September 18, 2001

MEMORANDUM TO: William H. Bateman, Chief
Materials and Chemical Engineering Branch
Division of Engineering

FROM: Edmund J. Sullivan, Chief **/ra/**
Component Integrity & Chemical Engineering Section
Materials and Chemical Engineering Branch

SUBJECT: NRC STAFF COMMENTS ON STEAM GENERATOR INSPECTION INTERVALS

At the conclusion of the August 29, 2001, meeting with industry on NEI 97-06, "Steam Generator Program Guidelines," the staff indicated that it would review the information presented on prescriptive inspection intervals in more detail and proposed that a telephone conference call be scheduled to discuss its comments. The staff has completed a preliminary review of the information presented and has prepared the attached comments, which include additional limitations the staff believes should be included on proposed inspection intervals and information the staff needs to complete its review. By copy of this memorandum, these comments are being provided to industry and other external stakeholders.

Attachment: As stated

CONTACT: E. L. Murphy, EMCB/DE
415-2710

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Prescriptive Inspection Interval Restrictions

Preliminary Evaluation
Request for Additional Information

1. <u>Industry Proposal</u>:

The industry is proposing that maximum inspection intervals not exceed the following:

- For SGs with Alloy 600 MA tubing, inspection intervals shall not exceed one fuel cycle
- For SGs with Alloy 600 TT or 690 TT tubing with "active' degradation, inspection intervals shall not exceed one fuel cycle
- For SGs with Alloy 600 TT tubing and no active degradation, inspect 100% of tubes in 120, 90, 60, 60, ... EFPM. More specifically, inspect 50% of the tubes by the refueling outage nearest the mid point of period and the remaining 50% by the refueling outage near the end of the period. No SG can operate for more than two refueling cycles without being inspected.
- For SGs with Alloy 690 TT tubing and no active degradation, inspect 100% of tubes in 144, 108, 72, 60, 60, ... EFPM. More specifically, inspect 50% of the tubes by the refueling outage nearest the mid point of period and the remaining 50% by the refueling outage near the end of the period. No SG can operate for more than three refueling cycles without being inspected.

These inspection intervals would also needed to be supported by a degradation assessment and an operational assessment.

"Active degradation" is not defined in the industry proposal. "Active damage mechanisms" are defined in the EPRI guidelines as follows:

- A combination of ten or more new indications of degradation (>=20% TW) and previous indications of degradation which display an adjusted, average growth rate equal to or greater than 25% of the repair limit per cycle in any one SG, or
- one or more new or previously identified indications of degradation, including cracks, which display a growth greater than or equal to the repair limit in one cycle of operation.

2. <u>Discussion</u>

Plants with Alloy 600 TT or 690 TT tubing with no active degradation would be permitted to implement multi-fuel cycle inspection intervals. For plants with Alloy 600 TT tubing and implementing 22 EFPM fuel cycles, the allowed inspection intervals (assuming successful outcome of operational assessment) would be two fuel cycles (44 EFPM) for the initial 220 EFPM following the first refueling outage. Beyond 220 EFPM, inspection intervals would alternate between one and two fuels cycles ad infinitum. For plants with Alloy 600 TT tubing and implementing 12 EFPM fuel cycles, the allowed inspection interval would be two fuel cycles (24 EFPM) throughout the remaining life of the steam generators (if supported by an operational assessment.

Attachment

For plants with Alloy 690 TT tubing and implementing 22 EFPM fuel cycles, the allowed inspection intervals (assuming successful outcome of operational assessment) would be three fuel cycles (66 EFPM) for the initial 176 EFPM following the first refueling outage. Beyond 176 EFPM, inspection intervals would alternate between one and two fuels cycles ad infinitum. For plants with Alloy 690 TT tubing and implementing 12 EFPM fuel cycles, the allowed inspection interval would be three fuel cycles (36 EFPM) for the initial 360 EFPM following the first refueling outage. Thus, with the exception of plants with very short fuel cycles, the proposed multi-cycle limitations would extend beyond the existing regulatory restriction of 40 calendar months for plants employing improved SG tubing material (Alloy 600 TT or Alloy 690 TT).

