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NUREG-1919

Resolution of Generic Safety Issue 188: Steam Generator Tube Leaks or Ruptures Concurrent with Containment Bypass from Main Steam Line or Feedwater Line Breaches

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Resolution of Generic Safety Issue 188: Steam Generator Tube Leaks or Ruptures Concurrent with Containment Bypass from Main Steam Line or Feedwater Line Breaches

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ABSTRACT

This report addresses Generic Safety Issue (GSI) 188, “Steam Generator Tube Leaks or Ruptures Concurrent with Containment Bypass from Main Steam Line or Feedwater Line Breaches,” which concerns the potential for additional tube leakage or ruptures from the growth of existing cracks in steam generator tubes resulting from the dynamic loads following a main steam line break (MSLB) or feedwater line break (FWLB). To address the issue, this report provides the technical findings from thermal-hydraulic transient analyses and sensitivity studies, a simplified finite-element model of steam generator support structures and tubes, and structural analyses and sensitivity studies of the potential for crack growth. The results show that the additional dynamic loads from an MSLB are greater than those from an FWLB. The report concludes that dynamic loads from an MSLB are low and do not affect the structural integrity of tubes and do not lead to additional leakage or ruptures beyond what would be determined using differential pressure loads alone. Therefore, GSI-188 is closed, and the staff recommends no changes to existing regulations or guidance with respect to the dynamic loads induced by a breach of the main steam or feedwater line.

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FOREWORD

The work discussed in this report was performed to resolve a principal assertion of Generic Safety Issue (GSI) 188, “Steam Generator Tube Leaks or Ruptures Concurrent with Containment Bypass from Main Steam Line or Feedwater Line Breaches.” Specifically, the principal assertion is that dynamic loads induced in steam generator tubes by a main steam line break (MSLB) or other secondary-side breaches would lead to growth of cracks and increased steam generator tube leakage or ruptures. The project required the use of thermal-hydraulics to evaluate pressure differentials on secondary-side steam generator structural components, as well as materials engineering to assess the integrity of the steam generator tubes. Staff from the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES), Division of Systems Analysis and Regulatory Effectiveness, Safety Margins and Systems Analysis Branch, performed the thermal-hydraulics work. The tube integrity analyses and research were conducted at Argonne National Laboratory (ANL), under the direction of the RES Division of Engineering Technology, Materials Engineering Branch.

The NRC initiated this work in response to a staff member’s concern about the impact of an MSLB on the integrity of steam generator tubes. If an MSLB occurs, the difference in pressure between the primary coolant side of the steam generator tubes and the secondary side would increase because the secondary side would be depressurized. In addition, a steam line break may impose dynamic loads on the tube support plates (TSPs), and these loads could be transferred to the tubes. The effect of these additional dynamic loads on the integrity of degraded tubes during an MSLB formed the basis for the staff member’s concern. Moreover, if the steam line break were to cause steam generator tubes to rupture, primary coolant (which contains radioactive particles) could be released to the atmosphere outside of the containment depending on the break location and plant design. A Generic Issues Review Panel reviewed the staff member’s concern regarding steam line breaks and the possible effect on tube integrity and classified it as GSI-188.

The Safety Margins and Systems Analysis Branch conducted the thermal-hydraulics work using the TRAC-M computer code and hand calculations. The results yielded comparable estimates of pressure loading on the steam generator TSPs. The results were also comparable to those that Westinghouse obtained using its own computer code. The ANL staff then used the dynamic pressure loads from the thermal-hydraulics calculations to evaluate the stresses transferred to the steam generator tubes using finite-element analysis techniques. Vertical motion of the TSPs relative to the tubes as a result of the pressure pulse associated with an MSLB could transfer loads to the degraded tubes if they are locked to the TSP. If the degradation is great enough or the loads are high, existing cracks could propagate and lead to a possible leak or rupture of the tubes. By contrast, if enough tubes are locked to the TSPs, the loads on individual tubes would be low, and only very long throughwall circumferential cracks would propagate. Field experience, examinations, and tube pullout force results indicate that in steam generators experiencing significant degradation at the TSPs, a majority of the tubes are locked in place by corrosion or crevice deposits. The results of the integrity analyses that considered both the differential pressure stress and the dynamic loads show that if at least 40 tubes (out of several thousand) are locked in the TSPs, the additional dynamic loads associated with an MSLB would not cause any additional damage to the steam generator tubes because these loads were found to be insignificant.

