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August 3, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
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METROPOLITAN EDISON COMPANY, ET AL.	)	Docket No. 50-289-OLA
	)	ASLBP 83-491-04-OLA
(Three Mile Island Nuclear Station, Unit No. 1)	)	(Steam Generator Repair)

LICENSEE'S PROPOSED FINDINGS OF FACT, CONCLUSIONS OF LAW, AND BRIEF IN THE FORM OF A PROPOSED INITIAL DECISION

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OFFICE OF SECRETARY
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I. OPINION

A. INTRODUCTION

1. Procedural Background

This is a decision on Licensee's request to amend the Technical Specifications contained in the NRC operating license for Unit 1 of the Three Mile Island Nuclear Station ("TMI-1"). The amendment would allow operation of TMI-1 with steam generator tubes which have been repaired in a manner not currently authorized by the Technical Specifications.

TMI-1 has been shut down since its last refueling outage in 1979, pending the outcome of restart proceedings before the Commission related to the accident at TMI, Unit 2. In November

1981, Licensee discovered primary-to-secondary system leakage in the steam generators while pressurizing the reactor coolant system for testing. The leakage was caused by cracking in the steam generator tubes, primarily in the upper tubesheet region, which Licensee has repaired by applying a kinetic expansion repair technique.

On May 9, 1983, Licensee submitted a request for amendment of the Technical Specifications of the TMI-1 operating license to approve the kinetic repair process. Without such a license amendment, TMI-1 would not be allowed to operate because the current Technical Specifications require leaking tubes to be plugged, and thus removed from service.

The Commission subsequently published a Federal Register notice captioned "Issuance of Amendment to Facility Operating License and Proposed No Significant Hazards Consideration Determination and Opportunity for Hearing," 48 Fed. Reg. 24231 (May 31, 1983), amended 48 Fed. Reg. 27328 (June 14, 1983), which provided an opportunity for any person whose interest might be affected by the proceeding to request a hearing and file a petition for leave to intervene. In the notice, the NRC directed that contentions should be limited to matters within the scope of the amendment under consideration.

Two intervenor groups -- Three Mile Island Alert, Inc. ("TMIA") and Ms. Lee, Mr. Aamodt, and Dr. Molholt ("Joint Petitioners") -- filed petitions for leave to intervene and requests for hearing. The Atomic Safety and Licensing Board issued a Memorandum and Order dated August 5, 1983 (unpublished) which ruled that TMIA and two of the Joint Petitioners (Ms. Lee and Mr. Aamodt) had established standing to intervene.

On August 12, 1983, the Commission issued a "Notice of Hearing on Issuance of Amendment to Facility Operating License" 48 Fed. Reg. 36707 (August 12, 1983), wherein the Commission stipulated that the subject matter of the proceeding would be limited to Licensee's request for authorization of the kinetic expansion repair process. This was clearly specified by the Commission's discussion of the subject matter of the proceeding at 48 Fed. Reg. 36707-08 (August 12, 1983) where it stated that:

> The amendment requested would revise the Technical Specifications to recognize steam generator tube repair techniques, other than plugging, provided such techniques are approved by the Commission.
>
> The licensee's application, dated May 9, 1983, further requested that the Commission approve, within the provisions of the proposed Technical Specification revision, the kinetic expansion steam generator tube repair technique used at the facility, thus permitting subsequent operation of the facility, with the as-repaired steam generators.

The Commission also gave notice that a special prehearing conference would be convened, inter alia, to permit identification of the key issues of the proceeding, consider the petitions to intervene, and to establish a schedule for further actions in the proceeding. The special prehearing conference was held on October 17, 1983 in Harrisburg, Pennsylvania.

In November 1983, the Board admitted TMIA and Joint Intervenors (Ms. Lee and Mr. Aamodt) as parties to the proceeding, and ruled on the admissibility of the intervenors' contentions.1/ The Board approved the admission of eight contentions advanced by TMIA and three contentions advanced by Joint Intervenors. The Board also granted Dr. Molholt's request to withdraw his petition for leave to intervene.

On February 24, 1984, Licensee and the NRC Staff filed motions for summary disposition pursuant to 10 C.F.R. § 2.749. The Staff filed a response supporting Licensee's motion on March 20, 1984. Joint Intervenors and TMIA filed their responses opposing the motions for summary disposition of their contentions on March 19, 1984 and April 3, 1984, respectively. With the Board's leave, Licensee filed its reply to Joint Intervenors' response to Licensee's motion for summary disposition on April 4, 1984 and its reply to TMIA's response to Licensee's motion for summary disposition on April 13, 1984.

After careful consideration of all of the filings, the Board granted the two motions for summary disposition in major

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1/ Memorandum and Order (Ruling on Contentions), LBP-83-76, 18 N.R.C. 1266 (November 29, 1983).

part on June 1, 1984. Memorandum and Order (Rulings on Motions for Summary Disposition), June 1, 1984 (hereafter cited as "Order"). All of Joint Intervenors' contentions, which essentially raised issues related to Licensee's ability to identify and control the source of the tube cracking, were dismissed. Joint Intervenors were thus dismissed as a party to this proceeding. Summary disposition was granted in part for two of TMIA's contentions; the remainder were dismissed in their entirety. For TMIA's Contentions 1.a and 1.b, the two contentions which were not totally dismissed, the Board identified specific sub-issues for which evidence was to be presented at hearing. Order at 23, 32, 91-92.

The evidentiary hearings on these matters were held on July 16-18, 1984, in Middletown, Pennsylvania with all parties -- Licensee, the Staff, and TMIA -- represented. Also participating in the hearing was the Commonwealth of Pennsylvania, which on July 9, 1984, had filed a motion requesting leave to participate in the hearing as an interested State pursuant to 10 C.F.R. §2.715(c).

2. Organization of the Initial Decision

Part I of the Board's Initial Decision is the Board's Opinion, which is largely comprised of discussion of the litigated contentions and their resolution. Parts II and III of the Initial Decision are the Board's Findings of Fact and

Conclusions of Law, respectively. The Board's Order, authorizing the operation of the Three Mile Island Nuclear Station, Unit No. 1 with the as-repaired steam generator tubes, is Part IV of the Initial Decision.

B. SCOPE OF HEARING

The scope of the evidentiary hearing was defined in the Board's Order ruling on the summary disposition motions of Licensee and the Staff. Both motions had sought dismissal of all of the contentions filed by the intervening parties. The motions contained extensive statements of material facts as to which the moving parties asserted there were no genuine issues to be heard. The statements were supported by affidavits, and were presented for the purpose of demonstrating the adequacy of the kinetic expansion repair process, including a demonstration of reasonable assurance that the cause of the cracking had been properly identified and that adequate steps had been taken to prevent its recurrence, a description of the extensive program conducted by Licensee to qualify the repair joint to the original licensing basis, and a description of the operating and surveillance measures to be taken to assure that tube defects in the future would be timely detected.

In broad summary, the Board's Order ruling on the motions for summary disposition established, inter alia, the following with respect to the kinetic expansion repair process for the TMI-1 steam generator tubes:

TMI-1 is a 776 megawatt pressurized water reactor ("PWR") having two vertical, straight tube and shell, once-through steam generators("OTSG"). Each steam generator contains 15,531 Inconel-600 tubes. Each tube is 56 feet, 2 3/8 inches in length, with a 0.625-inch outer diameter and a 0.034-inch minimum wall thickness. The ends are inserted into holes drilled in two 24-inch thick carbon steel tubesheets at the top and bottom of the steam generator. The tube is fully inserted, and protrudes about 1/2 inch beyond the upper face of the Inconel clad upper tubesheet and the lower face of the lower tubesheet, into the primary head at each end of the steam generator. There is a nominal 0.005-inch radial gap between the outer surface of the tube and the surface of the tubesheet hole. During manufacture of the steam generators, the tubes are sealed to the tubesheet at each end by rolling to a depth of about 1 1/4 inches, and welding on the primary side of the tubesheet surface. Licensee Material Facts, ¶¶ 1-3 at 60.2/

Primary coolant (at a pressure of about 2200 psig) flows within the tubes, and secondary system water and steam (at a pressure of about 950 psig) are heated outside the tubes. Thus the tubes, including the seal at each end, constitute part of

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2/ "Licensee's Statement of Material Facts as to Which There Is No Genuine Issue To Be Heard," Licensee's Motion for Summary Disposition of Each of TMIA's and Joint Intervenors' Contentions, February 24, 1984, at 59 et seq.

the reactor coolant pressure boundary between the primary and secondary systems. Licensee Material Facts, ¶ 4 at 61.

In November 1981, primary-to-secondary leakage was discovered following hot functional testing of the TMI-1 reactor coolant system. Visual, metallographic and electron microscopy examinations of tube specimens removed from the steam generators showed the leakage to be caused by intergranular stress assisted cracking ("IGSAC") of steam generator tubes. The initial examination by eddy current testing ("ECT") revealed that 95% of the defects occurred within the top seven inches of the upper tubesheet. Order at 4; Licensee Material Facts, ¶ 5 at 61 and ¶¶ 108-110 at 91-92.

After discovering the leakage experienced at TMI-1, Licensee developed and implemented an extensive series of evaluation programs to identify the extent and cause of tube failure and the potential for future tube failure. Order at 59. These evaluation programs included: 1) characterization of the failure mechanism; 2) detailed investigation of the conditions which could have caused the IGSAC; 3) the review of various publications concerning IGSAC; 4) the development of a failure scenario describing the initiation of IGSAC at TMI-1; 5) confirmatory testing of the failure scenario; 6) the examination of the role of potential causative agents other than sulfur such as carbon, chloride and other elements, possible synergistic reactions, and contaminants introduced during the repair process; and 7) various other issues related to the identification of the causative agent. Order at 60; see also Licensee Material Facts, ¶¶ 106-160 at 91-105; Staff Material Facts TMIA Cont. 2.a, ¶ 2 at 1;3/ Staff Material Facts J.I. Cont. 1(5), ¶¶ 2-3 at 1-2.4/

Licensee and Staff determined that sodium thiosulfate, a metastable intermediate species of sulfur, was the causative agent of the IGSAC experienced at TMI-1. They deduced, through extensive testing and analysis, that the reducing conditions which existed in the reactor coolant system ("RCS") during the August-September 1981 hot functional tests allowed thiosulfate which had previously contaminated the steam generator's primary system to be transformed towards more reduced metastable species. During the subsequent cooldown, oxygen was introduced into the primary system. This created the oxidizing conditions in the presence of aggressive metastable sulfur species that were responsible for the IGSAC. Order at 73-74; see Licensee Material Facts, ¶¶ 123-132 at 96-99 and ¶ 198 at 115; Staff

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3/ Staff's "Statement of Material Facts as to Which There is no Genuine Issue to be Heard (TMIA Contention ___)," NRC Staff Motion for Summary Disposition of TMIA Contentions 1.a, 1.b, 1.c, 1.d, 2.a, 2.b.1, 2.b.2, and 2.c, February 24, 1984 (hereafter cited as "Staff Material Facts TMIA Cont. ___").

4/ Staff's "Statement of Material Facts as to Which There is no Genuine Issue to be Heard (Joint Intervenors' Contention ___)," NRC Staff Motion for Summary Disposition of Joint Intervenors Contentions 2, 3, and 5, February 24, 1984 (hereafter cited as "Staff Material Facts J.I. Cont. ___").

Material Facts TMIA Cont. 2.a, ¶ 2 at 1; Staff Material Facts J.I. Cont. 1(5), ¶¶ 2-7 at 1-4, and ¶¶ 19-20 at 6-7.

Licensee, after successfully identifying the cause of the IGSAC, instituted a clean-up program designed to remove the sulfur from the tube surfaces and to prevent any further damage to the tubes. After assuring itself of the safety of the cleaning process through extensive testing, Licensee removed most of the residual sulfides by a hydrogen peroxide cleaning process without damaging the tubing or the remainder of the RCS. The efficacy and safety of cleaning process was confirmed by subsequent hot functional testing and long term corrosion testing. Order at 68, 87; see Licensee Material Facts, ¶¶ 174-188 at 109-112; Staff Material Facts TMIA Cont. 2.b.1, ¶¶ 4-6 at 2; Staff Material Facts J.I. Cont. 1(2), ¶¶ 11-14 at 5-6; Staff Material Facts J.I. Cont. 1(5), ¶¶ 5-8 at 2-4.

To further assure that reinitiation will not occur, Licensee has imposed a number of preventive administrative controls including: 1) physical disconnection of the thiosulfate tank from the RCS; 2) stronger controls on the additions and quality of the chemicals used in the RCS; 3) modified limits on the allowable concentrations of sulfates, chlorides and fluoride (0.1 ppm each) in the RCS; 4) analyses for the aforementioned constituents at least five times per week; and 5) several other conservative precautionary limits and analyses which provide closer control over the system chemistry as a whole. Order at 74. These controls in conjunction with the short term corrosion tests (which demonstrated that the RCS could sustain sulfur concentrations up to 1 ppm without experiencing reinitiation) and the long term corrosion test program (which served as a lead test program and included simulation of worst case chemistry environments anticipated in operation without evidence of any reinitiation of IGSAC) provide reasonable assurance that corrosion will not reinitiate in the steam generator tubes. Order at 75, 87-88; see Licensee Material Facts, ¶¶ 136-137 at 100, ¶¶ 201-214 at 115-118, ¶¶ 216-221 at 118-120; Staff Material Facts TMIA Cont. 2.b.2, ¶¶ 4, 6 at 2-3; Staff Material Facts J.I. Cont. 1(2), ¶¶ 10, 12 at 4-5; Staff Material Facts J.I. Cont. 1(3), ¶¶ 3-5 at 2; Staff Material Facts J.I. Cont. 5, ¶ 3 at 2.

The tubes were repaired by kinetically expanding the tubes within the tubesheet to provide a new seal to the tubesheet below where the defects were detected. Order at 5. This was done by detonating an explosive cord encased in a polyethelene insert which had been placed into the tube. The resulting explosive energy is transmitted to the tube wall by the polyetheline insert, pressing the tube against the tubesheet, thereby creating an interference pressure between the two. Order at 5. The tubes were expanded from the top of the upper tubesheet down either 17 inches or 22 inches, depending on the elevation of the lowest ECT indication within the upper tubesheet. Order at 5. This provided a six-inch or greater ECT indication-free expanded length between the lowest elevation ECT indication and the bottom of the expansion to serve as the new pressure boundary. Order at 5. The selected expansion lengths also guaranteed that there were no ECT indications in the 1/8-inch to 1/4-inch transition zone between the expanded and non-expanded portions of the tube. Order at 5; see Licensee Material Facts, ¶¶ 6, 7, 9-10 at 61-62.

Licensee undertook an extensive qualification program to develop and test the kinetic expansion process utilized before expanding the steam generator tubes. This program demonstrated that the expansion joint meets the licensing basis, and is at least as effective as the original rolled and welded joint in all relevant respects, including ability to withstand axial loads from worst case design basis operating and accident conditions, tube preload considerations, and residual stresses in the transition zone. Order at 6. The qualification program specifically demonstated that the expansion joint can safely sustain an axial tensile load of 3140 lbs., which is the maximum postulated load resulting from a main steam line break. Order at 6. The qualification program further demonstrated that the strength and dimension of the tubes would not be adversely affected by the kinetic expansion process with respect to the stress loads experienced by the tubes, and that the residual stresses and the resistance to stress assisted cracking in the transition zone are consistent with the original design of the steam generators. Order at 6. Finally, the qualification program demonstrated that the kinetic expansion process would not compromise the original design basis for steam generator tube leakage which provided that there would be no detectable leaks at shipment and controlled leakage at an acceptable operating level by monitoring and repair over the 40-year life of the plant. Order at 7; see Licensee Material Facts, ¶¶ 12-36 at 63-72; Staff Material Facts TMIA Cont. 1.a, ¶¶ 4-8 at 2-5.

