tubes are not highly reliable for detecting and sizing the cracks until they are actually beyond 40% through-wall. Further, it has been argued by the industry that the 40% plugging limit is overly conservative, at least for the case of axial ODSCC/IGA cracks confined to tube support plate intersections. The claim for over-conservatism is based on burst tests of cracked tubes removed from steam generators, e.g., pulled tubes. Detailed examinations of these tubes have revealed short cracks which, when tested, produced correspondingly high burst pressures even for up to through wall cracks.[1] NRC research results on tubes with idealized flaws (electrical discharge machined slots) 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 through-wall crack that would be predicted to result in a burst for 7/8 inch diameter, 0.050 inch wall thickness tubing under main steam line break (MSLB) differential pressure [2] (see attachment 2). Based on this data and supporting analyses, the industry has proposed an alternative to the Regulatory Guide 1.121 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 tube support plate intersections. The Office of Nuclear Reactor Regulation (NRR) has approved several licensee requests for steam generator APC on an interim (one fuel cycle) basis.

(2) Technical Precedent: The NRC's prior actions accepting industry requests for APC are not the first time that NRC has allowed specific exceptions to the 40% plugging limit for flaws in steam generator tubes.[3] Plants with steam generator tubes pitted beyond the 40% limit have been allowed to continue operation based on burst test results of pulled tubes. Exceptions to the tube plugging criteria have also been based on the F* criterion. "The F* criterion exempts a utility from the 40% plugging limit for that portion of the defective tubing within the tubesheet below a certain dimension (the F* distance) from the top of the tubesheet or from the top of the hardroll, whichever is lower."[3] The purpose of the F* exemptions was to provide a distance within the tubesheet beyond which it could be reasonably assured that a double-ended break in a tube would not result in the tube leaving the tubesheet.

(3) Support Plate Considerations: While there is a small gap between the TSP and the tube, the TSP should provide restraint against tube rupture for cracks contained within the TSP thickness (0.75 inches for the Trojan TSP's). The restraint would be provided by the rigid TSP as the tube expands against it under the influence of a differential pressure such as that caused by a MSLB.

(4) Degradation Mechanisms: While all of the initiation, growth, environmental sensitivity, and synergistic effects of the various mechanisms of steam generator tube cracking are not completely understood, growth of ODSCC cracks in TSP regions is not expected to be significant during one fuel cycle. For purposes of this report, significant can be defined as a through-wall crack growing on the order of 0.5 inches beyond the TSP. Evidence from the Trojan[1] pulled tube examinations has shown that the OD lengths of the cracks ranged almost up to the TSP thickness. For Trojan, the cracks were generally confined within the TSP thickness. Thus, for the Trojan cracks to become significant, they would have to extend on the order of 0.5 inches beyond the TSP intersection during one fuel cycle. Upper bound laboratory ODSCC growth rate data indicate that crack growth of this magnitude would not be expected to occur during one fuel cycle.[4]

(5) Probability of Initiating Event(s): The key initiating event for SGTR is considered to be a main steam line break (MSLB). The MSLB would cause approximately a 2600 psi pressure differential across the steam generator tubes. An MSLB has never occurred in a U.S. plant. Quoting from the enclosure to Reference 5, "Under the Evaluation and Improvement of NDE Reliability for Inservice Inspection of Light Water Reactors Program sponsored by the NRC, a team of experts estimated the median frequency of an MSLB to be 1.7×10^{-4} per reactor year ..... This extrapolates to a frequency estimate of 6.8×10^{-4} per reactor year for a four-loop plant."

(6) Steam Generator Tube Rupture Experience: U.S. industry experience since 1975 has documented only 6 SGTR's and only two of those were due to ODSCC cracking. The more recent of the two was the SGTR at McGuire Unit 1 in 1989. The McGuire SGTR was initiated by ODSCC at a manufacturers burnish marking.

The cracking progressed under the combined influence of residual stresses from the burnish marking and a "local metallurgical contaminant."[6] Failure was attributed to linking of several axial ODSCC cracks to form a 3.5 inch OD macrocrack on the cold leg side of the steam generator. The ODSCC cracking was in the free span away from TSP intersections. None of the documented SGTR's were associated with ODSCC at TSP intersections.