Therefore, the staff concludes that the dynamic loads from an MSLB do not affect the structural integrity of tubes in service and do not lead to additional leakage or ruptures beyond what would be determined using differential pressure loads alone. Therefore, the principal assertion of GSI-188 is closed, and the staff recommends no changes to existing regulations or guidance with respect to the dynamic loads induced by a breach of the main steam or feedwater line.

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EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) developed Generic Safety Issue (GSI) 188, "Steam Generator Tube Leaks or Ruptures Concurrent with Containment Bypass from Main Steam Line or Feedwater Line Breaches," in response to a concern about the potential propagation of existing flaws produced by the additional loads resulting from resonance vibrations in steam generator tubes during steam line break depressurization. This is the principal area addressed in this resolution.

GSI-188 postulates that (1) a main steam or feedwater line break in an unisolable portion of the secondary system may cause multiple steam generator tubes to leak or rupture, or (2) significant steam generator tube leakage or rupture may cause an unisolable secondary-side breach that may, in turn, exacerbate the leakage. Either postulated accident scenario could have significant consequences because primary coolant could be lost to the environment through the leaking or ruptured steam generator tubes and the break in the secondary system.

This report describes the approach that the NRC staff used to resolve the principal assertion, the results of its studies, and the basis for closure. The NRC conducted the following studies:

- thermal-hydraulic (TH) transient analysis for temperature and pressure pulse loading during main steam line break (MSLB) and feedwater line break (FWLB) events
- analyses of the loads that are transferred to the steam generator tubes from the tube support plates (TSPs) during the transients of interest using a simplified (albeit conservative) finite-element model
- sensitivity integrity studies using the TH pressure drops to evaluate the failure of flawed steam generator tubes in a Westinghouse Model 51 steam generator during MSLB and FWLB events
- crack growth evaluations in the presence of vibrations in addition to the differential pressure stress

For new generators or generators where there is little degradation and the tubes are not locked, the TSPs are free to slide, and therefore, there is no mechanism to transfer the loads to the tubes. For generators where the tubes are locked in place, the level of loading that can be transferred to a degraded tube depends on the number of tubes that are locked (thereby distributing the loads) and the breakaway loads required to free the tubes from the TSP. The tube integrity evaluation used conservative breakaway loads.

Results show that the dynamic loads transferred to the steam generator tubes during an MSLB have virtually no effect on the burst pressure and leak-rate integrity of the tubes with axial cracks beyond the effects of differential pressure. The results also show that if some of the tubes in the steam generator are locked to the TSPs by corrosion products, the dynamic loads associated with an MSLB will have little impact on the integrity of the tubes unless extensive circumferential cracking is present. If only a few tubes are locked in each of the four quadrants, short throughwall circumferential cracks could propagate. When only 10 tubes per quadrant are locked, circumferential throughwall cracks must be longer than 180° in order to propagate. If all of the tubes are locked, the circumferential throughwall cracks must be longer than 300° for the cracks to grow under the influence of MSLB loads. These latter cracks would generally not be present in the steam generator during an MSLB, since inservice inspection or leakage would have revealed them, and plant personnel would have repaired or plugged them before the steam generator returned to normal operation. Field experience, examinations, and tube pullout force results indicate that in steam generators experiencing significant degradation at the TSPs, most of the tubes are locked in place so that the dynamic loads transferred to degraded tubes are low and large cracks can be tolerated.