An inspection and monitoring program was conducted during the repair process which verified that the in-generator expansions conformed to those obtained in the qualification program. The program consisted of video surveillance within the upper head of the steam generator and measurements of the tube inner diameters by profilometry and by diameter gauging on a sampling basis. Order at 7; see Licensee Material Facts, ¶¶ 38-43 at 73-74.

Post-repair and plant performance steam generator testing provided additional assurance of the integrity of the in-generator repair process. Every expansion joint was leak tested twice by the extremely sensitive bubble testing method to determine if further repair or plugging was necessary. Order at 7. The tubes were also subjected to heatup, hot standby, and cooldown conditions which applied significant axial loads on the kinetic expansion joints. The leak tests performed during this hot testing program indicated an integrated leak rate for both generators well below the Technical Specification limits which allow up to 1 GPM (60 GPH) for such leakage. Order at 8-9; see Licensee Material Facts, ¶¶ 44-50 at 74-77; Staff Material Facts TMIA Cont. 1.a, ¶ 2 at 1.

In addition to the qualification program, the in-process repair testing and the post-repair testing and analyses, which demonstrated the adequacy of the kinetic expansion repair joint, Licensee will be subject to special license conditions which Licensee and the Staff assert provide added assurance against the possibility of tube rupture. Order at 9. Thus, if any significant degradation of the kinetic expansion joints were beginning to occur during plant operation, leakage would increase and the steam generators (and plant) would be shut down, tested and repaired, if necessary. Moreover, the plant will be shut down after a short period of operation for performance of a special ECT program. Order at 9. In addition, Licensee will be required to perform its power ascension program at staged intervals, with continuous leak testing and intervals for evaluation of the leakage trends after each stage. Order at 9; see also Licensee Material Facts, ¶¶ 51-55 at 77-79.

TMIA's Contention 1.a, which concerned post-repair and plant performance testing and analysis, and Contention 1.b, which alleged the possibility of multiple tube ruptures because of the repairs, were not totally dismissed. Summary disposition was granted in part, but the Board identified eight sub-issues encompassed within those contentions for which we requested evidentiary presentations of further clarifying information. Order at 23, 32. Licensee and the Staff presented testimony on each of these matters. TMIA presented no direct evidence. We discuss our findings on each of these matters in Sections C and D below.

C. CONTENTION 1.a

1. General

TMIA's Contention 1.a, as originally admitted, alleged with respect to the kinetic expansion repair technique that "post repair and plant performance testing and analysis" and "proposed license conditions" are inadequate to provide sufficient assurance that tube "ruptures" will be prevented during certain operating conditions and transients. Although TMIA raised a series of allegations to support the contention, most of these were dismissed on summary disposition. Specifically, the Board ruled that the qualification program and in-process testing were beyond the scope of the contention. Order at 14. We also rejected TMIA's suggestion that tubes in the steam generator should be individually inspected or subjected to deliberate design basis accident conditions. Order at 16. There remained seven sub-issues within the contention (referred to as Issues 1.a - 1.d and 2-5) for which evidence was presented at the hearing.

While the Board has examined each of these sub-issues in detail, it is of the opinion that a tube "rupture" in the sense of the large leakage associated with double-ended or fishmouth rupture cannot occur in the kinetically expanded area of the tubes. This is due to the fact that the tube in the area of the repair is captured by the tubesheet, and the movement of the tube is concomitantly limited. Accordingly, if the tube were to fail, the result would be tube slippage, not a rupture. Leakage, moreover, would be limited significantly by the tight crevice. FF 6.5/

2. Issue 1.a (Reliability of Leak Rate Measurements)

Issue 1.a, as stated at page 23 of the Board's Order, reads as follows:

> 1. The rationale underlying certain proposed license conditions should be addressed, with attention to:
>
> a. Reliability of leak rate measurements.

5/ Licensee's proposed Findings of Facts, as set out in Section II hereof, are herein cited as "FF."

The Board received extensive evidence from Licensee and the Staff on Issue 1.a.6/ No contrary evidence was presented by TMIA.

The purpose of the primary-to-secondary leak rate measurements at TMI-1, as at other operating pressurized water reactors in the United States, is to confirm that the steam generators are performing as anticipated. The leakage measurements during operation are made both to document the absolute value of leakage and to document any trends which may be cause for concern. The absolute value is required to both assess the performance of the steam generators and to ensure that technical specification limits are not exceeded. Trends are monitored because increasing leakage may indicate ongoing chemical or mechanical degradation of the tube. Increasing leak rates are investigated further to identify leak locations and take appropriate corrective action. Some small amount of leakage, however, is to be expected. FF 8.

6/ Applicant presented a panel of witnesses on this contention: Richard F. Wilson, Vice President of Technical Functions for GPU Nuclear Corporation; David G. Slear, Manager of Engineering Projects for TMI-1 at GPU; and Don K. Croneberger, Director of Engineering and Design for GPU. See testimony following Tr. 224 ("Licensee's Testimony of Richard F. Wilson, David G. Slear and Don K. Croneberger on Issue 1.a (Contention 1.a)," hereafter cited as "Licensee - Issue 1.a"). The Staff presented testimony of Conrad E. McCracken, Section Chief of Chemical and Corrosion Technology Section, Chemical Engineering Branch, NRC Division of Engineering, and Paul C. Wu, a Chemical Engineer in the Chemical and Corrosion Technology Section. See testimony following Tr. 589 ("Testimony of Conrad E. McCracken and Paul C. Wu on TMIA Contention 1.a," hereafter cited as "Staff - Cont. 1.a").

Licensee's existing license conditions relating to primary-to-secondary leakage through the TMI-1 OTSG tubes require that leakage be evaluated daily and that the reactor be placed in cold shutdown if leakage exceeds 1 gallon per minute ("GPM") total for both steam generators. Technical Specifications 3.1.6.3 and 4.1; FF 9.

An additional, more restrictive license condition, which is predicated on administrative limits voluntarily adopted by Licensee, is proposed to be added by the Staff. Under the new license condition, Licensee is to establish its baseline leakage from the leak rate data obtained during the post repair OTSG hot test program. An increase of more than 0.1 GPM (6 GPH) above this baseline at steady state operating conditions will require facility shutdown and leak testing. The baseline will be re-established following shutdown and leak testing, and operation can then continue until the increase in leakage exceeds the new baseline by 0.1 GPM (6 GPH). FF 10.

Licensee determined the baseline primary-to-secondary leakage to be 0.02 GPM (1 GPH) during the steam generator hot test program. This means that the facility is to be shut down if the leak rate reaches 7 GPH total for both steam generators, as compared to the existing limit of 60 GPH in Technical Specification 3.1.6.3. Because repairs have been performed since hot testing, a new baseline leak rate will be established on restart. FF 11.

Licensee testified that the nominal leak rate of 0.1 GPM above a baseline value was supported by a number of considerations including: the need to establish a leak rate monitoring capability sensitive enough to detect extremely low level leakage; the fact that some low level leakage is to be expected and does not indicate a reduction in load carrying capability; the need for confidence that a change in leakage is statistically meaningful; and the fact that multiple leakpaths contribute to the aggregate leakage. FF 14.

The TMI-1 leakage limitations in Technical Specification 3.1.6.3 are comparable to those at most other pressurized water reactors in the United States. A recent survey by Licensee of approximately 30 PWRs showed that the vast majority of the plants have limits similar to TMI-1's current 1 GPM limit, including plants that have been shutdown for a long period of time. Tr. 238 (Slear). One plant has a limit three times the current TMI-1 limit. A few of the more recently licensed plants have limits lower than Technical Specification 3.1.6.3. Mr. McCracken of the NRC Staff testified, however, that the proposed TMI-1 license condition of 0.1 GPM is more stringent than that for any other operating PWR in the United States. FF 12.

The witnesses agreed that the methods used to measure primary-to-secondary leakage, which include measuring radionoble gas concentrations on the secondary side, and measuring chemistry and radio-chemistry in secondary side steam generator water, are reliable. Continual readouts are provided by the instruments. FF 15.7/ In response to an inquiry by Judge Hetrick, Mr. Slear explained that Licensee would be able to detect a sudden increase in leakage in a matter of minutes. Tr. 274-275; FF 15.

Leak rate measurements are one aspect of an overall defense in depth approach to maintain OTSG integrity, which include leak rate monitoring during operation, periodic eddy current testing, and leak rates while shut down at cold conditions. All witnesses testifying on this issue agreed that the overall defense in depth program, including the leak rate measurements, is adequate to permit Licensee to correct defects in tubes in order to ensure that the steam generator tubes satisfy the licensing basis specified in General Design Criterion

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7/ The Commonwealth of Pennsylvania questioned whether Licensee would have adequate monitoring if the primary on-line monitor (RM-A5L) failed. Tr. 267-268. Mr. Broughton explained that there are additional monitors which monitor the condenser off-gas, and that Licensee also takes grab samples which would evaluate off-gas even if the on-line monitors are not functioning. Tr. 268-269. TMI-1's Technical Specifications provide that the on-line monitor can be out of service for up to 28 days providing Licensee is taking grab samples. Tr. 646 (McCracken). Licensee has a self-imposed administrative limitation which requires that if the on-line monitor is taken out of service, a grab sample will be taken immediately and repeated every four hours. Tr. 647 (McCracken). NRC Staff stated that they thought the addition of a license condition requiring operability of the on-line monitoring system is unnecessary for safety and health purposes. Tr. 644 (McCracken); FF 15.

14, 10 C.F.R. Part 50, Appendix A, i.e., "to have an extremely low probability of abnormal leakage, or rapidly propagating failure, and of gross rupture". FF 13.

TMIA's allegations and cross-examination raised two primary concerns with respect to the reliability of the leak rate measures. First, TMIA expressed concern that leak test results may be misleading since some leaks are "self-sealing" because corrosion products will deposit in the cracks. Second, TMIA questioned whether the loss of pretension might cause the leakage rate for some cracks to be reduced. It suggested that a decrease of the leakage rate might mask cracks that might propagate due to additional stress or corrosion.

Licensee's witnesses testified that the only potential for self-sealing would be for a small leak past the new repair joint.8/ It was undisputed that to be self-sealing, a leak past the joint would have to have a very small flow through a pathway sufficiently tight to enable the build-up of corrosion

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8/ Self-sealing can occur only for leakage pathways between the expanded portion of the joint and the tubesheet. The joint is formed between the Inconel tube and the carbon steel tubesheet. Since carbon steel has a propensity for general corrosion in a normal RCS chemistry environment, corrosion products are formed in the long, tight tube-to-tubesheet joint. Industry experience indicates that these corrosion products tend to plug up leakage paths in the tight tube-to-tubesheet crevice and to stop or slow (i.e., self-seal) leakage. A trend of decreasing leakage with time for joints tested in the qualification program further confirmed this industry experience. FF 20.

products adequate to seal the leak. A leak of this size would not adversely affect the load bearing capability of the joint, or increase the probability of rupture within the joint. Thus, the self-sealing would not mask leakage that could be of safety significance. FF 21.

Licensee's witnesses similarly testified that loss of pretension on some of the TMI-1 tubes does not affect the usefulness of leak testing. If there is leakage past the repair joint, it will be through the tight crevice between the tube and tubesheet. The loss of pretension does not affect the tightness of this joint 9/ and thus can not affect the potential leakage flow path once fixed. Monitoring of leakage through such a joint is therefore unaffected by a loss of pretension. FF 22, 24.

With respect to intergranular stress assisted cracking, Licensee's witnesses testified that although, in theory, a tube without pretension would exhibit a lower leak rate than a tube with pretension for a circumferential through-wall crack of a given size, in practice, this phenomenon is unlikely to mask the detection of a critical size crack at TMI-1. FF 25.

9/ The kinetic process relies on horizontal forces to expand the tubes, while pretension is an axial load (*i.e.*, vertical in direction). Since these load components are perpendicular with respect to each other, the loss of pretension does not affect the ability to expand the tube and form the new joint. FF 23.

The testing already conducted on each tube by Licensee--special eddy current testing, bubble testing and leak testing--shows that such cracks do not exist in the tube pressure boundary. Moreover, the conditions which caused the circumferential intergranular stress-assisted cracking in TMI-1 have been eliminated. If such a crack nonetheless were to exist, it would propagate only during conditions when the tube was placed in axial tension; such loads will be offset by the effect of pretension loss. However, as Mr. Slear explained, the steam generator hot functional testing program placed axial tensile loads on all tubes--including those which had loss of preload. The low leakage found confirmed that no large cracks remain undetected. FF 26, 27.

Licensee's witnesses also noted that if future cracks are hypothetically assumed to be propagating due to IGSAC at normal operating conditions, the principal direction of propagation will be axial along the tube. IGSAC propagation is principally perpendicular to the direction of highest stress. The highest tube stress is in the hoop direction at these conditions. A loss of pretension will not cause reduced leakage from axial tube cracks because there are no forces associated with loss of pretension trying to keep the crack closed. FF 28.

The NRC Staff witnesses corroborated and supplemented Licensee's testimony that some leakage is to be expected at any plant and that the proposed license condition provides adequate assurance that leakage will be detected and responded to prior to the potential for tube rupture. Tr. 625-626 (McCracken). In this context, Mr. McCracken emphasized that the steam generators had been returned to the original licensing basis. Tr. 626-629. He noted that in fact, none of the Staff members or Staff consultants have any reservation about any aspect of the repair from the point of view of health and safety. Tr. 637-638. FF 13.

After full consideration of the testimony, the Board believes that TMIA's concerns are without merit, and that the leak rate monitoring under the proposed license condition is a reliable precautionary measure.

3. Issue 1.b (Frequency of Eddy Current Testing)

Issue 1.b, as stated at page 23 of the Board's Order, reads as follows:

> 1. The rationale underlying certain proposed license conditions should be addressed, with attention to:
>
> * * * *
>
> b. Method of determining frequency of ECT tests.

Industry experience has shown eddy current testing is the preferred method for non-destructive examination of steam generator tubes to ascertain damage. It is used to provide knowledge of the generator state well before tubes degrade to the point of through-wall leakage or an unsafe condition develops within the generator. As ECT is a technique for inspecting tubing remaining in service as part of the primary pressure boundary, the role of eddy current inspection for the TMI-1 steam generators is the same as for generators at any other operating plant. FF 30.

The existing Technical Specification requirements for ECT at TMI-1 implement NRC's Regulatory Guide 1.83, Rev. 1 and track those for other nuclear plants.10/ Licensee has adopted supplements to the existing Technical Specifications which the NRC Staff proposes be added as a license condition. Under the new license condition, either 90 days after reaching full power or 120 calendar days after achieving 50% power (whichever occurs first), the plant will be shut down for eddy current inspection of the generators. In addition, ECT will be conducted at the subsequent shutdown refueling. The plant currently is loaded with fuel which will permit full power operation for a little less than one year. FF 32, 33.

10/ The Technical Specifications require at least 3% of the total number of tubes in the steam generators to be examined at each inspection (certain criteria on tube selection are included). Known indications will also be tested. The Technical Specification testing frequency is specified to be not more than 24 months after the previous inspection with provisions that the interval could be extended to a maximum of once per 40 months, contingent on prior inspection results. Further conditions are imposed on the inspection frequency if there are primary-to-secondary tube leaks, degradation is in excess of Technical Specification limits, and/or a loss of coolant accident or a main steam line or feedwater line break has occurred. FF 31.

