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MAY 20 1982

MEMORANDUM FOR: Gus Lainas, Assistant Director
for Safety Assessment
Division of Licensing

FROM: Stephen H. Hanauer, Director
Division of Safety Technology

SUBJECT: PROPOSED RECOMMENDATIONS REGARDING STEAM GENERATOR TUBE INTEGRITY

References: Memorandum from H. Denton to NRR Division Directors, "Development of Generic Recommendations Based on the Review of the January 25, 1982 Steam Generator Tube Rupture at Ginna," dated May 3, 1982.

The reference memorandum requests that each NRR Division provide generic recommendations relative to the Ginna Steam Generator Tube Rupture event. As you know, the issue of steam generator tube integrity has been studied under USIs A-3, 4, and 5 since about 1978. A draft report on this issue (NUREG-0844) has been prepared and is currently under management review. The principal focus of this study has been directed toward tube degradation resulting from various corrosion related mechanisms (e.g., wastage, stress corrosion cracking and denting). Consequently, the proposed recommendations developed under USIs A-3, 4, and 5 are directed toward minimizing corrosion induced failure by various mechanisms, and do not consider the failure mechanisms believed to be responsible for the tube rupture at Ginna (loose parts and tube stability). DST has not performed a detailed evaluation of the Ginna tube failure.

Our proposed generic recommendations regarding steam generator tube integrity are presented in the attached enclosure. Further information on these recommendations is contained in the draft copy of NUREG-0844 which you previously have reviewed. We have included a recommendation (No. 9) in the enclosure regarding improvements in inservice inspection; this is a major consideration in NUREG-0844. The new inservice inspection program is based, in part, on the tolerable number of postulated tube failures that could occur concurrently with a loss of coolant accident or main steam line break. The methods and assumptions to be used in these accident analyses to determine the tolerable number of postulated tube failures are currently under review by DSI. We will report to you at a later date regarding the required licensee analysis following completion of DSI's review of the issue. These analyses, coupled with the recommended inspection procedures, will determine the number of steam generator tubes

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to be inspected in the new program. The new procedure may result in a significant increase in the number of tubes to be inspected over and above that required by R. G. 1.83.

/S/

Stephen H. Hanauer, Director
Division of Safety Technology

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Stephen H. Hanauer, Director
Division of Safety Technology

Enclosure:
As stated

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ENCLOSURE 1

GENERIC RECOMMENDATIONS REGARDING STEAM GENERATOR TUBE INTEGRITY

The following proposed recommendations are based on the information contained in NUREG-0844 (draft). The section references in the recommendations refer to that document.

(1) The recommendations in Section 6.4.4 should be implemented. These include establishing a secondary water chemistry monitoring and control program in accordance with Section 6.4.2 and a condenser inservice inspection program in accordance with Section 6.4.3. The secondary water chemistry monitoring and control program should be submitted as license amendments for NRC review and approval. The condenser inservice inspection program should be submitted by the licensee for NRC approval and incorporation in the plant's technical specifications.

(2) The technical specifications for primary to secondary steam generator leakage rate limits for all operating PWRs should be made consistent with the Standard Technical Specifications unless special, more limiting conditions have been imposed because of severe degradation. In this regard, each plant should take appropriate actions to bring its technical specifications into agreement with the STS.

(3) Eddy-current testing techniques or data evaluation techniques which are capable of eliminating tube support plate, tube sheet, denting, or other similar unwanted signal interferences and discriminating among multiple defects should be used in all steam generator inservice

inspections. Each PWR plant should submit the eddy-current testing techniques and evaluation procedures it is using.

(4) For PWRs licensed after January 1, 1983, upper inspection ports as described in Section 5.1.3.1 should be installed before an operating license is issued.

(5) Guidance governing the design, installation, and inspection of steam generator tube sleeves should be developed by the NRC. This guidance should include the criteria delineated in Section 6.2.2 and should be addressed in a revision of Regulatory Guide 1.121 or in a new regulatory guide.

(6) Plant Technical Specifications should be revised so that it would not be possible to avoid the performance of unscheduled ISIs by shutting down a unit just before a known leak exceeds the technical specification leakage rate limit requiring such an inspection.

(7) The staff should perform an expeditious review and recommended improvements of utility QA procedures related to secondary-system inspection, repair, and maintenance. Also, the effectiveness and practicality of continuous secondary-side loose-parts monitoring should be investigated.

(8) The feasibility of secondary-side steam generator ISI should be investigated, and appropriate requirements for such ISIs should be developed in modified or new Regulatory Guides and incorporated in plant technical specifications.

(9) Each PWR should develop a revised steam generator inservice inspection (ISI) program based on the revised ISI criteria specified in Section 5.2.3.1 and the tolerable number of concurrent postulated tube failures. . The supplementary inspection requirement in the revised ISI criteria should provide a 0.05 probability of accepting a steam generator for continued operation with greater than the defined number of tolerable degraded tubes. The new inspection program developed by each utility should be submitted for NRC approval and incorporation in the plant's technical specifications.

(10) Revised ISI criteria as specified in Section 5.2.3.1 should be incorporated by the NRC into Regulatory Guide 1.83.

allow passage through the dent restriction or at least 0.235 inch less than the original inside diameter of the tube. Even when the plugging criterion (see Section 6.0) is set at some larger probe diameter, gauging should be continued to the lower limit stated above, in order to assure adequate ISI information. Furthermore, the increment in probe diameters used for gauging should not exceed 0.070 inch. This requirement will ensure adequate sensitivity in the discrete measurement intervals of dent magnitudes.