The basis for closure of this generic safety issue is that the dynamic loads produced by an MSLB or FWLB would cause no additional damage to SG tubes containing flaws beyond the effect of differential pressure loads alone. As discussed above, tubes with large throughwall circumferential cracks that might have the potential to grow are not expected to be in service (i.e., they would have been plugged or sleeved before the circumferential extent became significant). The lateral load on the tubes is also greatest during an MSLB, but the loads are too low to cause significant bending stress in the tubes. In addition, the TH analysis demonstrates that the MSLB transient would show, at most, one or two significant load cycles and, therefore, fatigue caused by resonance vibrations is not an issue.

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ABBREVIATIONS

ACRS	Advisory Committee on Reactor Safeguards (NRC)
ANL	Argonne National Laboratory
DE	Division of Engineering
EDM	electro-discharge machining
FWLB	feedwater line break
GSI	generic safety issue
ksi	kilopounds per square inch
kN	kilo-Newton
kPa	kilopascal
LOFT	loss-of-fluid test
lbf	pound-force
ME	Materials Engineering
MSLB	main steam line break
NRC	U.S. Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation (NRC)
PRA	probabilistic risk assessment
PWR	pressurized-water reactor
psi	pounds per square inch
RES	Office of Nuclear Regulatory Research (NRC)
SG	steam generator
SGTR	steam generator tube rupture
SRP	Standard Review Plan
TH	thermal-hydraulic
TSP	tube support plate

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1. INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) developed Generic Safety Issue (GSI) 188, "Steam Generator Tube Leaks or Ruptures Concurrent with Containment Bypass from Main Steam Line or Feedwater Line Breaches," in response to a concern regarding resonance vibrations in steam generator (SG) tubes during steam line break depressurization. A member of the NRC staff believed that such vibrations could affect the validity of previous SG tube leak and rupture analyses (Ref. 1). This NRC staff member essentially postulated the following two potentially risk-significant events that are not fully addressed as design-basis accidents in final safety analysis reports, industry analyses, the NRC's Standard Review Plan (SRP) (Refs. 2 and 3),[1] or staff reviews:

(1) Operating experience and design information suggest that the potential exists for a line breach to significantly increase SG leakage as a result of resonance vibration of SG tubes from a secondary-side blowdown.

(2) Multiple SG tube leaks or ruptures could cause the secondary side to overpressurize and cause a steam line break that could then result in additional SG tube leaks or ruptures.

A letter from Nilesh Chokshi to Ashok C. Thadani, dated May 21, 2001 (Ref. 4) describes the nature and scope of GSI-188. The objective of this report is to address the principal assertion of GSI-188. Specifically, this assertion is that the axial, bending, and cyclic loads induced in SG tubes from the shock wave and resonance vibrations resulting from a main steam line break (MSLB), or other secondary-side breaches, would lead to growth of cracks and increased SG tube leakage or ruptures outside the range of analyses and experiments done by the staff. A technical issue in GSI-188 related to calculations of the dynamic loads from an MSLB is that neither resonance vibrations nor cross-flow forces can be calculated by the one-dimensional RELAP thermal-hydraulic (TH) code that may have been previously used for similar evaluations. Another aspect of GSI-188 is its relationship to GSI-163, "Multiple Steam Generator Tube Leakage," since GSI-188 postulates a potential for multiple tube ruptures induced by the additional dynamic loads from an MSLB.

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[1] Applicable sections are 15.1.5, "Steam System Piping Failures Inside and Outside of Containment," and 15.6.3, "Radiological Consequences of Steam Generator Failure (PWR)." The reference list includes the draft update to the SRP (Ref. 3) because it documents and complies with regulatory requirements and staff positions that have been established elsewhere.

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2. PLAN FOR RESOLUTION

The NRC used the following plan to resolve the principal assertion of GSI-188:

(1) Prepare a Task Action Plan to resolve GSI-188.

(2) Use information from existing analyses, as well as new results from the NRC Office of Nuclear Regulatory Research (RES) TH calculations and sensitivity studies during an MSLB, to estimate upper-bound loads (including cyclic loads) and displacements on SG tubes and tube support plates (TSPs) using the TRAC-M code. Factors to be considered include TSP and wrapper design; crevices that are packed, open, or mixed; TSP motion; and tube locking. Review other codes for more accurate predictions and potential use. Determine the effect of other secondary system breaks on tube performance. This could include the main feedwater line, the steam line supplying steam-driven auxiliary feedwater, or other steam supply lines. If substantial growth of existing degradation is observed when using upper-bound loads, calculate more realistic loads for the integrity analyses.