Both Licensee and Staff witnesses testified that these supplements are reasonable precautionary measures which will act as confirmation of Licensee's conclusion that crack initiation or propagation is not anticipated by chemical or mechanical means following return of the steam generators to service.11/ TMIA presented no opposing evidence.

The time frame selected for ECT was viewed as reasonable in light of the following considerations:

(1) The failure mechanism is inoperative in the absence of sufficiently high levels of reduced sulfur species, and accordingly IGSAC will not reinitiate under the current TMI-1 operating conditions. Thus, there is reasonable assurance that the rapid IGSAC which caused the original damage will not affect the steam generators in the future. Mr. McCracken emphasized that, as a consequence, the 90/120 day time frames are not based upon a predicted rate of degradation (since none is predicted), but rather is simply a conservative corroborative measure. Tr. 594; FF 34(a), 37.

(2) The absence of leakage in excess of Licensee's new, stringent administrative limits on primary-to-secondary

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11/ Licensee presented a panel consisting of Messrs. Wilson, Slear and F. Scott Giacobbe, Manager of Materials Engineering/Failure Analysis. See testimony following Tr. 284 ("Licensee's testimony of Richard F. Wilson, David G. Slear and F. Scott Giacobbe on Issue 1.b (Contention 1.a)," hereafter cited as "Licensee - Issue 1.b"). Staff presented testimony by Mr. McCracken and Dr. Wu. See Staff - Cont. 1.a.

leak rate during hot functional testing supports the conclusion that unforeseen rapid or gross changes are not taking place. FF 34(b).

(3) No mechanism has been identified relating to mechanical crack propagation scenarios while operating at full power. FF 34(e).

(4) ECT will be most informative of plant conditions if it occurs after chemical equilibrium takes place. As used here, chemical equilibrium has had two aspects. First, in coming back from a long term lay-up, the system needs a period of operation to develop the oxide films that are typical of all steam generators. Second, a period of operation may be necessary for dissolution of residual sulfur remaining on the tube surfaces and its removal from the reactor coolant system. FF 35(a).

(5) Since the ECT program is designed to characterize change, there is a need to allow reasonable operating time on the generators to allow any unforeseen mechanism to cause change. FF 35.

(6) The time frame used is as restrictive or more restrictive than those implemented after steam generator repairs -- even at plants where continued corrosion is expected. FF 37.

Mr. Slear explained that Licensee will use both a special differential probe ECT and 8x1 absolute probe ECT as appropriate.12/ Licensee has special differential probe data on all tubes and special absolute probe data on approximately 800 tubes. FF 34. A sample of the latter tubes will be re-examined using the absolute probe to corroborate that there is no degradation. Tr. 312-315 (Slear); FF 33.

TMIA suggested that ECT should be conducted within 30-60 days after restart, relying on the tentative recommendation of NRC Staff in May 1982 that this time frame would be appropriate. Mr. McCracken explained, however, that the preliminary Staff view was predicated on the fact that at that time, little was known about the corrosive mechanism and whether degradation was expected. The Staff revised the time frame based on the extensive knowledge subsequently gained and the fact that no further degradation is expected. FF 37.

The Board finds that the above facts and experience suggest a minimal period of several months of initial operation is necessary to ensure that sufficient data can be obtained during the inspections to trend conditions within the steam generators. The new augmented eddy current test program is a judgment based on the available facts regarding generator condition

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12/ A differential probe uses two circumferentilly wound coils and is read by comparing one coil's signal to the other. As the first coil passes the defect, it unbalances the signal when compared to the second coil. In an absolute probe, the coils are essentially axially wound, and defects are indicated by an upset in the signal from the individual coil. Tr. 311-312 (Slear).

and potential failure mechanisms, and includes consideration of general industry experience Based on the foregoing, the Board finds that the proposed license condition on the frequency of ECT will provide the requisite degree of insight on changes, if any, in the generator. FF 38.

4. Issue 1.c (Power Ascension Limits)

Issue 1.c, as stated at page 23 of the Board's Order, reads as follows:

> 1. The rationale underlying certain proposed license conditions should be addressed, with attention to:
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> * * * *
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> c. Method of determining power ascension limitations.

As Licensee's witnesses on this issue explained,13/ the initial power ascension program was developed, prior to knowledge of the damage to the steam generators, by considering test requirements as a result of core reload, plant modifications made since the plant was last operated, and operator training requirements. These considerations resulted in a testing

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13/ Licensee presented a panel of three witnesses, consisting of Messrs. Wilson, Slear and T. Gary Broughton, Director of Systems Engineering. See testimony following Tr. 328 ("Licensee's Testimony of Richard F. Wilson, David G. Slear and T. Gary Broughton on Issue 1.c (Contention 1.a)," hereafter cited as "Licensee - Issue 1.c"). Staff witnesses of this issue were Mr. McCracken and Dr. Wu. See Staff - Cont. 1.a. TMIA presented no direct evidence.

sequence, power level plateaus and development of special tests for plant modifications and operator training. Primary factors in determining the test sequence and plateaus included verification that core physics parameters are as predicted and that nuclear instruments, the integrated control system and the turbine protective system are calibrated and functioning properly. FF 41.

The power ascension program was reviewed by Licensee in conjunction with the steam generator repair program. Because the pre-critical testing verified the adequacy of the repair and the operability of the steam generators, Licensee concluded that no additional tests were needed in the post-critical test program because of the repair. Licensee nonetheless determined that two 30-day hold periods should be added to the power ascension program. FF 42, 43.

Mr. McCracken explained that the Staff did not consider the power ascension limitations to be required as part of the steam generator repair program. However, because Licensee conservatively elected to perform a slow progression, the Staff has proposed a license condition that provides the Staff with an opportunity to review the results of tests performed at a given level of power prior to escalation to the next power level. This license condition is not intended to limit the power ascension itself. FF 44.

The first hold period will occur at 48 percent power following the RCS overcooling test. This point was chosen because it immediately follows tests which load the steam generator tubes (loss of feedwater and RCS overcooling) and because it allows operation with two main feed pumps, which is the normal plant configuration. The second hold point will follow testing at the 75 percent power plateau. Leak rate monitoring, surveillance testing and operator familiarity will occur during this hold period. Experience from leak rate monitoring performed during the steam generator pre-critical tests corroborated that 30-day hold periods would provide adequate time for stabilizing the plant and collecting statistically valid data. FF 46.

Licensee explained that the slow progression from power level to power level had several purposes, many of which related to plant operating in general but not to the kinetic expansion process. In addition, the slow progression will facilitate monitoring of leak rate changes and permit detection of abnormal trends as early as possible, and thereby provide information on the kinetically expanded joints. FF 45.

TMIA suggested that the power ascension limitations are not in accord with the Third Party Review (TPR) Group's recommendation of "substantial" extended operation at low power. The Board concludes otherwise. The TPR recommended two hold periods of "a month or more" at around 40 percent and 70 percent power (Att. 6 to the Staff's SER, TPR February 1983 Report at 11-12, Recommendation 2). Licensee thereafter added two 30-day hold periods, one at 48 percent power and one at 75 percent power. In its May 16, 1983 report, the TPR stated that "[t]he GPU Nuclear response is satisfactory." (Att. 6 to the Staff's SER, TPR May 1983 Report at 7.) We agree. FF 48,49.

The TPR also recommended that Licensee "consider the possibility of deliberately running one steam generator at a higher power than the other during the first escalation hold periods." (Att. 6 to the Staff's SER, TPR February 1983 Report at 12, Recommendation 3.) Licensee explained to the TPR, however, that this approach could only be implemented by operation of a single reactor coolant pump in one loop which would cause mismatched reactor coolant system flow, imbalanced feed flows and different coolant levels in each generator. This could mask changes in the plant conditions, including any abnormalities in the plant response to transients. This abnormal plant configuration would conflict with the intent of conducting the startup in a slow, deliberate manner under normal operating conditions. FF 50, 51.

The TPR considered this response satisfactory (May 16, 1983 Report at 7), and TMIA has failed to present evidence or even raise legitimate questions showing why it is not. FF 52. The Board has no reason to doubt the wisdom of the position taken by Licensee and the TPR on this matter.

Accordingly, the Board concludes that the proposed license condition on power ascension limitations will serve as a reasonable corroboration of the adequacy of the kinetic expansion repair process.

5. Issue 1.d (Long Term Corrosion Tests)

Issue 1.d, as stated at page 23 of the Board's Order, reads as follows:

> 1. The rationale underlying certain proposed license conditions should be addressed, with attention to:
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> * * * *
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> d. Adequacy of simulation of operating conditions by long-term corrosion tests.

The Board admitted this contention on the basis of the concern expressed by TMIA that the long-term corrosion tests may not demonstrate the adequacy of the kinetically expanded joint because the tests may not adequately simulate operating conditions. Licensee's witnesses14/ clarified for the Board, however, that these tests were not designed to confirm that Licensee has provided reasonable assurance against the

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14/ Messrs. Croneberger and Giaccobbe testified for Licensee. See testimony following Tr. 231 ("Licensee's Testimony of Don K. Croneberger and F. Scott Giacobbe on Issue 1.d (Contention 1.a)," hereafter cited as "Licensee - Issue 1.d"). Messrs. McCracken and Wu testified for the Staff. See Staff - Cont. 1.a. TMIA presented no witnesses or other direct evidence on this issue.

possibility of mechanically induced tube ruptures caused by various transients, as alleged by Contention 1.a, and, in fact, that the tests provide no information one way or the other on this subject. Rather, the purpose of the tests is to verify that sulfur-induced IGSAC will not reinitiate or propagate in the TMI-1 OTSGs under actual operating conditions. FF 56. The issue of reinitiation was disposed of on summary disposition, and the question whether Licensee has provided reasonable assurance that corrosion will not reinitiate was answered in the affirmative.

In light of this clarifying explanation in Licensee's testimony, the Board agrees that the long-term corrosion tests do not bear directly on the adequacy of the kinetically expanded joint.15/ Irrespective of whether the issue is relevant to Contention 1.a, or indeed to the subject matter of the hearing,16/ we can find no merit in TMIA's position.

While TMIA is correct that no test can precisely simulate actual operating conditions, the tests simulate typical

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15/ The long term corrosion tests are accordingly related to the kinetic expansion repair process only insofar as they verify that the repair did not render the OTSGs susceptible to reinitiation of IGSAC. (This is tested by including kinetically expanded tube samples in the test loops.) FF 57.

16/ Indeed, in light of the narrowness of the issue before us -- the adequacy of the tube repair process -- the Board questions, as it has in the past, whether the issue of the cause of the cracking and its potential for reinitiation is properly within the scope of this hearing.

conditions during steady state and transient operation as closely as is reasonably possible. In particular, the tests reproduced all the parameters which influence IGSAC, i.e., susceptible material, environment, and stress, and bounded the actual operating situation by including "worst case" chemistry conditions for controlled contaminants. FF 59, 60, 66.

Licensee's witnesses stated that, to assure that the influence of prior operation and layup on tubing was adequately represented, only tube sections removed from the TMI-1 steam generators were used as specimens. These specimens were selected from various regions of each OTSG including tube sections which had known defects. Representative samples of different metal heats were included in order to bound conditions in the steam generator. The use of actual OTSG tubes precluded any possibility that test specimens would not duplicate exactly the TMI-1 material. FF 61.17/

17/ Metallographic examination and testing analysis separate from the long term corrosion testings showed that the IGSAC did not affect the integrity of the base metal itself. To the extent that a crack reduces cross-sectional area, this would reduce the load-carrying capability of that area. This effect was taken into account in Licensee's analysis of the load carrying capability of the tube. Tr. 346-347 (Giacobbe, Croneberger).

TMIA questioned whether the IGSAC resulted in a loss of ductility. Mr. Giacobbe explained and emphasized that the long term corrosion test is not designed to assess ductility or other mechanical properties. Tr. 349 (Giacobbe).

Certain of the samples were subjected to the explosive expansion process using mockup tube sheets and then subjected to a peroxide cleaning process. This ensured that the influence of these processes on the inside surface condition was produced. Certain other samples were not peroxide cleaned, in order to test what could occur if Licensee had not undertaken the cleaning process, given the larger quantities of residual sulfur that would have remained on the tube surfaces. FF 64.

Environmental chemistry parameters were selected to either simulate, or be more aggressive than, the water chemistry which will be maintained in the RCS. In three of the four test loops, 100 ppb of sulfate, the maximum permitted under chemistry specifications, was used. In the fourth test loop, 100 ppb thiosulfate was put in solution. In addition, to ensure adequate conservatism, the levels of chloride and fluoride were set at the maximum amount permitted by Licensee's operating chemistry specifications (100 ppb each). FF 66.

Because the testing and operation of the plant necessitates heating up and cooling down of the steam generators, the tests included typical temperature cycles. Aeration and temperature conditions comparable to those which existed during the propagation of the original sulfur-induced IGSAC were also included. The introduction of oxygen provided the most rigorous test sequence in view of the fact that oxygen plays a major role in sulfur induced IGSAC. However, as explained by

Mr. Giacobbe, oxygen will not create a corrosive environment in the absence of sufficient levels of corrodant. Tr. 368; FF 67, 68.

In order to simulate the stress associated with changes in axial load, full tube specimens were loaded at a level corresponding to steady state loads during heatup, cold shutdown, and operation. Residual stresses induced by the explosive expansion were also taken into account by including full tube specimens simulating repaired joints which had been kinetically expanded using the same process as in the actual steam generators to ensure representative residual stresses. The C-ring specimens which were loaded to a level just slightly below yield, which is significantly higher than the load seen by the tubes in actual service, were also included. Because of the high stress, the C-rings bound loads induced by any accident transients. FF 71, 76.18/

The Staff witnesses corroborated that the long term corrosion tests adequately simulate actual operating conditions, or

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18/ In response to questioning by TMIA, Licensee's witnesses explained that the tests did not simulate flow-induced vibration for two reasons. First, the purpose of the test was to evaluate corrosion damage and not fatigue damage. It was determined that the loading cycles simulating heat-up and cooldown were sufficient to predict the effect of stress on corrosion. Tr. 346 (Croneberger). Second, as a result of analysis, Licensee concluded that from a fatigue damage standpoint, flow-induced vibration was not predicted to be a concern. Tr. 345 (Croneberger); FF 72.

expose tube samples to conditions worse than those the actual steam generators will face.

In light of these test parameters, the long-term corrosion tests provide a valid simulation of the conditions that the steam generator tubing will experience in future TMI-1 operations. For comparison, tests have also been included which simulate what could occur if Licensee had not taken the corrective measures of peroxide cleaning and removal of possible sources of thiosulfate. This test program provides a clear basis for empirically evaluating steam generator tube performance.

6. Issue 2 (Inadvertent Initiation of Emergency Feedwater Flow)

Issue 2, as stated at page 23 of the Board's Order, reads as follows:

> 2. The effect of inadvertent initiation of emergency feedwater flow at high power or following rapid cooldown after LOCA should be addressed, with attention to calculation of maximum transient stresses in steam generator tubes.

The Board received extensive evidence from Licensee and the Staff on Issue 2.19/ No contrary evidence was presented by

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19/ Licensee presented a panel of three witnesses on this issue: Douglas E. Lee, Manager of the Mechanical Engineering Section of the Engineering Department of Babcock & Wilcox, and Messrs. Croneberger and Slear. See testimony following Tr. 421 ("Licensee's Testimony of Douglas E. Lee, Don K. Croneberger and David G. Slear on Issue 2 (Contention 1.a)" hereafter cited as "Licensee - Issue 2"). The Staff witnesses on this issue were Mr. McCracken and Dr. Wu. See Staff - Cont. 1.a.