The industry has submitted very limited technical justification for this proposal (NRC/NEI meeting, August 29, 2001). The industry bases its proposal on the following:

- Plants have experienced many years of operating experience using Alloy 600 TT and 690 TT tubing. Alloy 600 TT plants have operated for as much as 15 EFPY with no confirmed corrosion. Alloy 690 TT plants have operated for as long as 8 EFPY with no confirmed corrosion.

- With increasing numbers of new and replacement steam generators, the aggregate of the Alloy 600 TT and 690 TT steam generators are sampled and inspected with increasing frequency.

- If any degradation is detected in any 600 TT or 690 TT steam generator, it must be considered in the degradation assessments of all other plants with the same tubing material and modify the inspection plans accordingly.

3. Evaluation

The proposed inspection interval limitations are prescriptive rather than performance based. This is necessary since industry guidelines for performing tube integrity assessments have significant shortcomings (documented in staff's August 2, 2001 letter to NEI) which limit their effectiveness in determining how long the SGs may be operated between inspections without exceeding the tube integrity performance criteria.

3.1 Proposed One Fuel Cycle Limitation

The proposed 1 fuel cycle limitation for the cases cited above are generally consistent with the existing regulatory restriction of 24 calendar months for plants with degradation activity of sufficient magnitude to be category C-2 or C-3 in accordance with the plant technical specifications. The current 24 calendar month restriction typically accommodates a complete fuel cycle unless the plant experiences significant down time during the cycle. In cases where plants have experienced significant down time, the staff has approved on a case basis extension of the inspection interval beyond 24 calendar months to the end of the fuel cycle. Staff approval in these cases has typically includes consideration of the licensee's operational assessment which supports operation to the end of the fuel cycle.

An inspection interval consisting of one fuel cycle will be subject to an operational assessment demonstrating that there is reasonable assurance that the tube integrity performance criteria will be maintained for the duration of the cycle. There have been relatively few cases where operational assessments or tube integrity considerations in general have led to inspection intervals less than a fuel cycle since the mid-1980's. Typically, no more than one or two plants at a time from among the PWR fleet are performing mid-cycle inspections. In such cases, the licensee's may elect to implement "mid-cycle" inspections only after extensive discussions with the NRC staff concerning the need for such inspections. Thus, although industry guidelines for performing operational assessments contain a number of shortcomings, the proposed one cycle restriction for inspection intervals for plants with active degradation will not result in any significant increase in inspection interval compared to existing requirements or current practice. This finding assumes that PWR fuel cycles will continue to be limited to less than 24 EFPY. The staff understands that fuel cycles currently range from 12 to 22 EFPY.

3.2 Proposed Multi-Cycle Limitation

3.2.1 Operating Experience

The industry maintains that the proposed multi-cycle operating intervals are justified, in part, by operating experience showing no confirmed corrosion after 15 EFPY with Alloy 600 TT tubing and 8 EFPY with 690 TT tubing. However, little supporting information has been provided. The industry is requested to provide comprehensive information on degradation experience with tubes and sleeves fabricated from these materials, both foreign and domestic.

The staff notes that the EPRI Report No. 1000805, "Steam Generator Progress Report," Revision 15, dated November 2000, reports that hundreds of Alloy 600 TT tubes have been plugged worldwide due to "stress corrosion cracking" (SCC). Some of this plugging took place after less than four calendar years of operation. When questioned about this at the August 29, 2001 meeting with the NRC staff, an industry representative stated that none of these hundreds of tubes had been removed for laboratory examination to confirm that the indications found by inspection were actually stress corrosion cracks. Thus, it seems it is more appropriate to conclude that the absence of corrosion or SCC in Alloy 600 TT tubing to date is not confirmed. The industry explanation does not inspire confidence that Alloy 600 TT tubing can be fully expected to operate five, ten, or fifteen years without SCC. Industry should provide the staff with additional information concerning the reported SCC and whether there is a preponderance of evidence that none of the hundreds of reported cracks are actually SCC.