(3) Estimate crack growth, if any, for a range of crack types and sizes using bounding loads and displacements (or more realistic loads and displacements if deemed necessary) in addition to the pressure stresses, and include any effects from TSP movement and cyclic loads.

(4) Based on the potential for flaw growth, as determined in item 3 above, decide whether more refined TH analyses are required to more accurately identify the forces and displacements of structures under MSLB conditions.

(5) Test degraded tubes under pressure and with axial and bending loads, simulating the MSLB and other secondary-side depressurizing loads, to validate the analytical results.

(6) Conduct analyses (similar to those described above) with refined load estimates if necessary.

(7) Evaluate whether increased steam generator tube ruptures (SGTRs) or leaks could result in secondary-side breaches, which could further increase tube leakage as a result of resonance vibration within the affected SG tube bundle.

(8) Establish the impact of GSI-188 on GSI-163.

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3. TECHNICAL FINDINGS

3.1 Thermal-Hydraulic Analyses

The TH analyses used in resolving GSI-188 are drawn from a report prepared by William J. Krotiuk, entitled “Analysis Report: Pressurized-Water Reactor Steam Generator Internal Loading Following a Main Steam or Feedwater Line Break,” dated September 2002 (Ref. 5).

The Krotiuk study includes TH calculations and sensitivity studies using the TRAC-M computer code to assess the pressure loads on the TSPs and SG tubes during an MSLB or feedwater line break (FWLB). It also contains sensitivity studies on code and model parameters including solution methods. In addition, the study includes development of a conservative estimate of loads and an evaluation of that estimate against similar analyses. Krotiuk also performed a TH assessment of flow-induced vibrations during an MSLB. Using the TH conditions calculated during the transient, Krotiuk then generated a conservative estimate of flow-induced vibration displacement and frequency assuming steady-state behavior.

Specifically, the Krotiuk report provides the SG internal pressure loadings following an MSLB or FWLB, which can affect the structural integrity of the SG tubes. The pressure loadings developed through this analysis were then used in a structural assessment of SG tubes to determine the potential for flaw growth that might lead to increased tube leakage or ruptures. Toward that end, Krotiuk used the TRAC-M code to calculate upper-bound pressure loadings on the TSPs in a Westinghouse Model 51 SG. Specifically, the cases analyzed for this study include a guillotine MSLB near the SG nozzle, a flow restrictor-limited MSLB near the SG nozzle, and a guillotine FWLB near the SG nozzle. Krotiuk then compared the pressure loads calculated using the TRAC-M code against similar calculations contained in the Westinghouse “Model 51 Steam Generator Limited Tube Support Plate Displacement Analysis for Dented or Packed Tube to Tube Support Plate Crevices,” dated August 1996 (Ref. 6). Additionally, Krotiuk compared the TRAC-M results against the results of a hand calculation performed using the Moody choked-flow method combined with calculations to follow the transport of the depressurization wave originating at the break location. In addition to the verification provided by comparing the results of the TRAC-M calculation with the Moody/acoustic hand calculation, Krotiuk also analyzed the Edwards Pipe Blowdown Experiment and the Loss-of-Fluid Test (LOFT) Semiscale Blowdown Test using the TRAC-M computer code. Results from the TRAC-M analysis of these two tests agree well with experimental measurements. Therefore, the staff concluded that the pressure loads calculated by Krotiuk are reliable.

The Krotiuk TRAC-M analysis, the Westinghouse analysis, and the Moody/acoustic hand calculation all conclude that a guillotine rupture of the steam line at hot standby conditions produces the largest pressure loadings on the TSPs. The peak loadings on the upper TSPs, calculated using TRAC-M, are close in value to those calculated using the Moody/acoustic method. The TRAC-M results are also close to the results of the TRANFLO and RELAP5 analysis presented in the Westinghouse report.