TMIA.

Both Licensee and the Staff testified that tube loadings resulting from inadvertent initiation of emergency feedwater (EFW) flow into the steam generator during full power operation would be extremely small. These loads, if any, would be far less than the tensile load of 3140 pounds to which the repair joint has been designed and qualified. FF 80, 81.

Licensee testified that the plant systems were designed such that inadvertent actuation of the EFW system would not result in the injection of water into the steam generators because the EFW valves, controlled by the water level in the steam generators, would not be opened. FF 76. Nevertheless, if both inadvertent actuation of the EFW pumps and inadvertent opening of the EFW valves were assumed, the physical configuration and thermal steam environment of the steam generators are such that there would be no impingement of water on the repair joints. Water impingement on the tubes would have been heated to temperatures approaching that of the secondary side steam, and would result in only minimal change in the axial loads on the tubes. FF 77-81.

With respect to rapid cooldown following a LOCA (loss-of-coolant accident), both Licensee and the Staff also testified that the resultant tube loadings would be significantly less than the design and qualification loads. The maximum transient loads on the tubes following a LOCA, including the effects of EFW injection into the tube bundle, have been conservatively calculated to be 2641 pounds. This is well below the 3140-pound load to which the repair joint was designed and qualified. FF 82.

Accordingly, consistent with the uncontradicted testimony of Licensee and the Staff, we find that the effects of inadvertent initiation of EFW flow at full power or following rapid cooldown after a LOCA are adequately accounted for and bounded by the design and qualification of the tube repairs.

7. Issue 3 (Hardness Testing)

Issue 3, as stated at page 23 of the Board's Order, reads as follows:

> 3. The reasons for not including hardness tests on repaired tubes in the post repair testing program should be addressed.

Uncontradicted testimony by both Licensee and the Staff 20/ demonstrated that hardness testing of repaired tubes was both unnecessary and impractical -- unnecessary because the tests would add no useful information not already available by other, more effective means, and impractical because the

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20/ Licensee presented Messrs. Douglas E. Lee, F. Scott Giacobbe and David G. Slear. See testimony following Tr. 423 ("Licensee's Testimony of Douglas E. Lee, F. Scott Giacobbe and David G. Slear on Issue 3 (Contention 1.a)," hereafter cited as "Licensee - Issue 3"). The Staff witnesses on this issue were Mr. McCracken and Dr. Wu. See Staff - Cont. 1.a.

equipment involved in hardness testing does not enable the performance of _in situ_ tests of the repaired tubes in the steam generators. FF 89, 90, 95.

Hardness testing was done on TMI-1 archival tube samples which had been kinetically expanded during the pre-repair qualification program. FF 91, 92. The tests were performed to compare the hardness, or degree of "cold working," in the transition zone of the kinetically expanded tubes to that of the roll expansion joint which was used during manufacture of the steam generators. FF 86. The tests indicated that there was less "cold working," and hence less residual stress and potential susceptability to stress corrosion cracking in the kinetically expanded joints. FF 87-89. The Staff testified that Licensee's tests were actually unnecessary because the conclusions drawn from the hardness tests were easily predicted mathematically. This information, once obtained mathematically or during the qualification program by hardness testing, did not need to be repeated on the repaired tubes in the steam generator, and indeed the tests could not be performed without destructively removing the repaired tubes from the steam generators. FF 89, 90, 95, 96.

The Board inquired at length about whether tests on TMI-1 archival tubes, _i.e._, tubes in storage which were manufactured with and to the same specifications as the tubes used in the steam generators, but which had not been installed in the generators, were applicable to tubes which had seen service in the steam generators. We are satisfied with Licensee's extensive testimony to the effect that tests conducted on both archive tubes and tubes removed from the steam generators demonstrated that the crucial parameters, strength and ductility, were the same, such that the results of tests on archival tubes, such as hardness tests, were validly representative of the tubes remaining in the steam generators. FF 92-94.

8. Issue 4 (Effectiveness of Kinetic Expansion as a Repair Versus a Manufacturing Process)

Issue 4, as stated at page 23 of the Board's Order, reads as follows:

> 4. Recalling Licensee's statement in ¶¶ 6-8 that the use of kinetic expansions to seal heat exchanger tubes within tubesheets has a broad base of successful experience, information is requested about whether tube integrity during subsequent operation depends on whether the process is a repair, or a manufacturing process using new materials.

The Board received extensive uncontradicted evidence from Licensee and the Staff on Issue 4 recounting the successful history of the various kinetic expansion repair and fabrication processes.21/ No evidence was presented by TMIA.

21/ Licensee presented Dr. David H. Pai, Senior Vice President of the Engineering and Services Division of Foster Wheeler Energy Applications, Inc. See testimony following Tr. 379

(Continued Next Page)

Both Licensee and Staff testified that the kinetic expansion process creates an effective seal irrespective of whether it is performed as a field repair on weathered tubes or as part of the original fabrication of new tubes, so long as the expanded material maintains certain key geometric and material parameters (specifically, yield strength and ductility). FF 99, 112. They also testified that the TMI-1 steam generators maintained all the requisite parameters for successful application of the process. FF 112-114.

Dr. Pai of Foster Wheeler, which was responsible for the kinetic expansion at TMI-1, testified that the TMI-1 steam generators are but one type of shell and tube heat exchanger and it shares all the relevant common characteristics with other heat exchangers, e.g., small diameter, thin-walled tubes attached to tubesheets and containment of the tube bundle in a shell which forms the component pressure boundary. Foster Wheeler has adopted the kinetic expansion process as the primary means of expansion for high pressure feedwater heaters. FF 101-103. It has successfully applied the kinetic expansion process to various field repairs since the mid-seventies,

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(Continued)

("Licensee's Testimony of Dr. David H. Pai on Issue 4 (Contention 1.a)," hereafter cited as "Licensee - Issue 4"). The Staff witnesses on this issue were Mr. McCracken and Dr. Wu. See Staff - Cont. 1.a.

including: 1) expansion of tubes below the tube-to-tubesheet weld region to effect a new joint; 2) expansion of new tubes into an existing tubesheet as part of a tube bundle replacement; 3) expansion of sleeves into existing heat exchanger tubes; and 4) tube plugging using the Detnaplug™ process. FF 104, 106. The tubing sizes, as well as most of the tubing and tubesheet materials, are similar to those in the TMI-1 steam generators, as are the operating temperatures and pressures. FF 105.

Licensee and Staff witnesses testified that there is also substantial experience with the kinetic expansion process in steam generators. Combustion Engineering and Westinghouse have used the process in U-tube units, and Babcock & Wilcox has used it in an OTSG unit. The process has been used in steam generators in Japan for both manufacturing and repair. None of these tubes have been stress-relieved after expansion. The experience in the above circumstances has been uniformly successful, with no evidence of degradation in the transition region. FF 107-111.

Licensee's witness testified that the above experience was directly applicable to and supportive of the use of kinetic expansion here because the key parameters (yield strength and ductility) of both the expanded archival and actual steam generator tube samples were thoroughly tested and found to be within the range necessary for successful expansion.

Licensee's conclusions have been confirmed by leak rate measurements, pull-out load tests and an extensive qualification program. FF 112-114.

Finally, the witnesses explained that the kinetic expansion process has been increasingly used as a means of closing the crevice between tubes and tubesheets because it has significant advantages over rolling. Tr. 412 (Pai); Tr. 631 (McCracken). The quality control of kinetic expansion is easier than that of rolling; the results of expansion are consistently uniform and the process is therefore more reliable. Tr. 620, 631 (McCracken). Moreover, a rolled tube is subjected to more cold working than is a kinetically expanded tube. The rolled tube would therefore have a higher surface hardness and is more susceptible to corrosion. Tr. 411-412 (Pai); Tr. 634 (McCracken); FF 100.

After careful consideration of the evidence, the Board is satisfied that the kinetic expansion process does indeed have a broad base of successful experience and that it is an effective method to seal heat exchanger tubes within tubesheets, including those in OTSGs, irrespective of whether the process is applied to new equipment during fabrication or to the repair of existing equipment. FF 116.

D. CONTENTION 1.b

1. Issue 5 (No Increased Probability of Simultaneous Tube Rupture)

Issue 5, as stated at page 32 of the Board's Order, states as follows:

> [T]he central issue is whether the repair process has increased the probability of [simultaneous tube ruptures involving both TMI-1 steam generators].

Licensee and the Staff provided testimony that the probablity of such an occurrence is not increased as a result of the repair process.22/ TMIA presented no evidence on the issue.

At the outset, we should reiterate the observation we made at the beginning of our discussion of Contention 1.a concerning the possibility of tube rupture at or in the vicinity of the repair joint. Licensee has testified that a tube rupture, as it is commonly understood in the industry, cannot occur in the tubesheet hole where the repair took place because of the physical restraint of the tubesheet hole in limiting the size of the leak. In our discussion, while we refer to the alleged

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22/ Licensee presented Messrs. Douglas E. Lee, Don K. Croneberger, and David G. Slear. See testimony following Tr. 424 ("Licensee's Testimony of Douglas E. Lee, Don K. Croneberger and David G. Slear on Issue 5 (Contention 1.b)" hereafter cited as "Licensee - Issue 5"). The Staff witnesses on this issue were Mr. Conrad E. McCracken and Dr. Paul C. Wu. See testimony following Tr. 652 ("Testimony of Conrad E. McCracken and Paul C. Wu on TMIA Contention 1.b" hereafter cited as "Staff - Cont. 1.b").

potential for "rupture", we are in actuality examining the potential for something considerably less in terms of leakage rate. FF 119.

Licensee and the Staff are in agreement that the repair has essentially returned the tubes to their original licensing basis, and therefore the liklihood of rupture has not been increased as a result of the repair. In our Order at 32, we noted that Licensee and the Staff had not provided us with sufficient information in their motions for summary disposition to enable us to accept the concept that the design basis for a new plant, constructed using new materials, is necessarily germane to restart of a reactor which has been repaired after operation. The Staff, however, testified at the hearing that the strength and ductility of Inconel-600, the tube material, are retained despite previous operation, and that these characteristics of the tubing material were not affected by the repair process. Therefore the tubes are just as resistant to rupture now, after the repair, as they were prior to operation when they were new. FF 120. The evidence was uncontradicted, and we accordingly agree that the original licensing basis can indeed be applied to the TMI-1 repaired tubes.

Licensee's witnesses testified that the primary objective of the repair program was to establish a system that would not increase the liklihood of tube rupture. This objective was met by establishing that the repair joint is not more susceptible to tube rupture that the original joint would have been, and that the repair process itself has not adversely affected the tube so as to increase the liklihood of tube rupture. FF 121. In this regard, Licensee's uncontradicted testimony established that the repair joint had been qualified by testing and analysis to the design basis transients established for the original tube-to-tubesheet joint; that if failure of the joint were to occur, it would be by slippage, rather than rupture, and the joint would remain leak resistant; that the residual stresses in the transition zone between the expanded portion of the new joint and the unexpanded portion of the tube do not increase the likelihood of stress corrosion cracking; and that loss of preload on the tubes as a result of the repair process has not increased the likelihood of tube failure. FF 122-130.

Thus, the uncontradicted evidence showed that the tubes have been returned to their original licensing basis and that the kinetic expansion repair process has not increased the likelihood of tube rupture due to failure of the joint, the transition zone, or the remainder of the tube. We therefore find there is not an increase in the likelihood of simultaneous tube rupture involving both steam generators as a result of the kinetic expansion repair process.

II. FINDINGS OF FACT

A. BACKGROUND

1. This Initial Decision pertains to a request to amend the Technical Specifications contained in the operating license for Unit 1 of the Three Mile Island Nuclear Station to permit operation of TMI-1 with steam generator tubes which have been repaired by a kinetic expansion repair process.

2. Following Licensee's submission of a request to amend the Technical Specifications contained in the operating license for TMI-1 on May 9, 1983, and the NRC's public notice of an opportunity for hearing on May 31, 1983, as amended on June 14, 1983, two intervenor groups -- Three Mile Island Alert, Inc. ("TMIA") and Ms. Lee, Mr. Aamodt and Dr. Molholt ("Joint Intervenors") -- filed petitions for leave to intervene and requests for hearing. Their requests were granted, with the exception of Dr. Molholt who withdrew his petition to intervene. Joint Intervenors were subsequently eliminated as a party as a result of Motions for Summary Disposition filed by Licensee and the NRC Staff.

3. An evidentiary hearing was conducted in July of 1984. Parties to the hearing were Licensee, TMIA and the NRC Staff. The Commonwealth of Pennsylvania participated as an interested State pursuant to 10 C.F.R. § 2.715(c). Licensee and the NRC Staff presented evidence on eight issues of concern specified

by the Board as distilled from two of TMIA's contentions. No testimony was presented by TMIA or the Commonwealth of Pennsylvania.

B. CONTENTION 1.a

4. TMIA's Contention 1.a, as stated by the Board in its ruling on summary disposition, provided that:

> 1. Neither Licensee nor the NRC Staff has demonstrated that the kinetic expansion steam generator tube repair technique, combined with selective tube plugging, provides reasonable assurance that the operation of TMI-1 with the as-repaired steam generator can be conducted without endangering the health and safety of the public, for the following reasons:
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> a. Post repair and plant performance testing and analysis including the techniques used, empirical information collected, and data evaluation, and proposed license conditions are inadequate to provide sufficient assurance that tube ruptures, including but not limited to those which could result upon restart, a turbine trip at maximum power, thermal shock from inadvertent actuation of emergency feedwater at high power or following rapid cooldown after a LOCA, will be detected in time and prevented to avoid endangering the health and safety of the public through release of radiation into the environment beyond permissible limits.

5. Except for the issues detailed below, Contention 1.a has been dismissed. The contention's focus on the adequacy of

the (1) "kinetic expansion steam generator tube repair technique," to provide reasonable assurance against (2) "tube ruptures," as evidenced by (3) "post repair and plant performance testing and analysis," provides the boundaries for the remaining subparts of the contention.

6. Because the kinetically expanded portion of the tube is within the tubesheet, any failure which theoretically could result from the repair process will not result in tube ruptures as such. The tube in the area of the repair is captured by the tubesheet and the movement of the tube is concommitantly limited. If the kinetic expansion joint were to fail, the result would be slippage, not a rupture. The leakage, moreover, would be significantly limited by the tight crevice. Tr. 476-477 (Slear); 508-509 (Slear, Croneberger).

1. Issue 1.a (Reliability of Leak Rate Measurements)

7. Issue 1.a, as stated by the Board in its ruling on summary disposition, provided that:

> The rationale underlying certain proposed license conditions should be addressed, with attention to:
>
> a. Reliability of leak rate measurements.

8. The purpose of the primary-to-secondary leak rate measurements at TMI-1, as at other operating PWRs in the United States, is to confirm that the steam generators are performing as anticipated. The leakage measurements during operation are

made both to document the absolute value of leakage and to document any trends which may be cause for concern. The absolute value is required to both assess the performance of the steam generators and to ensure that Technical Specification limits are not exceeded. Trends are monitored because increasing leakage may indicate ongoing chemical or mechanical degradation of the tube. Increasing leak rates are investigated further to identify leak locations and take appropriate corrective action. Licensee - Issue 1.a at 5-6.

9. The existing license conditions related to primary-to-secondary leakage through the TMI-1 once-through steam generator tubes are Technical Specifications 3.1.6.3 and 4.1. Technical Specification 3.1.6.3 reads as follows:

> If primary-to-secondary leakage through the steam generator tubes exceeds 1 gpm total for both steam generators, the reactor shall be placed in cold shutdown within 36 hours of detection.

