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U. S. Nuclear Regulatory Commission
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Washington, DC 20555-0001

Three Mile Island, Unit I (TMI Unit 1)
Operating License No. DPR-50
NRC Docket No. 50-289

Subject: Additional Information Regarding Kinetic Expansion Inspection and Repair Criteria (TAC No. MB6475)

References: 1) AmerGen Energy Company, LLC letter to NRC, dated May 3, 2005 (5928-05-20102), "Additional Information Regarding Kinetic Expansion Inspection and Repair Criteria."

2) AmerGen Energy Company, LLC letter to NRC, dated August 11, 2005 (5928-05-20102), "Additional Information Regarding Kinetic Expansion Inspection and Repair Criteria (TAC No. MB6475)."

The final TMI Unit 1 Report ECR #02-01121, Revision 2, "Inspection Acceptance Criteria and Leakage Assessment Methodology For TMI OTSG Kinetic Expansion Examinations," is provided in Attachment 1. This information is submitted for the NRC's review and acceptance in accordance with Section IWB-3630 of ASME Code Section XI. The revisions to ECR #02-01121, Revision 1, are indicated by revision bars in the margin. In Reference 1, AmerGen Energy Company, LLC (AmerGen) submitted a draft of this report, which provided the updated inspection acceptance criteria and updated leakage assessment methodology for the TMI Unit 1 once-through steam generator kinetic expansion examinations to address additional information regarding flaw growth rates, inspection scope and expansion criteria, structural integrity assessment, leakage assessment, and non-destructive evaluation techniques. The following changes 1 through 5 have been made to the Revision 2 Draft submitted in Reference 1, as discussed on September 27, 2005. Additional changes 6 through 8 have been made in order to provide consistency and clarity as a result of internal reviews.

1) Section 2.3.2, Section 4.4, and Table 2 were revised to address the allowable circumferential length of single indications.
2) Section 2.0 was revised to provide additional information regarding the FeedWater Line Break (FWLB) transient.

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3) The Reporting Requirements Table in Section 5.9 was revised to include the results of extreme value testing in the plant's outage 90-day report.
4) The Reporting Requirements Table in Section 5.9 was revised to include the results of projected leakage trending in the plant's outage 90-day report, including a reconciliation between leakage calculation methodologies used in prior outages.
5) Section 2.0 and The Reporting Requirements Table in Section 5.9 were revised to include a LBLOCA best-estimate leakage assessment (as was previously committed in Reference 2).
6) Section 6.0 was revised to be consistent with the wording in Section 4.1.4 and Section 3.2.
7) Sections 2.3.2, 3.2.1.1, and 4.4 were revised since a 100% examination scope is planned.
8) Section 2.7 was revised to incorporate options for sleeve dispositioning methods other than plugging, and indicate that any options require prior NRC approval.

As was discussed on September 27, 2005, the TMI Unit 1 Updated Final Safety Analysis Report (UFSAR) Section 1.3.2.39 will be further revised at the next update to state that any future changes to ECR # 02-01121, Revision 2, would be submitted to NRC for review and approval prior to implementation.

If any additional information is needed, please contact David J. Distel at (610) 765-5517.

Respectfully,

D. P. Helker

David P. Helker
Manager - Licensing

Attachment: 1) TMI Report ECR #02-01121, Revision 2, "Inspection Acceptance Criteria and Leakage Assessment Methodology For TMI OTSG Kinetic Expansion Examinations."

cc: S. J. Collins, USNRC, Administrator Region I,
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ATTACHMENT 1

Inspection Acceptance Criteria and Leakage Assessment Methodology For TMI OTSG Kinetic Expansion Examinations

ECR #02-01121, Revision 2

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ECR #02-01121, Rev. 2

INSPECTION ACCEPTANCE CRITERIA AND LEAKAGE ASSESSMENT METHODOLOGY FOR TMI OTSG KINETIC EXPANSION EXAMINATIONS

ORIGINATOR(S):

(Richard Freeman) 10-13-05

DATE

APPROVALS:

R.D. BARLEY 10-13-05

INDEPENDENT REVIEWER DATE

10/13/05

ENGINEERING MANAGER DATE

Leonard Rajkowski

INSPECTION ACCEPTANCE CRITERIA AND LEAKAGE ASSESSMENT METHODOLOGY FOR TMI OTSG KINETIC EXPANSION EXAMINATIONS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

FIGURE PAGE

LIST OF TABLES

TABLE PAGE

1.0 PURPOSE

TMI-1's Once Through Steam Generator (OTSG) tubes were repaired in 1982 – 1985 by forming new tube-to-tubesheet joints within the upper tubesheets using a kinetic expansion process. In 1997 GPU Nuclear (the prior owner of TMI-1) developed inspection criteria for use during ECT inspection of the kinetically expanded regions and these criteria were submitted to the NRC (References 25 and 26). In 2002 a single AmerGen document (Revision 0 of this ECR) was created to update those two 1997 submittals. This 2005 Revision 2 of this ECR, like the 2004 revision, was provided to incorporate additional information. Data from examinations of the kinetic expansions in the 1997 to 2003 outages is incorporated. In addition, this revision makes significant changes to the kinetic expansion criteria that further increase its conservatism:

- a 100% scope is implemented so that each in-service kinetic expansion is examined during each refueling outage,
- circumferentially-oriented flaw indications are removed from pressure boundary service,
- newly-identified flaws are removed from pressure-boundary service, and
- revisions to the leakage assessment methodology result in a more conservative (i.e., greater volume) estimate of accident-induced kinetic expansion leakage.

These inspection criteria identify the minimum required length of defect-free kinetically expanded tube that must be present, and provide acceptance criteria for any flaws that may be encountered, in order to ensure that the design capability of the joints is maintained. These criteria also ensure that margin is provided in depth against unacceptable performance of the joints (to prevent joint slipping, parting of the tube, or unacceptable accident-induced leakage.)

The purpose of this document is also to provide a summary of the conservative methods that are used to inspect and disposition the kinetically expanded joints. An assessment of the material condition of the joint is presented as regards the benefit of the residual stresses from formation of the joint in mitigating stress corrosion cracking. It is also shown that NDE performance characteristics for the several forms of potential damage in the joint are applied conservatively. This document also provides the inspection methodology, inspection scope, acceptance criteria, and reporting requirements to be implemented during the kinetic expansion examinations.

This document is only applicable to the kinetically expanded tubing within the upper tubesheets of the TMI-1 steam generators. The inspection criteria and leakage assessment methodology described herein are not applicable to unexpanded tubing within the TMI-1 upper tubesheets, or to the transitions between the unexpanded and kinetically-expanded tubing. (Other documents describe examinations of unexpanded tubing within the TMI-1 upper tubesheets and disposition of those examination results. For example, TMI-1 ECR TM 01-00328 (referenced in the plant's Technical Specification 4.19) describes examination requirements and acceptance criteria for unexpanded tubing within the TMI-1 upper tubesheets).

2.0 SYSTEM PERFORMANCE/KINETIC EXPANSION STRUCTURAL INTEGRITY ANALYSIS

The design basis performance for the kinetically repaired TMI-1 OTSG tubes is that, as a result of a Main Steam Line Break (MSLB), no tube shall break or separate from the tubesheet (Reference 27). In the following analysis, this performance requirement was practically applied as first, a condition that the tube is not permitted to part within the kinetically expanded joint (or at any other location). In addition, the repaired tube is expected to sustain a design basis axial load of 3140 lbs. with no slippage (Reference 28).

For the kinetic expansion areas within the upper tubesheet, it is necessary to consider only the axial load applied through the tube to the joint as a result of the MSLB. The axial tube loads that occur during normal operations, for example those resulting from a normal cooldown transient, are much lower and will not exceed about 35% of the faulted condition. Since the kinetically expanded tubing is captured within the steam generator upper tubesheets, applied bending loads are very low in magnitude, and bending stresses do not develop within the joint because no rotation can occur.

MSLB is the design-basis accident for the kinetic expansions since it represents a hypothetical accident where tube stresses are relatively high, and the potential exists for offsite dose consequences from tube leakage resulting from significant primary-to-secondary pressure drop. Other transients, such as the Small Break and Large Break Loss of Coolant Accidents (SBLOCA, LBLOCA) may result in relatively high tube stresses, but breaks of the primary system do not result in large primary-to-secondary pressure differentials. Primary-to-secondary pressure differential can be negative (i.e., pressure in the secondary system is greater than pressure in the primary system) during some LOCA events. FeedWater Line Breaks (FWLB) result in comparatively lower tube stresses than the MSLB and LOCA events.

As is described in more detail below, steam generator tubes will yield if subjected to significant axial loads. Tubes with lower yield strengths will begin to yield at lower loads than tubes with higher yield strengths. Tubes with a range of yield strengths are present in steam generator tube bundles. (For the TMI-1 kinetic expansions, initial testing revealed that expansions formed with low-strength tubing were limiting in terms of joint pull strength and leakage.) Each of the MSLB, SBLOCA, and LBLOCA events, when conservatively analyzed, may impart axial tensile loads that cause steam generator tubes to begin to yield. Since the MSLB event has a relatively high primary-to-secondary pressure differential along with the relatively high axial loads, it is the design basis accident for the kinetic expansions.

2.0.1 FeedWater Line Break (FWLB) Considerations

A hypothetical FWLB causes a heat-up transient (in contrast to the MSLB that causes an over-cooling transient). Consequently, the tubes are in axial compression during a FWLB. This compressive load on the tubes tightens the kinetic expansion joint, because the tube is pressed into the expansion. BAW 10146, "Determination of Minimum Required Tube Wall Thickness for 177 FA OTSG's," October 1980, Table 5-6, identified the expected magnitude and distribution of tube axial loads across the tubeheet for the FWLB transient. The tubes are in nearly uniform axial compression of about 600 lbs across the entire tubesheet. The uniform distribution indicates that there is very little tubesheet bow due to the resistance of the tubes as an elastic foundation for the tubesheet. In fact, the maximum tubesheet bow expected during a FWLB, also using the information in Table 5-6, is less than 10% of the maximum tubesheet bow expected for the MSLB transient, considering a nearly identical pressure difference of approximately 2500 psid in the original analysis of both transients.

The reduced tubesheet bow associated with the FWLB establishes the MSLB as a more limiting accident condition for leakage evaluation even considering more recent analyses that resulted in lower primary-to-secondary pressure differences for the MSLB. The compressive load due to the FWLB does not challenge the tube pullout resistance. In fact the compressive load increases the tube-to-tubesheet contact pressure due to Poisson expansion within the joint. The reduced tubesheet bow during the FWLB results in negligible dilation of the tubesheet hole bore, as compared to the dilation for the MSLB, which also contributes to maintaining the contact pressure in the kinetically expanded joint. Limited tubesheet bow is characteristic of the FWLB transient analyses because of the elevated primary temperature.

In addition, the expected leakage resistance for a hypothetical FWLB is also increased over that of a hypothetical MSLB by the thermal tightening of the Inconel tube against the alloy tubesheet. (The coefficient of thermal expansion for the Inconel tubes is higher than that of the alloy tubesheet.) The thermal tightening is greater for the FWLB, which involves higher primary system temperatures, than for the MSLB.

Furthermore, while a hypothetical FWLB has higher primary-to-secondary delta pressures than a MSLB, higher primary-to-secondary delta pressure tends to tighten the kinetic expansion joint. It is not realistic to assume that a FWLB is more limiting because of higher primary-to-secondary pressure drop while ignoring the fact that an increase in primary-to-secondary differential pressure also tends to tighten the expansion joint. One phenomenon cannot occur without the other. The radial amount that a tube expands when subjected to the FWLB-induced 2500 psid delta pressures is greater than the expected tubesheet bore dilations (since, as described above, tubesheet bow is reduced.) The restriction of the tubesheet greatly restrains crack opening in both the axial and circumferential directions.

The kinetic expansion acceptance criteria of this ECR take no credit for the limited leakage expected from expanded joints within the tubesheets, which is a very conservative and unrealistic assumption. Contact interference between the tubes and the tubesheets is maintained in the TMI-1 kinetic expansion joints. Calculation of potential leakage using a freespan leakage model is added as a conservatism recognizing that leakage through a realistically modeled joint would be at least an order of magnitude less than that for the freespan model. Considerable industry operating and laboratory experiences have shown that leakage expected from expansions is orders of magnitude lower than that expected from freespan flaws. For these reasons, to disposition eddy current indications in the kinetic expansions a comparison of freespan leakage for the FWLB with that for the MSLB is not necessary. The potential for loss of contact pressure, and hence loss of leakage integrity, in the kinetic expansion joint is much less for the FWLB than for the MSLB so that it is appropriate to use the MSLB, vice the FWLB, as the limiting accident transient for assessment of leakage.

In summary, leakage from the kinetic expansion joints is expected to be less for a hypothetical FWLB transient than the leakage from a hypothetical MSLB transient calculated using the methodology described in this ECR for the following reasons:

1. The Poisson effect from the tensile tube loads of an MSLB pulls the tubes away from the tubesheets, which tends to open theoretical leak paths. The Poisson effect from compressive loads of a FWLB pushes the tubes against the tubesheets, which tends to close theoretical leak paths.

2. The cooler primary temperatures of an MSLB tends to shrink the tube away from the tubesheet and decrease the tube-to-tubesheet contact pressure, which tends to open theoretical leak paths. The hotter primary temperatures of a FWLB expands the tubes within the tubesheets, which tends to close theoretical leak paths.

3. The calculated tubesheet bow, which tends to pull a tube away from the tubesheets at some locations, is considerably less for the FWLB transient than for an MSLB.

4. Primary-to-secondary delta pressure increases, by themselves, while tending to increasing primary-to-secondary leakrates, also tend to increase the tightness of the joints.

5. The TMI-1 leakage criteria, as proposed herein, are extremely conservative and take no credit for the significant contact pressures between the tubes and the tubesheets.

The backing provided by the tubesheet provides significant resistance of the kinetic expansion joints to strain in both the radial and tangential directions. Even if this significant resistance provided by the tubesheets is conservatively neglected for the purposes of analysis, there is evidence that the TMI-1 kinetic expansion indications are unlikely to leak at MSLB- or FWLB-induced pressures. In situ pressure tests have been conducted on numerous indications in the TMI freespan steam generator tubing without leakage. These tests were conducted at pressures at or exceeding 3ΔP, which is a greater differential pressure than that expected during a hypothetical MSLB or FWLB transient. The following table illustrates the axial lengths of the population of kinetic expansion volumetric indications detected during the plant's most recent 2005 Outage 1R15. (Approximately one third of the kinetic expansions were examined during that outage.) The table also provides the axial lengths of the volumetric indications that have been in situ pressure tested in the plant's freespan tubing to date. Note that the axial lengths of in situ pressure tested indications are similar to those typically found within the kinetic expansions.

Table 6

Distribution of Outage 1R15 Kinetic Expansion Volumetric Indication Axial Extents
and
Distribution of In Situ Pressure Tested Freespan Volumetric Indication Axial Extents to Date

Axial Extent in Inches	Number of Outage 1R15 Kinetic Expansion Volumetric Indications	Percent of Total Outage 1R15 Kinetic Expansion Volumetric Indications	Number of Freespan Volumetric Indications In Situ Pressure Tested	Percent of In Situ Pressure Tested Freespan Volumetric Indications
0.00 to 0.10	230	23.1%	7	9.3%
0.11 to 0.20	715	71.9%	48	64.0%
0.21 to 0.30	47	4.7%	14	18.7%
0.31 to 0.40	3	0.3%	6	8.0%
0.41 to 0.50	0	0.0%	0	0.0%
0.51 to 0.60	0	0.0%	0	0.0%
Total	995		75	

(Table 5 of this ECR provides a more detailed summary of the plant's in situ pressure test data to date.) These successful tests were conducted on flaws similar to those found in the kinetic expansions: the predominant flaw type found in both the freespan and kinetically-expanded tubing is ID-initiated Volumetric IGA (IDIGA).

The actual FWLB pressure difference is less challenging than the Condition Monitoring pressure differences used for in situ pressure testing at TMI-1. A differential pressure of 3ΔP is approximately 4000 psi, whereas the maximum expected FWLB pressure differential is approximately 2600 psi. Increases in differential pressure create increased hoop stresses on flaws with axial components (i.e., the pressure tends to "open" an axially-oriented flaw as a result of internal pressure.) The margin provided by the higher differential pressure tests can be estimated. Hoop stresses in the tested tube are directly proportional to differential pressure.

Thus, flaws tested at 3ΔP without leakage were tested to hoop stresses (4000/2600 =) 1.5 times greater than the maximum stress expected during a FWLB.

There are a number of industry burst relationships for steam generator tubing. (NUREG CR-6575, "Failure Behavior of Internally Pressurized Flawed and Unflawed Steam Generator Tubing at High Temperature: Experiments and Comparision with Model Predictions," March 1998, provides a discussion of several of the models.) Each of these models is based on equations where, for thin-walled tubing, the expected burst pressure is proportional to the thickness of the tubing. Thus, a factor of 1.5 difference in test pressure (versus FWLB pressure) also corresponds to an approximate 50% allowable flaw depth increase with respect to burst. For example, for flaws of the same geometry, a tube with a 70% through wall flaw might have an expected burst pressure at 3ΔP—the same flaw could be 100% TW (i.e., 50% deeper) and have an expected burst pressure at FWLB conditions.

In summary, the significant number of in situ tests conducted on freespan TMI-1 indications to date further demonstrate that the kinetic expansion flaws are likely to survive a FWLB or MSLB without leakage or burst.

2.0.2 LBLOCA Considerations

Note that, at the time of this writing, AmerGen is working with the other B&W plant owners to revise BAW-2374, the LBLOCA topical, to address the LBLOCA transient for all aspects of the steam generators' design and maintenance. Final resolution of the kinetic expansions with respect to LBLOCA loads will follow the industry resolution of BAW-2374 issues. In the interim TMI-1 has committed, each refueling outage, to determine the best-estimate total primary-to-secondary leakage that would result from the limiting LBLOCA based on the as-found circumferential and volumetric indications along the entire length of tubing inspected with appropriate allowance for flaws that may be located outboard of regions inspected, and to demonstrate that it is acceptable. For the purpose of this evaluation, acceptable means a best estimate of the leakage expected in the event of a LBLOCA that would not result in a significant increase of radiological release (e.g., in excess of 10 CFR 100 limits). A summary of this evaluation will be included in the plant's outage 90-day report and is discussed in Section 5.9, Reporting Requirements, of this ECR.

2.1 Finite Element Modeling/Benchmarking of the Design MSLB Transient

In order to evaluate the behavior of kinetically-expanded joints with hypothetical flaws, and under the theoretical conditions where the tubesheet may bow, a finite element analysis model was developed in 1997. The analysis model of the tube-to-tubesheet joint consisted of a tube, the tubesheet, and a contact element representing the interference/connection between the tube and tubesheet. (Reference 24)

The analysis model had the additional feature that tube material behavior in both the elastic and plastic regions was modeled using actual tube stress-versus-strain data. Also, tube internal pressure could be included in the analysis model. Finally, the effect of tubesheet bow was captured. (The tubesheet may bow slightly due to the combined effects of axial tube load and primary-to-secondary pressure differences.)

The effect of the drilled holes in the tubesheet upon tubesheet stiffness was conservatively included in the finite element structural model so that the amount of tubesheet bow was not underestimated. The effect of the drilled holes on the tubesheet stiffness was directly modeled and was captured in the structural analysis. Several independent solutions were integrated in the present structural analysis. The actual bending stiffness of the tubesheet, including the drilled holes, was addressed in the original design analysis performed to determine tube minimum required wall thickness.

Maximum tubesheet displacement, under load, was identified using a finite element structural analysis model. For the purpose of calculating the kinetic expansion joint pull-out resistance, a conventional, closed form, solution for a solid plate was used to identify the displacements through-out the tubesheet based upon the maximum displacement obtained using the finite element solution for the drilled tubesheet. No error is introduced by this method with respect to computing tubesheet strain, which is the key variable in determining tubesheet hole dilation and constriction.

Test results available from the original 1980's kinetic expansion qualification program (Reference 29) were used as the basis for benchmarking the finite element analysis model results. The benchmark process used qualification program tubes with high yield strength (57 ksi) and wall thickness slightly larger than design minimum tube wall (0.038" vs. 0.034"). [The resulting repair criteria assume that all tubes have minimum yield strengths and the minimum tube wall.] Qualification test results were available for expansion lengths equal to four, six and eight inches. High yield strength tube material was exclusively used for only the 4" and 8" expansions. Test results indicated that the joint's capacity to resist slip was the same for the 6" expansion as it was for the 8" expansion data.

The original 1980's qualification program's tube pullout test results at room temperature were used to benchmark the 1997 finite element model. More than eighty (80) tubes were pull tested. The majority of these tests were performed at room temperature, which is conservative since the kinetic expansion joints are tightened with increasing temperature. (The Inconel-600 tube's coefficient of thermal expansion is greater than that of the alloy steel tubesheet.) As described in Reference 29, during the original qualification some pullout tests were also performed at elevated temperatures. These elevated temperature pullout tests confirmed the conservatism of testing joint interference at room temperature.

Surface condition variabilities were addressed during the original qualification of the kinetic expansion joints in the 1980's (Reference 29). For example, pull testing on both uncorroded and corroded tubesheet blocks was performed. (The uncorroded blocks had lower pullout loads.) All of the kinetically-expanded tubes in the TMI-1 generators were kinetically expanded twice to ensure that the proper joint expansion was attained.

The 1997 finite element model was a conservative model that was based on the conservative testing and implementation of the kinetic expansion process implemented in the 1980's. For example, all repair criteria determined by the model assumed that the tubing had minimum wall thickness (0.034") and minimum yield strength (41 ksi). The 1980's testing confirmed that higher yield strength tubing resulted in a stronger joint. The 1997 model also neglected the effects of temperatures above room temperature upon the contact pressure of the joint. As described above, contact pressure (i.e., joint "tightness") increases with temperature because of the tubing's higher coefficient of expansion than that of the tubesheets.

The 1980's testing evaluated differences in diametral clearance between the tubing outside diameter and the tubesheet bore inside diameter before the kinetic expansions were installed. (The design tolerances of the steam generator allowed this annulus diametral gap to be from 0.003" to 0.016".) The 1980's study concluded that the size of the annulus before the tubes were expanded was insignificant with respect to the strength of the kinetic expansion joints (Reference 24).

The finite element model parameters that describe the performance of the expansion are the contact interference between the tube and the tubesheet that was achieved by the kinetic expansion, and the coefficient of friction. Use of a contact interference dimension equal to 0.0003" in the model produced the best agreement with the joints' original qualification test results when using a coefficient of friction equal to 0.2. The analysis model results accurately matched the minimum test results obtained for the 4" expansion and underpredicted the performance of the 6" and 8" expansions. The same contact interference and coefficient of friction were used throughout the analysis reflecting the assumption that the kinetic expansion was equally effective over the range of expansion lengths. No parameter adjustments were made to produce results matching the pullout capacities for the 6" and 8" expansions as accurately as that obtained for the 4" expansion, to more accurately represent the shorter expansion. The analysis results are conservative for the longer expansions as a consequence of not adjusting the expansion parameters. For the conditions of the original testing, the pullout resistance of the 4" expansion is predicted by the model to be 3260 lbs. where the minimum test data result was 3100 lbs., 4030 lbs. for the 6" expansion where the minimum test data result was 5000 lbs., and 4110 lbs. for the 8" expansion where the minimum test data result was 5000 lbs.

The 1997 finite element analysis incorporated the possibility that tubesheet bore dilations from tubesheet bow during an MSLB could adversely affect the joints. No "bowing" of the tubesheet mockup blocks was measured during the original 1980's pull testing. Since no tubesheet bow was expected or factored into the original 1980's pull testing, finite element analysis was used to address tubesheet bow effects. Tubesheet bow, which reduces the assumed pullout resistance of the kinetic expansion joints, was incorporated into the finite element model after the model was benchmarked against the pull testing results. The finite element model was benchmarked against the 1980's pull tests results using common conditions; later, tubesheet bow effects were calculated. Reference 24 provides detailed information regarding the benchmarking process that was utilized.

Bowing or flexure of the tubesheet mockup blocks would not have been expected to occur during the conditions of these original tests. (In addition, it is conservative to assume that no dilations occurred during these original tests. The original tests determined the pullout resistance for joints of measured lengths. For example, a 6" long joint may have had a pull strength of 5000 lbs. Had dilations occurred, a reduced effective length of joint would have been present, since some length would have been affected by the bow. Therefore, the pullout resistance, in lbs. force per unit length of joint, would have been greater –since the effective length would have been reduced. Had tubesheet bore constrictions occurred during the original testing, the opposite result would have occurred –the joint strengths could have been increased. However, as described above, the original tests were room temperature tests with small tubesheet blocks in which no significant tubesheet bore dilation or bore constriction occurred.)

2.2 Finite Element Model Results

The key performance features of the kinetically expanded joint are shown in Reference 24, which documented the finite element analysis. Figure 3-2 of Reference 24 shows the finite element analysis model results for a 6" expansion using high yield strength tube material. [The 6" expansion of the analysis model actually contained 5.5 inches of expanded tubing and a 0.5" expansion transition. The 0.5" transition does not contribute to the pullout strength of the kinetic expansion joint since the transition tubing is not in contact with the tubesheet. Actual profilometry data from a qualification test block indicated that a typical kinetic expansion has a transition of 0.5" length.] The residual contact pressure is shown in Figure 3-2 of Reference 24 as a function of distance above the transition region for both the condition of no applied load (dashed line) and the condition when slip begins (solid line). As described above, the effective length of the expansion is less than 6" because of the transition, which gradually tapers away from the tubesheet. (The analysis model ignored the fact that 17" and 22" long kinetic expansions were actually installed in the steam generator tubes.) Without applied load, the joint's residual contact pressure reaches a plateau a short distance away from the transition at a pressure equal to about 3300 psi.

The residual contact pressure abruptly decreases near the end of the expansion because of the effect of the free edge. The free edge is more flexible than the interior portion of the expansion so that the reaction at the edge is less for the same interference. The influence length of the effect of the free edge is determined by analysis to be approximately 0.25", which is reasonable in that this dimension is about three times the "decay length" of 0.08" based on widely used approximations of the structural influence of local discontinuities in thin tubes such as OTSG tubes (decay length = $0.78\sqrt{Rt}$, where R is the tube inner radius and t is the tube minimum wall thickness). An axial flaw, like the end of an expansion, also changes the local stiffness of the tube, and a change in the local stiffness influences the contact pressure of the kinetic expansion joint. The influence of a flaw on contact pressure decays outboard of the physical dimensions of a flaw (as depicted in Figure 3-12 of Reference 24). This is evident from shell theory with respect to displacement and moment reactions due to local changes in stiffness. The edge effect extends more than 0.125" on each side of a flaw (i.e. 0.25" total influence), but partial joint contact pressure is maintained at the edges. (A step change from full contact pressure to zero contact pressure does not occur.)

Under slip load conditions, the model demonstrated that residual contact pressure redistributes due to Poisson contraction of the tube wall. The reduction of residual contact pressure is less with increasing distance above the transition. This is because the tube reaction decreases with increasing distance above the transition due to the increasing total contribution of the friction reaction. The pullout capacity of the joint is the product of the total residual contact pressure, the contact area, and the coefficient of friction.

The design basis MSLB load for the OTSG tubes of 3140 lbs. was determined by assuming that all tubes remain fully elastic (Reference 17). In order to create a conservative finite element analysis model it was necessary to adjust the model to reflect that many of the 1980's pull testing results were obtained using tubes of high yield strength and greater wall thickness (for consideration of the minimum yield strength and nominal wall thickness tubes that may be present in the steam generators).

The tubes in the OTSG having the lower bound yield strength (41 ksi per Reference 29) are expected to be in the plastic range for the design basis MSLB load. The 3140 lb. load corresponds to an axial membrane stress equal to 49.5 ksi and a design basis tube strain of 0.16%. A stress-strain curve for the lower bound yield strength material was developed by conservatively adjusting actual tube material stress-strain data from a TMI-1 OTSG material heat. Using the design basis tube strain (0.16%) and the stress-strain curve for the lower bound yield strength material the maximum axial load that must be considered was 2400 lbs. The design basis load is caused almost entirely by an applied thermal displacement since the OTSG shell is at a higher temperature than the OTSG tubes after a MSLB. Using the site-specific stress/strain curve over both elastic and plastic stresses reduced the range of uncertainty in this analysis involving elastic/plastic material behavior.

The analysis model results indicated very little increase in pullout capacity for expansion lengths greater than 4". This is because the low yield strength tubing begins to yield at a load equal to 2400 lbs. Poisson contraction of the tube wall relieves the contact interference between the tube and tubesheet, particularly after the tube begins to yield. As an axial load is applied to a tube, Poisson contraction begins to relieve contact interference, and hence decreases contact pressure, and proceeds further into the expansion in proportion to the load. The relief of contact pressure due to local yielding permits a higher applied load to reach further into the expansion because the benefit of the friction reaction is reduced at the beginning of the expansion as higher loads are applied. Local yielding occurs further into the expansion so that contact pressure is relieved there as well, and so on, so that ultimately there is very little additional capacity achieved for the 6" and 8" expansion with regards to the 4" expansion. This trend of results was reported during the original 1980's joint qualification program, and is also present in the Reference 24 analysis model. In short, there is decreasing utility in increasing the length of the joint above 4". The analysis model also showed a change in the performance of the joint from friction limited, when the intact expansion is at a minimum, to yield strength limited when the intact length is longer and the applied axial load is higher. This was an expected result, since the joints must yield as applied load is increased.