The Krotiuk report also presents calculated pressure loads on SG tubes at the bottom of the SG and at the SG tube bend following an MSLB. In addition, the report presents pressure differentials for the cylindrical shroud, which separates the primary boiling flow region around the SG tubes from the surrounding annular area through which feedwater flows. These additional pressure loads can directly or indirectly affect the integrity of the SG tubes. This is because the cylindrical shroud supports the TSPs, and, therefore, loads on the shroud may be transmitted to the SG tubes.

The Krotiuk TRAC-M analysis also indicates that the pressure loadings from an FWLB are substantially lower than those resulting from an MSLB. Therefore, an FWLB need not be further considered.

The assessment of the SG analyses using the TRAC-M computer code and the hand calculation using the Moody/acoustic method reveals that the primary loads are developed by the short-term TH and acoustic effects occurring in the first few seconds following the break. The study also indicates that flow-induced vibration loading, developed as the result of quasi-steady flow present after the completion of the short-term effects, produced smaller loads than the short-term loads. Consequently, a comprehensive long-term analysis was not performed.

Krotiuk recommended that a multiplier of 1.2 be applied to the results calculated using the TRAC-M model to account for the lack of a two-phase pressure drop multiplier for the irreversible form loss calculation in the current version of TRAC-M. The pressure loadings calculated using the TRAC-M code were used in a structural assessment of the SG tubes to determine whether those loadings, in addition to the differential pressure loading, contribute significantly to the growth of existing cracks.

3.2 Estimates of Upper-Bound Loads and Tube Integrity Analyses and Tests

Under contract to the NRC, Argonne National Laboratory (ANL) conducted sensitivity studies concerning the failure of flawed SG tubes using the Westinghouse Model 51 SG during an MSLB or FWLB (Ref. 7). As previously stated, the most critical transient (from the standpoint of SG tube integrity) is an MSLB from hot standby conditions. Such an event causes the highest pressure drops across the TSPs. The lateral pressure drop across individual tubes is also highest during an MSLB, but those loads are too low to cause significant bending stress (<1 ksi) in the SG tubes. The TH analysis also shows that the periods of fundamental vibration modes of the SG tubes and TSPs are sufficiently short, when compared with the rise time of the pressure pulse during the MSLB, so the inertia effects can be ignored and resonant vibration of the tubes should not be an issue (Ref. 7).

Static-elastic finite-element analyses of a Model 51 SG TSP, including the supports with and without a single tube locked to the TSP, show that the maximum TSP displacement under a unit pressure loading is reduced from 1.12 cm (0.44 in.) with no locked tubes to 0.137 cm (0.054 in.) with one locked tube. Thus, very little if any movement of the TSP is expected when a small percentage of the tubes is locked in the TSP. These displacements are consistent with industry findings (Ref. 6).

To assess “worst-case” scenarios, in which only a small number of tubes are locked, ANL developed a simplified (albeit conservative) finite-element model of the seven TSPs of a Model 51 SG, including the supporting stay rods and wedges. In that model, the stay rods and wedges are assumed to provide rigid support to the TSPs. Interaction between the TSPs was modeled by the locked SG tubes only. The tubes were assumed to be fixed to the tubesheet, which was assumed to be rigid. Approximate analyses were carried out with 1, 2, 4, and 10 tubes in each quadrant locked to the TSPs. The location of the locked tubes was selected conservatively to be at the point of maximum transverse displacement of the TSP when the tubes are freely sliding within the TSPs. Unit pressure drop (upward) analyses for each TSP show that the pressure load was primarily transferred as tensile axial load on the locked SG tube sections below the loaded TSP, although about 10 to 15 percent of the load was carried as axial compressive load in the tube section above the loaded TSP. As expected, the axial load per tube steadily decreased as the number of locked tubes increased. The analyses show that the bending stresses in the tube from TSP movement are low because the axial stiffness of the SG tubes is far greater than the bending stiffness of the TSPs, which is significantly reduced by the numerous tube holes and flow holes. Thus, the direct axial stress is the controlling factor for tube integrity. Since the stiffness of the newer TSP designs (trefoil, quatrefoil) is expected to be similar to the drill-holed TSPs, the results from these studies are applicable to the newer designs.