Technical Specification 4.1. requires that leakage be evaluated daily. Licensee - Issue 1.a at 3.

10. The additional new license condition dealing with leakage provides that:

> Repaired Steam Generators
>
> In order to confirm the leak-tight integrity of the Reactor Coolant System, including the steam generators, operation of the facility shall be in accordance with the following:

* * * *

> 2. GPU Nuclear Corporation shall confirm the baseline primary-to-secondary leakage rate established during the steam generator hot test program. If leakage exceeds the baseline leakage rate by more than 0.1 GPM [6 GPH], the facility shall be shut down and leak tested. If any increased leakage above baseline is due to defects in the tube free span, the leaking tube(s) shall be removed from service. The baseline leakage shall be re-established, provided that the leakage limit of Tech. Spec. 3.1.6.3 is not exceeded.

Licensee - Issue 1.a at 3-4.

11. Licensee determined the baseline primary-to-secondary leakage to be 0.02 GPM (1 GPH) during the steam generator hot test program. This means that the facility is to be shut down if the leak rate reaches 7 GPH total for both steam generators, as compared to the existing limit of 60 GPH in Technical Specification 3.1.6.3. Licensee - Issue 1.a at 4. Because repairs have been performed since hot testing, the baseline leak rate will be re-established on restart. Tr. 327 (Wilson).

12. The TMI-1 leakage limitations in Technical Specification 3.1.6.3 are comparable to those at most other pressurized water reactors in the United States. A recent survey by Licensee of approximately 30 PWRs showed that the vast majority of the plants have limits similar to TMI-1's current 1 GPM (60 GPH) limit. One plant has a limit three times the current TMI-1 limit. A few of the more recently licensed plants have limits lower than Technical Specification 3.1.6.3. The new

TMI-1 license condition of 0.1 GPM, however, is more stringent than that for any other operating PWR in the United States. Licensee - Issue 1.a at 5; Tr. 240 (Slear); Staff - Cont. 1.a at 8; Tr. 611 (McCracken).

13. Leak rate measurements are one aspect of an overall defense in depth approach to maintain steam generator integrity which includes leak rate monitoring during operation, periodic eddy current testing, and leak rates while shut down at cold conditions as some leakage is to be expected at any plant. The overall defense in depth program, including the leak rate measurements, is adequate to permit Licensee to detect and correct defects in tubes prior to the potential for rupture, thereby ensuring that the steam generator tubes satisfy the licensing basis specified in General Design Criterion 14, 10 C.F.R. Part 50, Appendix A, i.e., "to have an extremely low probability of abnormal leakage, or rapidly propagating failure, and of gross rupture". Licensee - Issue 1.a at 6; Tr. 625-629 (McCracken).

14. A number of considerations support the selection of a nominal leak rate of 0.1 GPM, above a baseline value, which would dictate further action. These considerations include the need to:

(a) Establish a leak rate monitoring capability sensitive enough to detect a leak rate as low as 0.5 GPH (about 1% of the Technical Specification 3.1.6.3 limit) during power operations.

(b) Establish a baseline leakage rate to take into account the anticipated, low level leakage from the mechanical plugs and the kinetically expanded joint.

(c) Establish a shutdown limit sufficiently above the pre-established baseline so that Licensee can have confidence that the change is significant as compared with the anticipated variation in the nominal monitored leak rate. The steam generator hot testing results indicate that the monitored leak rate statistical variation (twice the standard deviation from the mean value) of approximately °Ø°¹ Λ→∂ $\leq$ 0.5GPH) can be expected during steady state operation.

(d) Establish a shutdown limit low enough to ensure conformance with the off-site exposure limits of 10 C.F.R. Part 50, Appendix I. Based on Licensee's 0.03% failed fuel percentage prior to the last refueling (which is likely higher than the actual failed fuel percentage which would occur upon restart), and use of the gaseous release mode (which results in the limiting off-site exposure dose closest to an Appendix I limit), a continuous 0.1 GPM primary-to-secondary leak rate contributes about 5 mr/year to the off-site thyroid dose rate. The Appendix I limit is 15 mr/year exposure to the thyroid due to iodine releases.

(e) Recognize the probability of multiple leakpaths within the steam generator contributing to the aggregate leakage. The baseline leak rate value was determined at operating conditions following a steam generator inspection and leak testing with a drip and bubble test. These cold leak tests conducted before the hot test program demonstrate that no single tube is causing all of the current 0.02 GPM (1 GPH) leakage. The results from these sensitive cold leak tests showed that the baseline leak rate value is and will be in the future the sum of multiple minor leakpaths which would not be expected to individually jeopardize the integrity of any steam generator tube. Licensee - Issue 1.a at 6-8.

15. Licensee's methods of measuring leakage at TMI-1 are reliable. These methods include measuring radionoble gas concentrations on the secondary side, and measuring chemistry and radio-chemistry in secondary side steam generator water. The radionoble gas concentration measurement is the most sensitive method of quantifying the primary-to-secondary leak rate. Licensee - Issue 1.a at 8-10. Continual readouts are provided by the off-gas monitors which are also alarmed. The leakage rate is calculated periodically by utilizing data from the on-line low range monitor and grab sample analysis. Licensee - Issue 1.a at 8; Tr. 240-241 (Slear). A sudden increase in leakage would be detected in a matter of minutes. Tr. 274-75 (Slear). If for some reason the low range on-line monitor was inoperable, the grab samples and additional monitors provide sufficient leakage data for safe operation. Licensee - Issue 1.a at 8-10; Tr. 267-269 (Broughton, Slear); Tr. 642-647

(McCracken). Licensee has a self-imposed administrative limitation requiring grab samples every four hours if the on-line monitor is inoperable. Tr. 647 (McCracken). A license condition requiring operability of the on-line monitoring system is accordingly unnecessary to protect safety and health. Tr. 644 (McCracken).

16. Licensee has evaluated the sensitivity of its monitoring equipment to determine its suitability for measuring primary to secondary leakage. For the expected ranges of condenser offgas flow, reactor power and failed fuel, the sensitivity is at least 0.001 GPM (0.07 GPH) during steady state operation (power operation) and 0.003 GPM (0.2 GPH) during plant cooldown (sub-critical conditions). The higher sensitivity during power operation is due to higher concentration of short half life radioisotopes in the reactor coolant system when the reactor is in operation. In addition, the statistical variation associated with the measurement technique during hot testing was found to be only 0.5 GPH. Tr. 242-243, 270-271 (Slear). Thus, the measurement technique being utilized at TMI-1 is sufficiently sensitive to support the 0.1 GPM licensing condition. Licensee - Issue 1.a at 10.

17. Licensee also relies upon two cold leak tests used to locate leaking tubes, the bubble test and the drip test. Licensee has evaluated bubble test sensitivity and determined it is the most sensitive cold leak test. Based on bubble test

experience, an 80-mil diameter bubble originating once every five seconds can be located during the bubble test. This correlates to a leak rate sensitivity of 0.000005 GPM for any individual leak. The bubble test was used to test about the top 18 feet of the 56 foot long steam generator tubes. Testing this upper portion of the tubes results in testing 100% of the new kinetic expansion joints. Licensee - Issue 1.a at 10-11.

18. The entire tube length was leak tested by the drip test. The sensitivity of the drip test is as low as 0.0002 GPM for any individual leak located at or near the lower tubesheet. For leak locations higher in the steam generators, the drip test sensitivity is reduced somewhat. Even so, the drip test sensitivity for leak locations high in the steam generators remains quite good, and is estimated to be about 0.002 GPM (three drops per second). Licensee - Issue 1.a at 11; Tr. 252 (Slear).

19. The relevance of leak rate measurements made at TMI-1 to the repairs made on the TMI-1 tubes is that the measurement total primary-to-secondary leakage from the steam generators include the contribution from leakage through the joints. Some leakage is to be expected, and small leakage through the joint does not indicate a reduction in load carrying capability. Tr. 269 (Slear). As previously described, if the nominal leak rate increases by 0.1 GPM, the plant will be shut down and the individual tubes, plugs and/or joints will be identified by the

nitrogen bubble test and drip tests discussed above. Licensee - Issue 1.a at 12.

20. The leak rate measurements are reliable even though in certain limited circumstances there may be a tendency for some leaks to be self-sealing. Self-sealing can occur only for leakage pathways between the expanded portion of the joint and the tubesheet. The joint is formed between the Inconel tube and the carbon steel tubesheet. Since carbon steel has a propensity for general corrosion in a normal RCS chemistry environment, corrosion products are formed in the tube-to-tubesheet joint. Industry experience indicates that these corrosion products tend to plug up leakage paths in the tight tube-to-tubesheet crevice and to stop or slow (i.e., self-seal) leakage. A trend of decreasing leakage with time for joints tested in the qualification program further confirmed this industry experience. Licensee - Issue 1.a at 12; Tr. 245-246 (Slear); Tr. 271-272 (Slear, Wilson).

21. To be self-sealing, a leak past the joint would have to have a very small flow through a pathway sufficiently tight to enable the build-up of corrosion products adequate to seal the leak. A leak of this size would not adversely affect the load bearing capability of the joint, or increase the probability of rupture within the joint, and hence is not of safety significance. Licensee - Issue 1.a at 12-13; Tr. 269 (Slear); see Tr. 260-264 (Slear, Wilson).

22. The loss of pretension of some tubes does not affect the usefulness of leak testing of the repaired joint. Pretension, or preload, was originally placed on the tubes during the manufacturing of the steam generators. This produced a tensile load on the tubes. At TMI-1, some tubes with complete circumferential cracks were freed from the original joint which fixed the tube in the upper tubesheet. These tubes contracted a small fraction of an inch, relieving all or part of the pretension. When the kinetic expansion was performed on these tubes, the tubes were again fixed at each end, but with the absence of part or all of the original pretension. This "loss of pretension" resulted in a reduction of axial tube load of only several hundred pounds. Licensee - Issue 1.a at 13; see Tr. 257-258 (Slear).

23. The kinetic process relies on horizontal forces to expand the tubes, while pretension is an axial load (i.e., vertical in direction). Since these load components are perpendicular with respect to each other, the loss of pretension does not affect the ability to expand the tube and form the new joint. Thus, kinetically expanded joints formed in tubes with loss of pretension are as tight, and therefore are no more prone to leakage, than tubes with preload. Licensee - Issue 1.a at 13-14.

24. Even if there is leakage past the repair joint, it will be through the tight crevice between the tube and

tubesheet. The loss of pretension does not affect the tightness of this joint and thus can not affect the potential leakage flow path once fixed. Monitoring of leakage through such a joint is therefore unaffected by a loss of pretension. Licensee - Issue 1.a at 14.

25. With respect to intergranular stress-assisted cracking ("IGSAC"), a tube without pretension, in theory, would exhibit a lower leak rate than a tube with pretension for a circumferential through-wall crack of a given size. In practice, however, this phenomenon is unlikely to mask the detection of a critical size crack at TMI-1. Licensee - Issue 1.a at 14; Tr. 273 (Slear).

26. The testing already conducted on each tube by Licensee -- special eddy current testing, bubble testing and leak-testing -- shows that such cracks do not exist in the tube pressure boundary. Moreover, the conditions which caused the circumferential IGSAC in TMI-1 have been eliminated. If such a crack nonetheless were to exist, it would propagate only during conditions when the tube was placed in axial tension; this will tend to offset the effect of pretension loss. Licensee - Issue 1.a at 14.

27. Tubes without a pretension load are placed in axial tension under some operating conditions, just as tubes with preload are sometimes in axial compression. During the steam generator hot testing program, transients placed axial tensile

loads of at least several hundred pounds on every tube in the steam generators -- even those which had lost preload. The test results confirmed the conclusion reached after eddy current, drip and bubble tests -- that no large cracks remain undetected in tubing in the TMI-1 steam generators. Licensee - Issue 1.a at 15; Tr. 276-283 (Slear, Croneberger). The fact that the steam generators have been returned to the original licensing basis, and that the experts have no reservation about the repair from a safety and health standpoint provides assurance of the adequacy of the repair notwithstanding the loss of preload. Tr. 626-629, 637-638 (McCracken).

28. If future cracks are hypothetically assumed to be propagating due to IGSAC at normal operating conditions, the principal direction of propagation will be axial along the tube. IGSAC propagation is principally perpendicular to the direction of highest stress. The highest tube stress is in the hoop direction at these conditions. A loss of pretension will not cause reduced leakage from axial tube cracks because there are no forces associated with loss of pretension trying to keep the crack closed. Licensee - Issue 1.a at 15.

29. Based on the foregoing findings, uncontradicted by evidence, the Board finds that Licensee's leak rate measurements under the proposed license condition are reliable precautionary measures to confirm that the steam generators are performing as anticipated. The condition provides adequate

assurance that leakage will be detected and responded to prior to the potential for tube rupture. Tr. 625-626 (McCracken).

2. <u>Issue 1.b (Frequency of Eddy Current Testing)</u>

Issue 1.b, as stated by the Board in its ruling on summary disposition, provided that:

> 1. The rationale underlying certain proposed license conditions should be addressed, with attention to:
>
> * * * *
>
> b. Method of determining frequency of ECT tests.

30. Industry experience has shown eddy current testing is the preferred method for non-destructive examination of steam generator tubes to ascertain damage. The technique has the ability to detect different types of tube damage states, such as different kinds and sizes of cracks, inside and outside surface defects, and tube erosion and wear. It is used to provide knowledge of the generator state well before tubes degrade to the point of through-wall leakage or an unsafe condition develops within the generator. Characterization of the signal gives insight as to the type of damage and substantially assists the investigator in understanding the damage mechanism. As ECT is a technique for inspecting tubing remaining in service as part of the primary pressure boundary, the role of eddy current inspection for the TMI-1 steam generators is the same as for generators at any other operating plant. Licensee - Issue 1.b at 3.

31. The existing once-through steam generator Technical Specification requirements for ECT at TMI-1 implement NRC's Regulatory Guide 1.83, Rev. 1. The requirements are the same as those for other nuclear plants in that they require that a random sample of at least 3% of the total number of tubes in the steam generators to be examined at each inspection. Certain criteria on tube selection are included, and known indications will also be tested. Tr. 325 (Slear). The Technical Specification testing frequency is specified to be not more than 24 months after the previous inspection with provisions that the interval could be extended to a maximum of once per 40 months, contingent on prior inspection results. Further conditions are imposed on the inspection frequency if there are primary-to-secondary tube leaks, degradation is in excess of Technical Specification limits, and/or a loss of coolant accident or a main steam line or feedwater line break has occurred. Licensee - Issue 1.b at 4.

32. Licensee has adopted supplements to the TMI eddy current test program which the Staff proposes to incorporate as an additional license condition. These supplements will act as a precautionary confirmation of Licensee's conclusion that crack initiation or propagation is not anticipated by chemical or mechanical means following return of the steam generators to service. Licensee - Issue 1.b at 4-5.

33. Under the new license condition, either 90 days after reaching full power or 120 calendar days after achieving 50% power (whichever occurs first), the plant will be shut down for eddy current inspection of the generators. Both special ECT differential probe and absolute probe techniques will be utilized. Tr. 312-315 (Slear). In addition, ECT will be done at the subsequent shutdown refueling. The plant currently is loaded with fuel which would permit full power operation for a little less than one year. Licensee - Issue 1.b at 5.