(7) Pulled Tube Burst Test Results: Pressure test results from the pulled Trojan steam generator tubes have shown no leakage under normal operating or MSLB pressure conditions.[3] When pressurized to failure, the burst pressures measured for the pulled tubes were in excess of the MSLB pressure by at least a factor of two.[3]

(8) Steam Generator Tube Rupture Tests and Research - Research results from burst tests of tubes using idealized flaws (uniform thinning and EDM slots) has provided a significant body of data on tube integrity. Equations which have been fitted to the data generated for EDM slot specimens have shown that 0.5 inches would be the length of through-wall flaw that would be expected to result in burst at MSLB pressures for 7/8-inch diameter, 0.050 inch wall thickness tubing[2] (see attachment 2). The equation for the through-wall EDM slot represents an extrapolation from data measured on up to 90% through wall slots. NRC sponsored research has shown that "the empirical equation developed from EDM notches provides a realistic estimate of remaining margin to failure for tubes with stress corrosion cracking when bounding flaw dimensions are used."[7] An empirical equation fitted to data from burst tests of uniformly thinned steam generator tubes has also been developed.[3] This equation is contrasted with the EDM equation in attachment 2. 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 below a/t = 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.

(9) Summary and Conclusions: Based on a review of steam generator tube operating experience, on destructive examinations of tubes removed from the Trojan plant, and on expert opinion concerning the frequency of main steam line break, it is concluded that it is reasonable to continue operation of the Trojan plant for one fuel cycle with flaws greater than 40% through-wall at TSP intersections. This conclusion is supported by the information provided in the preceding paragraphs, which is summarized below. Subsequent operation will require additional review after completion of one cycle and will include consideration of information developed at that time.

- Examination of tubes removed from the Trojan steam generator has revealed cracks which are generally confined to the TSP thickness. Pressure tests on these tubes showed no leakage under normal operating or MSLB conditions. The burst pressures were in excess of the MSLB pressure by at least a factor of two. Further, these tests did not account for the additional restraint that could be anticipated from the TSP which should further increase the burst pressure for the service geometry.

- Based on empirical correlations between burst pressure and crack size, validated by both laboratory data and by burst tests of tubes removed from service, for cracks to be significant, they must extend outside of the TSP intersection on the order of 0.5 inches. However, based on service experience and examination of tubes removed from the Trojan steam generators, the existence of cracks extending appreciably beyond the TSP intersections is unlikely at this time. Based on conservative laboratory test data on stress corrosion crack growth rates, it is unlikely that existing cracks within the TSP would extend to a critical length during one fuel cycle.

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Thus, cracks that are within the TSP can withstand the MSLB pressure, and it is unlikely that such cracks would extend to a critical length during one fuel cycle. On this basis, it is concluded that operation for one fuel cycle is justified.

References

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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 CLASS 2

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

3 - NUREG/CR-5150, Steam Generator Operating Experience, Update for 1984-1986, USNRC, June, 1988

4 - NUREG CR/5117, Steam Generator Tube Integrity Program/Steam Generator Group Project, Final Project Summary Report, USNRC, May 1990.

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

6 - NUREG CR/5796, Steam Generator Operating Experience, Update for 1989-1990, USNRC, December, 1991.

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

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Attachment 1

Chronology of staff related events relative to Steam Generator Tube Integrity

- The NRR staff had been reviewing Alternate Plugging Criteria (APC) during 1991, and in mid-December 1991, received a series of requests from Portland General Electric relative to operation of the steam generators of the Trojan Nuclear Plant, wherein use of the industry APC was an important issue.

- On December 23, 1991, Mr. J. Hopenfeld filed a Differing Professional Opinion (DPO), noting that "Recent experience at the Trojan plant indicates that the present inspection techniques are not sufficiently sensitive to detect steam generator degradation." Mr. Hopenfeld's DPO went on to note his concern "that a Main Steam Line Break (MSLB) outside containment could trigger a multiple steam generator tube failure which would than (sic) result in a core melt because of depletion of coolant inventory."

- A Safety Evaluation Report by NRR was published on February 5, 1992, which allowed operation of the Trojan Nuclear Plant for one additional cycle (cycle 14) under reduced leakage allowances, and under repair criteria that include application of APC.

- On March 16, 1992, Dr. Joseph Muscara published a Memorandum on "Steam Generator Tube Inspection, Integrity and Plugging Issues" wherein he stated his "concerns with generic acceptance of industry proposals for alternate tube plugging criteria which would allow operation of steam generators with known through-wall cracked (leaking) tubes."

- On March 27, 1992, J. Hopenfeld filed another paper titled "A New Generic Issue: Multiple Steam Generator Leakage." This document contained an analysis titled "Safety Issue Relating to Continuous Operation with Degraded Steam Generator Tubes" which indicated "a core melt probability frequency of 10 E-4/Ry with containment bypass."

- RES moved to decide on prioritization of this issue, via a Memorandum of September 28, 1992 from C. Heltemes to F. Gillespie titled "GI-163, Multiple Steam Generator Tube Leakage;" this prioritization evaluation was revised on November 16, 1992.