ANL used the results of the unit pressure drop analysis to calculate the axial loads that act on the various tube sections of the Model 51 SG under an MSLB transient pressure-drop loading on the TSPs. The ANL analysis used the TRAC-M pressure drops multiplied by an uncertainty factor of 1.5. This is conservative when compared to the factor of 1.2 recommended by Krotiuk. In the case where only a few tubes are assumed to be locked, initial analysis results show that unrealistically large loads were transferred from the TSPs to the locked SG tubes with the conservative assumption that the tubes were completely locked to the TSP under all loads. Loads will not be transferred to the tubes beyond the tube pullout load because the tube is released from the support plate. A review of tube pullout data from a retired SG from a foreign plant with drilled-hole carbon steel TSPs shows that the mean value of the tube pullout load at operating temperature was 2700 lbf (12 kN) per tube per intersection, and a reasonable upper bound (95-percent confidence limit) is 4000 lbf (18 kN) per tube per intersection, which was used for most of the tube integrity analyses. ANL also reviewed data for tubes pulled through four TSP intersections and part of the tubesheet (top 4 in.; the rest of the tubesheet-to-tube interfacial bond was removed by flame cutting before the tube pull) from a domestic nuclear power plant, which was removed from service (Table 1). Distributing the total pullout force equally among the five intersections, the mean pullout force at room temperature per intersection is 2725 lbf (12.12 kN), which is comparable to the mean pullout force of 3120 lbf (13.88 kN) for the foreign plant. (Note that this value corresponds to 2700 lbs at operating temperature, as previously discussed.) The staff recently received data from additional U.S. plants, and all of these pullout forces are consistent. The loads that can be transferred to the tube depend on the breakaway load (pullout load). The TSP design and material, tube material, environment, age of plant, and level of degradation all affect the breakaway loads. Newer plants with lower operating times and newer materials and designs (trefoil and quatrefoil) are expected to have either freely sliding TSPs or lower pullout forces than the TSPs described above. Since the 4000-lbf (18-kN) load used in this study is conservative for degraded plants, it is even more conservative for newer plants to which the results would also apply.

Even when the maximum tube pullout force is limited to more realistic values, the calculated axial tensile stresses on the locked tubes at lower elevations are close to the ultimate tensile strength if only one or two tubes are assumed to be locked at the TSPs. This alone would not suggest rupture of the locked tube if it was unflawed, because large plastic displacement of the tube would be required, and that cannot occur in the SG. However, this does imply that the tolerance for circumferential cracks in these tubes would be severely limited. It is highly improbable that only one or two tubes out of more than 3000 tubes in the SG that is experiencing degradation could be locked to the TSPs while the rest are free to slide. A more plausible assumption is that multiple tubes (at least 10 per quadrant) are locked to the TSPs. The analyses shows that if 10 neighboring tubes in a quadrant are locked to each TSP, the maximum axial load in the locked tubes is significantly reduced, and the maximum throughwall stable circumferential crack length in the tubes at all of the TSP junctions is 180°. If all of the tubes are locked, the stable throughwall crack length is 300°. The results also show that the dynamic loads transferred to the SG tubes during the transients have virtually no effect on the burst pressure and leak-rate integrity of the tubes with axial cracks, beyond the effects of differential pressure only. Therefore, the dynamic loads from an MSLB do not affect the structural integrity of the tubes with either axial or circumferential cracks and do not lead to additional leakage or ruptures in current or replacement SGs.