At Turkey Point 3 in March 2000, the licensee plugged 23 tubes (Alloy 600 TT) containing circumferential indications near the top of the tube sheet. In addition, the licensee identified 41 volumetric pit-like indications near the top of the tubesheet. The Turkey Point 3 SGs had been operated for a total of 12.2 EFPY at the time of the inspection. The licensee conservatively plugged the affected tubes. The licensee and the staff believe that the circumferential indications are most likely an inspection or geometry artifact rather than circumferential flaws. Note, the licensee reports that the 2000 inspection involved the first widespread use of the plus-point probe. The pit-like indications may be indicative of localized corrosion attack. Similar type pit-like indications have also been reported at Turkey Point 4. The upcoming inspections in Fall 2001 at Turkey Point 3 may shed additional light on whether there is corrosion degradation present. The finding of new indications not seen in 2000 might well indicate the presence of corrosion related degradation.

Byron Unit 2 with Alloy 600 TT tubing is currently operating with a small amount of primary to secondary leakage. The Byron 2 SGs have been operated for 10 EFPY. Byron 2 has plugged over 200 tubes in the past due to indications of wear and other mechanically induced flaws (e.g., from loose parts), but has not previously reported corrosion related indications. Byron 2 was shutdown in 1996 to repair a leak caused by a foreign object.

The available operating experience provides little basis to conclude that the time to detectable cracking of Alloy 600 TT tubing extends more than a few years. Alloy 690 TT is expected to prove more SCC resistant than Alloy 600 TT under expected chemistry environments. Industry must be able to build a better case regarding SCC experience to date in order to justify its proposal for multi-cycle inspection intervals.

Alloy 600 TT and 690 TT tubing is not expected to demonstrate improved resistance against wear or foreign objected induced damage compared to Alloy 600 MA tubing. A number of plants with Alloy 600 TT tubing have experienced significant wear degradation and foreign object induced degradation (e.g., Byron 2). Improved designs for replacement SGs, however, should improve tube wear performance.

The rest of the staff's evaluation below is based on the premise that the industry provides the requested information on operating experience and that there is a preponderance of evidence than none of the hundreds of reported cracks are actually SCC. If so, the staff believes that multi-cycle inspection intervals extending beyond the current 40 month regulatory requirement are acceptable for SGs with Alloy 600 TT and 690 TT tubing under certain conditions as outlined below with reasonable assurance that the tube integrity performance criteria will be maintained with no significant increase in risk.

3.2.2 Operational Assessment Considerations

One necessary condition for multi-cycle inspection intervals, as proposed by the industry, is that the SGs are free from "active degradation." "Active degradation" is not defined in the industry guidelines. Presumably, the definition in the guidelines for "active damage mechanisms" (given above) is what is intended. Under the industry's definition, limited amounts of degradation activity would not constitute "degradation activity" such that multi-cycle inspection intervals may still be implemented. However, the inspection interval would need to be supported by operational and degradation assessments demonstrating that the performance criteria will be met prior to the next scheduled inspection.

The staff believes that industry guidelines for performing tube integrity assessments have significant shortcomings (documented in staff's August 2, 2001 letter to NEI) which limit their effectiveness in determining how long the SGs may be operated between inspections without exceeding the tube integrity performance criteria. The staff concerns in this respect are most acute for cracks. The staff notes that had Indian Point been shutdown and inspected with appropriate techniques one day prior to the failure event, the u-bend indications by themselves would not have been “active degradation” by the industry’s definition. Pending resolution of the issues pertaining to the industry guidelines, the staff believes that the definition of active degradation needs to be tightened up such that there is reasonable assurance that known degradation mechanisms will be adequately managed pending the next scheduled steam generator inspection. Specifically:

- The industry definition of “active degradation” is ambiguous in terms of whether it applies to individual degradation mechanisms or to degradation in general. The staff believes that the definition should reflect the total state of degradation in each SG for all mechanisms.

- The use of the word “cycle” in the industry definition is ambiguous with respect to whether it refers to fuel cycle or inspection cycle (i.e., interval). Since it is total growth over the inspection interval that is of interest, “cycle” should be revised to state “inspection interval.”