2.3 Flaw Dispositioning Criteria Development

A flaw dispositioning criteria was analytically built, in part, on these performance features of the kinetically expanded joint. The analysis model was able to conservatively evaluate the performance of the intact and flawed kinetically expanded joints. For example, Reference 24, Section 3, Figure 3-12 shows the expected distribution of contact pressure in a 6" expansion [i.e., 5.5" of expanded tube and a 0.5" transition] of a peripheral tube after a 2" 100% through-wall axial defect is introduced midway through the expansion length. The axial defect completely relieves contact pressure along its length and, in fact, influences the contact pressure for a length greater than 2" because of the "edge" effect as previously described. The expected pull out load for this configuration is 2509 lbs., which compares well with the capacity of the 4" expansion in a peripheral tube from Figure 3-11 (2516 lbs.) of Reference 24. Thus, a 2" axial defect in a nominal 6" expansion, without including tube internal pressure, forms an equivalent 4" expansion that also satisfies the qualification program criterion for resisting slip. The general conclusion from this and other similar calculations is that the kinetic expansions are flaw tolerant of axial defects (and for circumferential defects of limited extent also, as will be shown below) with respect to pull-out load. The required intact expansion for slip/pull-out load may be continuous or distributed in segments anywhere within the expansion length, provided the tube condition prevents tube parting.

The prescriptive conditions that were used to develop the design basis axial load for the MSLB include primary pressure equal to 2500 psi (Reference 17). Tube internal pressure should be included in the tube-to-tubesheet analysis model in order to identify the increase in contact pressure, in addition to residual contact pressure from formation, due to "pressure tightening". As the internal pressure within the tube increases, the tube is tightened within the tubesheet. When this pressure tightening was included in the analysis model, the analysis model results

(Reference 24, Section 3, Figure 3-11) indicated that, for a lower bound yield strength tube having the design wall thickness, slightly less than a 2" expansion depth is required to resist pullout in a peripheral tube.

The finite element model conservatively assumed that contact pressure was completely released by the presence of a hypothetical flaw as a ring 360 degrees around the circumference of the tubing, and not only locally. This is a conservative treatment since compressive stresses are present in the expanded tubing, and the distribution of contact pressure around a flaw would actually follow the pattern expected for stress distribution of tension around a flaw in a plate. (The far field conditions maintain a uniform tension while a stress concentration develops locally around the flaw.) This conservative treatment, of relaxed contact pressure around the full circumference of the tube, is implemented irrespective of the estimated depth of the flaw. So flaws estimated as, for example, 10% throughwall result in an assumption of a complete release of contact pressure over a full 360 degree "ring" of tubing. [As an example of the conservatism of this assumption, suppose that a kinetic expansion flaw is an ID-initiated volumetric flaw with eddy current estimated dimensions of 0.2" axial extent by 0.3" circumferential extent. An estimate of the area of this flaw is (0.2" times 0.3", or) 0.06 square inches. The area of expansion that is assumed to be released of all contact pressure is (pi times the tubing external diameter of 0.625" times the axial extent of the flaw, or) 0.39 square inches. So, for this example, the affected area is more than a factor of 6 times larger than the estimated area of the flaw.]

2.3.1 Required Length of Expansion

The Reference 24 analysis model defined the maximum axial flaw length that could be present within a kinetic expansion and still meet the requirement to resist pullout (as a function of the radial location of the tubes.) Since the analysis model assumed that the flawed lengths of kinetic expansion do not contribute to the pullout capacity, subtracting the length of the maximum allowable flaw from the expansion length provided the minimum necessary length of defect-free expansion to resist pullout. Table 3-5 of Reference 24 provides results of analyses that were based on finite element modeling of a 6" expansion (5.5" kinetic expansion length plus a 0.5" expansion transition.) [Note 4 of that table states, "These criteria are only applicable for the fully-expanded region from 0.5" to 6" above the bottom of the kinetic-expansion joint." The length of the kinetic expansion transitions at the bottom of the kinetic expansions is approximately 0.5".] Table 3-5 provides "allowable defect lengths" within the 5.5" fully expanded length. For example, for a given tube location Table 3-5 may report that the allowable defect length is 4.4". Another way to state this is that a minimum of (5.5" minus 4.4", or) 1.1" of the kinetic expansion must be "defect free". In summary, the "required defect-free" lengths of the kinetic expansions, based on the finite element analysis, is the 5.5" modeled length of the kinetic expansions minus the calculated "allowable defect length".

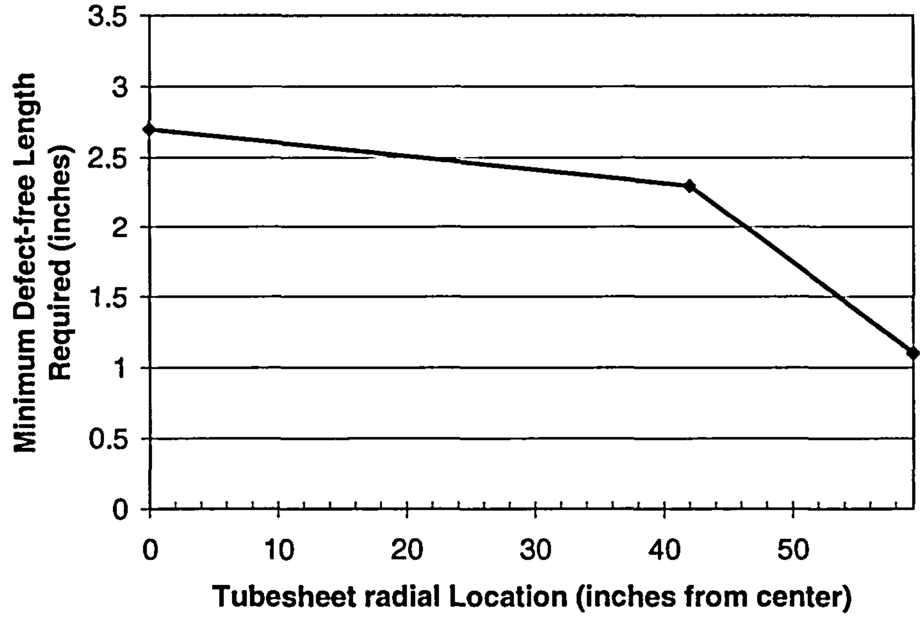
For the 17" expansions, Table 3-5 of Reference 24 may be summarized as follows:

Table A: Summary of Finite Element Modeling Results for 17" Expansions

Column A Tube Bundle Location	Column B Allowable Axial Defect Length		Column C Minimum Required Kinetic Expansion Length (= 5.5" minus Col. B)
Periphery (Radial Location = 59.344")	4.4"		1.1"
Mid-Radius (Radial Location = 42")	3.2"		2.3"
Center (Radial Location = 0.000")	2.8"		2.7"

Note that Column B values in Table A above were plotted in Figure 3-20 of Reference 24. If we plot the Column C values, the minimum "required defect free lengths" of the kinetic expansions are depicted over the radius of the tube bundle:

Figure 19
Summary of Finite Element Results for 17" Expansions

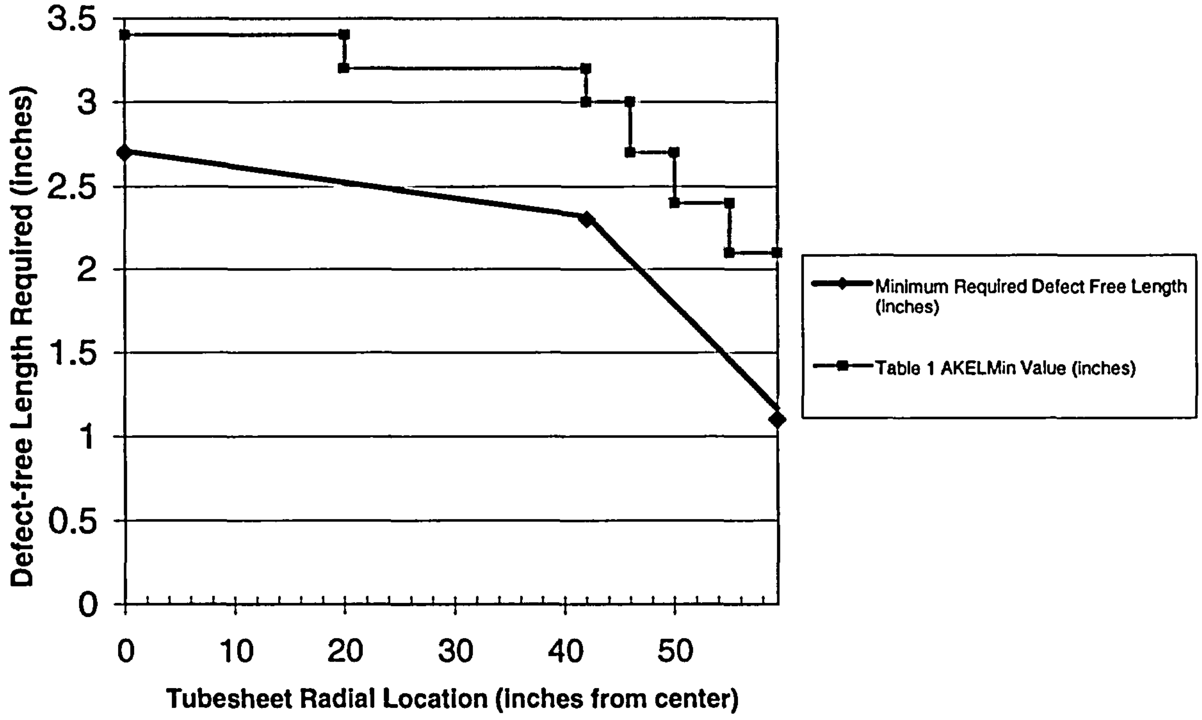


The minimum required length of kinetic expansion, as described in the above paragraph, is based on finite element analysis only; the required expansion lengths were increased to conservatively account for field examination uncertainties. (Reference 24 determined structural requirements for the kinetic expansions based on structural analysis only and did not consider examination uncertainties.) For the inspection acceptance criteria additional length was added to the dimensions calculated in Reference 24 to conservatively account for the expected uncertainty in locating eddy current indications along the axial length of the kinetic expansion with respect to the expansion transition, and any uncertainty in locating the transition reference point itself. When applied in the field the minimum "defect free" length is 2.1" for a peripheral tube. Table 1 provides the resulting list of minimum required lengths of defect-free expansion, $AKEL_{MIN}$, for the various kinetic expansion lengths and their radial locations within the OTSG tube bundles. Table 1 provides AKELmins that include the results of the finite element analysis plus additional length for conservatism and to account for possible examination errors.

The following plot (Figure 20) illustrates the conservatism of Table 1 with respect to the minimum defect free lengths for 17" expansions that were calculated by the model. Note that a fixed margin between the Table 1 value and the finite element modeling result was not used. A minimum of 0.5" margin was utilized. The minimum 0.5" margin was added to account for examination uncertainties.

FIGURE 20

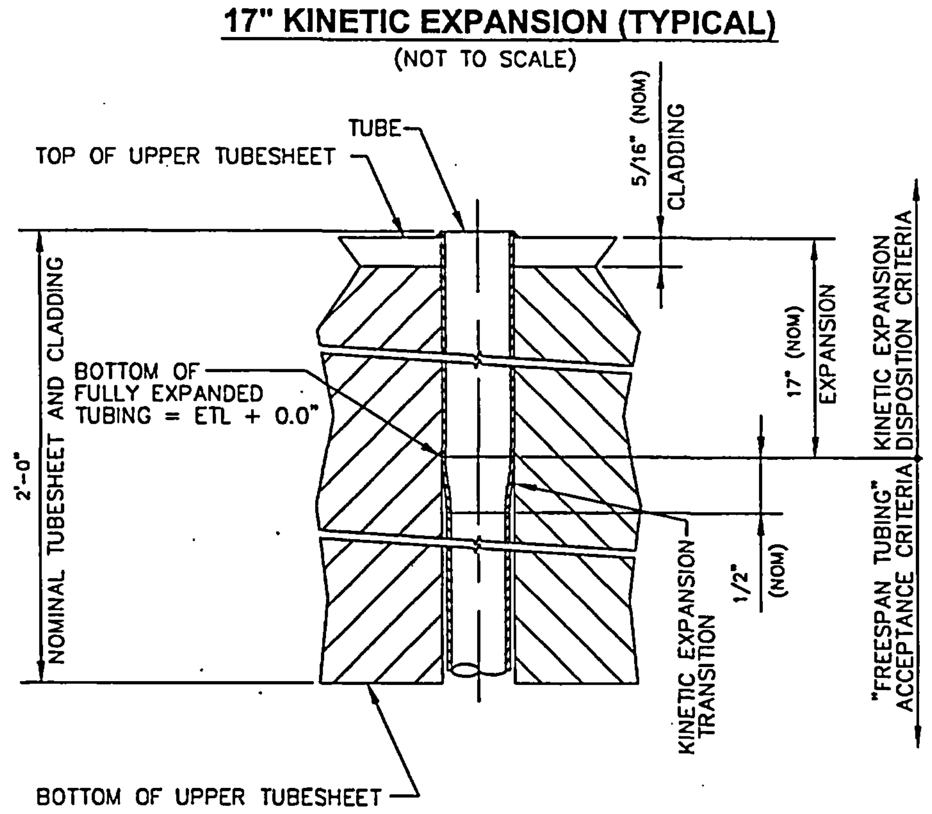
Comparison of Table 1 Values to Model Results (17" Expansions)



The derivation of Table 1 values for the 22" expansions was performed in a similar manner to the above. However, the 22" long expansions are discussed in Section 2.6 of this document.

Figure 1 provides an illustration of a typical 17" deep kinetic expansion within the TMI-1 upper tubesheet. As described above, TMI-1 uses required kinetic expansion lengths that are conservative and are longer than those defined by the analysis model. TMI inspects and dispositions only these required expansion lengths (Refer to Table 1). A TMI-1 eddy current analyst reviews the tube's MRPC signal to locate the top of the kinetic expansion transition (i.e., that point where the tube is fully kinetically expanded against the tubesheet bore). This point is designated by the eddy current analyst as location ETL+0.00" (ETL = Expansion Transition Location). The analyst reviews the eddy current signals from the fully-expanded section; if no flaws are detected over the minimum required defect free length then the tube is dispositioned as "NDD" (i.e., No Detectable Degradation). If a flaw is detected, it is characterized, located with respect to the ETL+0.00" reference point, and additional kinetic expansion length is reviewed by the analyst to detect/characterize any other flaws that might be present. If the additional analyzed length contains flaws such that sufficient defect free tubing is not identified, the tube is repaired. If the additional kinetic expansion length is analyzed and sufficient defect free tubing length is identified, the expansion then may be left in service (provided it meets all other criteria to remain in service).

FIGURE 1



The kinetic expansion acceptance criteria apply only to tubing that has been fully kinetically expanded. As described above, the plant's analysis guidelines require that that point at which the tubing is fully expanded against the tubesheet bore is identified and is given the ETL + 0.00" reference point. This provides a reference point to locate any indications that may be present. (See Figure 1 above.) All kinetic expansion examination results are referenced to the ETL+0.00" reference point. All minimum axial kinetic expansion lengths (AKEL$_{MIN}$s) are measured from the ETL+0.00" reference point.

2.3.2 Evaluation of Circumferential and Axial Indications

Note that, beginning in the 1R16 refueling outage scheduled for the fall of 2005, AmerGen will plug all tubes with circumferential flaw indications in their kinetic expansion's required length upon detection. As a result only ID Volumetric IGA indications will remain in service in the kinetic expansions' required lengths. This Section 2.3.2 remains in this document, however, to describe the treatment of the circumferential extents of volumetric indications. Volumetric indications have both axial and circumferential extents. That is, the axial extent of a volumetric indication is evaluated with respect to axial criteria, and the circumferential extent of a volumetric indication is evaluated with respect to the circumferential criteria.

Evaluation of circumferential defects in the kinetic expansions was performed based on tube parting considerations. A tube may have a through-wall circumferential defect of 130° (0.64", as measured on the ID) in extent and still have a sufficient ligament to resist the design axial load (36 percent of the tube circumference is permitted to be flawed). This evaluation assumed that the defect is located at the bottom of the expansion region where the axial force is at its maximum. (At higher elevations within the expansion region, part of the axial force would be transmitted to the tubesheet by the friction restraining force, thereby reducing the axial force in the tube wall. As a result, the allowable circumferential defect in higher areas of the expansion region would be greater than 0.64".) Note that, in order to be consistent with the plant's freespan criteria adopted under ECR 01-00328, AmerGen has adopted a single flaw circumferential length acceptance criterion of 0.52" (i.e., single indications with circumferential extents exceeding 0.52"in the required lengths of the kinetic expansions will be repaired).

For multiple circumferential defects in the expansion region, the allowable combined length of the defects would be 0.64" if the elevation difference is less than a separation criterion. These separation criteria were conservatively evaluated as part of the analytical work. The resulting flaw combination criteria are based on providing the required shear path between defect elevations in order to transfer the total load. It is conservative to include total load for shear transfer since membrane transfer also occurs. A reasonable separation distance was judged to be 1" considering that 1.13" of intact tube length is required at the plane of the defect for membrane stress. A 1" separation provides 2" of shear transfer path (1" at each side of a defect) at an allowable stress of 60% of that for membrane stress. For example, if two circumferential defects are separated by an axial distance greater than 1", each one may not exceed 0.52" in length. These criteria will ensure that the tube within the expanded region will not part.

The 1-inch separation distance represents the required shear path to transfer the axial load applied to the joint from the elevation of a circumferential flaw to the next elevation of another circumferential flaw. Flaws with separation distance greater than 1 inch do not interact. This separation criterion for combining the effective length of nearby circumferential flaws is based on the ASME Section III method for determining the maximum allowable average shear stress. The externally applied axial load is assumed to be reacted in shear by the ligament separating flaws at different elevations. If the required distance is not satisfied, then it is concluded that the flaws interact.

The 1-inch separation distance between two flaws assumes that the tube is freespan. No credit was taken for the expansion. In summary, the 1" separation distance over which flaws are combined was determined based on the freespan condition; no credit was taken for the presence of the tubesheet, or compressive stresses that are present from the tube-to-tubesheet expansion joint. This is a conservative practice because all of the axial load is assumed to be reacted in shear disregarding the portion of the load that is actually reacted by the friction force developed by contact pressure associated with the ligament between the flaws. The actual load reaching the flaw elevation is also assumed to be the maximum disregarding the reduction in load as a function of depth into the kinetic expansion joint.

The "edge" effect, described in Section 2.2, is an additional factor that must be included when evaluating the impact of circumferential defects. The edge effect of a circumferential defect degrades the pullout capacity of the tube much like an axial defect, as discussed above. For purposes of developing a flaw dispositioning criteria, a 0.25" axial influence will be added to each circumferential defect. In this way, the results for the contact pressure redistribution in the presence of only an axial defect form the basis for the comprehensive dispositioning criteria with respect to pullout resistance.

The resulting inspection acceptance criteria for the OTSG kinetic expansion region are given in Table 1 and Table 2. Note that criteria differ for periphery, mid-bundle, and center tubes due to the effect of tubesheet bow, to be described below. As a result, the Table 1 and Table 2 values for a given tube are a function of the radial location of that tube within its OTSG tube bundle. Table 2 provides an example to clarify how the edge effect is applied.

Note also that Table 2 requires that the 0.25" axial influence "edge" effect be added to the axial length of each axial defect, except the first defect. This exception is present because the finite element model's calculation of the minimum required expansion lengths assumed one defect was present, including that defect's edge effect. For multiple defects (i.e., the second, third, and so on), the axial length of each additional defect is considered and the additional edge effect is added. A 0.25" axial edge effect is assumed for all circumferential defects.

Note that the "edge" effect and the 1-inch separation distance are two different, and independent, parameters: The edge effect is a dimension (i.e. 0.25") that reflects the length of kinetic expansion tube-to-tubesheet joint that might be adversely affected due to the presence of an individual flaw. The 1-inch separation distance is the length of tube required between two adjacent flaws beyond which the two flaws will not interact. Edge effects are considered for all flaws; the separation distance is only applicable when considering the proximity of two (or more) flaws. Table 2 describes how the 1-inch separation criterion and edge effects are implemented. (Since the separation criterion was calculated assuming the tube was in a freespan condition, the edge effect 0.25" value and the separation criterion 1" value are not added to create a new 1.25" separation criterion. The 1" separation criterion is independent of the tube-to-tubesheet contact pressure and is a function only of the tubing material shear strength. If credit were taken for any additional benefit of tube-to-tubesheet contact pressure between the elevations of adjacent flaws, the required separation distance would be less than 1 inch.)

The loads, methods, and assumptions that were used in the analysis are conservative. The 3140 lb. axial load that was used to develop the inspection criteria is from a conservative analysis based on conservative assumptions with respect to TMI-1 regarding main steam line size, and maximum emergency feedwater flow and duration. For example, more recent analyses addressing expected MSLB thermal/hydraulic conditions and tube loads (described in Section 5.0) indicate that the maximum axial tube load is about 1300 lbs. as opposed to 3140 lbs. Thus, the use of the axial tube load from the analysis in the development of the inspection criteria incorporates a conservative factor of at least 1.8 with respect to the maximum axial tube load for the lower bound yield strength material, i.e., 2400 lbs.

Each kinetic expansion defect was assumed to locally relieve the tube-to-tubesheet contact pressure to the same extent as a 360° cut regardless of its circumferential extent. Therefore, the relief of contact pressure due to any acceptable circumferential defect is overestimated and actual pull-out capacity is higher than that calculated. In addition, with regard to acceptable circumferential defect location, no credit is taken for the reduction in applied axial tube load within the expansion due to friction. The assumption provides more conservative results for defects that are further within the expanded zone, (i.e., the full axial load is assumed to be imparted on a circumferential defect, regardless of its location within the expansion). These structural analyses of joint integrity assumed that all defects are 100% through-wall. Any difference between actual depth and the assumed 100% through-wall depth of the analysis model represents an additional conservatism.

2.4 Fatigue Analysis

The analysis of the joints also evaluated the possibility that defects that are acceptable for the faulted condition could propagate by fatigue during normal operation. The important contribution to propagation by fatigue is the axial tube load due to the cooldown, because bending stress, such as that due to flow induced vibration or due to local bending at the elevation of a defect, does not occur in the expanded tube above the transition. Crack propagation by fatigue was conservatively evaluated previously during the repair of the OTSGs considering a defect located in the free span. The previous calculation was useful for guidance because, while it did not identically match the kinetic expansion condition, it was representative. The previous calculation considered a smaller through-wall, circumferential defect (0.36" circumferential extent), but also included local bending stress. The sum of these is practically the same as the membrane stress for the kinetic expansion analysis (i.e., the kinetic expansion analysis had a longer defect and no bending stress). The results indicated that, on a per cooldown cycle basis, the expected crack propagation is about 10^{-4} inches in circumferential extent per cycle. For example, assuming six cooldown cycles per year for two years of operation, propagation by fatigue results in practically no increase in circumferential extent. It is, therefore, not necessary to reduce the extent of the acceptable critical defect size in the expanded tube because of expected propagation due to fatigue during the forthcoming operation cycle. In addition, re-inspection of representative ID volumetric indications left in service in the kinetic expansions will take place during subsequent refueling outages in order to verify that flaw extent is not increasing to unacceptable size. (Additional discussion regarding the possibility of growth of existing flaws in the kinetic expansions is provided below.)

2.5 Tubesheet "Bow" Analysis

The analysis model (and the resulting inspection criteria) for the OTSG tubes includes an additional feature of the performance of the joint: tubesheet bow (due to tube axial load and due to primary-to-secondary pressure differences during an MSLB) is assumed to open the tubesheet bores below the tubesheet center plane and close them above. The tubesheet bore dimension was adjusted in the analysis model to reflect the expected bending strain distribution at the elevations of the expansion due to tubesheet bowing. The effect is greatest for a center tube where bowing is maximum. There is no effect for a peripheral tube. As a result of the upper tubesheet bowing inward, the applied axial tube load on the affected tubing is reduced, with the minimum occurring at the center. However, as another result of tubesheet bow, the contact pressure of the tube-to-tubesheet joint is reduced due to enlargement of the tubesheet hole in the area of the joint. This effect is greatest at the secondary face of the tubesheet.

The greatest impact of tubesheet bowing is for the 22" deep expansions where the original 6" qualification length was further below the tubesheet center plane, and closer to the secondary face, than for the 17" expansions. In fact, for a 22" expansion at the center, tubesheet bow eliminates most of the residual contact pressure even when considering tube internal pressure. (The effects of tubesheet bow were not evaluated during the original kinetic expansion qualification program of the early 1980's.)

The kinetic expansion inspection criteria identify the minimum required defect-free kinetically expanded tube length that must be present within the inspected distance (Table 1) as well as the flaw, or combination of flaws, allowable within the inspected distance (Table 2). The inspection may continue beyond the nominal qualification length, if necessary, in order to demonstrate the presence of a satisfactory joint since the tubes were kinetically expanded over the entire length of the tubesheet above their original 6" qualification length. The absence of consideration of the effects of tubesheet bow as part of the original qualification program will not impact nuclear safety as long as the 22" expansions within the center and mid-radius locations of the tubesheet are inspected to the same elevation as the 17" expansions and evaluated to similar criteria. (Note that the lower 5" of the center and mid-radius 22" kinetic expansions [from ETL + 0.00" to ETL+5.00"] are also evaluated as freespan tubing, as is discussed below.)

2.6 Implementation of the Inspection and Repair Criteria

The inspection of a kinetic expansion always includes a concurrent inspection of its transition. (This is required by the plant's eddy current guidelines and is also necessary to determine the location of the ETL+0.00" reference point as described above.) All kinetic expansion examination results are referenced to the ETL+0.00" reference point at the top of the expansion transition. All AKEL_{MIN} minimum axial kinetic expansion lengths (for both 17" and 22" expansions) are measured from the ETL+0.00" reference point. Section 4.0, which follows, provides details regarding the eddy current inspection of the kinetic expansions.

Volumetric indications are dispositioned by combining the results that were derived separately for axial and circumferential defects. That is, the criteria for axial defects shall be used for the axial extent of the volumetric indication and the criteria for circumferential defects shall be used for the measured circumferential extent of the volumetric indication. (The majority of TMI-1 OTSG kinetic expansion flaws are volumetric ID IGA indications, similar to those found in the freespan tubing of the TMI-1 generators.)

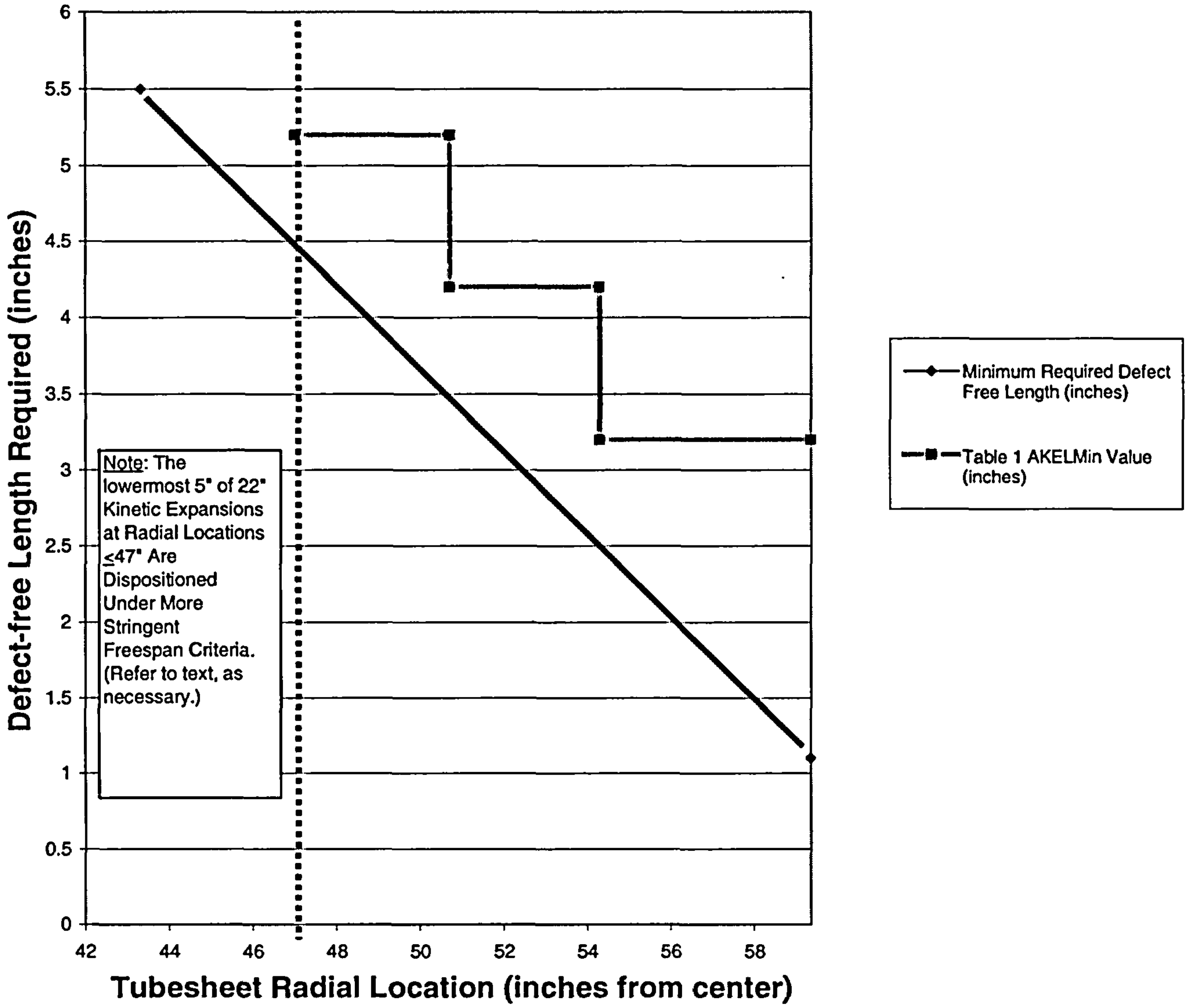
As is apparent in Table 1 and Table 2, field implementation of these inspection criteria is specific with respect to both tube location and expansion length. The analysis model determined allowable defect sizes (plus influences) as a function of relative radius of the tube bundle for 17" and 22" expansions. The analysis model calculated values at specific radial locations; it is conservative to apply results specifically for tubes that are located at a smaller radius as governing for tubes located at a larger radius. This logic represents an additional factor that contributes to the conservatism of the inspection criteria.