Although the TH results for the MSLB transient show at most one or two pressure pulse peaks, ANL conducted fatigue analyses to demonstrate that sufficient margin would exist for crack growth if the pressure-drop pulses occur repeatedly. The cyclic crack growth rate analyses show that the average growth rate for throughwall circumferential cracks just before rupture is on the order of only 0.1°/cycle. With as few as 16 tubes locked (4 tubes per quadrant), circumferential throughwall cracks that are less than or equal to 85° in extent would not grow to failure. Similarly, with 40 tubes locked (10 tubes per quadrant), cracks that are less than or equal to 230° in extent would not grow to failure. In addition, if the cracks are only partially throughwall, even longer cracks can be tolerated. The analyses were conducted using approximately 75 cycles at the peak load. As previously discussed and based on the TH results, an MSLB produces only one to two pressure pulse peaks. Therefore, no crack growth is expected under an MSLB attributable to resonant vibrations.

Table 1 Summary of Tube Pullout Force Data from the Domestic Plant Across Four TSPs and Partial (top 4 in.) Tubesheet Intersections

Tube Number	Breakaway Pressure (psi/kPa)	Multiplier (in.^{2}/cm^2)	Force (lbf/kN)	Force per Intersection (lbf/kN)
R14 C55	2100/14500	3.534/21.6	7421/33.01	1484/6.6
R5 C17	3500/24100	4.472/28.9	15652/69.62	3130/13.9
R45 C540	3800/26200	3.534/21.6	13429/59.73	2685/11.9
R5 C51	2000/13790	3.534/21.6	7068/31.44	1413/6.2
R7 C24	4400/30340	4.472/28.9	19677/87.52	3935/17.5
R4 C43	3000/20690	3.534/21.6	10602/47.16	2120.4/9.4
R17 C90	4800/33100	4.472/28.9	21466/95.48	4293/19.0
R39 C57	2800/19310	4.472/28.9	12522/55.83	2504/11.1
R5 C4	3200/22060	4.472/28.9	14310/63.65	2862/12.7
R13 C89	3000/20690	4.472/28.9	13416/59.67	2683/11.9
R33 C33	3200/22060	4.472/28.9	14310/63.65	2862/12.7
Mean per Intersection				2725/12.1

To confirm results from the tube integrity analyses, burst tests were conducted on 36-in. long Alloy 600TT SG tubes with 1-in. long axial electro-discharge machining (EDM) notches and 240°, 270°, and 300° circumferential EDM notches at the clamped end and the other end simply supported. Various transverse loads were then hung at the midsection to produce bending loads. The results of burst tests show that the transverse load had a significantly more pronounced effect on the burst pressure of specimens with circumferential EDM notches than on those with axial EDM notches. For the part-throughwall axial notch, the ligament rupture pressure increased slightly with increasing transverse load. By contrast, the burst pressure of tubes containing a throughwall axial notch was relatively insensitive to the transverse load. In addition, for specimens with a throughwall circumferential notch, the maximum notch opening displacement decreased and the burst pressure increased with decreasing transverse load. As previously discussed, the bending loads from TSP movement are negligible compared to direct axial loads from TSP movement and will not significantly affect the burst pressure under MSLB conditions. These tests validated model predictions for burst pressure and crack opening as a function of transverse loads.

As previously noted, industry calculations using RELAP5 and NRC staff calculations using the TRAC-M code yield comparable results for pressure drops across the TSPs as a result of an MSLB. In addition, both the industry and the NRC staff have undertaken bounding analyses of the pressure drops that yielded comparable results. Use of these conservative pressure drops from the TH results in tube integrity analyses shows that the dynamic loads had little effect on the propagation of existing flaws. Thus, there is no need for additional TH analysis to better define the loads for integrity evaluations.

3.3 Increased SGTRs or Leaks Inducing Secondary-Side Breaches

GSI-188 asserts that multiple SG tube leaks or ruptures could cause the secondary side to overpressurize and cause a steam line break that could then result in additional SG tube leaks or ruptures. In the event of a significant SGTR or leak, the reactor would scram and the operators would have to identify the source of the leak. The secondary-side radiation alarms would be activated, alerting the operators that an SG is the source of the leak. If the operators act quickly, they can identify which generator is leaking; however, if they wait, the contaminated water will reach the condenser, and all of the SGs will have contaminated water on the secondary side from the auxiliary feedwater system. The immediate operator action is to reduce the primary pressure to a value below the secondary-side pressure to stop the leaking of contaminated water out of the primary system. This is accomplished by isolating the SG with the leaking tube(s) and opening the steam dump valves on the nonleaking SGs.