- On November 24, 1992, NRR replied via a Memorandum from Gillespie to Heltemes titled Generic Issue 163, "Multiple Steam Generator Tube Leakage."

- RES submitted a subsequent Memorandum on November 30 from Heltemes to Gillespie , on the same subject, stating "we

agree that the preliminary prioritization of this issue that we sent to you for comment on September 28, 1992 may not have accurately reflected the current licensing position that has been applied to Trojan and other plants."

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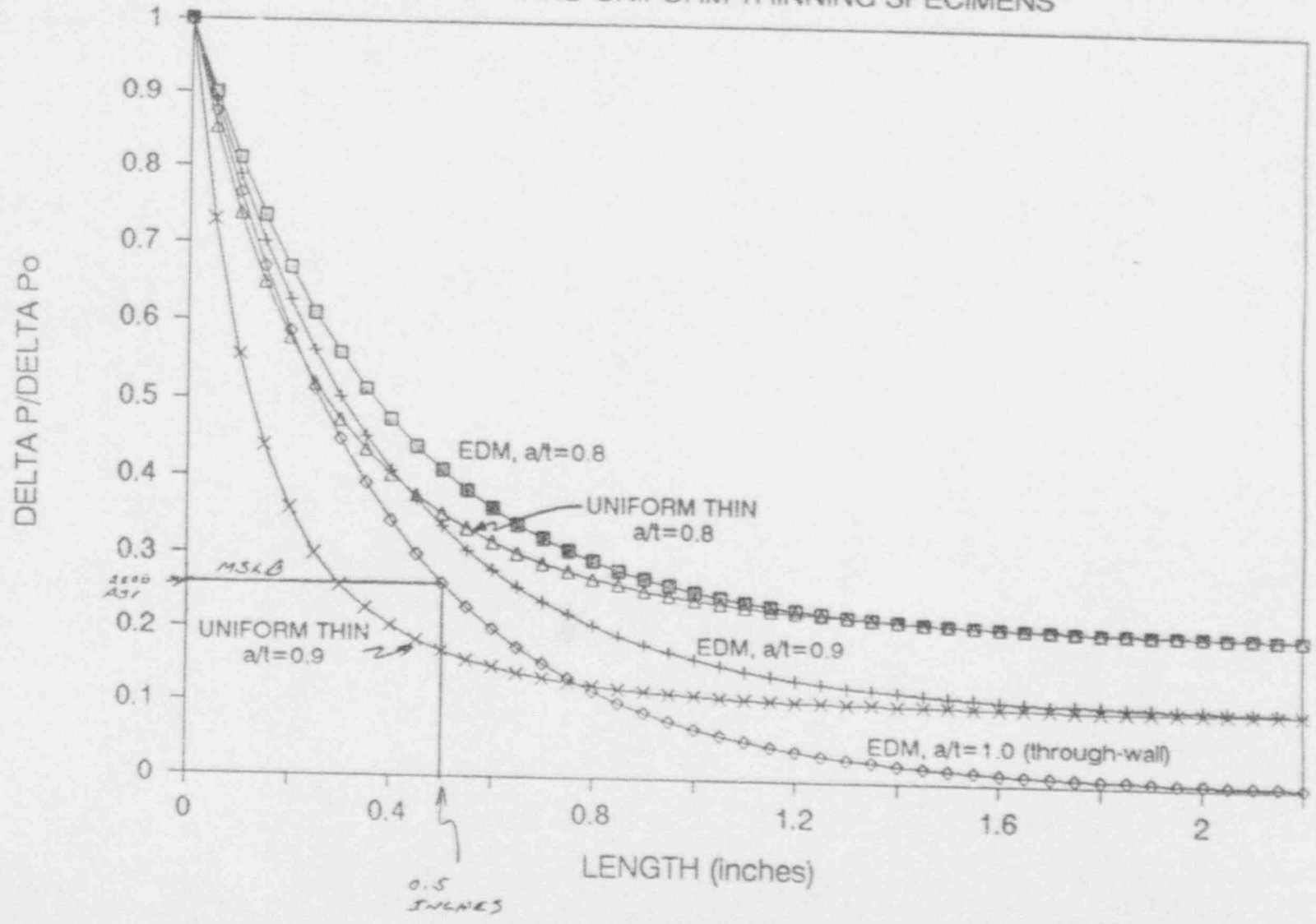
ATTACHMENT (2)

BURST PRESSURE PARAMETER CURVES

EDM SLOT AND UNIFORM THINNING SPECIMENS



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