As is also apparent in Tables 1 and 2, disposition of defects in the 22" expansions is notably different than for 17" expansions. (The majority of the TMI-1 kinetic expansions are 17" in length. Of 31,062 tubes in the TMI-1 steam generators only 431 tubes have 22" kinetic expansions that remain in service during the plant's current operating Cycle 15.) The lower 5" length of the 22" expansion at center and mid-radius locations does not contribute to slip resistance under postulated MSLB conditions due to the tubesheet bowing. For this reason the required defect-free expansion lengths ($AKEL_{MIN}$) for the 22" expansions located near the center of the tube bundle are 5" longer than that for 17" expansions located at the same tube bundle radial position. Indications in the lower 5" length of the 22" expansions located near the center of the tube bundle are dispositioned using more stringent free span criteria, since this length of expanded tubing loses contact with the tubesheet as a result of postulated tubesheet bow. Amendment #237 to the TMI-1 Technical Specifications incorporated a requirement to *implement the freespan tubing acceptance criteria for volumetric ID IGA indications within the* lower 5" of the 22" long expansions at the center of the tube bundles. Amendment 237 also implemented a requirement that 100% of the 22" long expansions at the center of the tube bundles be examined during each tubing inspection. In summary, the lower 5" of the 22" long expansions at center and mid-radius locations are a special subset in which both the freespan inspection acceptance criteria and the kinetic expansion acceptance criteria are applicable. (The freespan acceptance criteria are more stringent than the kinetic expansion criteria.)

To derive the Table 1 values for the 22" long kinetic expansions in the periphery of the tube bundles, Figure 3-20 of Reference 24 was used in a manner similar to that described for the 17" long expansions (-as described in Section 2.3.1, above). The following plot illustrates the conservatism of Table 1 with respect to the minimum defect free lengths for 22" expansions that were calculated by the model. Note that a fixed margin between the Table 1 value and the finite element modeling result was not used. A minimum of 0.5" margin was utilized.

FIGURE 21

Comparison of Table 1 Values to Model Results (22" Expansions)



2.7 Sleeved Tubes

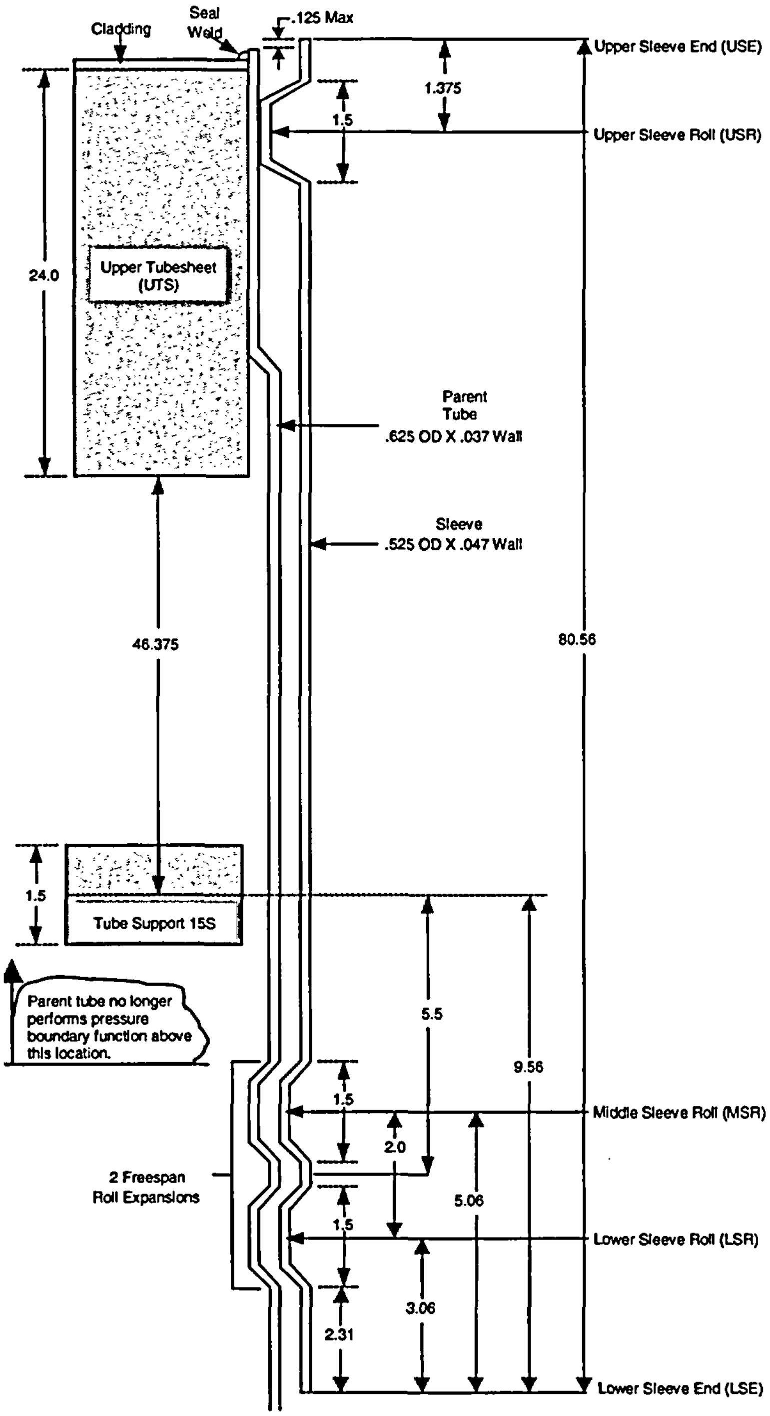
There are 502 tubes in the TMI-1 steam generators with kinetic expansions that have sleeves installed. These tubes were sleeved during the plant's 1991 and 1993 outages as a preventive measure to mitigate primary-to-secondary leakage resulting from high cycle fatigue cracks. (All of the in-service OTSG plants installed sleeves to prevent these fatigue cracks.) Each of the TMI-1 sleeves was manufactured from Inconel 690 material and completely spans its tube's kinetic expansion to form a new pressure boundary. The B&W rolled sleeves installed in the TMI-1 steam generators extend from the primary face of the upper tubesheet to a point more than 80 inches down into the steam generator tube (i.e., deeper into the tube than the 17" or 22" deep kinetic expansions). Figure 22 depicts a typical TMI-1 steam generator tube sleeve.

As was described in AmerGen's May 3, 2005 submittal of a draft of this ECR, AmerGen has committed that any tubes with flaws detected in the sleeves, or in the parent tube adjacent to the sleeve between the lower sleeve end and the parent tube kinetic expansion transition, will be "plugged-on-detection". In lieu of plugging, an alternate dispositioning method may be developed with approval of the NRC prior to implementation.

Given that the kinetic expansions in TMI-1 sleeved tubes have been removed from service, kinetic expansion examinations are not conducted in these sleeved tubes and the subject inspection and dispositioning criteria are not implemented in those tubes.

FIGURE 22

B&W ROLLED SLEEVE



Not to scale. Dimensions are nominal and provided in inches.

3.0 MATERIAL CONDITION ASSESSMENT

3.1 Stress Corrosion Cracking Mitigation Resulting From Kinetic Expansion

The impact of kinetic expansion on the TMI-1 OTSG tube material condition can be considered in two separate parts. First, there is the effect on pre-expansion defects. Secondly, there is the formation of, and benefits from, post-expansion residual stresses. Kinetic expansion is not a corrosive process; rather it is a mechanical, cold work process that produces plastic strain. It is reasonable to assume that defects that may not have been initially detectable may have been enlarged by the kinetic expansion and, thereby, made more detectable. It is possible, particularly for the axial component of defects because of the induced permanent circumferential strains, that defect dimensions increased due to the expansion, that the distance between defect planes (i.e., crack opening displacement) increased, that grain drop-out increased the defect volume, or that a combination of these changes occurred. As a result of the effects described above, kinetic expansion probably enhanced flaw detection. In addition, the eddy current techniques used to examine the kinetic expansions during recent refueling outages are more sensitive than the techniques used during the 1980's, when the expansions were created.

No defect growth has been observed over the course of recent operating cycles for kinetic expansion defects that have been reviewed with the same ECT technology.

3.2 Growth Monitoring and Examination Scope

TMI-1 has monitored the growth of eddy current indications within the kinetic expansions for the past several outages (since MRPC inspections were started) and has reported these results to the NRC (References 32, 35, 36, 37). Since the original 1997 submittals regarding the kinetic expansions (i.e., References 25 and 26) TMI-1 has provided additional details regarding growth of indications in the TMI-1 steam generators. Reference 30 provided information regarding the methods with which TMI-1 has monitored the growth of the ID degradation found in the kinetic expansions, and as well as growth within the unexpanded tubing. Indications have been evaluated for changes in axial extent and circumferential extent over successive outages, and over multiple outages. Analysis of indication growth, and an assessment of that indication growth relative to the repair criteria, is required by the plant as part of operational assessments each outage.

Reference 30 provided information regarding the reliability of ECT techniques used for indication detection and sizing. TMI-1 has examined all of the population of inservice kinetic expansions, by examining approximately one third of the tube population during each of the last four plant refueling outages (Outages 12R, 13R, 1R14, and 1R15).

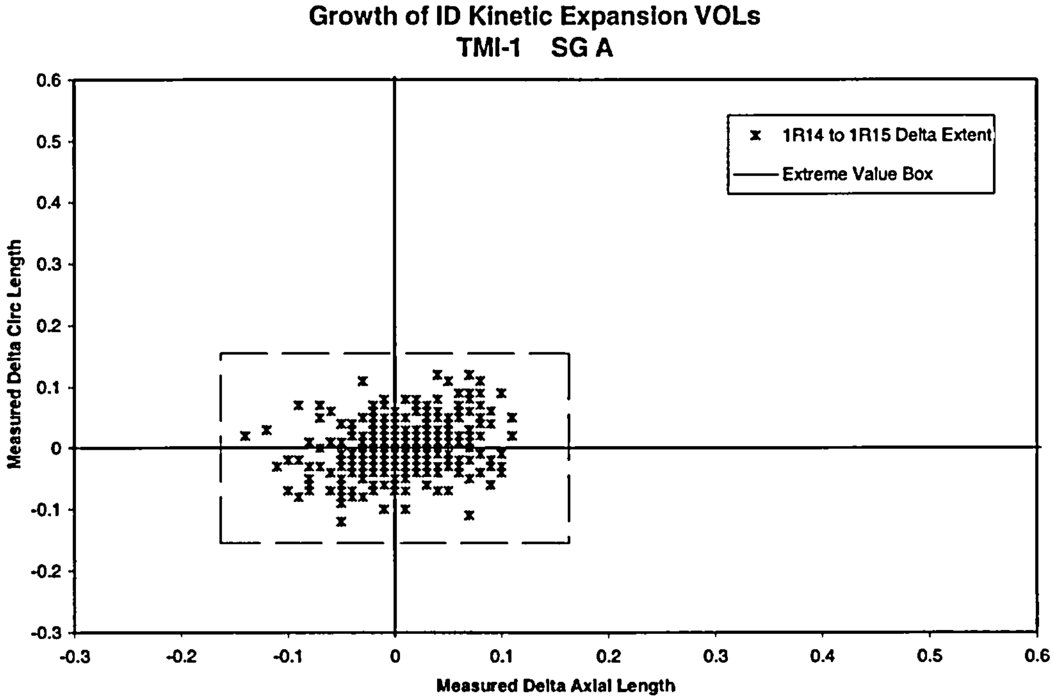
TMI-1 will continue to monitor for growth of flaws in its steam generators, including flaws in the unexpanded tubing within the tubesheets and kinetic expansions. The following parameters are compared for kinetic expansion flaw indications:

-change in axial extent of ID volumetric indications
-change in circumferential extent of ID volumetric indications
-whether or not new indications are detected

The results of these evaluations are evaluated in several ways: "scatter plots" of the data are created to visualize the trend of the data. Average changes, standard deviations of the changes, and maximum changes are calculated and reviewed. During the last TMI-1 outage, sign and paired-t statistical tests were performed on the ID volumetric IGA indications in the kinetic expansion region, as are performed for the ID volumetric IGA indications in the freespan tubing. (Refer to Sections 3.2.1.5 and 3.2.1.6 of this report.)

Statistical analysis of the growth results is necessary. The kinetic expansion indications are relatively small in size, and the variability of the eddy current examination process must be considered to evaluate the population for growth. For example, the following (Figure 23) is a "scatter plot" that depicts the change in axial and circumferential extents (in inches) of the ID volumetric indications in the "A" steam generator kinetic expansions over the last operating cycle. This plot illustrates some of the variability of the growth data.

FIGURE 23



In addition to monitoring for the growth of existing flaw indications in the kinetic expansions, TMI-1 also evaluates the population of new flaw indications identified during the examinations. Section 3.2.1, which follows, provides a technique with which new flaw indications will be evaluated during each examination.

The following tables (Tables D and E) provide the results of evaluations of changes in kinetic expansion indications from the plant's most recent Outage 1R15.

Table D
Historical Growth Summary for Kinetic Expansion Volumetric IDIGA Indications

Operating Period	Average Change in Circ. Extent		Average Change in Axial Extent	
	SGA	SGB	SGA	SGB
1R14 - 1R15	0.003"	-0.005"	0.005"	-0.008"
13R - 1R15	-0.010"	-0.024"	-0.008"	-0.034"
12R - 1R15	-0.013"	-0.049"	-0.001"	-0.034"

Table E
Growth of Kinetic Expansion Circumferential Indications

Operating Period	Average Change in Circ. Extent	
	SGA	SGB
1R14 - 1R15	+0.010"	-0.005"
13R - 1R15	-0.009"	-0.046"

From 12R to 1R15, the average change in circumferential extent of kinetic expansion circumferential indications (within the tubes' minimum required expansion length, AKELmin) in both steam generators was -0.02".

In order to monitor the kinetic expansions for the possible onset of new degradation, and monitor the existing degradation for possible growth, examination of the tubing is required each outage. Specifically, beginning with the 1R16 Refueling Outage planned for the fall of 2005, all of the non-plugged, non-sleeved tubes' kinetic expansions and their kinetic expansion transitions will be scheduled for inspection with rotating coil eddy current probes during each refueling outage. The TMI Unit 1 plant operating cycle length is presently 24 months.

Approximately one third of the plant's kinetic expansions have been examined during each of the plant's last four refueling outages (i.e., 1997 through 2003 refueling outages). These samples were sufficient to detect whether significant growth of existing flaws in the kinetic expansions was occurring, or if any new degradation began to appear within the kinetic expansions. The plant's steam generator program requires that condition monitoring assessments and operational assessments be performed based on the results of the outage examinations. The operational assessments must contain an evaluation of the potential for growth during the following operating cycle.

To conservatively address the appearance of new kinetic expansion flaw indications, TMI-1 will plug/repair any tubes having kinetic expansions with new flaw indications in their required expansion length that were not detected during the 1997 through 2001 refueling outage examinations. "Lookbacks" will be used to evaluate whether or not an indication may have been present in this previous outage data. (Each of the in-service kinetic expansions was first examined with an MRPC probe during the 1997, 1999, or 2001 outage.)

3.2.1 Procedure for Monitoring Growth of Kinetic Expansion Indications

3.2.1.1 Introduction

This section provides the procedure for continued growth monitoring of the indications within the kinetic expansions of the TMI-1 steam generators. [Note that much of this procedure is nearly identical to the growth monitoring procedures already incorporated into the TMI-1 Technical Specifications for monitoring of ID Volumetric IGA indications in the unexpanded tubing per ECR TM 01-00328. Approximately 80% of the indications in the kinetic expansions are ID Volumetric IGA, so the techniques used to monitor growth in the unexpanded tubing are also applicable to the majority of the kinetic expansion indications. (At the close of the 2005 refueling outage examinations, the only flaw indications remaining in service in the kinetic expansions' required lengths will be ID Volumetric IGA.) However, since the bobbin coil probe is not used in the kinetic expansion area, it was necessary to revise the growth monitoring procedures outlined in ECR TM 01-00328.] The procedure is a multi-step process including statistical tests to detect changes in the apparent growth distributions.

Eddy current indications found within the TMI-1 kinetic expansions during recent refueling outages have been of two types: ID-initiated volumetric IGA and circumferential indications. Thus, the appearance of new OD-initiated indications, axial indications, or other type of degradation differing from the aforementioned two types would be evidence of a new form of degradation. Beginning in the 1R16 refueling outage scheduled for the fall of 2005, AmerGen will plug all tubes with circumferential flaw indications in their kinetic expansion's required length upon detection.

The procedure for growth evaluation of the kinetic expansion ID Volumetric IGA indications consists of screening the data for extreme values, followed by two statistical tests that will be applied to axial and circumferential length measurements from the kinetic expansion ID IGA inspection data. The two tests will be the application of a sign test and a paired t-test. These two tests will be applied to each of the two variables. If all tests are passed (that is, if all four tests demonstrate that the ID IGA growth rate is less than a small positive value), it will be concluded that the kinetic expansion ID IGA population is not growing. If these tests are unsuccessful in demonstrating that growth is less than a small positive value, a cycle-specific growth model and NRC notification are required.

3.2.1.2 Capability of Statistical Tests to Detect a Change in Mean Growth of ID Volumetric IGA Indications in the Kinetic Expansions

Increases in measured eddy current parameters do not necessarily indicate actual growth of flaws as they also reflect the NDE uncertainties associated with sizing relatively small flaws (as discussed earlier in this report). The validity of classical statistical tests for no growth depends strongly on the assumption that the data are normally distributed. Departures from normality such as excessive peakedness or skewness affect the results of the tests and may lead to incorrect conclusions (for example, concluding that flaw dimensions have changed when, in fact, they have not). The methods described in this report may be applied even if the data does not have a normal distribution. Generally, large datasets tend to be normally distributed; so the risk of error is not substantial.

3.2.1.3 Procedure for Assessing ID IGA Growth in the Kinetic Expansions

As described above, a statistical procedure will be used to assess ID IGA growth. The procedure consists of initial screening of the data for extreme values, followed by two statistical tests that will be applied to axial and circumferential length measurements from the kinetic expansion ID IGA inspection data:

(1) Sign test
(2) Paired t-Test

These two tests will be applied to each of the two variables (i.e., axial and circumferential extent) for a total of 4 tests. If all tests are passed (that is, if all test statistics calculated from the ID IGA growth data are statistically insignificant), it will be concluded that the kinetic expansion ID IGA population is not growing.

If the test results are unsuccessful, then some evidence exists in the apparent growth data that the population of kinetic expansion ID IGA indications may have changed. At this point it is necessary to develop a cycle-specific growth model that should be applied in the operational assessment.

An outline of the procedure follows:

Perform Extreme Value Screening and Perform Statistical Tests for Change in the Kinetic Expansion ID IGA Flaw Population:

1. Extreme Value Screening
2. Sign Test
3. Paired t-Test

Because of the limited data population in the "B" OTSG, data from the two steam generators will be combined for these tests. (The majority of the kinetic expansion indications are in the "A" OTSG.)

Data from individual indications will be compared back to the first outage with acceptable MRPC data for these statistical tests.

3.2.1.4 Step Ia. Extreme Value Tests for Largest Growth Rates

An extreme value analysis will be used as an initial screening for kinetic expansion volumetric ID IGA indications that may be outliers in the datasets. For example, if an indication is mis-analyzed or mis-characterized as volumetric ID IGA (in either the current outage or a previous outage), the extreme value screening will help identify the indication. Similarly, if an indication were to grow or "shrink" by a large amount, this test will help to identify it. The extreme value screening serves to identify (mathematically) those indications that might also be found by visual inspection of a scatter diagram of the data for outliers.

Samples from normal distributions yield extreme (in this case maximum apparent growth) values that are described (for large sample sizes) by the so-called Type I Extreme Value distribution. Since the number of volumetric ID IGA flaws in the kinetic expansions of the TMI-1 steam generators is relatively large, the Type I distribution is expected to provide a good representation of the expected frequency of extreme growth values. This screening is performed by comparing the largest observed growth value with the 5% critical value. If the largest growth value is less than the critical value, it will be concluded that the IGA growth data extreme value is not statistically significant.

If the extreme value screening identifies indications with erroneous data, the erroneous data will be corrected prior to using that data in the subsequent screenings, or subsequent Sign and Paired t statistical tests. If the extreme value screening identifies indications with large apparent growth rates, and are not due to erroneous results, these indications will be used in the subsequent statistical tests.

In summary, the extreme value analysis will be performed to identify possible outliers or erroneous data.

3.2.1.5 Step Ib. Perform Sign Tests for Change in Kinetic Expansion ID IGA Population

The Sign test is a statistical test for detecting differences in the median of a binomial distribution from a reference value. This test will be used to identify the presence of statistically significant (i.e., positive) change in the kinetic expansion ID IGA flaws based on two eddy current measurements: measurements of axial and circumferential lengths. This approach will not require that the data be normally distributed.

The Sign tests will determine if the growth of the kinetic expansion ID IGA indications is bounded by the following small, positive reference values between examinations: 0.01" axial extent increase and 0.01" circumferential extent increase. (The use of small positive values will reduce the possibility that random process error alone could result in mistakenly concluding that actual physical growth has occurred. These small extent values are very small in comparison to the repair criteria.) The maximum Type I error (i.e., the probability of erroneously concluding that there is growth when there is actually no growth) is 5%.

The variables for the Sign tests are:

α = the significance level of the test = 0.05 for a one sided test

m_o = the standard = inches (for axial or circumferential length)

X_i = each observation (change in inspection parameter for each indication) for a given parameter, from 1 to n_{total}

n_{total} = the total number of indications for which there is data or observations for a given parameter

X = average of X_i

r = the number of observations less than the standard

r_{crit} = critical value of "r" for the sign test which is taken from Table A-33 in Reference 39

Note that the significance level of the test has been chosen to be equal to 0.05 which is a generally accepted value within industry. The significance level of the test, as well as the number of observations, affects the probability of making a correct determination.

If r is greater than r_{crit}, it is concluded that there is no reason to believe the measured parameter change is different from zero and therefore, there is no reason to believe the defects were growing in the given outage interval.

3.2.1.6 Step Ic. Perform Paired t-Tests for Change in Kinetic Expansion ID IGA Population

The Paired t-test is a standard statistical test for hypothesis testing as regards the significance of differences in sample means. The standard paired t-test will be used to further evaluate whether growth is indicated by this parametric test. For this application, again the null hypothesis is that the mean change (growth) in the kinetic expansion ID IGA flaws is bounded by the following small, positive reference values between examinations: 0.01" axial extent and 0.01" circumferential extent. (As in Step Ib, the use of small positive values will reduce the possibility that random process error alone could result in mistakenly concluding that actual physical growth has occurred.)

α = the significance level of the test = 0.05 for a one sided test

m_o = the standard = inches (for axial or circumferential length)

X_i = each observation (change in inspection parameter for each indications) for a given parameter,

X = average of X_i

n = the total number of defects for which there is data or observations for a given parameter

u = difference between the observed average and the standard = X - m_o

$t_{1-\alpha}$= percentile of the t distribution, taken from Table A-4 of Reference 39, as a function of level of significance, α and degrees of freedom, df

$$u_{crit} = t_{1-\alpha} \frac{s}{\sqrt{n}}$$

s = standard deviation

df = degrees of freedom = n - 1

If u is less than u_{crit}, it is concluded that there is no reason to believe the measured parameter change is different from zero and there is no reason to believe the defects were growing in the given outage interval. If u is greater than u_{crit}, it is concluded that the defects were growing in the given outage interval.

Sign and Paired t-testing were performed in accordance with the above procedure on both the axial and circumferential extent changes of 434 volumetric IDIGA indications found in the TMI-1 kinetic expansions during the plant's 1R15 and 1R14 Outages. The results of the tests supported the "no growth" assumption (i.e., no reason to believe that growth had occurred).

3.2.1.7 (This section, and Step II, were deleted.)

3.2.1.8 (Deleted)

3.2.1.9 Step III. Evaluate the Number of "new" Kinetic Expansion Indications

Identification of new indications is expected as analyst sensitivity and technique sensitivity (i.e., data quality) change. To conservatively address the appearance of new kinetic expansion flaw indications, TMI-1 will plug/repair tubes having kinetic expansions with new flaw indications in their required expansion length that were not detected during the 1997 through 2001 refueling outage examinations. "Lookbacks" will be used to evaluate whether or not an indication may have been present in this previous outage data.

As described above, detection of OD indications or axially-oriented indications will also be indicative of a new form of degradation, since these types of degradation are not normally found in the kinetic expansions. The results of this analysis will be provided to the NRC in the "90-day report" currently required by the plant's Technical Specifications 4.19.

3.2.1.10 Step IV. Develop Cycle Specific Growth Model

If Steps I through III, above, are successful in demonstrating the lack of statistically significant growth in the kinetic expansion eddy current indication population, Step IV is not necessary. However, in the event that future TMI-1 kinetic expansion field data indicates that growth is greater than a small positive value change from the historical population, or apparent growth as evidenced by the inability to demonstrate statistically insignificant growth via the procedures in Steps I through III, it will be necessary to develop a cycle-specific model of growth. This growth model will characterize changes in the mean, variability and extremes of apparent growth and will be important as a basis for a cycle-specific growth allowance to be used in operational assessments for forthcoming cycles.

After using the procedures in Steps I through III, TMI-1 will notify the NRC during any outage in which growth is greater than a small positive value change from the historical population, or apparent growth as evidenced by the inability to demonstrate statistically insignificant growth. (Refer to Section 5.9 regarding reporting methods.)

It may be necessary to re-verify the analyst-to-analyst variability that is applicable to the field data at hand and to evaluate the components of variability so that an accurate model of actual growth can be obtained. Any growth analysis performed using the cycle specific growth model described here will require a revision to this report to include information substantiating the growth conclusions reached and the basis for the conclusions. The revised report will be submitted to the NRC well ahead of the subsequent refueling outage with any actions to address potential growth.

3.3 Residual Stresses

Kinetic expansion produces residual compression in both the circumferential and axial directions. This can be understood by considering the mechanics of the process. The residual contact pressure from formation is an external pressure on the tube OD due to the interference between the tube and tubesheet. The resulting residual hoop stress in the tube is compressive at a level approaching the yield strength of the tube material. In addition, during the expansion, as contact between the tube and tubesheet increases, the tube is extruded against the friction that is also developing in the contact zone. The friction reaction due to contact pressure causes residual axial compression by resisting extrusion.

Service conditions will not completely remove residual compression of the kinetic expansions in either the circumferential or axial directions. At operating conditions, increases in both internal pressure and temperature cause an increase in contact interference, resulting in higher compressive circumferential stresses. Axial tube loads applied during normal operation will not remove residual axial compression completely because contact pressure due to radial interference is not lost. Axial load on the joint is at a maximum during the normal cooldown transient but will not exceed about one-third of the applied axial load during the faulted condition. The normal cooldown transient will not remove contact interference even for the limiting 22" expansion at the tubesheet center. Any reduction in axial compression is temporary with full elastic restoration following any (and all) cooldown transient(s).

The kinetic expansion joints, under normal operation, have compressive residual stresses in both the axial and circumferential directions. Mitigation of stress corrosion cracking, both for new damage and propagation of existing damage, is accomplished by maintaining these compressive residual stresses within the kinetically expanded regions. Since the analytical model and structural repair criteria assume that all defects are 100% through-wall, and that circumferential defects result in a full relaxation of the tube-to-tubesheet contact pressure over 360° of the tube circumference, there exists substantial allowance for flaw growth. In addition, the MRPC eddy current techniques provide conservative measurements of flaw extents within the kinetic expansions. (See Section 4.0, which follows). With these conservatisms and the other conservatisms of the finite element model, the as-called eddy current indication length and widths are evaluated with respect to the repair criteria. Additional factors or increments to account for flaw growth are not used and are not necessary.

4.0 BASIS FOR DISPOSITION OF INDICATIONS AND NDE PROCESS VARIABILITY

The basis for dispositioning indications in the kinetic expansion has been, and continues to be, that even full through-wall damage can be acceptable with respect to both structural integrity and primary-to-secondary leakage, depending on indication location and extent. Post-expansion ECT inspections of the kinetic expansion performed in the 1980's identified previously undetected indications. Depth sizing was not possible with the inspection technology that was used at the time (i.e., 8X1 probe). It was concluded (NUREG 1019, Table 3.3-1) that small indications possibly having through-wall extent would not impact the reliability of the joints. More recent analyses, described herein, have also reached this conclusion.