34. The above change in eddy current test frequency takes into account considerable detailed information available on the state of the generator, and its recent repair. Licensee has in place a special ECT differential probe characterization of all tubes remaining in service (approximately 29,000 tubes) and special absolute probe ECT data on over 800 tubes. There is a clear understanding of the type of damage which occurred in the generator and the reasons therefore. Licensee performed an extensive qualification program on the repair which has tested kinetically expanded joints out to five years of load cycling and 15 years of thermal cycling. There is also a general industry understanding of experience with explosively expanded tubes in tubesheets for other applications. Licensee - Issue 1.b at 4-5. This information has been used to draw a number of conclusions on the predicted behavior of the tubes remaining in service:

(a) The initial intergranular stress-assisted cracking of the steam generator tubes occurred with reduced sulfur species and with the plant cooling down or cold. Tests have shown that the failure mechanism is inoperative in the absence of sufficiently high levels of reduced sulfur species, and that IGSAC will not reinitiate under the TMI-1 operating conditions. Thus, there is reasonable assurance that the rapid IGSAC which caused the original damage will not affect the steam generators in the future. Licensee - Issue 1.b at 6.

(b) There currently exists hot operational experience on the repaired steam generator of about 40 days with no indication of leakage in excess of Licensee's new, stringent administrative limits on primary-to-secondary leak rate. This available test data supports the conclusion that unforeseen rapid or gross changes are not taking place. Licensee - Issue 1.b at 6-7.

(c) The long term corrosion lead tests support the conclusion that under the conditions attendant to operation, rapid chemical attack is not predicted. Licensee - Issue 1.b at 7.

(d) The possibility of steam flow-induced mechanical vibration propagation of small cracks was examined analytically and found to be non significant. Licensee - Issue 1.b at 7.

(e) No mechanism has been identified relating to other mechanical crack propagation scenarios while operating at full power. Crack propagation due to thermal cycling has been shown to be small and to occur principally during the act of cooling down. Thus, mechanical crack propagation is not expected to change tube condition during operation. Licensee - Issue 1.b at 7.

(f) In addition, there are considerations other than those relating to the steam generators, i.e., the overall question of plant accessibility, other operational sequences being conducted, and prudent operating practices, which dictate that the opening of steam generators, with its attendant exposure to oxygen, should be minimized. Licensee - Issue 1.b at 5.

35. Since the ECT program is designed to characterize change, there is a need to allow reasonable operating time on the generators to allow any unforeseen mechanism to cause change. It is a matter of judgment as to the period of time required, but several factors support the 90/120 days/next refueling intervals:

(a) Eddy current examination should take place after chemical equilibrium is obtained within the system. As used here, chemical equilibrium has two aspects. First, the gradual dissolution of the residual sulfur in the oxide films and its removal from the reactor coolant system (RCS). Second, development of the oxide films that are typical of all steam generators. An extended period of time may be necessary for this to occur. Tr. 308-309, 317-320 (Giacobbe); Licensee - Issue 1.b at 7-8; see Tr. 603 (McCracken).

(b) Mechanical propagation due to flow induced vibration at steady state operation, if any, will only occur at full or near-full steam flow conditions. To confirm these analytic conclusions the generator must be operated at full steam flow. Thus, a period of time of OTSG operation at power is required if eddy current examination is to be most meaningful. Licensee - Issue 1.b at 8.

(c) The plant extended startup and power escalation program is designed to maximize operator training, plant refamiliarization, and allow non-OTSG related performance testing along the way. This same extended power escalation program allows significant time to be accumulated on the generators at reduced power. The period of time at reduced power is also a means of accumulating generator experience when the consequences of any hypothetical crack propagation are reduced. Licensee - Issue 1.b at 8.

(d) Detailed technical assessments of the repair within the tubesheet do not reveal mechanisms which could lead to catastrophic failure. Licensee - Issue 1.b at 8.

36. The above facts and experience suggest a minimal period of several months of initial operation is necessary to ensure that sufficient data can be obtained during the inspections to trend conditions within the steam generators. The new license condition is a judgment based on the available facts regarding generator condition and potential failure

mechanisms, and includes consideration of general industry experience. Licensee - Issue 1.b at 8.

37. The NRC Staff's early, tentative view in May 1982 that ECT should be conducted 30-60 days after restart was predicated on the fact that at that time, little was known about the corrosive mechanism and whether further degradation was expected. The Staff properly revised the time estimate given the extensive knowledge subsequently gained about the causative agent and the fact that no degradation is predicted. Tr. 605-607 (McCracken). Even as revised, the time frame used is as or more restrictive than those implemented at other plants whose steam generators have been repaired -- even where continued corrosion is expected. Staff - Cont. 1.a at 7-8. At TMI-1, frequency increase was not based upon a predicted rate of degradation (since none is predicted), but rather is simply a conservative corroborative measure. Tr. 594 (McCracken).

38. Based on the foregoing, the Board finds that the proposed license condition on the frequency of ECT, together with the existing license conditions, will provide the requisite degree of insight on changes, if any, in the generator.

3. Issue 1.c (Power Ascension Limitations)

39. Issue 1.c, as stated by the Board in its ruling on summary disposition, provided that:

1. The rationale underlying certain proposed license conditions should be addressed, with attention to:

* * * *

c. Method of determining power ascension limitations.

40. The license condition concerning power ascension limitations is set forth as condition B.3. in the Safety Evaluation Report, NUREG-1019, Supplement 1, at 27:

> GPU Nuclear Corporation shall complete the post-critical test program at each power range (0-5%, 5-50%, 50-100%) in conformance with the program described in Topical Report 008, Rev. 3, and shall have available the results of that test program and a summary of its management review prior to ascension from each power range and prior to normal power operation.

Licensee - Issue 1.c at 3.

41. The initial power ascension program was developed, prior to knowledge of the damage to the steam generators, by considering test requirements as a result of core reload, plant modifications made since the plant was last operated, and operator training requirements. These considerations resulted in a testing sequence, power level plateaus and development of special tests for plant modifications and operator training. Primary factors in determining the test sequence and plateaus included verification that core physics parameters are as predicted and that nuclear instruments, the integrated control system and the turbine protective system are calibrated and functioning properly. Licensee - Issue 1.c at 4.

42. In conjunction with the steam generator tube repair program, Licensee developed special pre-critical tests to demonstrate steam generator operability, including drip tests, bubble tests, normal and accelerated cooldowns (with their transient loads) and long periods of steady state leakage monitoring. These tests have now been performed and evaluated. The results confirmed the adequacy of the repair process and the operability of the steam generators. Licensee - Issue 1.c at 4-5.

43. Additionally, Licensee reviewed the power ascension/post-critical testing program described above for its effect on the steam generators. Because the pre-critical testing verified the adequacy of the repair and the operability of the steam generators, no additional tests were needed in the post-critical test program because of the repair. Licensee determined, however, that two 30-day hold periods should be added to the power ascension program. Licensee - Issue 1.c at 5.

44. Because Licensee conservatively elected to add these hold periods, the Staff proposed a licensee condition which is intended to require that the results of the tests performed at the various power levels be made available to the Staff. The new licensee condition is not intended to limit power ascension and is not necessary to assure the adequacy of the steam generator repair, which has been assured by returning the OTSGs to their original licensing basis. Rather, the new license

condition is an additional precautionary measure. See Staff - Cont. 1.a at 10; Tr. 639-640 (McCracken).

45. The slow progression from power level to power level adopted by Licensee has several purposes:

a. To facilitate monitoring leak rate changes, especially after load-inducing transients, which will provide information on the condition of the kinetically expanded joints.

b. To detect abnormal trends as early in the program as possible.

c. To slowly increase plant power and operating history to aid in mitigation of unplanned events.

d. To gain additional experience in operating the plant with systems in normal line-ups, that is, operating all systems that would be used if the plant were at full power. Tr. 335-336 (Broughton).

Licensee - Issue 1.c at 5.

46. The first hold period will occur at 48 percent power following the RCS overcooling test. This point is appropriate because it immediately follows tests which load the steam generator tubes (loss of feedwater and RCS overcooling) and because it allows operation with two main feed pumps which is the normal plant configuration. The second hold point follows testing at the 75 percent power plateau. Leak rate monitoring, surveillance testing and operator familiarity will occur during this hold period. Experience from the leak rate monitoring performed during steam generator pre-critical tests corroborates that a 30-day hold period provides adequate time for

stabilizing the plant and collecting statistically valid data. Licensee - Issue 1.c at 5-6; Tr. 332-333 (Broughton).

47. Management reviews are scheduled prior to power increases following the 48 percent power hold period and the 100 percent turbine trip test. These reviews will assure that the people, plant, facilities and procedures are in a state of readiness such that the plant can be safely operated at the next power plateau. These reviews also provide management the opportunity to review all open items at that time that may have potential impact on power operations. Licensee - Issue 1.c at 6.

48. Licensee's power ascension limitations are in accordance with the recommendations of the Third Party Review (TPR) Group. In its February 18, 1983 report, the TPR recommended that GPU Nuclear consider "substantially extended operation at low power" and suggested a hold period of perhaps a month or more at 40 percent power followed by another month or more at 70 percent power before final escalation to 100 percent power. (Att. 6 to the Staff's SER, TPR February 1983 Report at 11-12, Recommendation 2.) Licensee - Issue 1.c at 6-7.

49. In accordance with the TPR's recommendations, Licensee modified the power ascension program to add two 30-day hold periods, one at 48 percent power and one at 75 percent power. As the TPR stated in its May 16, 1983 report, the TPR stated that "[t]he GPU Nuclear response is satisfactory." (Att. 6 to

the Staff's SER, TPR May 1983 Report at 7.) Licensee - Issue 1.c at 7.

50. The TPR also recommended that Licensee "consider the possibility of deliberately running one steam generator at a higher power than the other during the first escalation hold periods." (Att. 6 to the Staff's SER, TPR February 1983 Report at 12, Recommendation 3.) The TPR recognized, however, that this recommendation "may involve other operating considerations which would have to be weighed before a decision could be made." Ibid; Licensee - Issue 1.c at 7.

51. Licensee explained to the TPR that significant operating considerations rendered this suggested approach infeasible and imprudent. In particular, the mismatch can only be implemented by operation of a single reactor coolant pump in one loop which would cause mismatched reactor coolant system flow, imbalanced feed flows and different coolant levels in each generator. This could mask changes in the plant conditions, including any abnormalities in the plant response to transients. This abnormal plant configuration would conflict with the intent of conducting the startup in a slow, deliberate manner under normal operating conditions. Licensee - Issue 1.c at 7-8.

52. As the TPR stated in response to Licensee's explanation, that "[t]he GPU Nuclear response is satisfactory." (Att. 6 to the Staff's SER, TPR May 16, 1983 Report at 7.) Licensee - Issue 1.c at 8.

53. Based on the foregoing findings, uncontroverted by direct evidence, the Board finds that the power ascension limitations are not required to establish the adequacy of the OTSG program because the steam generator have been repaired to their original license basis, which is consistent with full power operations.

54. The Board also finds, however, that the power ascension limitations adopted by Licensee and incorporated in the proposed License condition provide conservative, additional corrobation of the adequacy of the kinetic expansion repair process.

4. Issue 1.d (Long Term Corrosion Tests)

55. Issue 1.d, as stated by the Board in ruling on summary disposition, provided that:

> 1. The rationale underlying certain proposed license conditions should be addressed, with attention to:
>
> * * * *
>
> d. Adequacy of simulation of operating conditions by long-term corrosion tests.

56. The purpose of the long term corrosion test program, the operations phase of which has now been completed, is to verify that sulfur-induced intergranular stress-assisted cracking will not reinitiate or propagate in the TMI-1 steam generators under actual operating conditions. The tests were

designed to confirm that the metallurgical, environmental, geometric and surface conditions which exist after the repair of the tubes are not detrimental to tube integrity. From the test program it will be possible to conclude whether or not the proposed chemistry limits are acceptable, whether the peroxide cleaning itself was beneficial or damaging, and, more importantly, whether the changes in electrochemical potential during operations will cause reinitiation of corrosion. Licensee - Issue 1.d at 2-3; see Staff - Cont. 1.a at 11-13.

57. The long term corrosion tests are accordingly related to the kinetic expansion repair process, but only insofar as they verify that the repair did not render the steam generators susceptible to reinitiation of IGSAC. (This is tested by including kinetically expanded tube samples in the test loops.) Except in this one respect, the long term corrosion tests have no relationship to the adequacy of the kinetically expanded joint. Licensee - Issue 1.d at 3; see Staff - Cont. 1.a at 12.

58. The tests were not designed to confirm that Licensee has provided reasonable assurance against the possibility of mechanically induced tube ruptures caused by various transients, as alleged by Contention 1.a, and, in fact, the tests provide no information one way or the other on this subject. Licensee - Issue 1.d at 3.

59. The long term corrosion test program includes tests which closely simulate the typical operating environment of the

steam generator tubing during steady state and transient conditions. The program also includes comparative tests which closely simulate steam generator operation but use tubes with high residual sulfur levels (non-peroxide cleaned) and expose the tube samples to the contaminant which originally caused the IGSAC damage (thiosulfate). Licensee - Issue 1.d at 4; see Staff - Cont. 1.a at 12.

60. The tests reproduced all the parameters which influence IGSAC, i.e., susceptible material, environment, and stress. Licensee - Issue 1.d at 5.

61. To assure that the influence of prior operation and layup on tubing was adequately represented, only tube sections removed from the TMI-1 steam generators were used as specimens. These specimens were selected from various regions of each steam generator, including tube sections which had known defects. The use of actual steam generator tubes precluded any possibility that test specimens would not duplicate exactly the TMI-1 material. Licensee - Issue 1.d at 5; see Staff - Cont. 1.a at 12.

62. The specific tube sections for the long term corrosion test were selected from tubes that had been previously removed from the steam generators for use in the failure analyses. Within the available material, the tube sections were selected to provide a maximum range of properties. These included:

a) Chemistry - test specimens were selected from representative heats of material removed from the generator. This provided a range of chemistry typical of most steam generator tubes.

b) Mechanical Properties - yield strengths of the specimens spanned the range of those tubes present in the steam generators.

c) Material susceptibility - specimens for testing were selected from tubes which displayed various levels of susceptibility to corrosion damage. Some came from tubes with no defects and others from tubes with up to eight indications.

Licensee - Issue 1.d at 5-6.

63. The test samples also contain a representative sample of tubes from various axial locations within each steam generator. The largest portion of the samples are from the upper tubesheet area, which contained the most defects. There are also samples from the lower face of the upper tubesheet, 15th tube span, and 9th tube support plate areas. Licensee - Issue 1.d at 6; see Staff - Cont. 1.a at 12; Tr. 353 (Giacobbe). The samples were also representative of various heats, and bounded the heats of the metal present in the tubes. Analysis showed that no correlation could be found between heat number and any propensity for cracking. Staff - Cont. 1.a at 12; Tr. 355-356 (Giacobbe).

64. Subsequently, certain of the samples were subjected to the explosive expansion process using mockup tube sheets and then subjected to a peroxide cleaning process. This ensured

that the influence of these processes on the inside surface condition was produced. Certain other samples were not peroxide cleaned, in order to test what could occur if Licensee had not undertaken the cleaning process, given the larger quantities of residual sulfur that would have remained on the tube surfaces. Licensee - Issue 1.d at 6; see Staff - Cont. 1.a at 12; Tr. 362 (Giacobbe).

65. C-ring samples made from actual TMI-1 tubes were also included in the test program. These samples provided a means for metallographically examining test specimens during the testing phase to look for any microstructural changes or incipient cracking. Licensee - Issue 1.d at 6.