- The industry definition gives no consideration to whether the past inspection interval may consist of a single fuel cycle and is to be followed by an interval consisting of several cycles. Growth rates which lead to innocuous growth increments over a single fuel cycle may lead to significant growth increments over two or three cycles. In cases where a single cycle inspection interval is to be followed by a multiple cycle inspection interval, the growth rate (per interval) observed during the previous operating interval should be scaled upward to reflect the length of the next scheduled inspection interval.

- Staff concerns with respect to industry guidelines for performing tube integrity assessments are most acute for SCC. Plants with detected SCC should not be implementing multi-cycle inspection intervals. Thus, any SCC indication should be considered to constitute “active degradation.”

An industry representative stated during the NEI/NRC staff meeting on August 29, 2001 that observed damage from loose parts and foreign objects could be considered inactive once the causal objects are retrieved from the steam generators. Actually, there is nothing in the industry’s definition of “active damage mechanisms” which appears to accommodate this statement. In the staff’s judgement, the foreign object/loose part damage mechanism should be considered active until a subsequent inspection confirms no further damage from objects which may not have been detected previously.

Under the industry’s proposal, plants with 690 TT tubing could go directly from single cycle to three cycle inspection intervals. The staff is concerned that projecting past growth rates over a single cycle to growth rates over the next three cycles will unduly magnify the growth rate uncertainty. Plants with 690 TT tubing should implement a two cycle inspection interval prior to implementing a three cycle inspection interval.

A recent paper titled “Structural Integrity of SG Tubes with AVB Wear,” by R. Keating (W), H. Lagally (W), and R. Lieder (Seabrook), June 2001, maintains that ligament failure of flat wear scars, 0.3 inches axial length, does not constitute “burst.” Thus, the paper concludes that structural performance criteria do not apply to such ligament failure and that the minimum required ligament is controlled by accident leakage criterion. This is satisfied by limiting probability of ligament tearing at MSLB pressure to an appropriate value (e.g., 95%). The staff notes that similar arguments could applied to other volumetric flaw types such as pitting or wastage. The staff further notes that ligament tearing of the wear scar may lead to “hole” with diameter of approx. 0.3 inches, not a throughwall crack with limited crack opening displacement. Arguably, this is “burst.” Irrespective, the staff is concerned that a tube whose condition is such that it may leak several dozen gpm under pressures slightly above MSLB pressure under normal temperature conditions may have significant implications for severe accident risk. The staff believes that the risk implications of the proposed approach needs to be evaluated before being implemented as part of tube integrity assessments, particularly from the standpoint of supporting multi-cycle inspection intervals.

3.3.3 Degradation Assessment Considerations

Given that known degradation mechanisms are adequately managed during multi-cycle inspection intervals, the next issue to be considered is whether the multi-cycle inspection interval ensures that potential degradation mechanisms (i.e., mechanisms which have not previously identified but which could potentially occur in the future) or anticipated degradation mechanisms (degradation mechanisms not previously identified at the site, but which are anticipated in the future based on experience at similar plants) do not exceed the performance criteria. This is the apparent purpose of the degradation assessment cited in the industry's prescriptive inspection interval proposal. The staff notes, however, that the concept of degradation assessment in this context is not fully defined in NEI 97-06 or supporting EPRI guidelines. According to these guidelines, degradation assessment is intended to assess potential degradation mechanisms, anticipated mechanisms, and degradation mechanisms previously identified at the site to identify the necessary inspection techniques to detect these mechanisms. Degradation assessments may include assessment of when anticipated mechanisms may begin to reach detectable levels. However, the guidelines do not address degradation assessments from the standpoint of predicting when potential or anticipated mechanisms may begin to challenge the performance criteria. Furthermore, the guidelines do not address how licensees should establish that the performance criteria will be maintained for the next two or three fuel cycles given that potential or anticipated degradation has initiated, but not yet reached the NDE detection threshold.