4.1 Examination Techniques and Variability

4.1.1 Examination Techniques

Kinetic expansion examinations are currently performed with MRPC probes (i.e., Motorized Rotating Pancake Coil). These probes contain a mid-frequency Plus-Point coil and a 0.080" diameter high frequency shielded pancake coil that are used to detect and/or evaluate indications in the kinetic expansions. The 300 kHz Plus-Point coil data is used for detection and depth sizing of detected flaws in the kinetic expansion region. The 300 kHz Plus Point coil data is used for length sizing of kinetic expansion circumferential or axial "crack-like indications." The 600 kHz 0.080" pancake coil data is used for measuring the axial and circumferential extents of ID volumetric flaws. These examination techniques are able to characterize the flaws in terms of morphology, surface extent, depth of the flaws, and axial location of the flaws within the expansions.

TMI-1 will not change eddy current techniques used for examining the kinetic expansions unless prior NRC approval has been obtained.

4.1.2 Noise Levels

Prior to the 2001 Outage 1R14, Outage 13R (October 1999) eddy current noise levels in the steam generator were compared to the applicable qualification data for the Plus Point coil by measuring the volts peak-to-peak and vertical volts ("volts vert-max"). This comparison was based on 300 actual in steam generator noise measurements and 168 qualification data set noise measurements. The comparison revealed that the general population of tubes was expected to have noise levels equivalent or less than the qualification data set noise levels. In fact only one of the 300 in-steam generator noise measurements exceeded the measured qualification noise measurement and the vertical volts noise measurement difference at this location was less than 0.05 volts. (The volts peak-to-peak measurements were all less than the maximum measured volts peak-to-peak measurement for the qualification data.)

Prior to 2003 Outage 1R15, Outage 1R14 eddy current data noise levels were compared to prior examination data for tubes that were in situ pressure tested at TMI. The in situ pressure tested flaw population at TMI-1 is large in comparison to the flaw population in the industry qualification data and structural and leakage performance has been acceptable for all of the flaws in situ pressure tested to date. The in situ pressure tested flaw population also provides a more diverse population of flaws. To date, more than 69 ID IGA flaws having eddy current measured circumferential and axial extents up to 0.37" and 0.40" extents, respectively, have been in situ pressure tested. To date, 10 circumferential indications have been in situ pressure tested with the maximum measured eddy current extent being 0.51". (Refer to Table 5 for a summary of TMI-1 steam generator tube in situ pressure tests performed to date.) All of the in situ pressure tested flaws were located below the kinetic expansion and the test results are conservative compared to expected performance for a similar flaw inside the expansion because the tested flaws would not have had the tubesheet ligament providing structural support. Thus, if the measured noise in the kinetic expansion region is equivalent or less than the measured noise in the in situ pressure tested tubes, similar or better examination results will be expected. These measurements were made using RMS noise vertical and horizontal measurements as described in the EPRI Steam Generator Examination Guidelines (Reference 38). The in situ pressure tested tube noise values were based on 32 tubes with 107 flaw locations. The kinetic expansion tube noise measurement values were based on 70 tubes evenly distributed in both steam generators in order to obtain a representative sample of the tube bundles. Tube locations in the generator were chosen to assure a sampling across the tubesheet array. The noise values were measured for both the 300 kHz Plus Point coil channels and the 600 kHz 0.080" shielded pancake coil channel (the channels used for kinetic expansion flaw detection and sizing). The study illustrated that the noise within the kinetic expansion data is comparable to (i.e., is not more noisy than) data from TMI-1's in-situ pressure tested tubes.

Eddy current noise levels are monitored during TMI-1 steam generator tubing examinations as part of the data quality verification process. There are currently no formally accepted procedures for quantifying the effects of measured noise levels on the probability of detection (POD) or sizing of flaws. The tube noise studies described above determined that the eddy current noise in the kinetic expansion region was similar to the noise in other regions where MRPC probes are utilized in the TMI-1 generators. These studies also confirmed that the eddy current noise levels in the kinetic expansion region are comparable to the noise levels that were present in the data used to qualify the MRPC probes. This confirmation supports a conclusion that in generator POD and sizing errors are similar to, or better than, those supported by the qualification data and in situ pressure tested flaw population. Noise monitoring will continue to be performed during future TMI-1 examinations.

4.1.3 Examination Technique Qualification

1997 Analyses

PWSCC and ID IGA sizing performance of rotating coil examinations in OTSG tubes were evaluated prior to TMI-1's 1997 Outage 12R. Machined flaws were introduced into OTSG tubes in order to represent circumferential, axial and volumetric damage. Table C below provides a summary of the machined OTSG tubing flaws used in this study. The study concluded that the 300 kHz mid-frequency Plus Point coil examination technique provided the best depth sizing performance and the best flaw extent measurement performance for axially- and circumferentially-oriented flaws. The 600 kHz 0.080" high frequency shielded pancake coil examination technique provided the best extent measurement performance for ID volumetric (ID IGA) indications.

Table C
OTSG Tubing Machined Flaws Used in 1997 Study

Flaw Type	Flaw Quantity	Nominal Depth Range in Percent Throughwall	Nominal Axial Length Range in Inches	Nominal Circumferential Length Range in Inches
Axial Notch	10	20 to 80	0.06 to 0.25	0.004
Circumferential Notch	20	20 to 100	0.004	0.06 to 0.50
Volumetric Pit-Like	23	20 to 100	0.02 to 0.16	0.02 to 0.16

Data from EPRI Appendix H qualifications for axial and circumferential PWSCC (ETSS's 96703, 96702, and 96701 based on 0.750" and 0.875" diameter tubing) was evaluated with the same analysis techniques in order to confirm the validity of the measured performance from the OTSG machined flaw tubing examinations. A comparison of the Appendix H qualification results against the OTSG machined flaw results confirmed the validity of the defined examination performance in the study and that use of the examination technique performance in evaluating kinetic expansion data would result in a conservative dispositioning of identified in generator degradation.

Prior to examining a large number of kinetic expansions in the 1997 12R Outage, the contributing sources of expected error during the MRPC examinations were segregated and evaluated separately. The primary source of error was technique error involving differences between the "as-called" values compared with metallurgical "truth". The other contributing factors were analysis variability due to differences between the results of eddy current analysts, and equipment/technique variability due to differences among multiple trials for the same analyst.

In order to establish examination extent and acceptance criteria it was necessary to establish the magnitude of each of these contributing sources of examination error. Using length sizing performance as an example, the relative sizing error was greater than the sum of analysis variability and equipment/technique variability. This result has significance because the average error for both circumferential and axial length sizing is an overcall. This means that the sum of all of the error contributing factors remains an overcall for axial and circumferential extent. Since the overall performance was shown to be consistent overcall of flaw lengths, this helps ensure that tubes with unacceptable flaw lengths will be removed from service. Since the examination techniques overcall these extents, the "as-called" circumferential and axial dimensions, without any statistical correction, are used for length sizing.

Only those defects estimated to be greater than 67% through-wall are included in the kinetic expansion accident–induced primary-to-secondary leakage evaluation. (Leakage is highly improbable from shallow defects.) The logic for addressing the expected errors when depth sizing was similar to that for length sizing. In this case, however, an additive correction is used because the typical Plus-Point depth sizing error is an undercall. (ECT estimated the throughwall extent to be less than the actual throughwall depth.) The additive correction to the "as-called" depth is large enough to ensure the sum of all factors that contribute to error will result in an overestimate of throughwall depth.

Specifically, the additive correction factor for the mid-frequency Plus-Point probe depth estimate is 32.6% through-wall. Thus, for field implementation, any indication having an "as-called" depth greater than 67% through-wall is considered as potentially contributing to primary-to-secondary leakage, and is included in the leakage assessment calculations.

1999 Analyses

Subsequent to the 1997 outage, additional analyses were performed to evaluate eddy current analysis errors for TMI-1 steam generator tube flaws. This study included the addition of 9 TMI-1 pulled tube ID IGA flaws and 6 OTSG tube laboratory induced PWSCC flaws. The majority of TMI-1 flaws are volumetric ID IGA indications. Axial and circumferential extents of the volumetric ID IGA indications in the freespan are measured using the 0.080" shielded high frequency pancake coil operated at 600 kHz. AmerGen's Reference 30 (RAI Question 1) response provided to the NRC the following information concerning length and width sizing of volumetric ID IGA indications:

> "...TMI-1 has evaluated eddy current techniques and expected analyst uncertainties so as to assure that the dispositioning of the ID IGA indications using MRPC probes is conservative. Before 1997's Outage 12R, a study was performed to evaluate the acquisition, analysis, and technique errors expected during the MRPC examinations of the ID IGA indications. Volumetric flaws manufactured by EDM were used in the 1997 study. This study was updated before 1999's Outage 13R so as to incorporate the data from the ID IGA flaws in the tube samples pulled during the 1997 outage. A team of 5 production analysts and 1 senior (resolution) analyst was used in the study.
>
> "Acquisition variabilities were obtained by running three separate MRPC exams of the ID volumetric flaws. Comparison of the three separate exams by a single analyst enabled the acquisition errors to be evaluated. Since each flaw was a separate test, a pooled variance was used to combine the results. For the 0.080" HF pancake coil (the coil utilized by TMI-1 to measure the extents of the ID IGA indications), the acquisition pooled standard deviations were 0.0114" for axial length and 0.0084" for circumferential length.
>
> "Analysis variabilities were obtained by comparing the different analysis results of the six different eddy current analysts. For the 1999 study, this dataset included 23 EDM flaws and 9 flaws from the 1997 TMI-1 pulled tube, for a total of 32 volumetric flaws. For the 0.080" HF pancake coil (the coil utilized by TMI-1 to measure the extents of the ID IGA indications), the analysis pooled standard deviations were 0.022" for axial length and 0.031" for circumferential length.
>
> "Technique variabilities were obtained by comparing the results of the eddy current analyses to the actual metallurgy of the flaws. Again, for the 1999 study, this dataset included the 23 EDM flaws and 9 flaws from the 1997 pulled tube, for a total of 32 volumetric flaws. For the 0.080" HF pancake coil (the coil utilized by TMI-1 to measure the extents of the ID IGA indications), the technique standard deviations were 0.039" for axial length and 0.033" for circumferential length. For the 0.080" HF pancake coil, the technique average errors were a 0.124" overestimate of axial extent and 0.127" overestimate of circumferential extent.
>
> "The conclusion of the 1999 error analysis and performance evaluation is that "...the rotating coil techniques have demonstrated that axial and circumferential extents are consistently overestimated. Even when analysis and technique / equipment variability are applied at a 95% confidence level, the extents measured by eddy current are larger than the actual extents." The overestimation of axial and circumferential extents is of sufficient magnitude that no correction to the repair limits is necessary to account for eddy current acquisition, analysis, or technique uncertainty. Since the eddy current coils interrogate a volume of metal larger than the volume of the flaws themselves (i.e., "look ahead" and "look behind") the result is a consistent overestimate of flaw extents.
>
> "Note that tube pull results from the 1997's Outage 12R demonstrated that the MRPC probe typically overestimates the axial extents of the ID IGA flaws by a factor of approximately three. This occurs due to the "look ahead" and "look behind" phenomena

of eddy current coils used in steam generator tube examinations. Additional information on analyst uncertainty is provided in the response to RAI Question No. 4."

Similar length sizing studies were performed for axially- and circumferentially-oriented indications prior to the 1997 and 1999 outages using the 30 machined notches from the 1997 study and 6 laboratory-induced, axially-oriented PWSCC cracks (added during the 1999 study). These measurements were made using the mid-frequency Plus Point coil similar to measurements made in the field. The results of these studies indicated that the Plus Point coil, like the pancake coils, overestimates crack length.

In addition to the "look ahead" and "look behind" effects described above, another reason that the eddy current probes tend to overestimate the extents of the kinetic expansion flaws is that the flaws are typically small in comparision to the eddy current probe coil field sizes. No studies were performed to investigate whether the eddy current probes would overestimate the extents of flaws larger than those used in the sizing study. Refer to Section 4.1.4 for flaw sizes recorded during the 2003 examinations.

In the kinetic expansion region flaw depth measurements are made using the mid-frequency Plus Point coil. Prior to the 1997 and 1999 outages Plus Point coil depth sizing performance studies were performed in a manner similar to that described above for the length sizing studies. The 1999 study was performed using 68 total flaws that were comprised of 10 machined axial notches, 20 machined circumferential notches, 23 machined ID volumetric IGA like indications, 6 laboratory grown PWSCC indications in OTSG tubing, and 9 TMI pulled tube ID IGA indications. The 6 PWSCC samples were axially oriented ranging from 0.08" in length to 0.32" in length and 35% to 99% through wall. The 9 ID IGA pulled tube flaws ranged from 0.016" to 0.032" in circumferential length, 0.020" to 0.066" in axial length, and 19% to 49% through wall. The studies indicated that the measured 95% lower confidence level (LCL) through wall measurement error is expected to be -28.1% through wall. [Note that the additive correction factor for the mid-frequency Plus-Point probe depth estimate was not changed from 32.6% to 28.1% after the 1999 study. Thus, for field implementation, any indication having an "as-called" depth greater than 67% through-wall is considered as potentially contributing to primary-to-secondary leakage, and is included in the leakage assessment calculations.]

It should be noted that the measured eddy current through wall estimate is used for estimation of accident-induced leakage only; the eddy current measured axial and/or circumferential extent is assumed to be 100% through wall for evaluation of structural integrity (resistance to pull-out) as described in previous sections of this report. Based on the eddy current examination results, and in situ pressure tests of freespan indications performed at TMI to date, accident-induced leakage from kinetic expansion indications remaining in service is expected to be very small.

In summary, the eddy current techniques used at TMI-1 are based on qualification datasets that included pulled tube samples from TMI-1 and other samples representative of TMI-1's ID degradation. Performance studies have demonstrated that eddy current sizing is conservative, and both pulled tubes and in situ pressure testing to date have demonstrated that the techniques used at TMI-1 are able to reliably disposition steam generator tube flaws.

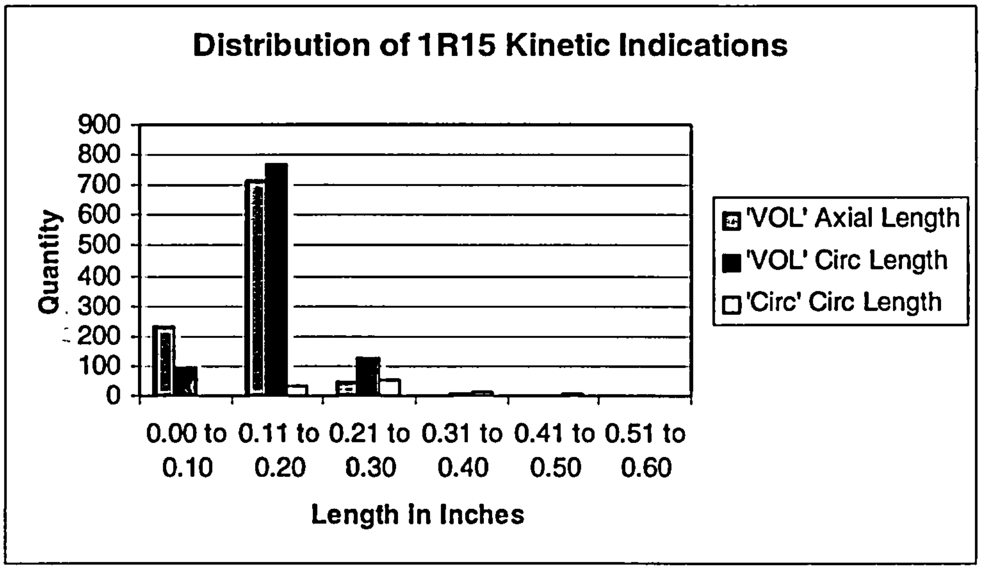
4.1.4 Examination Technique Qualification Performance Applicability for TMI-1 OTSG's

Sections 4.1.1 through 4.1.3 provide information on the extensive examination performance studies that were performed using machined flaws, laboratory induced cracking flaws, in situ pressure tested tubes and TMI-1 pulled tube flaws. The techniques and examination errors provided in these studies can be applied to TMI-1. The eddy current qualification described in this report provides a strong case that the errors identified are applicable to TMI-1, however, other applicable factors have validated the examination techniques. The factors are listed below and will be further described in this section:

- The qualification data represents TMI-1 flaws
- In situ pressure testing of similar freespan degradation has supported structural and leakage integrity conclusions
- There is a large population of known flaws examined each outage
- Flaws caused by this damage mechanism have successfully been in service since the mid-1980's
- Primary-to-secondary leakage is not present
- Statistical evaluations conclude that this damage mechanism is non-active

The qualification data represents TMI-1 flaws – The TMI-1 OTSG tubing qualification data represents the in steam generator degradation in terms of morphology, size and through wall dimension. Both the qualification data and indications remaining in service are ID initiated. The 1997 destructive examination of a TMI-1 tube with known ID volumetric degradation did not identify additional degradation beyond that identified with eddy current. Figure 24 below provides the measured axial and circumferential extent of "VOL" (ID IGA indications) and circumferential extent of "Circ" (circumferential) indications detected and sized during Outage 1R15. Figure 24 below is based on 995 ID volumetric indications and 110 circumferential indications detected during Outage 1R15. Only 3 of the ID volumetric indications measured >0.30" axial extent and 8 measured >0.30" circumferential extent. In fact, 86% of the ID volumetric indications measured ≤0.20" circumferential extent and 94% of the ID volumetric indications measured ≤0.20" axial extent. Of the circumferential indications only 3 exceeded 0.50" in circumferential extent. The qualification flaw dimensions are similar to these dimensions (see Table C). The qualification flaw data set included flaws from 20% through wall to 100% through wall (essentially the full spectrum of flaw depth).

Figure 24



In situ pressure testing of similar freespan degradation has supported structural and leakage integrity conclusions – TMI-1 has in situ pressure tested a large population of flaws. To date this includes more than 69 ID volumetric indications and 10 circumferential indications. The maximum tested ID volumetric indication axial and circumferential extents in situ pressure tested to date are 0.40" and 0.37" respectively. The maximum circumferential extent of a tested circumferential indication is 0.51". All of these ID indications were tested at locations below the kinetic expansion (more conservative test because the tubesheet ligament does not provide additional structural support). All of these indications demonstrated acceptable structural and leakage integrity. Based on results from Outage 1R15; the maximum ID volumetric indication axial and circumferential extents of indications remaining in service is 0.35" and 0.41" respectively and the maximum measured circumferential extent of circumferential indications remaining in service is 0.60". Based on the Outage 1R15 examination results, the prior in situ pressure tested flaw population strongly represents the remaining inservice population of kinetic expansion indications.

Table 5 provides summary data of the in situ pressure tests performed on TMI-1 flaws during Outages 12R (1997), 13R, (1999), and 14R (2001). This data was excerpted from the outage reports previously forwarded to the NRC (References 32, 35, and 36). [Note that TMI-1 changed its voltage normalization criteria between Outages 12R and 13R; therefore voltages between Outage 12R and later outages must be adjusted to make voltage comparisons.]

There is a large population of known flaws examined each outage – The planned initial sample of tubes to be examined in the kinetic expansion region is large (approximately 30,000 tubes each outage). This scope is100% percent of the in-service tube population. This large population assures that, even if there were a lower than expected probability of detection, new degradation would be evident in the examination results. This large population of known flaws assures that changes to flaw dimensions will be successfully identified.

Flaws caused by this damage mechanism have been in service since the middle 1980's – The kinetic expansion flaws are due to the sodium thiosulfate intrusion that occurred in the early 1980's. Tubes damaged by this mechanism have been in service since that time and no active growth has been shown based on statistical studies. Tubes damaged by this mechanism have demonstrated structural and leakage integrity since restart following repairs for this damage mechanism (about 18 calendar years of service) and the sodium thiosulfate inventory has been eliminated from the plant's design.

Primary-to-secondary leakage is not present – The TMI-1 steam generators have demonstrated acceptable primary-to-secondary leakage during recent operating cycles. This indicates that tubes damaged by the sodium thiosulfate intrusion continue to perform acceptably.

Statistical evaluations conclude that this damage mechanism is non-active – Detailed statistical evaluations referenced in this report have concluded that this damage mechanism is non-active. The statistical evaluations also provide evidence that the applied examination techniques are repeatable. This document requires that growth studies be continued in future examinations, with the results reported to the NRC.

In summary, all information provided in Section 4.1 of this report, when considered as a whole, provides strong evidence that the applied examination techniques and their related uncertainties have been demonstrated to be applicable and conservative for TMI-1.

4.2 Conservatism of Measured Depth Criterion

The 67% throughwall threshold for the leakage estimate is a very conservative criterion considering:

- the 33% TW eddy current accuracy (i.e., 100% minus 67%) was based on the results of the 1997 eddy current analysis with a 95% single tailed lower confidence level. A team of analysts was used for the study to evaluate error. In addition, a 1999 evaluation determined that 28% accuracy could have been used.

- a number of additional conservatisms are incorporated into the leakage assessment methodology. For example, volumetric indications are hypothesized to form both a circumferential crack and an axial crack, with the entire measured eddy current extents used to calculate expected accident leakage.

- the majority of the indications within the TMI kinetic expansions are ID volumetric IGA indications. In-situ pressure testing of ID volumetric IGA indications at TMI to date has not identified any indications that have demonstrated measurable leakage (i.e., leakage above detectable levels) at simulated normal operating or accident conditions. For example, 69 ID volumetric indications were in situ pressure tested, without leakage, during the plant's 1R14 refueling outage in 2001 (Reference 32).

The results of in situ pressure tests performed during recent refueling outages also provide some additional evidence that the depth estimates of TMI-1 steam generator tube flaws are conservative. For example, during the 1R14 Outage, seven TMI-1 tube indications whose estimated depth by Plus-Point was greater than 80% throughwall were insitu pressure tested (Reference 32). None of these seven indications leaked at a delta pressure equivalent to three times the delta pressure during normal plant operation (i.e., 3NODP). One of these seven indications, with an estimated depth of 97% throughwall, leaked at a rate of 0.014 gpm, a small leakrate, at a delta pressure of 6450 psi, approximately five times the delta pressure during normal plant operation. All seven of these indications had estimated depths greater than 67% throughwall and would have been assumed to leak at MSLB delta pressure, which is less than 3NODP delta pressure, under the kinetic expansion leakage criteria.

4.3 Evaluation of Kinetic Expansions with Indications

If any flaws are detected within a kinetic expansion, the eddy current analysts document the locations, measurements, and types of flaws within the expansions. Evaluation of the flaws with respect to the repair criteria, and leakage estimates, are performed by the plant's engineers.

Note that the expansion transition (i.e., below the ETL+0.00" reference point) is considered freespan for indication disposition purposes. The kinetic expansion transitions are treated as freespan tubing since they are not expanded against the tubesheet bore and do not benefit from any compressive residual stresses such as those present in the expansions. |

4.4 Repair Criteria Application

As described above, kinetic expansion evaluations are performed beginning at the ETL + 0.00" location to verify that sufficient defect-free lengths are present. Structural evaluations of the kinetic expansions require that a kinetic expansion be removed from service if insufficient defect-free length is identified over its examined length. That is, if a defect (or a combination of defects) is detected that exceeds the allowable circumferential extent acceptance criterion, or an insufficient axial length of defect-free expansion is present, the expansion is removed from service. The inspection of a kinetic expansion may proceed farther (i.e., higher) in the tubesheet if flaws detected during the course of the examination within that expansion are within the conservative structural acceptance criteria. Figure 2, below, provides a visual presentation of the "defect-free" concept for a kinetic expansion with two indications.

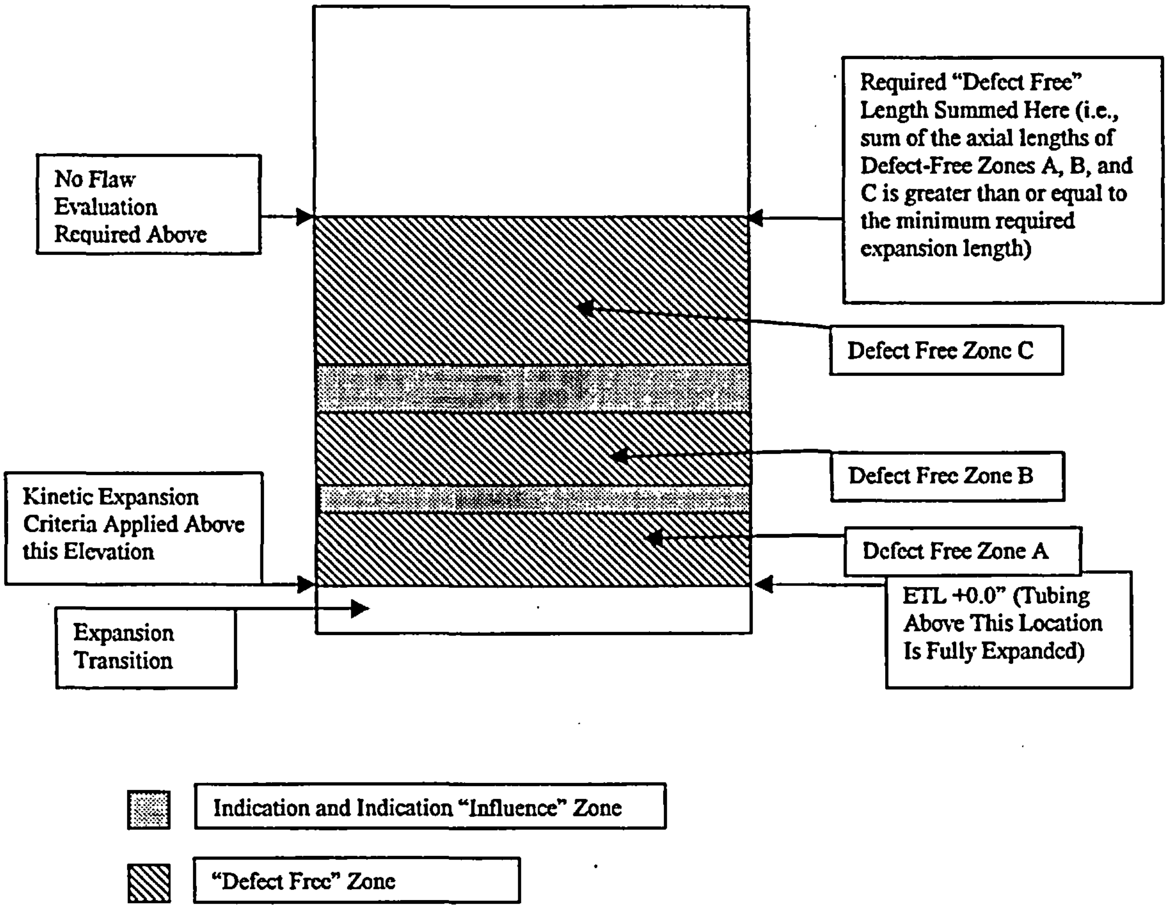
If a volumetric ID IGA flaw is detected in a kinetic expansion, the TMI-1 dispositioning criteria conservatively assume that the joint is not usable for structural purposes over the entire axial length of that flaw. For example, if a small volumetric flaw is detected with an eddy current-measured axial extent of 0.15", the entire 0.15" length of the expansion (360 degrees around the surface of the tube) is not credited in the evaluation of the joint structural integrity. In addition, no credit is taken for defect-free tubing along additional axial lengths of the joints adjacent to flaws (known as flaw "influence zones"). In summary, sufficient defect-free tubing must be detected to verify the integrity of an expansion during an inspection; no credit is taken for the length of the kinetic expansion where any defect is present, or where any defect might influence joint integrity.

Note that, beginning in the 1R16 refueling outage scheduled for the fall of 2005, AmerGen will plug all tubes with circumferential flaw indications in their kinetic expansion's required length upon detection.

While the kinetic expansion structural dispositioning criteria are very conservative, there is no requirement that the defect-free joint length be "continuous." The kinetic expansions are flaw tolerant. (Burst is precluded due to the presence of the tubesheet; residual compressive stresses are present; bending stresses and vibration are limited; secondary side loose parts are prevented from impacting the tubing.) Small defects do not influence the reliability of the kinetically expanded joints. For example, a small volumetric ID IGA pit on the surface of a kinetic expansion will not impact the ability of defect-free tubing, located above or below that pit, to maintain the structural requirements of the joint (e.g., no tube parting, no joint pullout). Outside of the flaw influence zones a small ID-initiated axial crack present along the length of a kinetic expansion would not adversely affect the structural integrity of defect-free tubing located above or below that crack. From a structural standpoint, so long as no single flaw is present with circumferential extent greater than 0.52", or combination of flaws is present with a circumferential extent greater than 0.64", the defect-free tubing located above or below the flaw is an integral part of the kinetic expansion joint. (If these circumferential extent values are exceeded prior to the required defect-free length being observed, the kinetic expansion is repaired, since the tube, conservatively assuming 100% throughwall degradation, could theoretically be parted under calculated accident-induced loads.) The expansion evaluations only "move higher into the tubesheet" if the examination data is available, and the repair criteria are not exceeded. The technical basis for this continued inspection (i.e., higher in the tubesheet) is provided in the finite element analyses of Reference 24.

FIGURE 2
"Defect Free" Concept

(Inside Surface of a Hypothetical Kinetic Expansion "Flattened" for this Sketch)
---Not to Scale---



5.0 LEAKAGE ASSESSMENT METHODOLOGY

5.1 Introduction and Background

Primary-to-secondary leakage during an accident must not degrade the ability to provide adequate core cooling capacity nor cause unacceptable or unanalyzed radiological consequences. The kinetic expansion inspection criteria provide assurance of joint structural integrity to the ends that joint failure will not occur either by slipping or by tube parting. Each of these failure modes has as a theoretical consequence the introduction of primary-to-secondary leakage.