The maximum pressure that the secondary side can experience is determined by the setpoints on the secondary-side safety relief valves, which are normally set a small percentage above normal operating pressures. Because the components are designed with much larger margins, no secondary-side breaches are expected.

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4. SUMMARY, CONCLUSIONS, AND CLOSURE

This report describes the approach that the NRC staff used to resolve the principal assertion of GSI-188 and associated issues and provides the basis for closure. Specifically, the principal assertion is that the axial, bending, and cyclic loads induced in SG tubes by the additional dynamic loading from an MSLB or other secondary-side breaches would lead to growth of cracks and increased SG tube leakage or ruptures beyond the effects of differential pressure stress alone. Also, a proposed scenario suggested that multiple SG tube leaks or ruptures could cause the secondary side to overpressurize and cause a steam line break that could then result in additional SG tube leaks or ruptures.

To address the structural integrity of degraded tubes under the dynamic loads of an MSLB or other secondary-side breaches, TH evaluations of the pressure loads were conducted and used in structural analyses. In his TH work, Krotiuk estimated conservative values of differential pressures on the TSPs by using the TRAC-M computer code and Moody/acoustic hand calculations. These two evaluations produced similar results. Krotiuk's results were also similar to results from Westinghouse analyses using TRANFLO and RELAP5. The TRAC-M code was successfully benchmarked by analyzing the Edwards Pipe Blowdown Experiment and the LOFT Semiscale Blowdown Test. Therefore, the staff concluded that the conservative pressure loads calculated by Krotiuk are reliable, and those loads were used for the integrity analyses. The TH calculations determined that of all secondary-side breaches, the MSLB produced the highest pressure loads.

The structural analyses of tube integrity conducted at ANL using the conservatively adjusted Krotiuk results for MSLB show that bending loads transmitted to the tubes from TSP movement were low. Therefore, these loads will have minimal effect on the structural integrity of the tubes. The results also show that when 1 to 2 percent of the tubes are locked in the TSPs, the axial loading imposed on the SG tubes from MSLB dynamic loads does not significantly affect the structural integrity of even severely degraded tubes. Consequently, the staff concluded that dynamic loads from an MSLB will not affect the structural integrity of tubes in service and will not lead to additional leakage or ruptures beyond what would be determined using differential pressure alone. Therefore, the principal assertion of GSI-188 is not substantiated, and the issue is closed.

The staff also evaluated the contention that multiple SG tube leaks or ruptures could lead to additional secondary-side breaches. This evaluation led the staff to conclude that because the secondary-side pressures cannot exceed the relatively low pressure of the relief valve setpoints, there is virtually no potential for failures based on design margins. Therefore, the principal assertion is not substantiated, and the issue is closed.

The results of the structural tube integrity evaluations from Reference 7 show that the dynamic loads from an MSLB or FWLB will not significantly affect tube failure or leakage. Thus, these dynamic loads need not be considered in evaluating the potential for multiple tube ruptures under GSI-163.

The staff met with the NRC's Advisory Committee on Reactor Safeguards (ACRS), Subcommittees on Materials and Metallurgy and Thermal-Hydraulics, on February 3–4, 2004, and with the main Committee on February 5, 2004, to discuss progress on tasks in the Steam Generator Action Plan, which include Task 3.1 related to the principal assertion of GSI-188. The staff presented the technical basis for resolution of the principal assertion related to effects of dynamic loads on tube integrity during an MSLB. In a letter, dated May 21, 2004, to W.D. Travers (the NRC's Executive Director for Operations at that time), the ACRS agreed that "the analyses of the effects of depressurization during an MSLB on tube integrity have been completed, and item 3.1 is appropriately closed out" (Ref. 8). Therefore, the ACRS supports the closeout of the principal assertion of GSI-188.

5. REFERENCES

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