66. Environmental chemistry parameters were selected to either simulate, or be more aggressive than, the water chemistry which will be maintained in the RCS. In three of the four test loops, 100 ppb of sulfate, the maximum permitted under chemistry specifications, was used. In the fourth test loop, 100 ppb thiosulfate was put in solution. In addition, to ensure adequate conservatism, the levels of chloride and fluoride were set at the maximum amount permitted by Licensee's operating chemistry specifications (100 ppb each). Licensee - Issue 1.d at 6-7; see Staff - Cont. 1.a at 12.

67. Because the testing and operation of the plant necessitates heating up and cooling down of the steam generators, the tests included typical temperature cycles. Temperatures

were held constant at operating temperature to assess any high temperature corrosion phenomenon. Periodically, the tests were cycled between 600°F and 500°F to simulate unit load changes. Licensee - Issue 1.d at 7.

68. The test loops were also subjected to cooldown cycles, some of which included the introduction of oxygen (as would occur when the RCS was open for inspection) and some of which did not (as would occur during normal shutdown). These cycles provided the most rigorous test sequence in view of the fact that primary-side sulfur corrosion is a low temperature phenomenon in which oxygen has a major influence. Licensee - Issue 1.d at 7. Unless a corrodant in sufficient levels is present, however, oxygen will not create a corrosive condition. Tr. 359-360, 368 (Giacobbe); see Staff - Cont. 1.a at 12.

69. Each HFT or operating cycle included a hold step for a minimum of one week in which the loop was aerated and maintained at a temperature between 130° and 150°F. This portion of the cycle simulated the aeration-temperature conditions which existed during the propagation of the original sulfur-induced IGSAC. Licensee - Issue 1.d at 7.

70. During heatup, operation, and cooldown, tubes in the actual steam generator undergo changes in stress. A net axial tensile stress could exist in the tubes during cold shutdown and steady state operation. The stress is reduced during heatup and increased during cooldown due to differential

thermal expansion effects. Licensee - Issue 1.d at 8; see Tr. 359 (Giacobbe).

71. In order to simulate the changes in axial load, full tube specimens were loaded at a level corresponding to steady state loads during heatup, cold shutdown, and operation. During cooldown, the loads were increased to approximate the maximum allowed cooldown rate. Full tube specimens simulating repaired joints were kinetically expanded using the same process as in the actual steam generators to ensure representative residual stresses. These specimens were also exposed to the axial loads described above so that the worst case combination of loads was tested. Licensee - Issue 1.d at 8.

72. The C-ring specimens were intended to give an early indication of possible problems. Therefore, they were loaded to a level just slightly below yield, which is significantly higher than the load seen by the tubes in actual service. This bounds any load that would be experienced under accident transients, and would make them more susceptible to IGSAC than are the actual steam generator tubes. Licensee - Issue 1.d at 8; Tr. 369-370 (Giacobbe). The tests were not designed to simulate fatigue damage. Therefore, Licensee correctly did not include a simulation of flow induced vibration on the tubes. The loads that were applied (heatup and cooldown) were sufficient to predict the effect of stress on corrosion. Tr. 345-346 (Croneberger).

73. The long term corrosion test program includes tests which provide a valid simulation of the conditions that the OTSG tubing will experience in future TMI-1 operations. For comparison, tests have also been included which simulate what could occur if Licensee had not taken the corrective measures of peroxide cleaning and removal of possible sources of thiosulfate. Parameters known to influence corrosion and more specifically IGSAC were reproduced to the greatest extent possible. Licensee - Issue 1.d at 9; Staff - Cont. 1.a at 12.

74. The fact that the tests do not completely simulate operation in every conceivable respect does not render the tests suspect. Laboratory tests cannot be expected to achieve the precise conditions of operation; the question is whether simulation is sufficiently close to provide meaningful data. That criterion is met here. This test program provides a clear basis for empirically evaluating steam generator tube performance over approximately a one year period.

5. <u>Issue 2 (Inadvertent Initiation of Emergency Feedwater Flow)</u>

75. Issue 2, as stated by the Board in ruling on summary disposition, provided that:

> 2. The effect of inadvertent initiation of emergency feedwater flow at high power or following rapid cooldown after a LOCA should be addressed, with attention to calculation of maximum transient stresses in steam generator tubes.

76. Inadvertent actuation of the emergency feedwater system at full power, i.e., a failure that results in starting of the EFW pumps while the plant is operating normally at full power, will not result in the injection of emergency feedwater into the steam generators. The design of the TMI-1 EFW system is such that once the EFW pumps are started, the actual flow to the steam generators is controlled by automatic valves which respond to a flow demand signal generated by the steam generator level control system. The water level in the steam generator at conditions of power operation is higher than the steam generator EFW level setpoint at which the EFW flow control valves are initiated to open. Licensee - Issue 2 at 3-4.

77. In the unlikely event that both inadvertent actuation of the EFW pumps and inadvertent opening of the EFW valves were to occur, resulting in injection of emergency feedwater into the steam generators at full power, the resulting thermally induced axial tube load would not be sufficient to cause rupture of the steam generator tubes. Licensee - Issue 2 at 4; Staff - Cont. 1.a at 13-15.

78. Emergency feedwater is injected horizontally into the steam generator tube bundle steam space via six auxiliary feedwater nozzles located at approximately equal spacing around the circumference of the steam generator shell. The nozzles have a 2-1/2" diameter throat with a 4" diameter flow expansion. The injection points are located near the top of the

tube bundle with the nozzle centerlines 2'11" below the bottom surface of the upper tube sheet. Licensee - Issue 2 at 4.

79. As the EFW is injected into the steam space in the tube bundle, upward turbulent steam flow quickly heats and partially vaporizes the water before it reaches the top of the steam generator. At the top of the steam generator, there is a horizontal steam flow from the center to the periphery of the steam generator. This horizontal steam flow prevents any residual EFW liquid, which is now at saturation temperature, from reaching the upper tubesheet and thus prevents it from contacting any repair joints of the steam generator tubes, all of which are within the upper tubesheet. Licensee - Issue 2 at 4; Tr. 433 (Lee).

80. The auxiliary feedwater nozzles penetrate the steam generator shell and pass through the steam annulus between the steam generator shell and the tube bundle shroud. As incoming emergency feedwater passes through the nozzles and enters the tube bundle steam space, the high heat transfer rate from the steam to the incoming water quickly heats the water. By the time that the EFW reaches the tubes, it is approaching the same temperature as the secondary side steam. Thus, the affected tubes experience only a small temperature change in the small portion of the tube being sprayed, which results in an insignificant axial load change in the tube. Temperature measurements taken at an operating steam generator during EFW

injection confirm that the temperature change of the affected tubes and thus the change in tube axial load is minimal. Licensee - Issue 2 at 4-5; Tr. 434 (Lee).

81. The absence of any significant load change can be addressed quantitatively by making some extremely unrealistic and conservative assumptions. If one were to ignore the turbulent and superheated steam environment and assume that unheated emergency feedwater (40°F minimum) were able to be sprayed directly on the tubes, the water would impinge directly on only about eight tubes opposite each individual nozzle. And if one were further to assume that water spray from the 4"-diameter nozzles causes impingement on a 12-inch length of each tube, the cooling effect has been conservatively calculated to produce an approximate change in axial tube load of only 70 pounds tension. This tensile load, in conjunction with the loads on the affected tubes at full power operation, which are at less than 100 pounds tension, is insignificant compared to the joint design and qualification load of 3140 pounds tension, or the cooldown load of 1100 pounds tension. Thus, EFW injection into the steam generators does not induce large changes in tube axial loads and does not cause rupture of a steam generator tube. Licensee - Issue 2 at 5-6; Staff - Cont. 1.a at 13-15; see Tr. 434-435, 439-440 (Lee).

82. With respect to rapid cooldown following a LOCA (loss-of-coolant accident), the maximum transient loads on the

steam generator tubes following a LOCA have been conservatively calculated to be 2641 pounds. These calculations included the effects of EFW injection into the tube bundle. This load is considerably less than the design basis load of 3140 pounds to which the repair joint was designed and qualified. The maximum transient load and the design basis load are the same for both the repaired tubes and the tubes in the original design condition. Therefore, the likelihood of tube rupture during a rapid cooldown following a LOCA has not been increased by the repair procedure. Licensee - Issue 2 at 6; Staff - Cont. 1.a at 13-15.

6. Issue 3 (Hardness Testing)

83. Issue 3, as stated by the Board in ruling on summary disposition, provided that:

> 3. The reasons for not including hardness tests on repaired tubes in the post repair testing program should be addressed.

84. Hardness is a material property which is indicative of the resistance of metals or alloys to plastic deformation, usually by indentation. Sometimes it also refers to resistance to scratching, abrasion, or cutting. Licensee - Issue 3 at 3; Staff - Cont. 1.a at 15.

85 The kinetic expansion process used at TMI-1 resulted in "cold working" of the expanded portions of the tube, which increased the hardness of the material. The roll expansion

process used in the original tube-to-tubesheet joints also produced cold working and thereby increased the material's hardness. Cold working can result in higher residual tensile stress, which can be indicative of increased susceptibility to intergranular stress assisted cracking. Licensee - Issue 3 at 3; Staff - Cont. 1.a at 16-17.

86. Hardness testing was used during the qualification program to determine how the kinetic expansion process compares to the non-stress-relieved roll expansions in terms of cold working. Licensee - Issue 3 at 4.

87. These tests showed the kinetically expanded joints to be less hard, and therefore to have less cold working of the inside diameter surface, than non-stress-relieved rolled joints. Less cold working results in lower residual tensile stresses. This suggests that the kinetically expanded joint will be less susceptible to intergranular stress assisted cracking (which is associated with residual tensile stress) than are non-stress-relieved rolled joints. Such rolled joints have operated successfully in many steam generators in nuclear power plants. Licensee - Issue 3 at 4; Tr. 465-67 (Lee).

88. Licensee's kinetic expansion repair process increased the transition zone length between the expanded and unexpanded tube sections by approximately a factor of 2 to 4 from the original as-fabricated zones. The increased transition zone length results in a corresponding decrease in strain and

residual stress. Licensee's tests showed reduced hardness in the longer kinetically expanded transition zone when compared to the original as-fabricated transition length. Staff - Cont. 1.a at 16-17; see Licensee - Issue 4 at 6.

89. The only conclusion that can be inferred is that due to reduced hardness, the residual stresses will be less and therefore the tubes at the transition zone may be less susceptible to stress corrosion cracking than the original as-fabricated tubes. The fact that the transition zone of the kinetically repaired tubes may be less susceptible to stress corrosion cracking was easily predicted mathematically. Therefore, the hardness measurements conducted by the licensee on test specimens simply confirmed what was already known, and hardness tests are not necessary. Staff - Cont. 1.a at 16-17.

90. Further, hardness is not a parameter indicative of the adequacy of the kinetic expansion joint. The joint was qualified for a range of material tensile strengths bracketing those of the TMI-1 steam generator tubes and a range of possible tubesheet annulus geometries and conditions. Joint adequacy was established by qualification tests and internal tube diameter measurements. Post-repair testing in the steam generator included measurements to verify that the expansion process was in accordance with the qualification program. This provided a much more direct and informative means of assessing the adequacy of the joint than would any measurement of hardness. Licensee - Issue 3 at 4.

91. Licensee's hardness tests were performed on TMI-1 archival tubes which had been kinetically expanded in the same manner as the actual repaired tubes in the steam generator. Archival tubes are tubes which were set aside as a matter of record from the same manufacturing lot or heat as those used in steam generators, instead of being actually installed in the steam generators. Tr. 384 (Pai); Tr. 441-42, 464-65 (Giacobbe).

92. In using archival tubes in the qualification program, including their use for hardness testing, Licensee selected heats of archival tubes which bracketed the range of properties of heats present in the as-manufactured steam generators. Tr. 540 (Slear); Tr. 384 (Pai); see Licensee - Issue 4 at 6; Tr. 527-528 (Giacobbe).

93. In using archival tubes in the repair qualification program, including hardness testing, Licensee tested tubing removed from the generators to determine that the relevant properties were unchanged such that valid and representative conclusions could be drawn from tests conducted on archival tubing. The tensile strength and ductility (the two properties germane to the acceptability of the repair joint) were determined quantitatively for TMI-1 tube specimens of varied heats, and compared with pre-operational mill specification testing results for the same heats of material. The specimens which had been in operation at TMI-1 performed within the range of

expected behavior for the heat as-manufactured. Tr. 461-64, 514-515, 527 (Giacobbe); Tr. 546-548 (Slear, Giacobbe). In addition, strip specimens bent around mandrels to look for unanticipated damage exhibited the high ductility expected for Inconel-600, and showed no incipient damage. Tr. 515, 572-573 (Giacobbe). Further qualitative confirmation was provided by kinetically expanding an actual TMI-1 tube specimen containing a crack, which did not grow as a result of the expansion. Tr. 472-475, 515-516 (Slear, Giacobbe). The retention of as-manufactured yield strength and ductility is expected behavior for Inconel-600 in steam generators, and is, in fact, one basis for its selection in design. Tr. 634-635 (McCracken); Staff Cont. 1b at 2; see also Tr. 528-548.

94. Thus, the conclusions drawn from qualification testing on archival tubing, including hardness testing, are valid and representative of the tubes in the TMI-1 steam generators. Tr. 539 (Slear).

95. Hardness testing is done with relatively large equipment, and cannot be performed on the repaired tubes within the steam generator. The transition zone is located a minimum of 17 inches deep in a 3/8-inch tube, and hardness measuring devices do not exist which are capable of measuring under those conditions. Therefore, to measure hardness, tubes would have to be severed, sectioned and removed from the repaired steam generators. This is an extensive effort which would result in

radiation exposure to the workers. Licensee - Issue 3 at 4; Staff - Cont. 1.2 at 17.

96. Since information which could be obtained on the hardness of removed tube transition zones is not necessary for acceptance of the repair process, as discussed in the preceeding responses, tube removal for hardness measurements is not consistent with the Commission goals to maintain occupation radiation exposure to levels "as low as reasonably achievable." Licensee - Issue 3 at 4; Staff - Cont. 1.a at 17.

97. In light of the foregoing, the evidence demonstrates that it was neither necessary nor practical to include hardness testing as part of the post-repair testing program for the repaired steam generator tubes.

7. Issue 4 (Effectiveness of Kinetic Expansion as a Repair Versus a Manufacturing Process)

98. Issue 4, as stated by the Board in its ruling on summary disposition, provided that:

> 4. Recalling Licensee's statement in ¶¶ 6-8 that the use of kinetic expansions to seal heat exchanger tubes within tubesheets has a broad base of successful experience, information is requested about whether tube integrity during subsequent operation depends on whether the process is a repair, or a manufacturing process using new materials.

99. The kinetic expansion seal is an effective means of sealing heat exchanger tubes within tubesheets, whether

performed as a field repair or as part of the original fabrication. The industry has had considerable experience with this process in both situations. Licensee - Issue 4 at 2.

100. The kinetic expansion process has been increasingly used as a means of closing the crevice between tubes and tubesheets because it has significant advantages over rolling. Tr. 412 (Pai); Tr. 631 (McCracken). The quality control of kinetic expansion is easier than that of rolling; the results of expansion are consistently uniform and the process therefore more reliable. Tr. 620, 631 (McCracken). Moreover, a rolled tube is subjected to more cold working than a kinetically expanded tube. The rolled tube would therefore have a higher surface hardness and is more susceptible to corrosion. Tr. 411-412 (Pai); Tr. 634 (McCracken); Tr. 506 (Lee).