Theoretically, through-wall defects that may be present in the kinetic expansion region may leak when subjected to MSLB conditions, even if these defects are not large enough to create a tube slipping or parting concern. The hypothetical MSLB axial loads and differential pressures could cause defects to open and provide a less restrictive leakpath than that provided by the tube-to-tubesheet joint during normal operation.

Primary-to-secondary leakage from the expansions is expected to increase during a postulated MSLB. The joint was originally qualified as leak-limiting and not leak-tight. However, in order to address even the possibility of increased primary-to-secondary leakage due to defects in the joint, a number of very conservative assumptions have been made in the leakage assessment methodology.

Defects that are judged to be through-wall, or near through-wall, by the inspection techniques are included in the primary-to-secondary leakage evaluation. While the analysis model for kinetic expansion structural evaluation assumed 100% through-wall, the analysis of accident-induced leakage utilizes through-wall depth information provided by the ECT.

In addition, some potential defects could be located at elevations where contact pressure between the expanded tube and the tubesheet bore remains, albeit reduced, during the accident. The presence of contact pressure considerably reduces leakage. The analysis model results showed that, for tubes that are not affected by tubesheet bowing (i.e., peripheral tubes), no part of the minimum required intact expansion loses residual contact pressure during the accident. Tubes that are affected by tubesheet bowing (i.e., tubes near the center of the bundle and mid-radius tubes) will locally lose contact pressure during the MSLB event. As a result, the radial location of a tube within the bundle affects the estimation of leakage from flaws found in its kinetic expansion.

"As found" and "as left" leakage estimates for the kinetic expansions are calculated after each inspection. Because no flaw growth has previously been detected, and no growth is expected, it is necessary only to consider defects found in the joint that are dispositioned as acceptable and left in service as potential sources of future primary-to-secondary leakage. Defects that are unacceptable are repaired by plugging.

The purpose of this section is to describe the methodology that is used to evaluate the total primary-to-secondary leakage that may occur during a guillotine rupture of a main steamline as a result of assumed through-wall (>67% throughwall as measured by eddy current) cracks in the kinetic expansion region of the OTSG tubes. In Reference 17 it was demonstrated that the limiting accident scenario which results in the largest tube loads is that which results in a large SG tube-to-shell temperature differential (ΔT). The most restrictive limits were determined to be when the tubes are colder than the steam generator shell.

In order to establish the total primary-to-secondary leakage that would be acceptable during the MSLB event from assumed through-wall cracks in the kinetic expansion region, a calculation determined the maximum leakage that would meet the offsite dose criteria of 10% of 10CFR100 limits for the 2 hour Exclusion Area Boundary (EAB) and 30 day Low Population Zone (LPZ) (Reference 2). The revised dose consequences for the FSAR MSLB analysis were submitted to the NRC for approval (Reference 3). The results were as follows:

1. Integrated Primary Coolant Leakage @ 2 hrs (gallons @ 579 F) = 3228.
2. Total Integrated Primary Coolant Leakage (gallons @ 579 F) = 9960

The methodology used to estimate leakage from the kinetic expansion indications, and to determine if these leakage limits are met, is discussed in the following sections. Section 5.2 provides an overview of the methodology and the subsequent sections provide additional detail.

5.2 Overview of Methodology

As described in Section 2.2, the structural criteria utilized to disposition the kinetic expansion indications were based on Reference 17, a Main Steam Line Break analysis performed in 1980. The resulting peak axial, tensile load on the steam generator tubes from this analysis was 3140 lbs.

In order to evaluate theoretical accident-induced leakage from the kinetic expansions new TMI-1 plant-specific MSLB analyses were completed in 1997. The Reference 17 1980 MSLB analysis was updated for the following reasons:

- The 1980 analysis was a 'generic' analysis for the B&W Owners Group (BWOG) plants (i.e., the analysis was not TMI-1-specific).
- The 1980 analysis assumed an EFW flow of 1650 gpm with operator action to isolate EFW to the affected OTSG after 20 minutes. The TMI EFW design includes cavitating venturies and a safety grade level control system. The response of the TMI-1 EFW system to a MSLB would be to limit break flow to a maximum of about 570 gpm to the affected (depressurized) OTSG and to control level at 25 inches in the unaffected OTSG. The difference in EFW flow to the affected OTSG of 1650 gpm vs. 570 gpm has a very significant effect on the cooldown of the steam generator tubing.
- The 1997 analysis assumed operator action to terminate EFW after 10 minutes. This is consistent with the plant's licensing basis FSAR MSLB analyses and emergency procedures. Since the volumetric flowrate of EFW used in the 1997 analysis (590 gpm was conservatively used) is considerably less than that of the 1980 analysis (1650 gpm), there would only be a small effect on the 1997 results if the EFW isolation time was changed from 10 minutes to 20 minutes. (The difference in termination times would be very significant for the 1980 analyses since a very large EFW flowrate was assumed.)
- The 1997 analysis was more conservative than the 1980 analysis regarding reactor vessel mixing.
- The 1980 analysis assumed a 36-inch break at the OTSG nozzle to bound all of the BWOG plants. For TMI-1, this assumption was conservative because the plant has four 24-inch steam lines that only connect downstream of the Main Steam Isolation Valves, at the turbine chest. This difference has the most pronounced effect during the initial blowdown of the OTSG. (After the initial blowdown, the cooldown is dominated by the amount of EFW that is boiled out of the OTSG and would not be any different for a 24-inch or 36-inch break.) The 1997 analysis assumed rupture of a 24-inch TMI-1 steam line.

The computer codes used for the 1997 analysis differed from those used for the 1980 analyses. The 1997 analyses used RETRAN for the short term analysis and GOTHIC for the long-term analysis. The 1980 analyses used TRAP2.

The following sections describe the 1997 MSLB analyses performed to evaluate kinetic expansion tube leakage in more detail.

The methodology used for the MSLB-induced leakage analysis performed in 1997 involved the following activities that are depicted in Figure 3:

A. Develop the time varying thermal hydraulic (T-H) information from the design basis Main SteamLine Break (MSLB) event analysis.

B. Determine the OTSG tube tensile and differential pressure loads from the T-H data. The loads vary as a function of time throughout the transient and as a function of radial distance from the center of the steam generator to the peripheral tube.

C. Calculate the theoretical crack opening area (COA) separately for postulated circumferential and axial cracks. The COA varies with the applied load, crack orientation, and crack length.

D. Determine the theoretical leakage flow as a function of the crack area. The total mass released from the crack is obtained by integrating the leakage flow over the first 2 hours and over the entire transient interval.

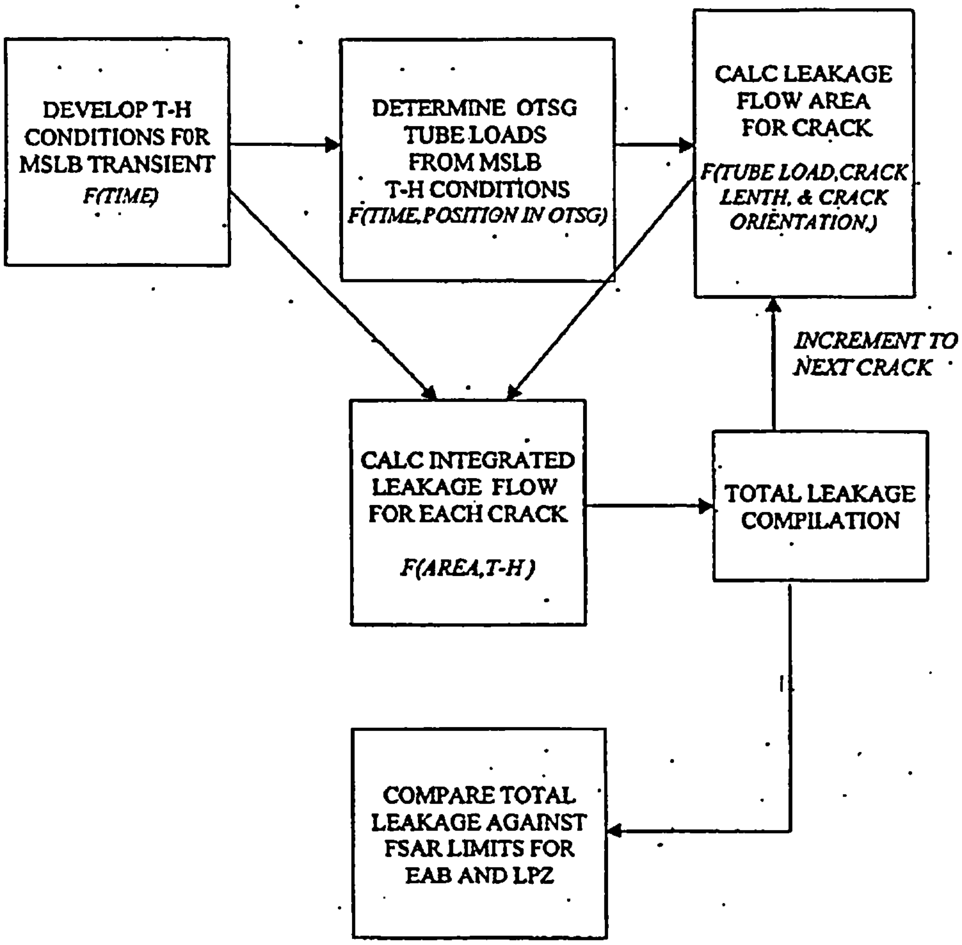
E. The integrated leakage flow for each of the identified cracks (based on crack size and radial position within the tube bundle) is summed and the total is compared against the leakage limits specified in the offsite dose calculation (Reference 2) based upon 10% of the 10CFR100 limits.

If the calculated leakage exceeds the limits established in Reference 3, then a decision will be made as to which tube(s) will be repaired (i.e., the leakage contribution from the repaired tube(s) can be eliminated from the total to meet the allowed as-left leakage limits.)

Additional details and references regarding each of the activities discussed above are provided in the sections which follow.

FIGURE 3

LEAKAGE EVALUATION METHODOLOGY OVERVIEW



5.3 Main Steam Line Break Analysis

5.3.1 Overview

A conservative plant MSLB analysis was used to generate the transient thermal hydraulic parameters that were needed as input to define the OTSG tube loads and to calculate the leakage from each kinetic expansion flaw.

The transient analysis was accomplished in two phases: a short term phase and a long term phase. The short term phase duration was 10 minutes (600 sec) and utilized the transient systems analysis code RETRAN-02, Mod 5 (Reference 5). The long term phase thermal hydraulic conditions were developed by applying assumed operator actions, based upon TMI-1 Anticipated Transient Procedures (ATPs), to recover from the event and to calculate the OTSG shell metal cooldown rate in order to develop a technical basis for cooling down to DHR conditions without violating tube-to-shell differential temperature limits. The long-term analysis began at 10 minutes and extended to the end of the transient (approximately 24 hours). Details of these evaluations are provided below.

5.3.2 Short Term Analysis

5.3.2.1 Basis of Duration

As indicated above, this portion of the MSLB thermal hydraulic analysis included the first 10 minutes (600 sec) of the event. There were multiple reasons for choosing this duration. First, this portion of the transient is characterized by the most complicated and dynamically changing thermal hydraulic attributes. The affected OTSG is blowing down, the Heat Sink Protection System initiates a closure of the Main Feed Water (MFW) control valve and the MFW block valve and also initiates Emergency Feed Water (EFW) on low OTSG level. The RCS is depressurizing and cooling down, the pressurizer is emptying and refilling, an RPS trip occurs, ESAS is initiated, etc. Because of the complexity of this portion of the transient, a relatively sophisticated systems analysis code (RETRAN 02, Mod 5) was used to establish the thermal hydraulic parameters during this period (Reference 5).

Another reason for this duration is that no operator recovery actions were assumed to take place until after 10 minutes had passed. This is a licensing basis for TMI-1.

Following the first 10 minutes, credit for operator actions is permitted.

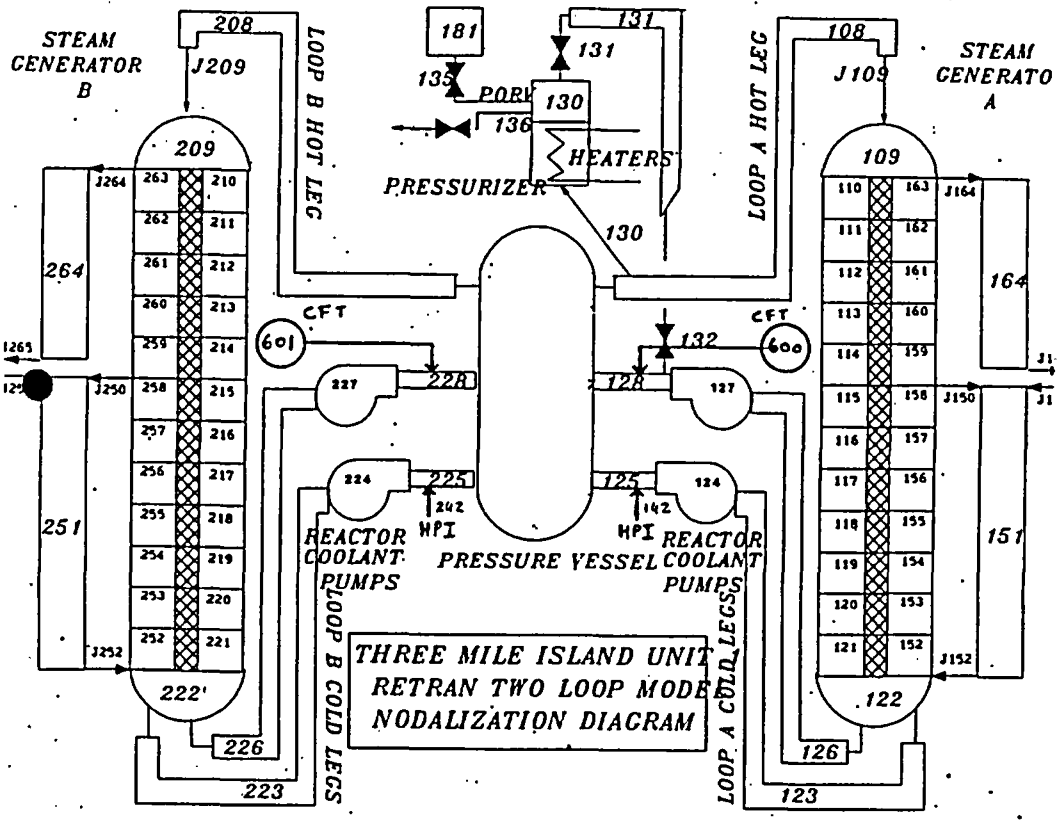
The peak axial, tensile tube loads for this event also occur within the first 10 minutes and the thermal hydraulic conditions at the end of this duration are important since they represent the end of the peak load period and the transition to reduced OTSG tube loads.

In this manner, the first 10 minutes of the MSLB analysis set the stage for the entire leakage determination effort. At the end of this period, the system is not characterized by rapid changes in thermal hydraulic conditions and is in transition to the recovery from the event.

5.3.2.2 Methodology

The RETRAN-02 MOD005 computer code and a TMI plant model were used to perform this analysis (Reference 4). The TMI RETRAN model has been extensively benchmarked against plant data and previously approved licensing codes. The benchmarks demonstrate the adequacy of the TMI RETRAN model for performing safety analysis. The TMI RETRAN model has also been approved by the NRC for referencing in licensing applications (Reference 5). The TMI Base deck (Reference 6) as shown in Figure 4 was used for this analysis.

FIGURE 4 – Three Mile Island Unit 1 RETRAN Two Loop Model Nodalization Diagram



5.3.2.3 Assumptions

The analysis assumptions and initial conditions as discussed below were chosen to provide a conservative RCS overcooling and pressure history for the MSLB event and the resulting tube loads.

5.3.2.3.1 Initial Conditions

The reactor was assumed to be operating at rated power prior to the hypothetical MSLB accident (2568 MWt). The initial pressurizer liquid level was set at 220 temperature-compensated inches, which is the typical hot full power (HFP) pressurizer level. The initial RCS pressure was 2170 psia in the hot leg, which is the normal operating value. The TMI design basis MSLB assumes that offsite power is available and that was the assumption in this analysis. The effect of high RCS loop flow is to minimize the OTSG tube average temperature during the initial phase of the event. Thus, OTSG tube axial loads are maximized.

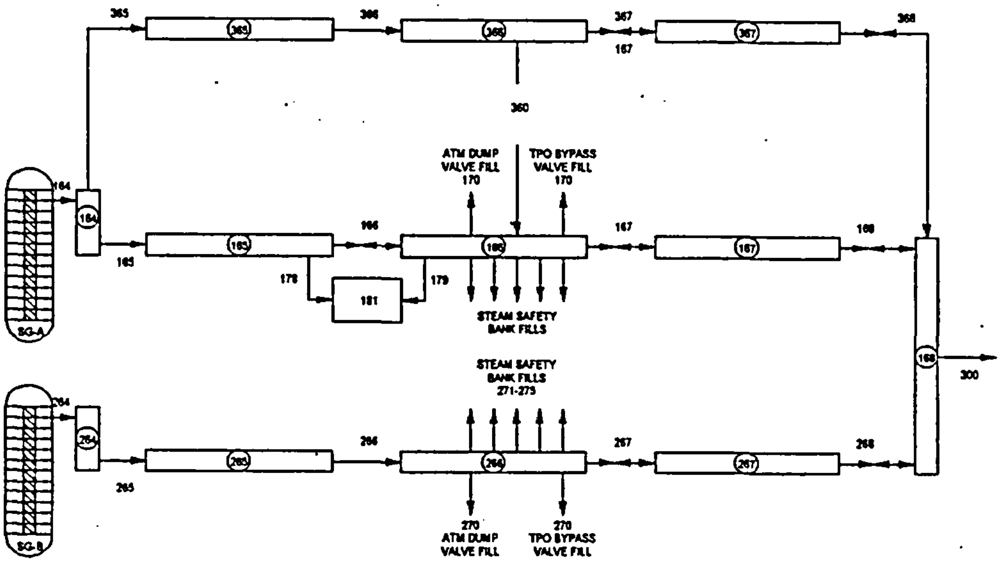
5.3.2.3.2 Break Modeling

The initiating event was assumed to be a double-ended rupture of a 24-inch steam line on one steam generator. This is the largest possible break which results in the maximum cooldown rate. The faulted steam generator steam line was nodalized as shown in Figure 5, so as to model each steamline individually. The flow area of the two break junctions were consistent with the 24-inch steam line piping.

A Moody choking model was used for these break junctions with a contraction coefficient of 1.0 to maximize break flow rate.

The break was assumed to occur in the plant's Intermediate Building upstream of the Main Steam Isolation Valve (MSIV). This is an appropriate break location because it results in a ground level release of coolant activity.

FIGURE 5-Break Nodalization



5.3.2.3.3 Reactor Vessel Mixing

The amount of mixing that was assumed to occur within the reactor vessel was a ratio of the difference in hot leg temperatures to the difference in cold leg temperatures:

$$\text{RATIO} = \frac{T_{HOT}(\text{unfaulted}) - T_{HOT}(\text{faulted})}{T_{COLD}(\text{unfaulted}) - T_{COLD}(\text{faulted})}$$

A value of RATIO = 0.0 implies perfect mixing while RATIO = 1.0 implies no mixing. For the purposes of this analysis, a target value of RATIO = 0.5 was chosen to conservatively bound the analyses at an upper value.

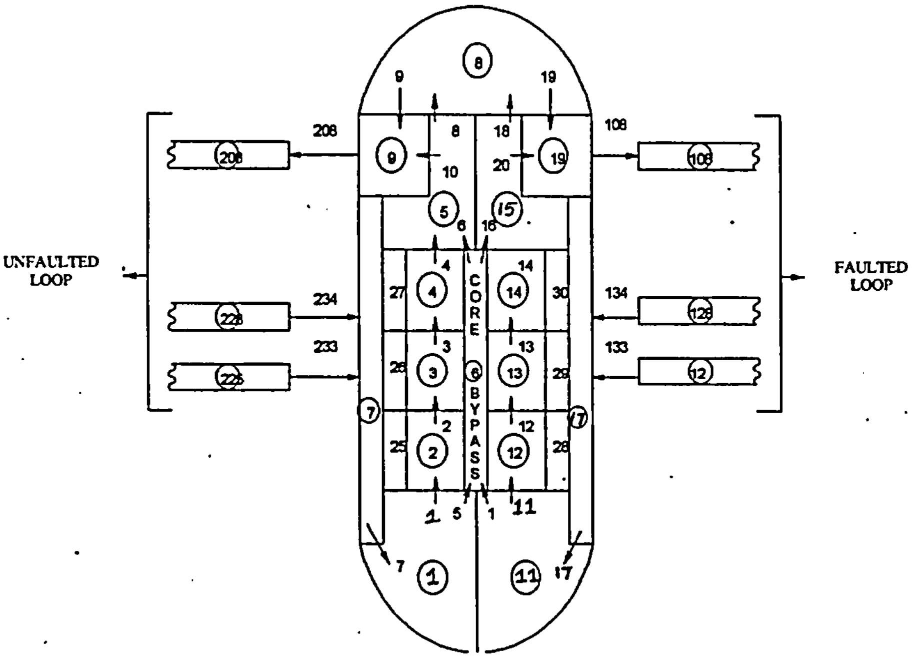
To simulate this mixing in RETRAN, the reactor vessel was modified to include two equal parallel flow paths by splitting the downcomer, the lower plenum, the core, and the upper plenum as shown in Figure 6. For the most part, these parallel flow paths behave independently, with the exception of common connections with the bypass and upper head volumes. These common flow paths keep the loop pressures in balance but contribute little to mixing of loop flows.

5.3.2.3.4 Reactor Kinetics Parameters

To minimize the power increase response to the core temperature decrease, the moderator temperature coefficient (MTC) was set to a value of zero. This was conservative since it will not increase the power prior to trip and results in lower RCS temperatures. Post trip, the MTC determines the extent to which the core energy generation is increased by sub-critical multiplication. An MTC of zero will assure that the post trip reduction in temperature will not lead to increases in power generation above the normal decay heat power. The absence of a return to power after the trip results in a greater cooldown, and therefore a larger axial load on the steam generator tubes.

Decay heat was based on the ANS5.1 1979 decay heat standard. In order to maximize RCS cooldown following reactor trip, a 0.95 multiplier on decay heat was used. The 5% reduction was chosen since it is greater than a 2(sigma) uncertainty for thermal fission of U^{235} under equilibrium operating conditions.

FIGURE 6
RPV Nodalization



5.3.2.3.5 Reactor Trip

With an MTC of zero, the reactor power will not increase with the decrease in moderator temperature, so the reactor will trip on low RC pressure. Since this analysis was primarily interested in steam generator tube temperature, a trip setpoint of 1900 psig plus a 30 psi error was used. This limits the amount of energy the core model generates, resulting in a lower primary system temperature during the event. It should be noted that this setpoint results in an earlier trip, which is conservative for tube temperature calculations. For the steam line break event, the trip setpoint will be reached rapidly due to the dramatic overcooling which would occur.

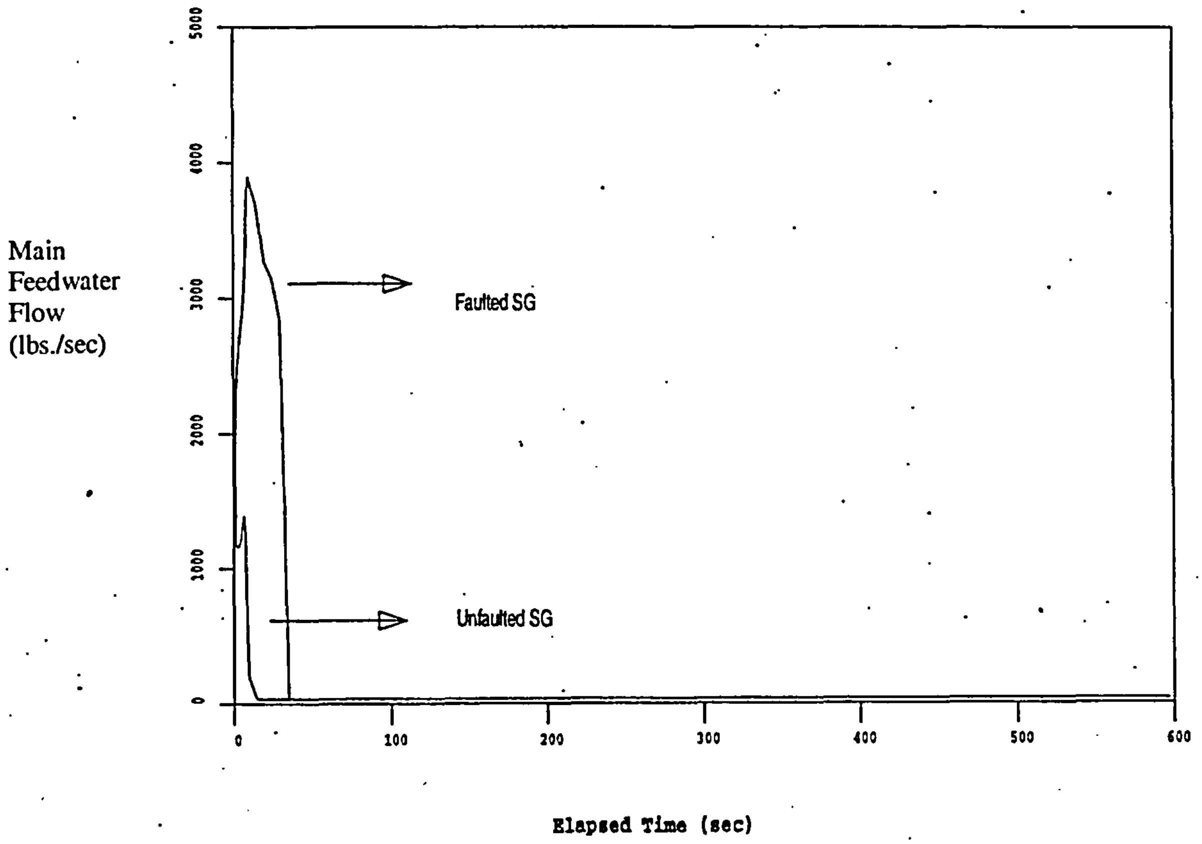
5.3.2.3.6 Initial Steam Generator Mass

The initial steam generator inventory provides a measure of the heat removal capability of the secondary system. For a steamline break, a larger initial secondary system inventory in the steam generator associated with the break will lead to a higher integrated heat removal. The larger the heat removal, the lower the resultant reactor coolant temperature. The OTSG design has the maximum inventory at full power conditions. Thus the event should start from full power to maximize the heat removal capability of the steam generator. The steam generator inventory can increase if fouling of the SG tube bundle region occurs. The inventory predicted for full power and fouled conditions has been conservatively determined to be approximately 55,000 pounds per SG, and this value was used in the model. In addition, the mass of feedwater between the isolation valves and the affected steam generator, which was calculated to be 35,500 lbm, was also modeled and available to cool the affected steam generator.

5.3.2.3.7 Main Feedwater and Emergency Feedwater Flow

The MSLB accident in this calculation assumed the worst single failure, which is the failure of the feedwater regulating valve to close on the affected generator. This maximizes the overcooling of the event by maximizing the main feedwater

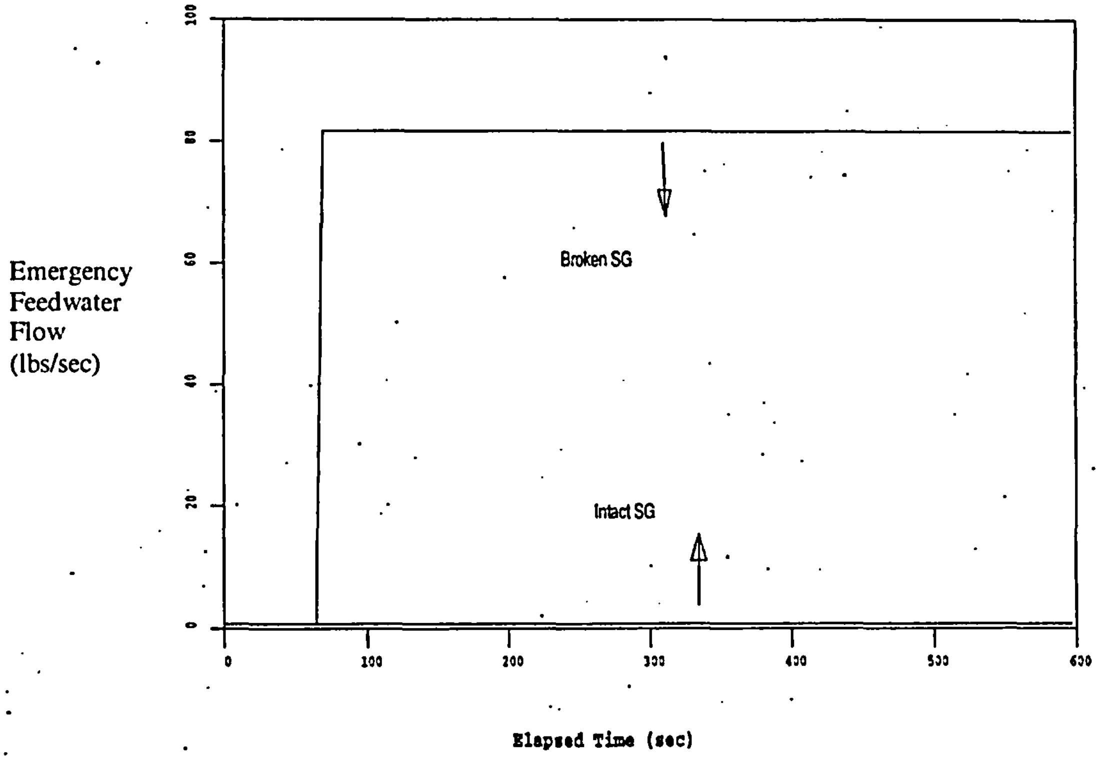
FIGURE 7
Main FeedWater Flow Rates



(MFW) flow to the affected generator as a result of the preferential feeding to the broken, depressurized, side. Feedwater flow to the affected steam generator is shown on Figure 7 above. MFW flow was terminated to the affected steam generator after the MFW block valve closes in about 30 seconds after a low SG pressure of 600 psig is reached.