3.3.4 Additional Restrictions on Multi-Cycle Inspection Intervals to Ensure Tube Integrity

In the absence of acceptable quantitative methods for performing degradation assessments, the staff concludes that multi-cycle inspection intervals should not cross an equivalent, accumulated operating time threshold beyond which detectable cracking has been detected industry-wide for Alloy 600 TT or 690 TT, as applicable. The initial finding (industry wide) of indications associated with a cracking mechanism should define the "time to detectable cracking threshold" for Alloy 600 TT SGs or Alloy 690 TT, as applicable. The time to cracking threshold should be normalized to a reference temperature. Inspections shall be performed at each refueling outage after the equivalent accumulated full power operating time on the SGs (i.e., normalized for reference temperature) exceeds 75% of the "time to detectable cracking threshold." The 75% is intended to allow for variations in material micro-structure and stress levels from plant to plant. The "time to detectable cracking" should be revised downward as necessary to lower bound subsequent findings (industry wide) of crack indications occurring after equivalent, accumulated full power operating times less than that observed earlier.

Until the initial occurrence of SCC for either tubing material type, lead plants (in terms of equivalent accumulated operating time) may continue to implement multi-cycle inspection intervals provided they continue to satisfy the no active degradation criteria in all other respects.

The staff believes that the likelihood of degradation exceeding the performance criteria and risk can be maintained acceptably low as follows:

- Inspection intervals extending over multiple fuel cycles should be preceded and followed by inspections which utilize qualified NDE techniques for all potential degradation mechanisms and locations. Axial SCC is a potential degradation mechanism over the entire tube length. Circumferential SCC is a potential degradation mechanism at locations of geometry variations with length, including expansion transitions, u-bends, and dings or dents.

- Data analysts must frequently make judgements concerning whether flaw-like indications are in fact flaws or whether they due to tube surface deposits, tube and/or tube geometry, or other inspection artifacts. Such indications should be assessed conservatively. That the presence of degradation is "unconfirmed" (e.g., through tube pulls, UT examination) is not a sufficient basis in-of-itself to conclude that degradation is not active. Indications not detected in previous inspections or which have changed compared to previous inspections may be service induced flaws. In cases where the affected tube and location along the tube has not been previously inspected with a qualified technique, it may be difficult to make a firm determination on the nature of the indication with reasonable confidence. (This further underscores the importance of having baseline or early inspection data for all tubes and locations with techniques which are qualified for all potential degradation mechanisms.) In the absence of such confidence, the indication should be considered to be a service induced flaw.

- Primary-to-secondary leakage may be indicative of a degradation mechanism not previously detected or of previously observed degradation that is growing throughwall at rates higher than anticipated. For plants implementing multi-cycle inspection intervals, the staff believes that the occurrence of such leakage should trigger an inspection at the next refueling outage. Such inspections will significantly enhance the likelihood that the tube integrity performance criteria will continue to be maintained and provide added assurance that tubing conditions failing to meet the performance criteria will be promptly detected. To ensure the full benefit of this restriction, the leakage threshold necessitating a refueling outage inspection should be as low as practical, about 5 gpd. The refueling outage inspection should be performed in accordance with the EPRI SG Examination Guidelines for leaker forced outages as a minimum.

The above restrictions ensure that conditions which may impair tube integrity will be promptly detected, and that plants will revert to single cycle inspection intervals before tube integrity is challenged. These restrictions ensure that from an industry wide perspective, risk will not increase from presently assumed levels as a result of multi-cycle inspection intervals and, in fact, will likely be reduced significantly by virtue of the increased SCC resistance of the Alloy 600 TT and 690 TT tubing. These restrictions also ensure that risk will not be concentrated significantly among lead plants.

4. Preliminary Conclusions

The staff believes that the industry's prescriptive proposal should not significantly increase risk subject to certain additional provisions identified below. This finding is contingent on receipt of additional information from industry indicating a clear preponderance of evidence that early experience with Alloy 600 TT and 690 TT tubing and sleeves has been crack free. That said, the staff recommends that the industry revise its proposal to incorporate these provisions which are as follows:

1. The one fuel cycle limitation should be one fuel cycle or 24 EFPM, whichever is shorter. Similarly, the two cycle limitation should not exceed 48 EFPM and the three cycle limitation should not exceed 72 EFPM.