101. The kinetic expansion process used for the TMI-1 steam generator repair was developed by Foster Wheeler over 20 years ago. The Foster Wheeler process utilizes a controlled amount of explosive, generally a primacord containing the explosive which imparts the necessary energy to expand tubes. A plastic insert encapsulating the primacord is used to transmit this energy and attenuate the shock waves. The use of this plastic material also enhances the ability to accommodate dimensional tolerance between the tube and the tube hole. Licensee - Issue 4 at 2-3.

102. For a power station (nuclear or fossil), there are different kinds of heat exchangers (e.g., feedwater heaters and moisture separator reheaters), most of which are of the shell and tube type. The TMI-I steam generators are but one type of shell and tube heat exchanger, and it shares all the relevant common characteristics with other heat exchangers, e.g., small diameter, thin-walled tubes attached to tubesheets and containment of the tube bundle in a shell which forms the component pressure boundary. Heat transfer takes place between the shell side and tube side fluids through the tubewalls, generally at certain pressure and temperature differentials between the two fluids, depending on the functional requirements of the system. Licensee - Issue 4 at 3.

103. Foster Wheeler initially used the kinetic expansion process to support its shop fabrication. Foster Wheeler has expanded some 5,000,000 tubes to date. Since 1967, Foster Wheeler has adopted the kinetic expansion process as the primary means of tube expansion for high pressure feedwater heaters. Licensee - Issue 4 at 3.

104. Since the mid-seventies, Foster Wheeler has also applied the kinetic expansion routinely to field repairs. The various repair methods include:

a) Expansion of tubes below the tube-to-tubesheet weld region to effect a new joint similar to what was done on the TMI-1 steam generators.

b) Expansion of new tubes into an existing tubesheet as part of a tube bundle replacement.

c) Expansion of sleeves into existing heat exchanger tubes to prevent erosion-corrosion of the tubeside inlet regions.

d) Tube plugging using the Detnaplug™ process. This process kinetically expands a serrated plug into the inside diameter to form a mechanical seal.

Licensee - Issue 4 at 3-4.

105. All of the above methods of repair utilize the kinetic forming principle. The tubing sizes, as well as most of the tubing and tubesheet materials, are similar to those in the TMI-1 steam generators. Tr. 382 (Pai). In addition, the operating temperatures and pressures of the repaired equipment bracket the TMI-1 steam generator conditions. The typically repaired high pressure feedwater heaters operate in the range of 3,000 to 5,000 psi. This range is similar to that experienced by the TMI-1 steam generators. Licensee - Issue 4 at 4.

106. Foster Wheeler's experience in both the manufacturing and repair context has been extremely successful. Licensee - Issue 4 at 5; Tr. 403 (Pai).

107. Manufacturers other than Foster Wheeler have also utilized the kinetic expansion process. Combustion Engineering uses the process in the manufacture of all their steam generators, and approximately 13 or 14 plants using these generators are now in operation. Tr. 620, 630 (McCracken). The tubes are

not stress relieved after expansion. Tr. 491 (Slear). There have been no instances of corrosion, cracking, or other types of failure mechanisms of the transition joint in those generators. Although these are U-tube generators, many of the tubes in these generators have become fixed (due to corrosion mechanisms) and consequently, like the TMI-1 steam generators, do experience loads on heatup and cooldown. Tr. 620-621 (McCracken)

108. Combustion Engineering also ran a number of model boilers with full depth expansion of the tubes for two to three years under extreme chemistry conditions. The company thereafter sectioned the tubes for examination, and found the tubes were still in as-new condition, indicating the expansion had remained leak-tight. Tr. 633-634 (McCracken).

109. Babcock & Wilcox (B&W) used the kinetic expansion in the manufacture of a number of tubes put in place in the once-through steam generators of the Oconee nuclear plant. These tubes were not stress relieved after kinetic expansion of the joints. These tubes have been in service for over ten years with no indication of any degradation in the transition region. Tr. 490, 511 (Slear).

110. Westinghouse has kinetically expanded tubes in steam generators overseas prior to service, and has not thereafter subjected the tubes to stress-relief. That company has indicated that there is no evidence of degradation of the expanded joints. Tr. 491 (Slear).

111. The kinetic expansion process has been used successfully in Japan both in the manufacturing process and as a means of closing crevices in in-service units. The tubes of entire tubesheets have been expanded through this process. No evidence of degradation has been observed. Tr. 631-632 (McCracken).

112. The above experience is directly applicable to and supports the use of the kinetic expansion process to repair the TMI-1 steam generators. So long as the tube metal retains its ductility and yield strength, the structural integrity of the tubes during subsequent operation does not depend on whether the process is a repair, or a manufacturing process using new materials; it also does not depend on whether the unit being repaired is a once-through steam generator or some other high pressure feedwater heater. Licensee - Issue 4 at 5; Staff - Cont. 1.a at 18; Tr. 412 (Pai). Inconel-600, the alloy used in the TMI-1 steam generators tubes, was selected precisely because it maintains its mechanical strength and ductility even after prolonged service. Staff - Cont. 1.b at 2; Tr. 634 (McCracken). The yield strength and ductility of the TMI-1 tubes are within the range of material properties which had been kinetically expanded in the past. Licensee - Issue 4 at 6; Tr. 382-383 (Pai). Testing performed by Licensee, moreover, has specifically confirmed that the yield strength and ductility of the TMI-1 steam generator tubing has not been

significantly changed by general use, the ICSAC experienced by the tubes or the kinetic expansion process. Tr. 514, 527, 546-548 (Giacobbe, Slear).

113. The geometry of tube and tubesheet may also influence the integrity of kinetically expanded joints. As with ductility and yield strength, the tube-to-tubesheet geometries at TMI-1 are within the range of geometries of heat exchangers which had been expanded in the past. Licensee - Issue 4 at 4-5.

114. The fact that the TMI-1 tube and tubesheet geometries and materials were within the range of geometries and materials Foster Wheeler had dealt with in the past renders the industry's prior successful experience directly applicable to TMI-1, and strongly indicated its use was appropriate. Licensee took additional steps, however, to ensure that the kinetically expanded tubes and tube joints satisfied the design requirement in as-built and in-service conditions. For example, a qualification program was performed which demonstrated that the repaired tube have been repaired to the original licensing basis. Pull-out load and leak tightness tests performed on expanded archival tubes demonstrated that the tube joint maintains its integrity through years of operations and under normal transient and accident loading conditions. See Licensee Material Facts, ¶ 15 at 64. Additional tests confirmed that the yield strength and ductility of the tubing used in the qualification

program was consistent with that of the actual TMI-1 steam generator tubing. See FF 31, supra. In addition, because tube samples removed from TMI-1 steam generators showed that only a very thin oxide layer was present on the tube outer surface and tubesheet hole, the tubes and tubesheets used in the qualification program duplicated this oxide film. Licensee - Issue 4 at 6.

115. The repair of the TMI-1 steam generator tubes was accomplished with more than the usual care. Stringent nuclear quality assurance procedures were followed with respect to the qualification program, as well as the procurement and use of the explosive inserts on-site. Important issues, such as pull-out load and qualification program leak rate measurement accuracy and reliability, chemical composition of insert material and the traceability of all components going into the making of the insert assembly, were fully documented. The care with which the repair was implemented gives further assurance of its reliability. Licensee - Issue 4 at 7.

116. Based on the foregoing, the Board finds that the kinetic expansion repair process is a reliable method of repairing steam generators such as those of TMI-1.

C. CONTENTION 1.b

1. Issue 5 (No Increased Probability of Simultaneous Tube Rupture)

117. Issue 5, as stated by the Board in its ruling on summary disposition, provided that:

> [T]he central issue [raised by TMIA's Contention 1.b] is whether the repair process has increased the probability of [simultaneous tube ruptures involving both TMI-1 steam generators].

118. There are several reasons why the kinetic expansion repair process has not increased the likelihood of tube rupture, and therefore has not increased the probability of simultaneous tube ruptures involving both steam generators.

119. First, a "rupture" as it is commonly understood in the industry cannot take place at or in the vicinity of the repair joint. A 360-degree circumferential break, separated to allow unrestricted flow, or a large "fishmouth" break of equivalent flow, has no room to occur because the new joint is closely confined within the tubesheet hole. Moreover, any leakage would be significantly restricted by the tight crevice formed by the tubesheet hole and the outside of the tube. Tr. 508-510 (Slear); see also Tr. 476-477 (Slear).

120. Second, the kinetic expansion repair has returned the TMI-1 steam generators to their original licensing basis. Because Inconel retains its strength and ductility despite previous operation of the steam generators, and because the repair

itself did not affect that strength and ductility, the tubes are as resistant to rupture now, after the repair, as they were when they were new and had not experienced operation. Therefore, the probability of simultaneous ruptures involving both steam generators is no greater now than it was at the time of the original licensing. Staff - Cont. 1.b at 5.

121. Third, the primary objective of the TMI-1 once-through steam generator repair program was to establish a system that would not increase the likelihood of tube rupture. This objective was met by establishing that the repair joint is not more susceptible to tube rupture than the original joint would have been, and that the repair process has not adversely affected the tube in a manner that would increase the likelihood of tube rupture. Licensee - Issue 5 at 3.

122. The design basis transients specified for the original design tube-to-tubesheet joint were specified as applicable to the repaired steam generator tube-to-tubesheet joint. The repair joint was qualified by testing and analysis for transients in a postulated main steam line break load of 3140 pounds tension, the maximum design basis loading of the tube-to-tubesheet joint. All other normal operating or postulated accident loadings are enveloped by this loading. Moreover, the only conceivable "failure" of the kinetic expansion joint would be by slippage under applied axial load, rather than by tube rupture. Licensee - Issue 5 at 3-4; Tr. 509-510 (Slear, Croneberger).

123. Thus, the likelihood of tube rupture due to the failure of the tube-to-tubesheet joint is no greater than for the original joint. Licensee - Issue 5 at 4.

124. The kinetic expansion repair produces a new transition zone between the expanded and non-expanded portions of the tube. A similar transition zone existed previously at the original roll expansion. However, the transition for the kinetic expansion was carefully developed to be more gradual than that of the original shop roll expansion, and, in general, the kinetic expansion process tends to result in less cold working than the roll expansion process. While the residual stresses in the kinetic expansion transition may be slightly higher than those in roll expansions which have experienced the fabrication stress relief heat treatment, residual stresses and the amount of cold working in the kinetic expansion are both less than in non-stress-relieved roll expansion transitions for which there is a considerable body of satisfactory operating experience in nuclear power plants. Licensee - Issue 5 at 5; Staff - Cont. 1.a at 16; Tr. 410-413 (Pai), 465-468 (Lee), 489-497 (Slear, Lee), 506 (Lee), 634 (McCracken).

125. The residual stresses within the transition zone are not a concern from a static or fatigue stress standpoint, but could affect the susceptibility of the material to intergranular stress-assisted cracking. The resistance of the kinetic expansion transition zone to IGSAC is demonstrated by operating

experience of OTSGs containing non-stress-relieved roll expansions, and by Licensee's accelerated and long-term corrosion testing. Licensee - Issue 5 at 5; Staff - Cont. 1.a at 17; Tr. 497 (Lee).

126. To date, there have been no failures, by cracking in the transition zone, of tubes with non-stress-relieved roll expansions in B&W once-through steam generators in service. Short-term (accelerated) corrosion testing, which was performed as part of the TMI-1 qualification program, showed no evidence of cracking in either kinetic or non-stress-relieved roll expansion transitions during the simulated life of the repair when exposed to a caustic (10% NaOH at constant potential) environment. Licensee - Issue 5 at 5-6.

127. Thus, the likelihood of tube rupture of the new transition due to either loading or IGSAC is no greater than that for tubes currently operating in other once-through steam generators. Licensee - Issue 5 at 6.

128. The potential effects of the kinetic expansion process on the balance of the tube were also carefully evaluated. The only effect warranting further analysis was the change in tube preload. The kinetic expansion repair process produces less than a 30-pound decrease in tube preload for normal steam generator tubes. A small percentage of the tubes in the steam generators may have lost all preload due to the IGSAC completely severing the tube in or near the original roll

expansion at the top of the tube. This allowed the tube to slip down slightly and relieve the existing preload in the tube. In some cases, vibrations from nearby kinetic expansions may have contributed to the slipping process. Licensee - Issue 5 at 6; <u>see</u> Tr. 477-478 (Slear, Lee).

129. The increase in the compressive load due to loss of any or all of the tube preload when added to the maximum compressive load (which occurs during a normal heat-up transient of 100°F/hr) is less than the compressive load required to cause contact between adjacent tubes. Accordingly, there is no increased potential for tube ruptures due to increased wear. Furthermore, the loss of the tube preload does not increase the likelihood of fatigue failure because preload, being a constant load, is not a factor in the fatigue load range and does not reduce natural frequency to a level which would be of concern. Total loss of tube preload reduces the tube natural frequency by approximately 15% which is less than the variation in natural frequency within some individual steam generators. Another plant with similar steam generators operates with tube natural frequencies 15% lower than those expected for TMI-1. Licensee - Issue 5 at 6; Tr. 482-483, 499-502 (Slear).

130. Thus, the kinetic expansion repair process does nothing to the balance of the tube to increase the likelihood of tube ruptures. Licensee - Issue 5 at 7.

131. Therefore, for the reasons indicated above, the repair process has not increased the likelihood of tube ruptures, and hence of simultaneous tube ruptures involving both steam generators.

III. CONCLUSIONS OF LAW

The Board has considered all of the evidence submitted by the parties and the entire record of this proceeding. Based on the Findings of Fact set forth herein, which are supported by reliable, probative and substantial evidence in the record, this Board, having decided all matters in controversy, concludes that, pursuant to 10 C.F.R. § 2.760a and 10 C.F.R. § 50.92, the Director of Nuclear Reactor Regulation should be authorized to issue to Licensee, upon making requisite findings with respect to matters not embraced in this Initial Decision, an amended license authorizing operation of the Three Mile Island Nuclear Station, Unit No. 1, with the as-repaired steam generator tubes.

IV. ORDER

IT IS HEREBY ORDERED, pursuant to the Atomic Energy Act of 1954 and the Commission's rules and regulations, based on the Findings of Fact and Conclusions of Law set forth in this Initial Decision that the Director of Nuclear Reactor Regulation is authorized, upon making all requisite findings not embraced by this Initial Decision, to issue Licensee an amendment to its operating license recognizing steam generator repair techniques other than plugging, specifically the kinetic expansion tube repair technique, thereby authorizing operation of the Three Mile Island Nuclear Station, Unit No. 1, with the as-repaired steam generator tubes.

Respectfully submitted,

SHAW, PITTMAN, POTTS & TROWBRIDGE

By ______________________

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Dated: August 3, 1984

DOCKETED
USNRC

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION '84 AGO -6 P3:00

Before the Atomic Safety and Licensing Board

OFFICE OF SECRETARY
DOCKETING & SERVICE
BRANCH

In the Matter of	)	
	)	
METROPOLITAN EDISON COMPANY, ET AL.	)	Docket No. 50-289-OLA
	)	ASLBP 83-491-04-OLA
(Three Mile Island Nuclear	)	(Steam Generator Repair)
Station, Unit No. 1)	)	

CERTIFICATE OF SERVICE

This is to certify that copies of the foregoing "Licensee's Proposed Findings of Fact, Conclusions of Law, and Brief in the Form of a Proposed Initial Decision" were served, by deposit in the United States mail, first class, postage prepaid, to all those on the attached Service List, except those marked with an asterisk were served by hand delivery this 3rd day of August, 1984.

Bruce W. Churchill, P.C.

Dated: August 3, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

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	)	ASLBP 83-491-04-OLA
(Three Mile Island Nuclear	)	(Steam Generator Repair)
Station, Unit No. 1)	)	

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