For this transient, the Emergency Feed Water (EFW) system would be initiated by a low OTSG level signal. The OTSG low level indication signal of 10 inches is measured by the startup range instruments. The setpoint is calculated in the RETRAN model as the collapsed liquid level in the tube region. (Zero inches indicated level is 6 inches above the upper face of lower tube sheet.) EFW controls level at 25 inches indicated. Due to the continued MFW flow to the broken SG until the MFW block valve closes, the OTSG level does not drop below the low level initiation signal until about 67 seconds after the start of the transient.

FIGURE 8
Emergency Feedwater Flow Rates



The start of the motor driven EFW pumps (MDP) is delayed by 5 seconds after the initiation signal and a coastup time of 10 seconds. Subsequent to the EFW initiation signal, the steam admission valve to the turbine driven pump (TDP), MS-V13A, receives an immediate open signal and is fully open in 24 seconds. Turbine testing shows the TDPs are at full speed in 11 seconds after the steam admission valves are full open. An additional 8 seconds for flow coastup is typically modeled resulting in TDP flow delivery at 43 seconds.

For this analysis, 2 MDPs and TDP were conservatively assumed to deliver flow instantaneously to the steam generator following an EFW initiation signal (See Figure 8 above).

5.3.2.3.8 High Pressure Injection

The plant's high pressure injection (HPI) system is actuated during the cooldown period following a large area steam line break. The system supplies borated water to the RCS to recover the RCS shrink and to provide core cooling if necessary, and to increase the core shutdown margin. Boron addition to the reactor coolant, during the controlled cooling to atmospheric pressure, will prevent criticality at lower temperatures. For this analysis, no credit was taken for boron addition resulting from HPI actuation, since the BOL kinetics and best-estimate rod worth will result in keeping the core shutdown. To minimize the primary system temperature, and thus tube temperatures, full HPI was initiated in the model on a signal of 1600 psig plus a 30 psi error at the pressure measurement tap location. This is conservative, since a rapid actuation of HPI will maximize the overcooling.

5.3.2.3.9 Steam Generator Downcomer Modeling

The RCS cooldown was maximized by minimizing the amount of liquid carried over from the steam generator out of the break. To minimize the liquid carryover, the downcomer was modeled with a single bubble rise volume and a large bubble velocity (1E6 ft/sec) which produced less liquid carryover.

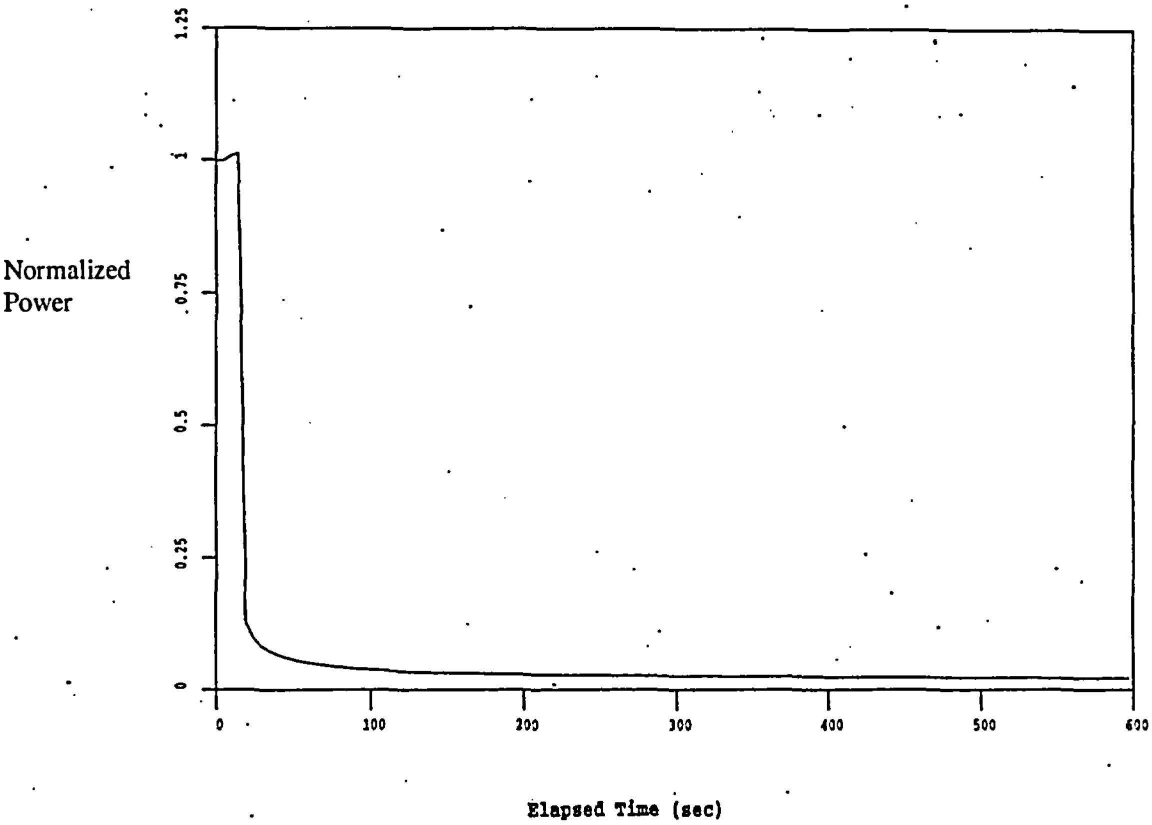
5.3.2.4 Summary of Results

5.3.2.4.1 Power Results

The results of the MSLB analysis for the first 10 minutes (600 sec) are provided in this section. The reactor scram occurs on low reactor pressure in about 10 seconds as shown in Figure 9. This reflects a trip setpoint of 1900 psig plus a 30 psi error.

The reactor power in Figure 9 also indicates that there is no return to power as a result of the absence of a negative moderator temperature feedback. This is a conservative result with respect to the cooldown.

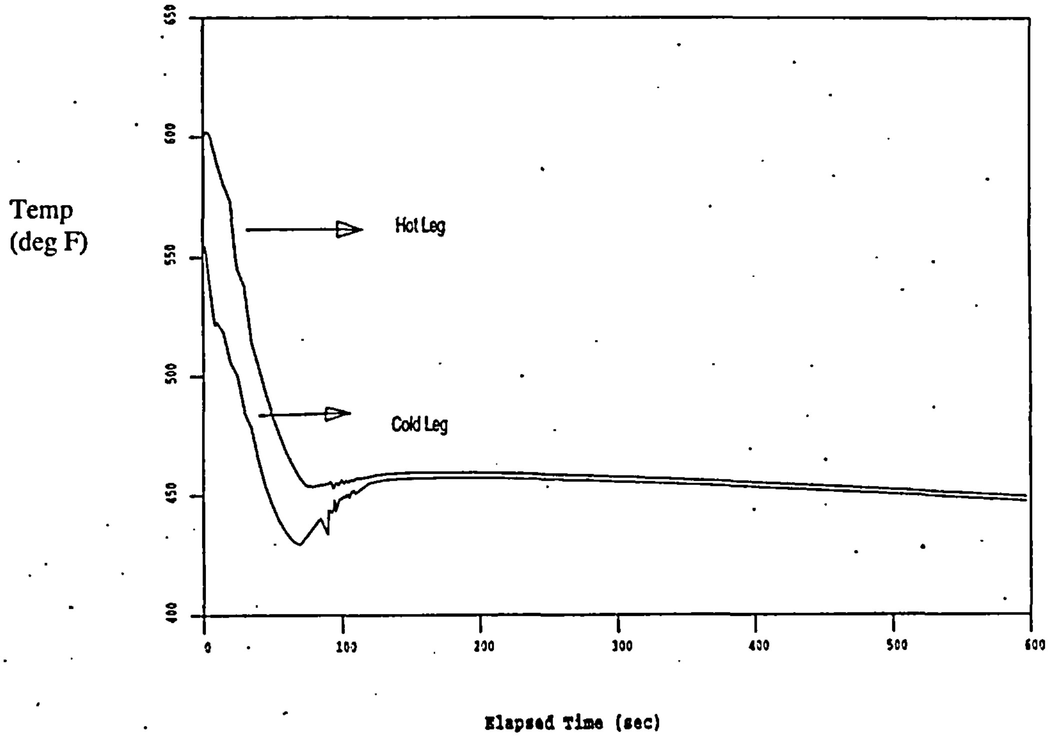
FIGURE 9
Reactor Power



5.3.2.4.2 Loop Temperature Results

The hot and cold leg temperature responses to the MSLB are shown in Figure 10. A rapid overcooling results from the event with the cold leg temperature reaching about 435 degrees F about 70 seconds after the break. After the OTSG blowdown is completed, the primary to secondary heat transfer is reduced and the cold leg and hot leg temperatures are essentially the same. The temperature is about 450 degrees F at this point and is maintained for the duration of this portion of the event. The final temperature for this phase of the event reflects the fact that the intact OTSG acts as a heat source as discussed below.

FIGURE 10
RCS Faulted Loop Temperatures



5.3.2.4.3 OTSG Pressure Results

The pressure response results for both the faulted and unfaulted OTSG are shown in Figure 11. The faulted OTSG is fully depressurized in about 100 seconds.

The unfaulted OTSG responds initially in a normal post trip manner, increasing to the MSSV setpoint, but is slowly reduced in pressure as a result of reverse heat transfer to the RCS.

5.3.2.4.4 RCS Pressure Results

The RCS pressure results are depicted in Figure 12 and reflect a rapid drop in pressure due to the initial cooldown. The decrease in pressure results in a reactor trip, ESAS actuation, and a small influx of Core Flood Tank flow. After the cooldown has stabilized, the RCS repressurizes in response to HPI injection flow refilling the pressurizer. At the end of 10 minutes, the RCS subcooling margin is less than 100 degrees F.

FIGURE 11
Steam Generator Pressure Response

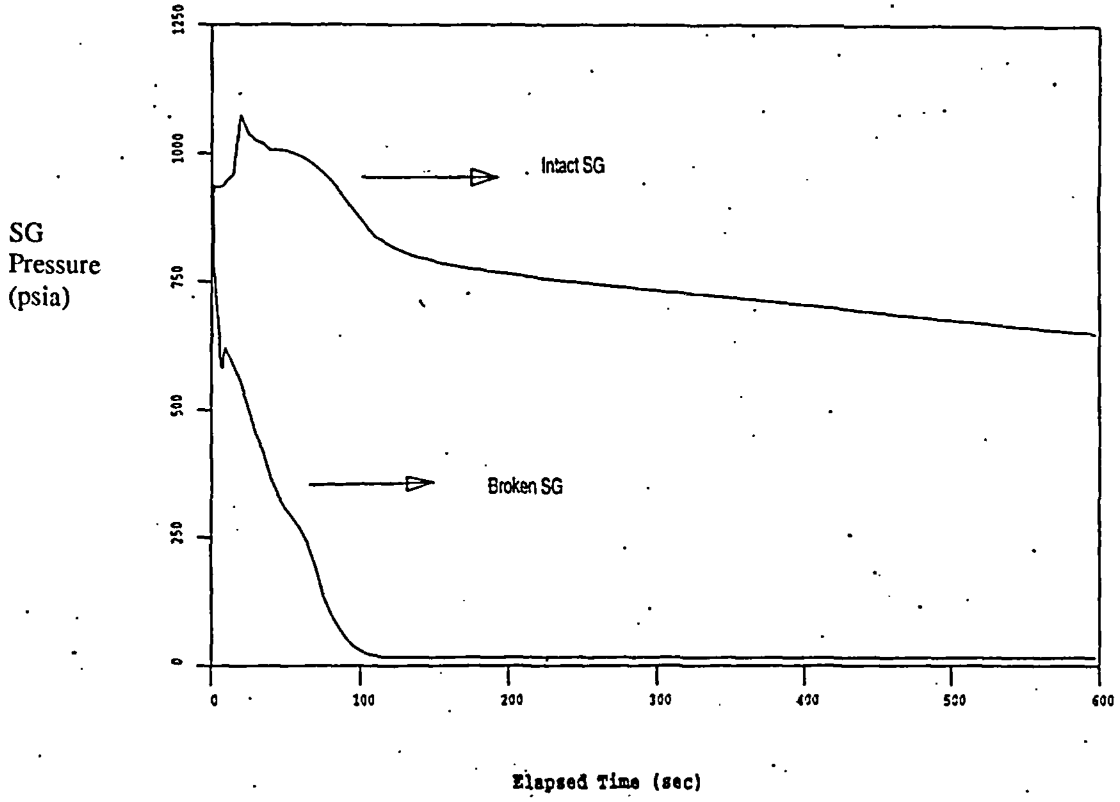
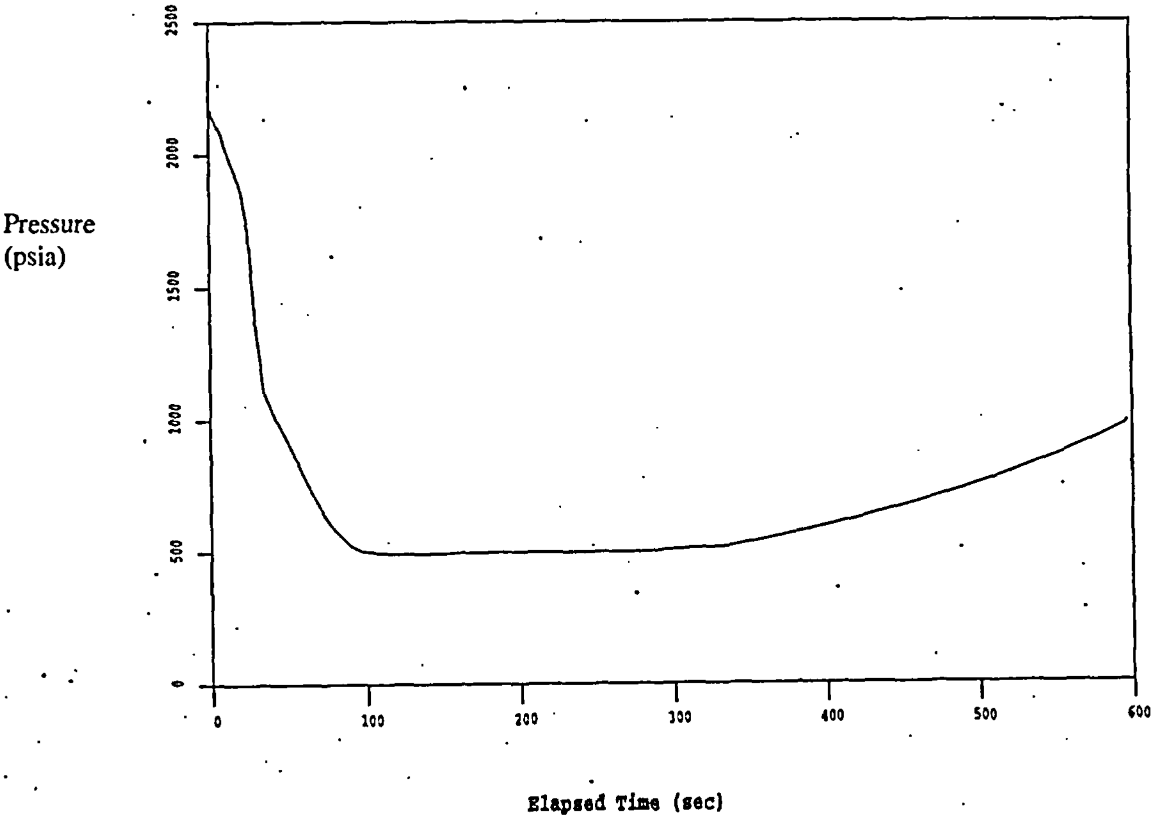


FIGURE 12
Pressurizer Pressure



5.3.3 Long Term Analysis

5.3.3.1 Approach

Following the first ten minutes, it was assumed that operator action would be taken to terminate EFW to the affected OTSG and to begin a controlled cooldown and depressurization to DHR conditions using the unaffected OTSG. The limitations imposed by the various cooldown P-T limits and tube-to-shell differential temperature limits would be observed. The following assumptions reflected this approach.

5.3.3.2 Assumptions

1. The operator will control the NSSS such that the tube-to-shell differential temperature tensile limit of -70°F (tube temp minus shell temp) is observed (Reference 9).

2. RCS temperature will not be allowed to increase to reduce the tube-to-shell differential temperature (Reference 10). Procedure guidance has the operator minimize the RCS reheat following an overcooling event. Increasing RCS temperature for this analysis would reduce (i.e., make less negative) the tube-to-shell differential temperature and reduce the tube load. Reduced tube load would lead to reduced tube leakage.

3. RCS pressure will be maintained at a subcooled margin of 75°F. Reference 10 directs the operator to minimize the RCS pressure increase following an overcooling event. The minimum SCM limit is 25°F (Reference 9). An RCS pressure control value of 75°F SCM is reasonable. Higher RCS pressure leads to greater tube leakage.

4. As RCS temperature and pressure decrease, additional pressure limitations are established. The operator will maintain RCS pressure in excess of the emergency RCP NPSH limit (Reference 9). A margin of 50 psi is considered to be adequate. A high margin maintains RCS pressure high, increasing tube leakage. However, a large margin to the NPSH curve could prevent initiation of DHR. Therefore, a margin of 50 psi is reasonable. Additionally, the operators will maintain RCS pressure such that the minimum RCP seal differential pressure (275 psid) is maintained (Reference 12). Seal return can be dumped to the sump instead of being sent to the Makeup Tank. A margin of 25 psig is maintained to the limit of 275 psid. Therefore, a minimum RCS pressure of 300 psig is established.

5. The transient after 600 seconds is quasi-steady-state. Therefore, large time steps could be used in the model. A time step size of 600 seconds was chosen as reasonable.

6. Operator action is assumed to take place at 10 minutes. The following actions would be taken by the operator for a MSLB event (Reference 9 and 10):

    a. Terminate EFW to the broken OTSG (MFW is already isolated).

    b. Control/terminate HPI to the RCS to control RCS pressure.

    c. Adjust the TBV on the Unbroken OTSG to prevent RCS temperature from increasing.

5.3.3.3 OTSG Cooldown Analysis

As indicated above, the operator will control the NSSS such that the tube-to-shell differential temperature tensile limit of -70°F is observed. The maximum possible cooldown rate that meets this criterion is established by the rate at which the affected OTSG shell cools down.

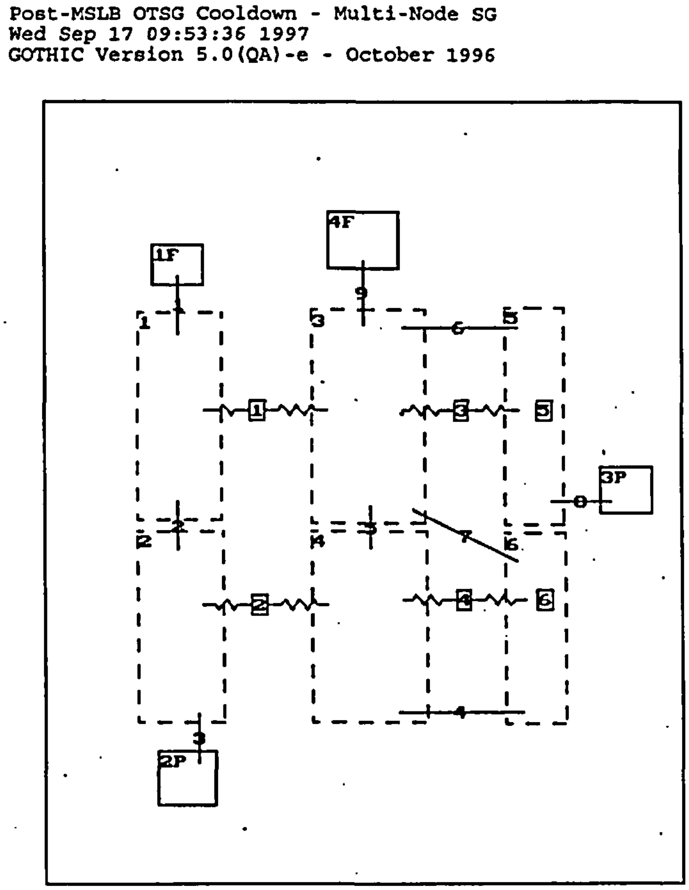
To determine the shell cooldown rate, the GOTHIC computer code, version 5.0e, was used with a six (6) volume model as shown in Figure 13 (Reference 11). Two volumes (volumes 1 and 2) represented the primary (tube) side of the OTSG, two volumes

(volumes 3 and 4) represented the secondary (steam side) side of the OTSG shell inside the shroud, and two volumes (volumes 5 and 6) represented the secondary side of the OTSG outside the shroud (i.e., between the shroud and the shell metal). The volumes were divided to correlate with the division of the downcomer region into upper downcomer and lower downcomer regions.

The analysis began at 10 minutes and allowed the RCS to cool down as the shell cooled down to preserve the –70 deg limit and thus account for the impact of the cooler RCS tube temperature on the cooldown rate of the shell.

The shell cooldown rate results from this analysis are shown in Figure 14 below.

FIGURE 13
GOTHIC Model For Shell Cooldown Analysis



```
Post-MSLB OTSG Cooldown - Multi-Node SG
Wed Sep 17 09:53:36 1997
GOTHIC Version 5.0(QA)-e - October 1996
```

5.3.3.4 Results

Figures 14 and 15 below provide the results of the long term analysis. The figures also include data from the first 600 seconds of the analyzed event as well. The results reflect the application of the criteria described above. The average shell temperature is a weighted average of the upper and lower shell temperatures at the outside metal surface of the OTSG. The RCS temperature is the average of the hot and cold leg temperatures for the affected OTSG.

FIGURE 14

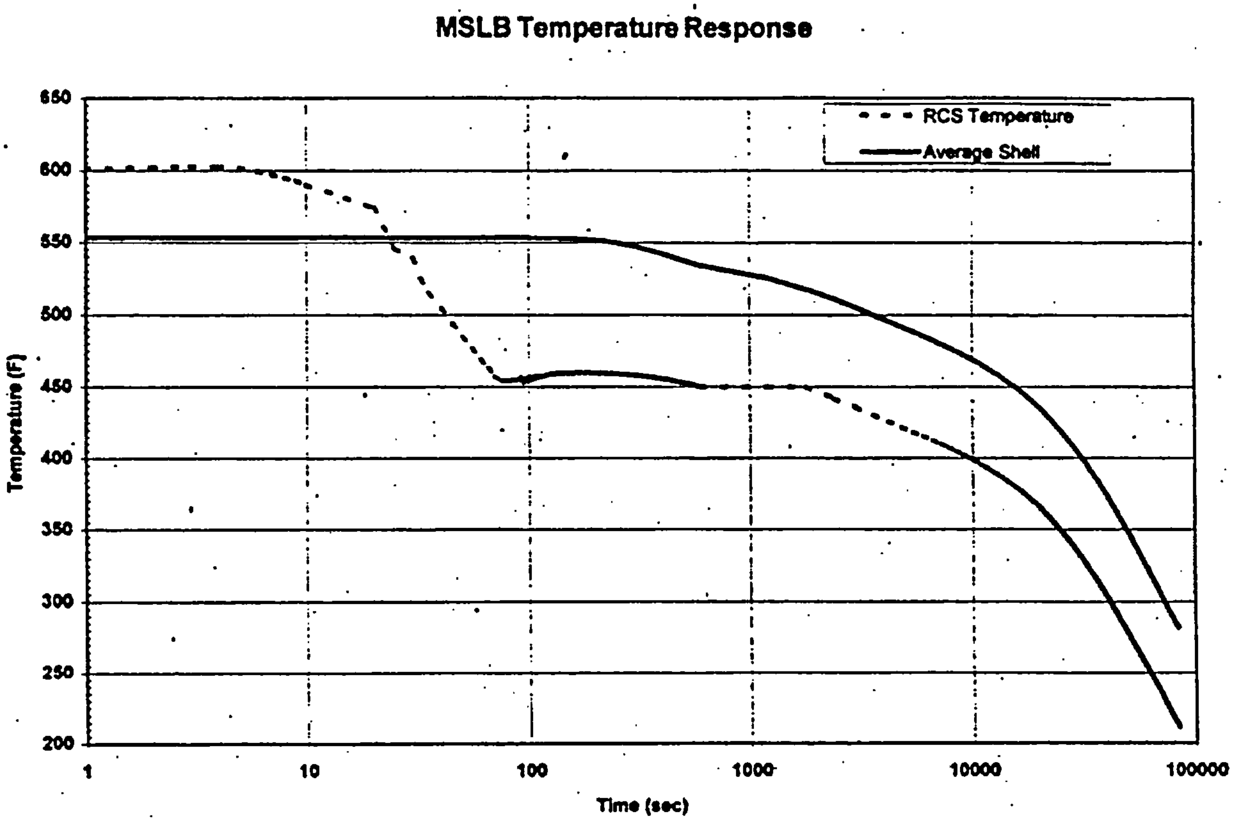
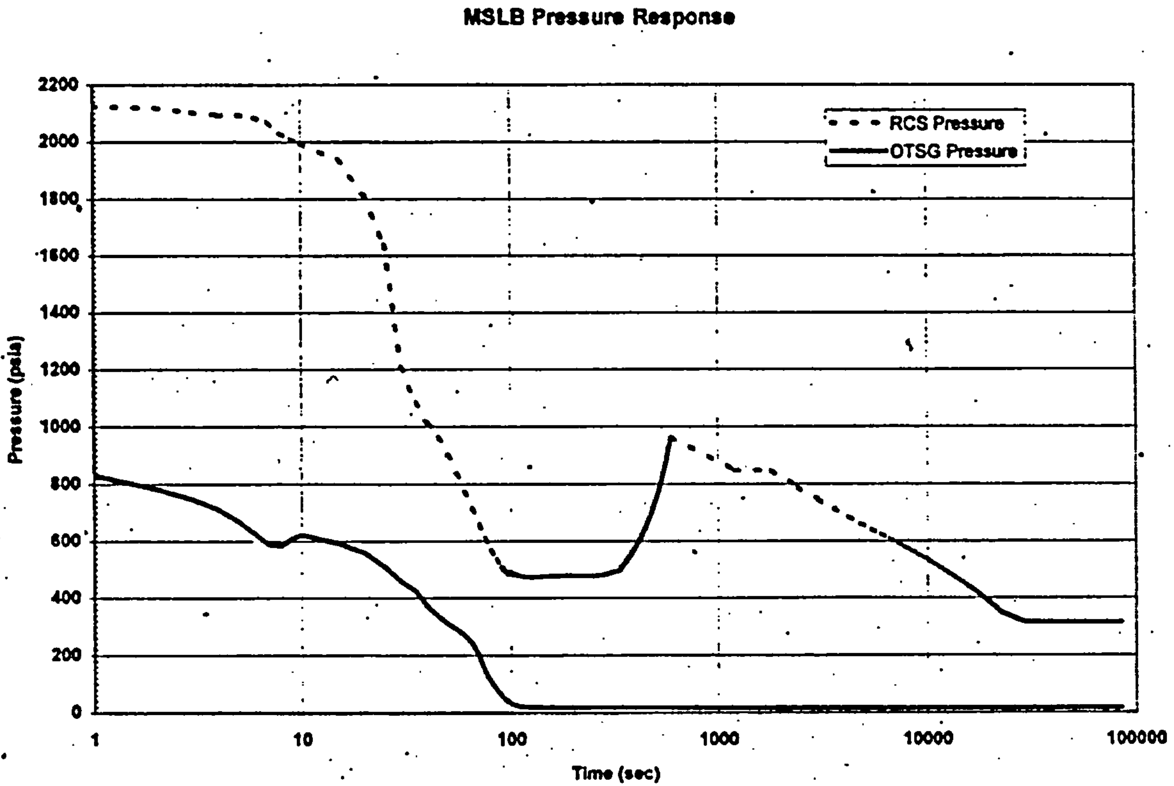


FIGURE 15



5.4 OTSG Tube Loads

5.4.1 Introduction

The resulting steam generator tube loads were determined from the T-H parameters provided from the analysis presented in Section 5.3 above. The method of calculating the tube loads evaluated the theoretical tubesheet deflection under a differential pressure and tube axial load and as a function of the different OTSG tube, tubesheet and shell metal temperatures. The resulting pressure and tensile loads were used to determine the leakage area that would develop for a given crack length and orientation as described in Section 5.5 below. Since the thermal hydraulic conditions changed with time, the resulting tube loads also change accordingly. As a consequence of the tubesheet deflection from the center to the periphery, the tube loads varied as a function of the radial distance from the center of the OTSG. In this way, a plot of the tube loads as a function of radial distance from the OTSG center to the OTSG periphery would be different for each set of consistent T-H conditions. The discussion below provides an overview of the methodology used by both GPUN and FTI to independently determine the OTSG tube loads using the T-H data in Section 5.3, and a presentation of the results.