2. Definition of "active damage mechanism" should be redefined as follows:

   Active ~~damage mechanism~~ degradation:

   – A combination of ten or more new indications of degradation (>=20% TW) and previous indications of degradation which display an adjusted, average growth rate equal to or greater than 25% of the repair limit per ~~cycle~~ **inspection interval** in any one SG. **Adjusted growth rate refers to scaling the growth rate for the previous inspection interval to reflect the length of the next scheduled inspection interval. For example, if the next schedule inspection interval is twice the length of the previous interval, the adjusted growth rate is twice the value observed over the previous inspection interval.**

   – one or more new or previously identified indications of degradation~~, including cracks,~~ which display ~~a~~ **an adjusted** growth **rate** greater than or equal to the repair limit in ~~one cycle of operation~~ **per inspection interval**.

   – damage related to loose parts or foreign objects is subject to the above criteria, irrespective of whether the causal objects are believed to have been retrieved.

   – **any indications associated with cracks**

3. For plants with Alloy 690 TT tubing, three cycle inspection intervals shall be preceded by a two cycle inspection interval.

4. The initial finding (industry wide) of indications associated with a cracking mechanism shall define the "time to detectable cracking threshold" for Alloy 600 TT SGs or Alloy 690 TT, as applicable. The time to cracking threshold shall be normalized to a reference temperature. The licensee shall take action as necessary to ensure that cognizant personnel at all plants utilizing the same tubing material are promptly informed of the finding. Upon receipt of such information, the other licensees shall consider the information as part of the degradation assessment which is to be performed prior to the next scheduled <u>refueling</u> outage to assess the need for modification to the schedule for the next SG inspection. Inspections shall be performed at each refueling outage after the equivalent accumulated full power operating time on the SGs (i.e., normalized for reference temperature) exceeds 75% of the "time to detectable cracking threshold."

5. The "time to detectable cracking" should be revised downward as necessary to lower bound subsequent findings (industry wide) of crack indications occurring after

equivalent, accumulated full power operating times less than that observed earlier. Again, the affected licensee shall take action as necessary to ensure that cognizant personnel at all plants utilizing the same tubing material are promptly informed of the finding. The other licensees shall respond as described in item 4.

6. For purposes of tube integrity assessments supporting multi-cycle inspection intervals, ligament tearing of volumetric flaws shall be considered "burst." That is, volumetric flaws should have a factor of three margin against such ligament tearing.

7. Inspection intervals extending over multiple fuel cycles should be preceded and followed by inspections which utilize qualified NDE techniques for all potential degradation mechanisms and locations. Axial SCC is a potential degradation mechanism over the entire tube length. Circumferential SCC is a potential degradation mechanism at locations of geometry variations with length, including expansion transitions, u-bends, and dings or dents.

8. Indications shall be considered service induced flaw indications in the absence of compelling evidence that the indications are actually associated with manufacturing flaws, surface deposits, tube and/or tube geometry variations, or other inspection artifacts for purposes of determinating whether there is active degradation.

9. If primary-to-secondary leakage exceeds 5 gpd prior to shutdown for a refueling outage, an inspection in accordance with the EPRI SG Examination Guidelines for leaker forced outages shall be performed as a minimum.

5. Requested Information

1. Provide detailed information on degradation experience with tubes and sleeves fabricated from Alloy 600 TT and 690 TT, both foreign and domestic.

2. Provide additional information concerning hundreds of reported SCC indications in 600 TT tubing worldwide and discuss whether there is a preponderance of evidence than none of these indications are actually SCC.

3. Submit revised, complete proposal for prescriptive limits on inspection intervals, including supporting definitions.

4. Submit proposed industry protocol for ensuring that the initial occurrence of SCC, industry wide, for Alloy 600 TT or Alloy 690 TT is communicated to all applicable licensees. This protocol should identify the reference temperature at which the "time to detectable cracking" is determined. This protocol should also address the communication of subsequent findings (industry wide) of crack indications occurring after equivalent, accumulated full power operating times less than that observed earlier.