5.4.2 Methodology

5.4.2.1 GPUN Methodology

The methodology that was employed by GPUN for the determination of the tube loads is described in Reference 16 and comprised the following steps:

- Establish the tubesheet behavior as a function of applied load and material properties as a function of temperature.
- Establish the tube loading (pre-load) in the OTSG as a function of the measured gap between the separated sections of a failed tube at the temperature at the time of measurement. The calculation will be based on the assumption that very few tubes have parted so that the loading on the balance of the intact tubes is unchanged.
- Separate the three major OTSG components (tubes, shell, and tubesheet) to free components (bodies), remove all loads acting on them and find their unloaded geometry.
- Establish the physical variables that will result in deformation of the free bodies and calculate these deformations, including an accounting for the Poisson effect on the tubes and on the shell.
- Re-combine the deformed free components by pulling the tubes until they meet the final tubesheet location. The final tubesheet location must simultaneously satisfy both of the following conditions:
  - The tubesheet periphery must be at the same location as the shell.
  - The tensile load from all of the tubes must be equal to the shell compressive load.

5.4.2.2 Framatome Technologies, Inc. (FTI) Methodology

An ANSYS finite element model of the OTSG was used to determine the tube load contribution for various system operating parameters. The ANSYS model was basically identical to the NASTRAN model used in the 'OTSG Tube Topical Report' (Reference 17). The NASTRAN model was converted to ANSYS due to some extra features ANSYS possessed at the time.

The model was an axisymmetric thermal and structural model of the OTSG. The model included the steam generator shell sections, upper and lower heads, upper and lower tubesheets, support skirt, and twelve beams representing twelve effective tube regions. The tubesheet model accounted for the material properties which were adjusted to account for the tubesheet temperature and the effects of the perforated plate.

Several different load cases (parameter study) were executed to establish the variation in tube loads due to change in primary pressure, secondary pressure, tube-to-shell delta T (both tubes hotter and cooler than the shell), and average tube temperature. The end result was a series of equations as a function of average temperature and tubesheet radius, that provided the load in the tubes for each of the pertinent system parameters.

Using the postulated MSLB system transient parameters discussed in Section 5.3 above, the total tube loads for the transient, as a function of transient time and tubesheet radius, were determined.

5.4.3 Results

5.4.3.1 GPUN OTSG Tube Loads

The GPUN analysis results are provided in Figure 16. This figure shows the OTSG tube loads for three radial positions in the OTSG (Center, Average, and Periphery) as a function of time from the start of the MSLB transient. The peak axial tube load of 1310 lbs. occurs 60 seconds into the transient at the periphery of the OTSG. The smallest loads occur at the center of the OTSG tube bundle as was discussed earlier.

5.4.3.2 FTI OTSG Tube Loads

The FTI results (Reference 22) are provided in Figure 17. As can be seen, they were very similar to the GPUN load results. The peak axial tube load was 1135 lbs. at 60 seconds and also occurs at the OTSG periphery, with the smallest loads at the center as well.

A comparison of the GPUN and FTI results is provided in Section 5.4.4 below with an explanation for the loads that were used to perform the subsequent tube-to-tubesheet interface pressure and the leakrate analyses (which are described in Sections 5.5 and 5.6).

FIGURE 16

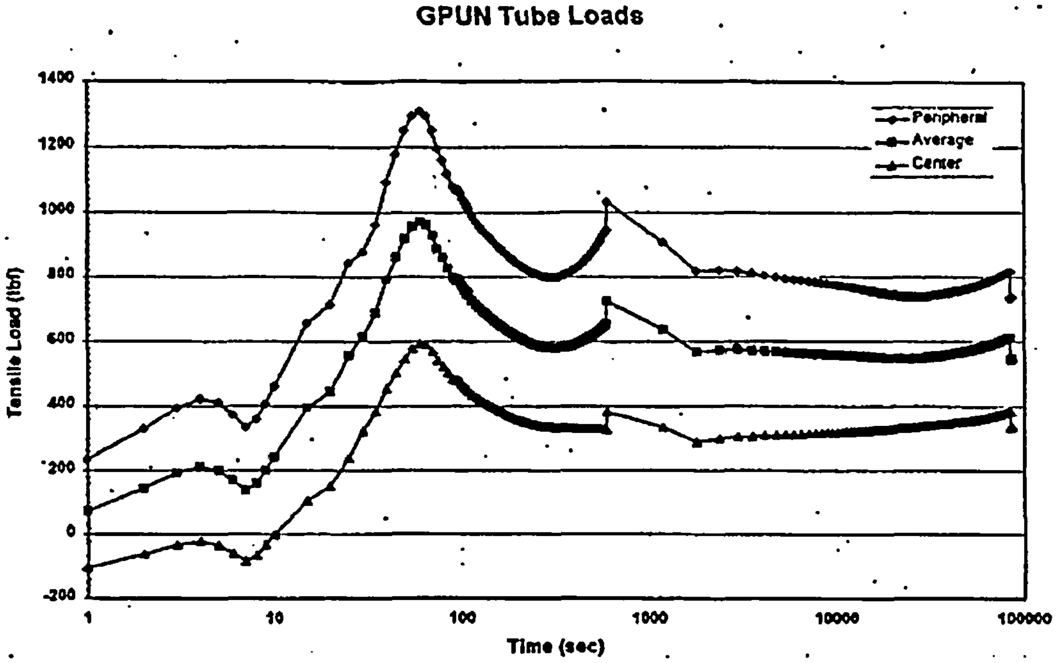
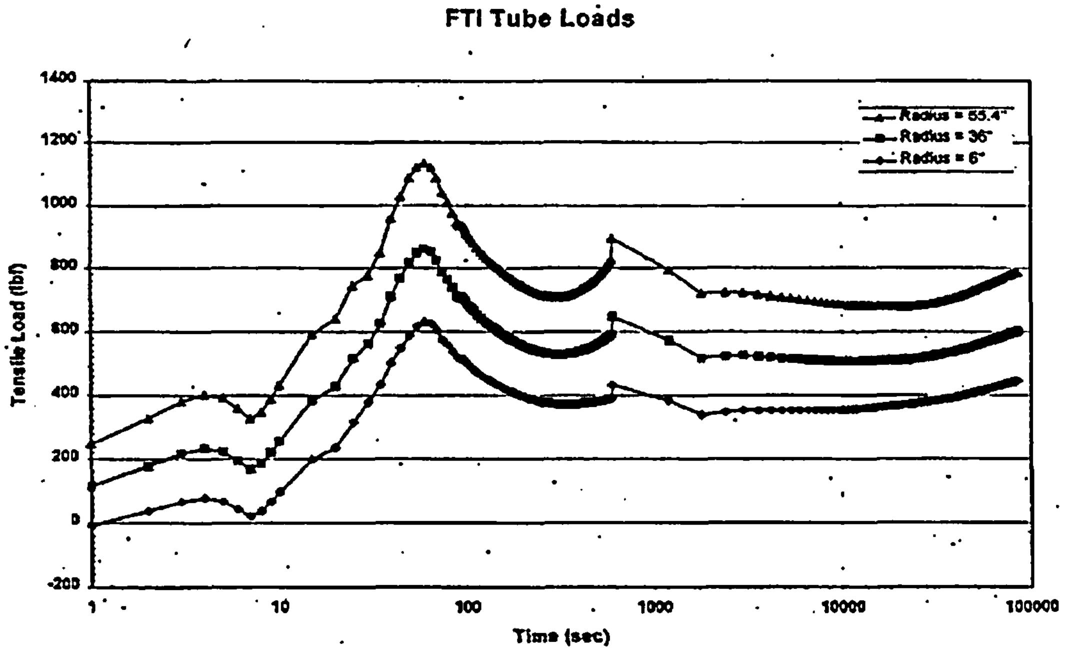


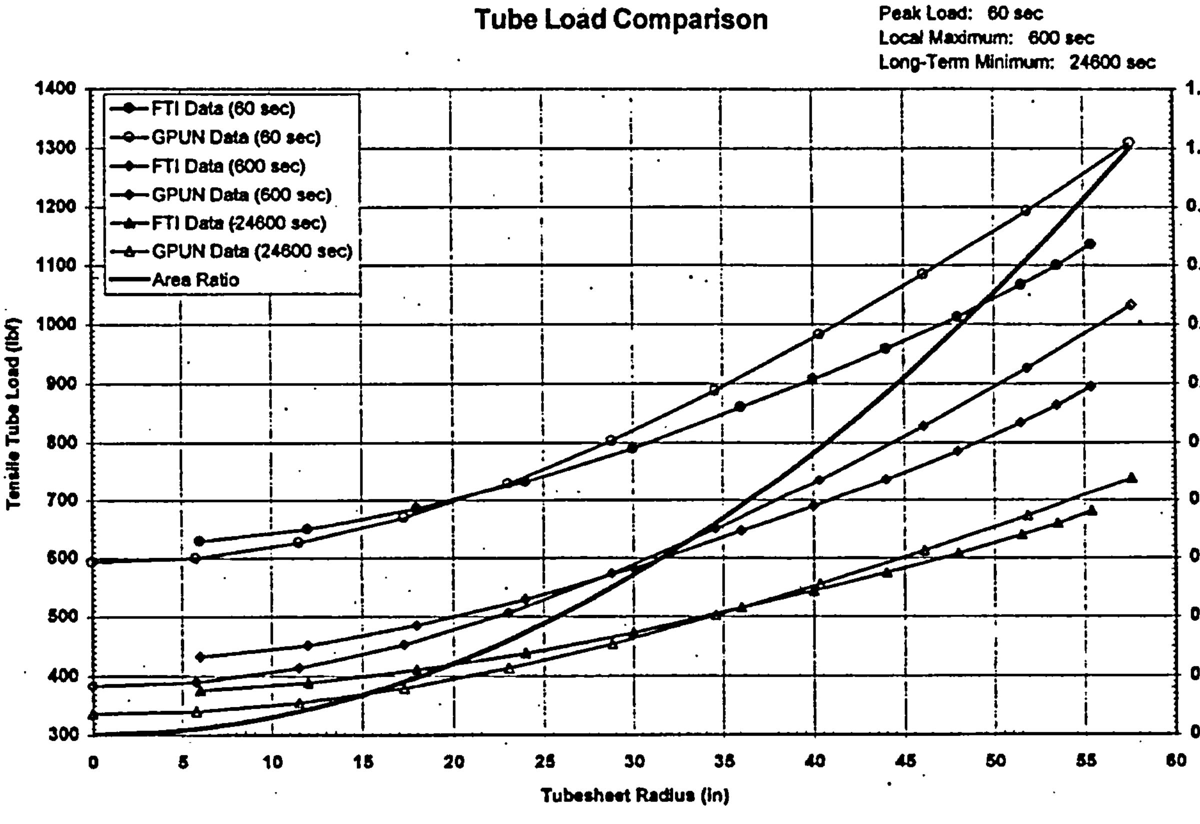
FIGURE 17



5.4.4 Analysis of Loads

Figure 18 provides a comparison of the FTI and GPUN OTSG tube load results. Results are presented for three points in time as a function of radial distance from the OTSG center to the periphery. While the results were very close, it can be seen that the GPUN results tended to be more conservative than the FTI results as radial location (R) increases. Similarly, for smaller R, the FTI results were slightly more conservative. The plot of area ratio vs. radial position (right side ordinate axis is the area ratio) shows that there are substantially more tubes at the higher R values than at the lower R values. It was judged that the GPUN results would be more conservative since they would result in higher loads on a greater number of tubes. As a result, for this study, the GPUN-calculated loads were used to perform the subsequent crack area and crack leakage analyses described below.

FIGURE 18



The two sets of independent analyses were confirmatory and demonstrated that the calculated OTSG tube loads are reasonable.

5.5 Crack Area Determination

5.5.1 Introduction

The crack opening area (COA) determination was based upon the methodology provided in Reference 13 and established a method for calculating the crack opening area for through-wall cracks in tubes. Primary-to-secondary leakage was calculated using two potential crack orientations in combination with a specific applied load (Reference 14). These were:

1. Circumferential Through-Wall Crack in Tension (Note: The contribution of primary pressure is included in the applied tension load.)
2. Axial Through-Wall Crack Subjected to Internal Pressure

Using these methods, the user could calculate the crack opening area (COA) for a crack given the specified conditions and use that area to determine the tube leakage (See Section 5.6).

There are conditions particular to the capture of the tube within the kinetic expansion region that separates the COA within the kinetic expansion from the COA for a defect in the free span. (Therefore, the subject leakrates calculated for flaws in the kinetic expansion are not usable for flaws in the free span.)

It is arguable whether any COA occurs at all within a kinetic expansion because the tube will not slip or rotate within the expansion. Within any expansion region, the tubesheet, due to its proximity alone, guides the tube and prevents rotation at the elevation of a defect that could result in increasing COA. In addition, remaining contact pressure on the tube OD surface further provides a friction reaction that prevents bending of the tube that could result in increasing COA.

Therefore, for the purpose of leakage assessment from flaws in the kinetic expansions, COA depends on applied axial tension only because there is no rotation at the elevation of a defect due to remotely applied tension. COA is assumed to develop because of asymmetry local to the section as the symmetrically distributed load comes into equilibrium with the asymmetrical section containing the defect.

NUREG/CR-3464 (Reference 13) provides the solution for COA for circumferential defects in OTSG tubes under applied axial tension. The COA for axial defects is also provided. This reference has been widely used in the nuclear industry and, in particular, was the source for COA evaluation for the leak-before-break analysis of RCS piping in B&W plants (Reference 18).

5.5.2 Methodology (Kinetic expansion region)

Reference 13 provided the equations necessary to calculate the crack opening area for circumferential through-wall cracks in tension and axial through-wall cracks subjected to internal pressure. The methodology was implemented in Reference 14 and is summarized herein.

5.5.2.1 Circumferential Through-Wall Crack in Tension

The crack opening area as a function of the axial, tensile, tube load was calculated based on the applied axial stress (σ_t), Young's Modulus (E) for the tube material, and a non-dimensional function ($I_t(\theta)$) formulated from the stress intensity factors:

$$A_t = \frac{\sigma_t}{E}\left(\pi R^2\right)I_t(\theta)$$

The applied stress was calculated given the axial tensile load (P) and the mean tube radius (R) with the tube wall thickness (t), or the inner and outer tube radius (R_i and R_o, respectively):

$$\sigma_t = \frac{P}{2\pi Rt} = \frac{P}{\pi\left(R_o^2 - R_i^2\right)}$$

5.5.2.2 Axial Through-Wall Crack Subjected to Internal Pressure

The crack opening area for an axial through-wall crack with internal pressure was calculated based on the membrane stress (σ), Young's Modulus (E) for the tube material, mean tube radius (R), tube wall thickness (t), and a non-dimensional function ($G(\lambda)$) formulated from the stress intensity factors:

$$A = \frac{\sigma}{E}(2\pi Rt)G(\lambda)$$

The applied stress was calculated given the differential pressure (p), mean tube radius (R), and tube wall thickness (t):

$$\sigma = \frac{pR}{t}$$

This methodology was used to calculate the crack opening area for through-wall cracks of tubes with an outer radius to wall thickness ratio (R/t) of less than or equal to 10.0 with no bending moment applied. The crack opening areas for R/t ratios of less than 10.0 are conservatively large.

5.6 Crack Area Leakage Analysis

5.6.1 Overview

The leakage flow for a given crack area (from Section 5.5) was determined by the PICEP (Pipe Crack Evaluation Program) computer code developed by EPRI (Reference 15). A brief description of the code is provided in this section.

The crack area as a function of time for a given crack length and crack orientation was provided from the analysis described in Section 5.5 above. The T-H parameters were provided in Section 5.3 above. The PICEP code utilizes a crack area, the RCS pressure, RCS temperature, and OTSG pressure at a single point in time and calculates a leak rate through the crack for that specific time. In order to develop a leak rate as a function of time, the code has to be run numerous times throughout the MSLB transient duration. The PICEP analysis was run at the MSLB transient model data intervals. The result was a leak rate as a function of time, which was then integrated to provide a total leakage volume for a given crack. This process was repeated for each type of crack indication at different radial locations within the tube bundle. (See Section 5.7.)

The contact pressure between the expanded tube and the tubesheet causes a significant reduction in leakage. However, the calculations took no credit for the leakpath between the tube and the tubesheet.

5.6.2 Code Description

The PICEP program (Reference 15) was used to calculate the crack opening area, the critical crack length and the flow rate through various sizes and types of cracks in kinetic expansions. Options are available to calculate the leakage with a crack area that is supplied by the user. For subcooled or saturated liquid discharge, the critical flow equations are based on the Henry/Fauske homogeneous non-equilibrium critical flow model with modifications to account for fluid friction due to surface roughness, crack turns, and non-equilibrium 'flashing' mass transfer between liquid and vapor phases. The flow was assumed to be isenthalpic and homogeneous with non-equilibrium effects introduced through a parameter, N, which is a function of equilibrium quality and flow path length-to-diameter ratio, L/D.

The PICEP program was used to estimate calculate the theoretical leakage from the axial, circumferential, and volumetric indications in the TMI-1 kinetic expansions. (As described above, volumetric indications are conservatively assumed to result in both a circumferential crack and an axial crack.) The PICEP program predicts the theoretical flow through straight cracks. The volumetric morphology of the ID IGA flaws, the predominant flaws within the kinetic expansions, is dissimilar to the morphology of straight cracks. However, given the constraint of the tubesheet, it is very conservative to predict leakage based on the assumption that each volumetric flaw will result in one circumferential, throughwall, straight crack and one axial, throughwall, straight crack.

Numerous inputs were required for the PICEP calculations to estimate the leakage from the kinetic expansion flaws:

- Tensile loads on the tube were set to zero for the axial cracks (since tensile loads tend to tighten these cracks and reduce leakage).

- Surface roughness was set to 0.0002 inches, a value of roughness typical for corrosion-induced cracks.
- No credit was taken for any tortuosity of the crack channel. (The number of 45 degree turns was set to zero for the computer code runs.)
- Minimum tube wall thickness of 0.034" was assumed.

Validation/benchmarking of the PICEP program was based on a large number of flaws and is described in Appendix C of EPRI NP-3596-SR (Reference 15). PICEP crack flow results were assessed using several sets of leak data including data from EPRI (Battelle Columbus and Wyle Laboratory), NRC (UC Berkeley), Canada (AECL), Italy, and Japan. The types of cracks used for this validation work were varied. For example, PICEP results were compared with flow data from cracks formed by parallel plates, pipes with circumferential cracks, and rectangular slits. Among the test results with which PICEP was compared were those results described in NUREG/CR-3475, "Critical Discharge of Initially Subcooled Water Thru Slits". (The PICEP results showed good agreement with the NUREG's results.) Additional work to benchmark the PICEP code is described in EPRI NP-6897-L, "Steam Generator Tube Leakage Experiments and PICEP Correlations" (Reference 33). In that study the PICEP results were benchmarked against numerous steam generator tube laboratory leak tests. (48 leak tests were conducted on I-600 steam generator tube specimens with laboratory-generated flaws.)

5.6.3 (This Section was deleted.)

5.6.4 (This Section was deleted.)

5.6.5 Leakage from Defects Above the Required Kinetic Expansion Length

Estimated leakage from flaws that are located above the $AKEL_{MIN}$ expansion lengths will be very small in comparison with flaws that are located nearer to the expansion transitions. In classical equations for laminar flow through a small annular orifice formed by concentric members with circular cross sections - a highly idealized representation of the kinetic expansions in which the tubing was expanded, twice, against a drilled tubesheet bore with explosive force - flow is linearly inversely proportional to length of the orifice (Reference 34). Thus, if it was conservatively assumed that a kinetic expansion flaw's leakpath were a concentric annulus, expected leakage from a hypothetical flaw 3.0" into the expansion would be 10% of the expected leakage from an identical flaw located 0.3" into the expansion.

To conservatively account for flaws that may be present above the kinetic expansions' required lengths, where the tubing is not examined, an MSLB-induced leak rate will be assumed. As previously described, the kinetic expansion joints were designed to be "essentially leaktight". The results of the original leak rate testing (Reference 29) for the kinetic expansions indicated a 99% confidence that 99% of the expanded tubes will have leak rates less than 460 x 10^{-6} lb/hr-tube during normal plant operations. A 6" minimum defect-free length was used for the original design leak testing.

For the purposes of outage kinetic expansion evaluations, TMI-1 will assume 15 gallons of accident-induced leakage over the first 2 hours of the MSLB transient, and 170 gallons of accident-induced leakage over the duration of the MSLB transient, from the uninspected lengths of each steam generators' kinetic expansion joints (i.e., deeper into the kinetic expansion joints). These are conservative values that were derived as follows:

- The shortest required kinetic expansion length is 2.1" (Table 1). This is approximately 1/3 of the original leak tested joint, so the expected leakage from a hypothetical leak into a "concentric annulus", as described above, would be 3 times greater than a leakrate at 6" deep into the expansion under the same conditions.

- The peak MSLB break differential pressure at TMI-1 is less than twice the normal plant operations' differential pressure. If a factor of 2 increase in differential pressure is assumed, the expected primary-to-secondary MSLB leakage, based on Bernoulli's theorem, would be increased over the normal plant operations leakage by a factor of the square root of 2. A factor of 2 will be used, which is conservative. (Figure 15 of this report shows the expected primary-to-secondary differential pressure for a MSLB event.)

- Each TMI-1 steam generator has less than 15,000 tubes in service.

- Combining these factors yields:
  (460E-6 lbs/hr-tube) (3) (2) (15000 tubes/generator) = 42 lbs/hr-generator

A reference density of 0.7094 grams/cc was used for the kinetic expansion leakage evaluations, which is equal to 5.92 lbs/gallon. (Primary side temperature was 579F. Refer to Section 5.1.) Therefore, to convert this mass flow rate to a volumetric flow rate:

(42 lbs/hr-generator) / (5.92 lbs/gallon) = 7.1 gals /hr- generator

Accident-induced leakrates are tabulated in this document on a volume basis over a 2-hour period and over the duration of a hypothetical MSLB, as described in Section 5.1. (The duration was calculated to be 23.5 hours.) Converting this leakrate to provide consistent units with these other calculated leakrates:

2 hour leakage = (7.1 gals/hr-generator) (2 hrs.) ≈ 15 gallons/generator
Duration Leakage = (7.1 gals/hr-generator) (23.5 hrs.) ≈ 170 gallons/generator

Note that primary-to-secondary leakage from the TMI-1 kinetic expansions has been less-than-detectable over the past several operating cycles, so there is no evidence that the kinetic expansion joints leak during normal plant operations.

5.7 Total Leakage Evaluation

5.7.1 Overview

This section describes the approach taken to determine the total leakage for the purposes of comparison against the leakage limits. A calculation methodology was developed that integrates the OTSG tube loads with the thermal hydraulic data and analysis needed for leakage through the cracks and combines the results into leakage assessment tables. These calculated leakages are based on implementing the methodology discussed in Sections 5.3 through 5.6 above. Also discussed in this section are the ways in which the unaffected OTSG will be treated since the tube loads are quite different (i.e., smaller) and the steamline is intact.

5.7.2 Leakage Results

Calculations were created to apply the methodology discussed in earlier sections of this report to calculate the leakrates from postulated tube cracks in the kinetic expansions of the OTSGs(Reference 21). The crack opening area was calculated based on the tube tensile load or the differential pressure depending on the orientation of the crack. The mass flux was calculated using the PICEP computer program given the crack geometry and the fluid properties as discussed in Section 5.6. The mass flux was converted to a volumetric leakrate based on a reference density (579 degrees F and 2200 psi) and the crack opening area. (This reference density corresponds to the same value as was used in determining the FSAR leakage limits.) The calculated leakage from cracks of various sizes was integrated over a period of 2 hours and for the duration of the MSLB transient. The results of this calculation can be provided by 'binning' of integrated leakage from cracks in the range of sizes for circumferential and axial leakage. The circumferential crack size bins for a given radial position in the OTSG are the same, but the integrated leakage for a given crack size is different as a function of radial position. This is necessary for circumferential crack leakage-- but is not necessary for axial crack leakage which is not sensitive to radial position, only differential pressure.

The circumferential crack integrated leakage results, presented as leakage tables according to crack size for 5 concentric, radial "zones" (from the center of the tube bundle to the periphery), are provided in Table 4. For axial cracks, the leakage is provided as crack size bins in Table 4. The bins for all of the circumferential crack tables range from 0.05 inch crack size (.05 inch leakage is used for all cracks from 0.02 to 0.05 inches) through 0.65 inches. Table 4 also provides the leakage calculation results for axial indications up to 1 inch in length. In the field all circumferential and axial extents are 'rounded up' to the next 0.05 inch increment. [Note that the circumferential crack integrated leakage 5 bins are slightly different than the 11 bins of the original version of this document. Reference 26 originally placed the results into 11 bins. One of those 11 bins was eliminated since it was for the very center of the steam generator (radius = 0") and there are no tubes at the center of the generators. The remaining 10 bins were combined into 5 bins.]

As previously described, if an indication is determined to be volumetric, it is treated as two cracks. Each volumetric indication is treated independently as if there were one axial and one circumferential crack of lengths equal to the volumetric flaw's measured axial and circumferential extent, respectively. It is very conservative to estimate the theoretical leakage from volumetric flaws in the kinetically expanded tubing by considering them as a combination of a 100% throughwall circumferential crack of length equal to the as-called circumferential extent of the volumetric flaw and a 100% throughwall axial crack of length equal to the as-called axial extent of the volumetric flaw. This treatment of the volumetric flaws is conservative for a number of reasons including:

- the fact that the tubing is expanded into the tubesheet and is unlikely to crack axially. (Expansion and deformation of the tube in the hoop direction are prevented by the constraint of the tubesheet.)

- pulled tube examination results from TMI-1 have demonstrated that the MRPC examinations tend to overestimate the extents of the ID volumetric IGA flaws (as a result of the "look-ahead/look behind" effect and the proximity of the ID flaws to the surface-riding coils). The majority of flaws within the kinetic expansions are ID volumetric IGA flaws, as is also the case for the freespan tubing in the TMI-1 steam generators.

- bending of the tubing is prevented by the presence of the tubesheet. (Crack formation is less likely since movement/displacement of the tubing is severely restricted.).

- the presence of the tubesheet prevents formation of a volumetric "hole"; thus only a tortuous flow path through an intergranular flaw surface (similar to a crack) would be expected.

5.7.3 Affected OTSG Versus Unaffected OTSG

Since both the affected OTSG and the unaffected OTSG will experience tube loads, leakage is possible from both generators. Since either of the two OTSGs might be the affected one, it is necessary to assume that the OTSG with the greatest volume of estimated leakage is the affected generator.

The leakage from each of the indications has to be summed, and the total leakage for the OTSG can then be compared against the total leakage limits of 3228 and 9960 gallons (at 579 degrees F, 2200 psia) for the 2 hour EAB and 30 day LPZ, respectively, discussed in Section 5.1. Since OTSG tube loads were not specifically determined for the unaffected OTSG, it is necessary (and conservative) to treat the unaffected generator as if it had the same loads as the affected generator. Thus, the same process used for the affected OTSG will be used for the unaffected OTSG. The leakage calculations assume that either steam generator could leak (as if it were the affected generator during an MSLB) and determine the leakage based on the sum of the cracks in that generator without taking credit for the intact steamline of an unaffected generator.

The estimated leakage from kinetic expansions is calculated for each of the steam generators based on outage inspection results. Since either of the TMI-1 steam generators could have been the affected OTSG during a hypothetical MSLB that occurred in the operating cycle prior to the inspection, it is necessary that each of the OTSGs has an "as-found" estimated leakage less than the above leakage limits. Since either of the TMI-1 steam generators could be the affected OTSG during a hypothetical MSLB that occurs during the operating cycle following the inspection and required tube repairs, it is necessary that each of the OTSGs has an "as-left" estimated leakage less than the above leakage limits. (Note that estimated leakage from flaws in the steam generator tubing located in areas other than the kinetic expansions, possible leakage from other tubing repairs, and possible primary-to-secondary leakage during the operating cycle must also be considered in this evaluation of possible leakage versus the steam generator performance criteria limits.)

5.8 Leakage Assessment Methodology Summary

The leakage assessment methodology allows for a determination of the leakage that may occur during a Main Steam Line Break (MSLB) event from conservatively assumed through-wall cracks in the kinetic expansions in the upper tubesheets. Eddy current indications with throughwall estimates greater than 67% are assumed to be 100% through-wall cracks that will leak during the MSLB.

The amount of leakage is determined by calculating the leakage area resulting from the MSLB-induced tube loads (differential pressure only for axial cracks), and then calculating the subsequent leakage flow rate and total event integrated leakage for each applicable indication based upon the thermal hydraulic conditions associated with the MSLB event. The estimated leakage for all cracks is compared against 2 hour and event duration leakage limits. These leakage limits for the TMI-1 steam generators ensure that exclusion area boundary and 30 day low population zone doses do not exceed a small fraction of 10 CFR 100 requirements if the MSLB event were presumed to occur.

The implementation of this leakage assessment methodology using OTSG eddy current data provides reasonable assurance that the leakage that could occur during a design basis MSLB from indicated cracks in the kinetic expansion region may be conservatively determined.

5.9 Reporting Requirements

Kinetic expansion inspection results will be reported to the NRC. These results will include the number of tubes plugged, the types of degradation detected, the radial location and required expansion lengths of tubes with degradation, results of growth assessments, and the calculated theoretical MSLB-induced leakage from kinetic expansion indications. The following is a list of the information to be reported to the NRC, including the method by which it will be reported, and the time period in which it will be reported.

ITEM TO BE REPORTED	TYPE OF REPORT	DATE DUE TO NRC
Number of kinetic expansions inspected.	Written report. This information will be reported with the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).	Shall be reported to the NRC within 90 days following completion of the inspection and repairs (main generator breaker closure). [Same as the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).]
Location, percent of wall-thickness penetration, voltage, and axial and/or circumferential extent for each kinetic expansion indication.	Written report. This information will be reported with the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).	Shall be reported to the NRC within 90 days following completion of the inspection and repairs (main generator breaker closure). [Same as the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).]
Tubesheet radius location and minimum defect-free kinetic expansion length required (AKEL$_{MIN}$) associated with each tube with degradation detected in its required kinetic expansion region.	Written report. This information will be reported with the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).	Shall be reported to the NRC within 90 days following completion of the inspection and repairs (main generator breaker closure). [Same as the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).]
Number of tubes plugged due to kinetic expansion indications.	Written report. This information will be reported with the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).	Shall be reported to the NRC within 90 days following completion of the inspection and repairs (main generator breaker closure). [Same as the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).]
An assessment of the growth of indications within the kinetic expansions in accordance with Sect. 3.2 of this report, including the number of tubes with new indications located in the required kinetic expansion region, and including the results of extreme value testing.	If no growth is detected: This information will be reported with the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).	Shall be reported to the NRC within 90 days following completion of the inspection and repairs (main generator breaker closure). [Same as the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).]
	If growth is detected: NRC shall be notified by telephone during the outage in which growth is detected. Additional notifications/reports, shall be made in accordance with the requirements of 10CFR50.72 and 10CFR50.73, if applicable.	Telephone call to NRC shall be during the outage in which growth is detected. Report(s) required by 10CFR50.72 and 10CFR50.73, if applicable, shall be made in accordance with schedule prescribed in those documents.

ITEM TO BE REPORTED	TYPE OF REPORT	DATE DUE TO NRC
An assessment of the theoretical MSLB-induced leakage from indications within the kinetic expansions in accordance with Sects. 5.7 and 5.8 of this report	If as-found leakage is projected to be less than 3228 gals for 2 hour duration leakage and less than 9960 gals. over the MSLB duration: Written report. This information will be reported with the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b). This assessment in the 90-day report shall include a discussion of the leakage trend with respect to the prior outage(s), including a reconciliation of the leakage projections if the assessment methodology is revised from that used in a prior outage.	Shall be reported to the NRC within 90 days following completion of the inspection and repairs (main generator breaker closure). [Same as the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).]
	If as-found leakage is projected to be greater than 3228 gals for 2 hour duration leakage or greater than 9960 gals. over the MSLB duration: NRC shall be notified by telephone during the outage in which said leakage is determined. Additional notifications/reports, shall be made in accordance with the requirements of 10CFR50.72 and 10CFR50.73, if applicable.	Telephone call to NRC shall be during the outage in which said leakage is determined. Report(s) required by 10CFR50.72 and 10CFR50.73, if applicable, shall be made in accordance with schedule prescribed in those documents.
A summary of the evaluation to determine best estimate leakage resulting from the limiting LBLOCA as described in Section 2.0 of this report.	Written Report. This information will be reported with the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5(b).	This summary shall be provided as part of the 90-day report currently required by TMI-1 Tech. Spec. 4.19.5 (b).]

6.0 INSPECTION CRITERIA AND LEAKAGE ASSESSMENT SUMMARY

Kinetic expansions were installed in the upper tubesheet region of more than 30,000 TMI-1 steam generator tubes in the early 1980's. Finite element analysis modeling has demonstrated that the kinetic expansions are relatively flaw tolerant. These expansions are protected from a number of types of stresses, vibrations, bending, and secondary-side loose parts by the presence of 24" thick tubesheets.

Eddy current inspections of the TMI-1 kinetic expansions are required by the plant's steam generator program. This document provides the required inspection scope, reporting requirements, leakage assessment methodology, and acceptance criteria that conservatively disposition kinetic expansion inspection results. Kinetic expansions that contain flaws that might be adversely influenced by MSLB-induced stresses are removed from service under the subject conservative criteria. This document also requires a conservative evaluation of the estimated leakage that might occur from flaws detected within the kinetic expansions.

The criteria require, beginning with the Fall 2005 refueling outage, that only ID volumetric indications may remain in service in the kinetic expansions' required lengths, that new indications be removed from service, and that 100% of the in-service kinetic expansions be scheduled for examination each refueling outage. These and other conservatisms implement conservative criteria with which to disposition the kinetic expansions during each examination.

7.0 REFERENCES

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TABLE 1

INSPECTION ACCEPTANCE CRITERIA FOR OTSG KINETIC EXPANSION REGION (REQUIRED EXPANSION LENGTH)

Kinetic Expansion Length	Radius From Center of Tube Bundle	Minimum Defect-Free Kinetic Expansion Length Required $AKEL_{MIN}$
17"	0.00" – 20.00"	3.4"
	20.01" – 42.00"	3.2"
	42.01" – 46.00"	3.0"
	46.01" – 50.00"	2.7"
	50.01" – 55.00"	2.4"
	> 55.00"	2.1"
22"	0.00" – 20.00"	8.4"
	20.01" – 42.00"	8.2"
	42.01" – 47.00"	8.0"
	47.01" – 50.70"	5.2"
	50.71" – 54.30"	4.2"
	>54.30"	3.2"

TABLE 2
INSPECTION ACCEPTANCE CRITERIA FOR OTSG KINETIC-EXPANSION REGION (FLAW DISPOSITIONING CRITERIA)

Defect Type (Note 1 and Note 2)	**Requirement(s)**
Axial	The $AKEL_{MIN}$ length (Table 1) of defect-free tubing must be present. For multiple defects, ¼-inch shall be added to the length of each defect, except the first defect. Also, for each circumferential defect, a defect length of ¼-inch shall be added. Example: Three axial defects are found, with one defect 1-inch long and two defects each ½-inch long. In addition, two circumferential defects are found. The effective length of the ½-inch defects is: ½ inch + ¼ inch = ¾ inch. The combined length of the three axial defects is: 1-inch + ¾-inch + ¾-inch = 2 ½-inch. The effective axial influence of the two circumferential defects is: ¼-inch + ¼-inch = ½-inch. The total length of axial influence is 2 ½-inches + ½-inch = 3inches.
Circumferential	The $AKEL_{MIN}$ length (Table 1) of defect-free tubing must be present. For single defects, no defect may be longer than 0.52 inches. For multiple defects: • If separated axially by less than 1-inch, their length shall be combined, and the total shall be less than 0.64-inch. • If separated axially be more than 1-inch, the individual defects shall each be less than 0.64-inch in extent.

NOTES:

1. For volumetric defects, the criteria for axial defects shall be used for the axial length of any volumetric defect, and the criteria for circumferential defects used for the circumferential length of any volumetric defect.
2. Note that flaws other than ID volumetric IGA in the kinetic expansions' required lengths are removed from service under this criteria. (Only ID volumetric flaws may remain in this area, provided they meet the requirements of this table and steam generator projected total leakage required by this report is not exceeded.) This table is used to disposition the axial extents and circumferential extents of the ID volumetric IGA defects. This table is also used for condition monitoring of axial or circumferential defects in the kinetic expansions' required lengths, prior to their removal from service.

TABLE 3

[This table was deleted.]

Table 4
Leakage Assessment Evaluation Data

CIRCUMFERENTIAL INDICATIONS:

Theoretical MSLB Leakage Based on Circumferential Extent

Tubesheet Radius Location of Tube (inches)	Circ. Extent (Inches)	2 Hour Leakage (gal)	Duration Leakage (gal)
0.0 – 11.525	0 - 0.01	0	0
	0.02 - 0.05	0	0.05
	0.06 - 0.10	0.03	0.28
	0.11 - 0.15	0.08	0.85
	0.16 - 0.20	0.18	1.93
	0.21 - 0.25	0.35	3.77
	0.26 - 0.30	0.61	6.66
	0.31 - 0.35	1.01	11
	0.36 - 0.40	1.61	18.21
	0.41 - 0.45	2.63	29.93
	0.46 - 0.50	4.1	47.04
	0.51 - 0.55	6.21	71.34
	0.56 - 0.60	9.14	105.1
	0.61 - 0.65	13.17	151.16
11.526 - 23.05	0 - 0.01	0	0
	0.02 - 0.05	0.01	0.06
	0.06 - 0.10	0.04	0.35
	0.11 - 0.15	0.11	1.07
	0.16 - 0.20	0.24	2.42
	0.21 - 0.25	0.46	4.7
	0.26 - 0.30	0.81	8.3
	0.31 - 0.35	1.34	13.98
	0.36 - 0.40	2.28	24.02
	0.41 - 0.45	3.66	38.99
	0.46 - 0.50	5.64	60.54
	0.51 - 0.55	8.42	90.73
	0.56 - 0.60	12.25	132.12
	0.61 - 0.65	17.43	187.93

Table 4 (Cont'd)
CIRCUMFERENTIAL INDICATIONS:

Tubesheet Radius Location of Tube (inches)	Circ. Extent (Inches)	2 Hour Leakage (gal)	Duration Leakage (gal)
23.051 - 34.575	0 – 0.01	0	0
	0.02 - 0.05	0.01	0.08
	0.06 - 0.10	0.05	0.47
	0.11 - 0.15	0.15	1.42
	0.16 - 0.20	0.34	3.22
	0.21 - 0.25	0.65	6.25
	0.26 - 0.30	1.15	11.08
	0.31 - 0.35	2.05	20.02
	0.36 - 0.40	3.41	33.81
	0.41 - 0.45	5.4	53.99
	0.46 - 0.50	8.19	82.54
	0.51 - 0.55	12.04	121.84
	0.56 - 0.60	17.25	174.88
	0.61 - 0.65	24.18	245.4
34.576 - 46.1	0 – 0.01	0	0
	0.02 - 0.05	0.01	0.11
	0.06 - 0.10	0.07	0.63
	0.11 - 0.15	0.21	1.9
	0.16 - 0.20	0.47	4.3
	0.21 - 0.25	0.92	8.35
	0.26 - 0.30	1.74	15.93
	0.31 - 0.35	3.05	28.43
	0.36 - 0.40	4.99	47.19
	0.41 - 0.45	7.76	74.12
	0.46 - 0.50	11.6	111.51
	0.51 - 0.55	16.79	162.14
	0.56 - 0.60	23.69	229.5
	0.61 - 0.65	32.78	318.02
46.101 - 57.625	0 – 0.01	0	0
	0.02 - 0.05	0.02	0.14
	0.06 - 0.10	0.1	0.84
	0.11 - 0.15	0.29	2.5
	0.16 - 0.20	0.64	5.65
	0.21 - 0.25	1.32	11.51
	0.26 - 0.30	2.5	22.24
	0.31 - 0.35	4.31	38.98
	0.36 - 0.40	6.94	63.64
	0.41 - 0.45	10.64	98.41
	0.46 - 0.50	15.67	145.89
	0.51 - 0.55	22.37	209.32
	0.56 - 0.60	31.18	292.75
	0.61 - 0.65	42.65	401.91

Table 4 (Cont'd)

AXIAL INDICATIONS:

Theoretical MSLB Leakage Based On Axial Extent

Axial Extent (Inches)	2 Hour Leakage (gal)	Duration Leakage (gal)
0 - 0.01	0	0
0.02 - 0.05	0.01	0.02
0.06 - 0.10	0.04	0.13
0.11 - 0.15	0.12	0.45
0.16 - 0.20	0.31	1.19
0.21 - 0.25	0.7	2.73
0.26 - 0.30	1.53	5.72
0.31 - 0.35	3.14	11.21
0.36 - 0.40	5.81	20.49
0.41 - 0.45	9.87	36.51
0.46 - 0.50	15.64	61.2
0.51 - 0.55	23.45	96.42
0.56 - 0.60	33.61	144.31
0.61 - 0.65	46.45	206.92
0.66 - 0.70	62.33	286.28
0.71 - 0.75	81.64	384.43
0.76 - 0.80	104.81	503.54
0.81 - 0.85	132.33	646.46
0.86 - 0.90	164.68	815.41
0.91 - 1.00	245.97	1238.97

Table 5

In Situ Pressure Test Data Summaries

Outage 12R (1997)

TMI-1 IN-SITU PRESSURE TEST LIST
OTSG-A

TUBE AND EDDY CURRENT INFORMATION											IN-SITU TEST RESULTS			
	Tube Information				Plus Point Data			Bobbin Data						
Region	Row	Tube	Location	Length (in.)	Volts	Est.% TW	Orientation	Volts	Est.% TW	Comments	GPM @ NOPD	GPM @ MSLB	GPM @ R.G. 1.121	Max Pressure
Upper Tubesheet	93	119	UTS + 1.50	0.25C	17.15	87%	ID SCI	2.39	93%	Upper Tubesheet Circ	0	0	0	4400
	93	119	UTS +1.93	0.21A x 0.25C	9.2	N/A	ID VOL	2.39	93%	UTS Volumetric	0	0	0	4400
	93	119	UTS +0.55	0.24A x 0.27C	3.69	N/A	ID VOL	0.95	40%	UTS Volumetric	0	0	0	4400
	107	120	ETL – 0.49	0.27A x 0.25C	2.36	N/A	ID VOL	NDD	N/A	KET Volumetric	0	0	0	4400
	107	120	ETL – 2.85	0.12A x 0.19C	3.81	N/A	ID VOL	1.47	27%	UTS Volumetric	0	0	0	4400
	107	120	ETL – 3.95	0.16A x 0.16C	2.42	N/A	ID VOL	1.44	13%	UTS Volumetric	0	0	0	4400

TMI-1 IN-SITU PRESSURE TEST LIST
OTSG-B

TUBE AND EDDY CURRENT INFORMATION											IN-SITU TEST RESULTS			
	Tube Information				Plus Point Data			Bobbin Data						
Region	Row	Tube	Location	Length (in.)	Volts	Est.% TW	Orientation	Volts	Est.% TW	Comments	GPM @ NOPD	GPM @ MSLB	GPM @ R.G. 1.121	Max Pressure
Upper Tubesheet	58	13	UTS – 0.17	0.29C	6.99	N/A	ID SCI	4.28	67%	UTSF Circ	0	0	0	4400
	134	19	UTS – 0.20	0.14A x 0.30C	6.04	N/A	ID VOL	2.88	60%	UTSF Volumetric	0	0	0	4400
	118	38	UTS + 1.74	0.51C	5.11	N/A	ID SCI	9.88	43%	UTS Circ	0	0	0	4400
Freespan	79	58	15 + 40.30	0.86A x 0.50C	1.39	N/A	OD VOL	1.38	13%	Freespan NQI	0	0	0	4400
Freespan	79	60	15 + 41.57	0.69A x 0.39C	3.5	N/A	OD VOL	4.77	28%	Freespan NQI	0	0	0	4400

Table 5 (Continued)
In Situ Pressure Test Data Summaries

Outage 13R (1999)

IN SITU PRESSURE AND LEAK TEST RESULTS
TMI-1 SG B 09/99 13R

TUBE AND EDDY CURRENT INFORMATION														IN-SITU TEST RESULTS			
SG	Region	Tube Information			Plus Point Data					Bobbin Data			Comments	GPM @ NOPD	GPM @ MSLB	GPM @ 3xNOPD	Maximum Pressure
		Row	Col	Location	Axial Length	Circ Length	Volts	Est. %	Orientation	Ind	Volts	Est. %					
SG B	Upper TS	61	19	ETL -0.31		0.31	4.51	94	ID SCI	NDD			UTS Circ	0	0 *	0	4350
	Freespan	80	50	15S +29.05 to +33.79	4.74		0.46		OD SAI	NQI	0.37	47	Freespan Ax	0	0	0	4350
		113	2	14S +27.94 to +29.07	1.13		0.43		OD SAI	NQI	0.67	67	Freespan Ax	0	0	0	4350

* Note: An additional axial load was applied during this test to impart 1402 lbs. axial tensile load on this indication. This indication was also tested at 500 psi with a 2350 lbs. axial load applied (to simulate SB LOCA) with no leakage.

Table 5 (Continued)
In Situ Pressure Test Data Summaries

Outage 14R (2001)

In Situ Test List and Results: OTSG-A

TUBE AND EDDY CURRENT INFORMATION													IN-SITU TEST RESULTS					
REGION	TUBE INFORMATION			PLUS POINT DATA					BOBBIN DATA				GPM @	GPM @	GPM @	GPM @	MAXIMUM	EXP
	ROW	COL	LOCATION	AX LEN	CI LEN	VOLTS	EST %	ORIENTATION	IND	VOLTS	EST %	COMMENTS	NOP	MSLB	3NOCP	8450psi	PRESSURE	(Inch)
Freespan	69	72	07S +13.67	0.10	0.10	0.13	65	OD Volumetric	NQI	0.22	58	OD IGA/SCC	0	0	0	-	4412	17
Upper TS	53	46	ETL +1.43		0.17	3.14	97	ID Circ.	NDO			ID IGA/SCC	0	0	0	0.014	8450	17
Upper TS	121	89	ETL -0.14		0.50	0.63	86	ID Circ.	NDO			ID IGA/SCC	0	0	0	0	8450	17
Freespan	2	25	13S -18.12	0.14	0.12	0.18		ID Volumetric	NDO			ID IGA/SCC	0	0	0	-	4394	17
			13S -16.64	0.19	0.16	0.30			NDO				0	0	0	-	4394	
			13S -15.28	0.13	0.11	0.11			INR	0.44			0	0	0	-	4394	
			13S -8.75	0.24	0.16	0.20			NDO				0	0	0	-	4394	
			13S -7.37	0.19	0.22	0.30			NDO				0	0	0	-	4394	
			13S -4.87	0.39	0.22	0.19			NDO				0	0	0	-	4394	
			13S -1.26	0.29	0.22	0.52			NDO				0	0	0	-	4394	
			13S +6.14	0.15	0.16	0.34			NDO				0	0	0	-	4394	
			13S +10.01	0.29	0.22	0.39			IDI	0.47	20		0	0	0	-	4394	
			13S +10.82	0.34	0.22	0.38			IDI	0.47	23		0	0	0	-	4394	
			13S +11.17	0.24	0.22	0.40			NDO				0	0	0	-	4394	
			13S +14.08	0.24	0.16	0.15			INR	0.25			0	0	0	-	4394	
			13S +14.40	0.24	0.16	0.31			NDO				0	0	0	-	4394	
Freespan	135	2	14S -2.85	0.18	0.18	0.15		ID Volumetric	SVC	0.38		ID IGA/SCC	0	0	0	-	4400	17
			14S -2.20	0.13	0.12	0.14			IDI	0.38	17		0	0	0	-	4400	
			14S -0.24	0.13	0.12	0.10			NDO				0	0	0	-	4400	
			14S +2.42	0.13	0.17	0.23			IDI	0.45	23		0	0	0	-	4400	
			15S +11.89	0.27	0.17	0.31			IDI	0.45	17		0	0	0	-	4400	
			15S +15.70	0.13	0.12	0.20			INR	0.38			0	0	0	-	4400	
			15S +17.82	0.13	0.17	0.31			INR	0.40			0	0	0	-	4400	
			15S +19.39	0.13	0.17	0.38			INR	0.30			0	0	0	-	4400	
			15S +21.94	0.13	0.23	0.34			INR	0.51			0	0	0	-	4400	
			15S +24.73	0.09	0.12	0.35			NDO				0	0	0	-	4400	
			UTS -17.24	0.08	0.11	0.33			NDO				0	0	0	-	4400	
			UTS -13.39	0.09	0.12	0.23			INR	0.30			0	0	0	-	4400	
			UTS -11.75	0.13	0.12	0.22			NDO				0	0	0	-	4400	
			UTS -10.63	0.18	0.17	0.42			IDI	0.58	30		0	0	0	-	4400	
			UTS -8.86	0.09	0.12	0.21			NDO				0	0	0	-	4400	
Freespan	112	85	07S -9.54	0.40	0.17	0.14		ID Volumetric	IDI	0.54	17	ID IGA/SCC	0	0	0	-	4403	17
			07S -7.93	0.27	0.12	0.18			NDO				0	0	0	-	4403	
			15S +16.18	0.13	0.17	0.19			SVC	0.23			0	0	0	-	4403	
Freespan	96	127	12S +7.70	0.16	0.15	0.22		ID Volumetric	NDO			ID IGA/SCC	0	0	0	-	4400	17
			12S +9.92	0.11	0.15	0.25			NDO				0	0	0	-	4400	
			12S +11.55	0.11	0.15	0.43			NDO				0	0	0	-	4400	
			12S +13.19	0.32	0.23	0.38			SVC	0.26			0	0	0	-	4400	
			13S -11.87	0.11	0.13	0.18			SVC	0.20			0	0	0	-	4400	
			13S -11.41	0.11	0.13	0.37			NDO				0	0	0	-	4400	
			15S +13.32	0.15	0.17	0.40			SVC	0.36			0	0	0	-	4400	
			15S +13.67	0.20	0.17	1.35			NDO				0	0	0	-	4400	
Upper TS	72	124	ETL -2.46	0.33	0.37	1.48		ID Volumetric	NDO			ID IGA/SCC	0	0	0	-	4392	17
Upper TS	1	6	ETL -0.06		0.34	0.75	71	ID Circ.	NDO			ID IGA/SCC	0	0	0	0	8450	17

Table 5 (Continued)
In Situ Pressure Test Data Summaries

Outage 14R (2001)

In Situ Test List and Results: OTSG-B

TUBE AND EDDY CURRENT INFORMATION													IN-SITU TEST RESULTS				
REGION	TUBE INFORMATION			PLUS POINT DATA					BOBBIN DATA			DEGRADATION MECHANISM	GPM @ NOP	GPM @ MSLB	GPM @ SNOOP	MAXIMUM PRESSURE	EXP (Inch)
	ROW	COL	LOCATION	AX LEN	CI LEN	VOLTS	EST %	ORIENTATION	IND	VOLTS	EST %						
Upper TS	80	58	ETL -0.27	0.38	0.24	1.08		ID Volumetric	NDD			ID IGA/SCC	0	0	0	4400	17
			ETL -0.38	0.30	0.19	0.95			NDD				0	0	0	4400	
			ETL -0.51	0.38	0.29	0.83			NDD				0	0	0	4400	
Freespan	143	43	06S +8.04	0.11	0.10	0.29		ID Volumetric	INR	0.29		ID IGA/SCC	0	0	0	4400	17
			06S +18.77	0.11	0.10	0.16			INR	0.28			0	0	0	4400	
			06S +21.45	0.16	0.10	1.02			NDD				0	0	0	4400	
			08S +14.78	0.11	0.15	0.17			INR	0.29			0	0	0	4400	
			09S -13.23	0.18	0.10	0.13			BVC	0.25			0	0	0	4400	
			09S -7.23	0.18	0.15	0.13			BVC	0.31			0	0	0	4400	
			09S +1.74	0.10	0.15	0.20			NDD				0	0	0	4400	
			10S +7.91	0.14	0.12	0.38			BVC	0.39			0	0	0	4400	
			11S -11.92	0.10	0.10	0.28			BVC	0.32			0	0	0	4400	
			11S -8.47	0.18	0.15	0.23			BVC	0.32			0	0	0	4400	
Freespan	98	1	UTS -7.05	0.43		0.10	44	OD Axial	NCI	0.11		Groove IGA	0	0	0	4400	17
			UTS -8.19	0.39		0.09	61		NDD				0	0	0	4400	
			UTS -5.73	0.34		0.10	49		NCI	0.24			0	0	0	4400	
			UTS -4.82	0.16		0.13	52		NCI	0.21			0	0	0	4400	
			UTS -4.88	0.21		0.15	51		NCI	0.17			0	0	0	4400	
			UTS -4.16	0.32		0.17	38		NDD				0	0	0	4400	
Freespan	65	131	15S +45.55	8.30	0.43	4.87	62	OD Volumetric	NCI	0.65	81	Mechanical Wea Damage	0	0	3.2*	4360	17
	67	130	15S +44.85	6.51	0.38	3.69	41		NCI	0.63	67		0	0	0	4350	17
Freespan	119	2	14S -5.37	0.35		0.29	38	OD Axial	NCI	0.44		Groove IGA	0	0	0	4400	17
			14S -4.55	0.74		0.21	40		NDD				0	0	0	4400	
Freespan	80	31	UTS +0.26		0.26	12.50	90	ID Circ.	NCI	1.01		ID IGA/SCC	0	0	0	4350	17
Freespan	44	75	15S +1.32	0.21	0.15	0.32		ID Volumetric	BVC	0.31		ID IGA/SCC	0	0	0	4400	17
			15S -2.59	0.16	0.15	0.17			BVC	0.35			0	0	0	4400	
			15S -9.71	0.18	0.15	0.40			IDI	0.44	20		0	0	0	4400	
			15S -14.07	0.16	0.15	0.41			NDD				0	0	0	4400	
			14S -8.87	0.16	0.15	0.32			IDI	0.46	23		0	0	0	4400	
			14S +16.12	0.10	0.14	0.30			BVC	0.36			0	0	0	4400	
			14S +9.43	0.16	0.15	0.24			IDI	0.47	27		0	0	0	4400	
			14S +5.84	0.16	0.15	0.14			BVC	0.29			0	0	0	4400	
			14S -13.47	0.16	0.15	0.21			BVC	0.37			0	0	0	4400	
			13S +17.34	0.16	0.15	0.26			NDD				0	0	0	4400	
			13S +12.38	0.18	0.15	0.29			BVC	0.37			0	0	0	4400	
			13S +9.00	0.16	0.13	0.21			IDI	0.35	39		0	0	0	4400	
			13S -18.12	0.16	0.20	0.33			IDI	0.42	27		0	0	0	4400	
			12S +12.45	0.16	0.15	0.24			NDD				0	0	0	4400	
			09S +10.59	0.16	0.15	0.15			NDD				0	0	0	4400	
Upper TS	149	1	ETL +0.00		0.28	0.88	81	ID Circ	NDD			ID IGA/SCC	0	0	0	6500	17
			ETL -1.01	0.17	0.13	0.15		ID Volumetric	NDD			ID IGA/SCC	0	0	0	6500	
Freespan	65	129	UTS -0.60	2.75	0.33	1.24	38	OD Volumetric	NCI	0.55	82	Mechanical Wea Damage	0	0	0	4350	17
TSP	133	1	12S +0.88	0.44		0.78	88	OD Axial	NDD			OD Indication	0	0	0	4400	17
			12S -0.35	0.37		0.91	88	OD Axial	NCI	0.17	43		0	0	0	4400	
Upper TS	148	26	ETL +0.00		0.17	1.75	98	ID Circ.	NDD			ID IGA/SCC	0	0	0	6450	17

* Tube 66-131 in OTSG-B ruptured at 4360 psig. The 3.2 gpm leak rate occurred with a measured pressure at the pump of approx. 450 psig (and a calculated differential pressure at the defect of less than 100 psig).

Table of Acronyms

AECL	Atomic Energy of Canada, Ltd.
AKEL	Axial Kinetic Expansion Length
ASME	American Society of Mechanical Engineers
ATP	Abnormal Transient Procedure
BOL	Beginning of [Core] Life
BWOG	B&W Owners Group
CFR	Code of Federal Regulations
COA	Crack Opening Area
DHR	Decay Heat Removal
EAB	Exclusion Area Boundary
ECT	Eddy Current Test
EDM	Electro-Discharge Machine
EFW	Emergency Feed Water
EPRI	Electric Power Research Institute
ESAS	Engineered Safeguards Actuation System
ETL	Expansion Transition Location
F	Fahrenheit
FSAR	Final Safety Analysis Report
FTI	Framatome Technologies, Inc.
FWLB	FeedWater Line Break
GPU	General Public Utilities
GPUN	GPU Nuclear Corp.
HF	High Frequency
HFP	Hot Full Power
HPI	High Pressure Injection
ID	Inside Diameter
IGA	InterGranular Attack
KET	Kinetic Expansion Transition
LBLOCA	Large Break Loss of Coolant Accident
LCL	Lower Confidence Limit
LPZ	Low Population Zone
LRF	Leakage Reduction Factor
MDP	Motor Driven Pump
MFW	Main Feed Water
MRPC	Motorized Rotating Pancake Probe
MSIV	Main Steam Isolation Valve
MSLB	Main Steam Line Break
MSSV	Main Steam Safety Valve
MTC	Moderator Temperature Coefficient
NDD	No Detectable Degradation
NDE	Non-Destructive Examination
NODP	Normal Operating Delta Pressure
NOPD	Normal Operating Pressure Differential
NPSH	Net Positive Suction Head
NQI	Non-Quantifiable Indication
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
OD	Outside Diameter

Table of Acronyms (continued)

OTSG	Once-Through Steam Generator
PICEP	Pipe Crack Evaluation Program
P-T	Pressure-Temperature
PWSCC	Primary Water Stress Corrosion Cracking
R	Radius
RAI	Request for Additional Information
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RPS	Reactor Protection System
RPV	Reactor Pressure Vessel
SBLOCA	Small Break Loss of Coolant Accident
SCC	Stress Corrosion Cracking
SCM	Sub-Cooling Margin
SG	Steam Generator
TBV	Turbine Bypass Valve
TDP	Turbine Driven Pump
T-H	Thermal-Hydraulic
TMI	Three Mile Island
TMI-1	Three Mile Island, Unit 1
TS	Tubesheet
UFSAR	Updated Final Safety Analysis Report
UTSF	Upper Tubesheet Secondary Face