5.1.3 Secondary Side Inservice Inspections and Loose-Parts Monitoring

5.1.3.1 Discussion

Eddy-current testing and tube gauging alone are not always sufficient to monitor and assess the condition of steam generator tubes and secondary-side steam generator internals. Steam generators are generally equipped with access ports between the tube sheet and lowest tube support plate. These ports allow periodic evaluation of sludge pile buildup, sludge lancing, and examination of secondary-side degradation.

Sludge buildup on the lower tube sheet results from corrosion of secondary-system components or intrusions into the secondary system. Residual elements in the sludge pile have been associated with various forms of tube thinning and cracking. In Westinghouse and Combustion Engineering steam generators, the lower access ports are used periodically to perform sludge lancing to remove sludge remaining from insufficient or ineffective blowdown. Sludge lancing is a water-blasting process in which a water jet from a nozzle introduced through the access port forces sludge from between the rows of tubes into the annulus between the steam generator wrapper and the tube bundle. A second flow of water introduced through the access port then flushes the sludge around the annulus to the access port on the opposite side of the steam generator where it is removed by a suction hose.

The lower steam generator access ports are also important in examining and evaluating secondary-side degradation, particularly tube support plate deformation and cracking resulting from denting. Support plate deformation and cracking are monitored by visual and photographic examinations through the lower access ports. Since cracking of the tube support plates can result in loss of lateral support for the tubes or loose parts, it is important to have this inspection capability.

In addition to inspecting the structural integrity of secondary-side steam generator components, Westinghouse has developed a finite element model used to define inspection boundaries for gauging and estimating the progression of denting. This model simulates denting by applying a uniform thermal expansion to a finite element model of the tube support plate with supports represented by the appropriate boundary conditions. The uniform thermal expansion simulates the expansion resulting from the formation of magnetite in the tube/support plate crevices. Actual field measurements of tube/support plate deformation, specifically flow-slot hourglassing and tube-support-plate-to-wrapper clearances, are used to confirm the accuracy of the model. Isostrain lines predicted by the model and empirically correlated to dent magnitudes are then used to establish tube gauging boundaries. Although this model is somewhat coarse, it has been successful in providing insight and general guidance for inspecting and evaluating the denting phenomenon.

Steam generators are generally equipped with only the lower inspection ports discussed above. Many operating units including Surry Units 1 and 2, Turkey Point Units 3 and 4, Indian Point Units 2 and 3, Trojan, and Millstone Unit 2 have found it necessary to install ports at an elevation just above the upper tube support plate. The primary reasons for installing these ports has been to evaluate and monitor the effects of denting in the upper portion of the steam generator and to remove tube specimens for examination. However, specimens removed have included tubes degraded not only by denting, but also by other modes of degradation. Before extensive hourglassing of the tube support plate flow slots, limited inspection of the upper portion of the steam generator can be conducted by photographing through the flow slots from the lower ports. This technique allows for only limited inspection and ports located at the higher elevation provide a much more effective means of inspection. Furthermore, denting usually affects the lower support plates first and when the flow slots in the lower plates close up, which has happened in several operating units, the upper portion of the steam generator secondary side is inaccessible for inspection.

Recent operating experience has suggested that the need exists for improved methods for ensuring that no loose parts exist in the secondary system. The October 2, 1979, steam generator tube rupture at Prairie Island was caused by a loose part in the secondary side of the steam generator. Similarly, the January 25, 1982, steam generator tube rupture at R.E. Ginna also may have been the result of a loose part in the secondary side of the steam generator, although a conclusive study is not complete. Thus, two of the four major domestic tube ruptures appear to be the result of loose parts on the secondary side of the steam generator. In addition, Genkai-1, a Japanese plant, experienced a steam generator tube leak (~ 0.24 gpm) because of a loose part in the secondary system on June 10, 1975.

On the basis of the staff's experience to date, it appears that a significant reduction in the frequency of steam generator tube ruptures could be accomplished by effective control of loose parts. Methods for accomplishing this objective include improved QA procedures, secondary-side ISI, and continuous loose-parts monitoring.

Utility QA procedures for secondary-side inspection, maintenance, and repair should be reviewed and updated to provide increased assurance that loose parts will not be introduced into the secondary system during inspection, maintenance, and repair procedures. This effort should also include evaluation of the Regional Offices' effectiveness in enforcing existing or new QA procedures. It appears that considerable room for improvement exists in past and current QA procedures. Periodic secondary-side inspections may also be useful in controlling loose parts. These inspections could include visual, fiberoptic, and video examinations through existing steam generator access ports. The feasibility and practicality of performing such ISIs during scheduled steam generator ISIs should be investigated, and requirements for such ISIs should be developed in modified or new Regulatory Guides and incorporated in plant technical specifications.

Loose parts can also be introduced into the secondary system through processes other than sloppy maintenance or repair procedures. Pieces from cracked support plates that may be generated during operation are an example. To protect against loose parts generated during operation or overlooked in the

QA process, the feasibility of secondary-side loose-parts monitoring should be investigated. Currently, there are requirements for loose-parts monitoring of the primary sys' m only. These requirements are delineated in Regulatory Guide 1.133, "Loose-Part Detection Program for the Primary System of Light-Water-Cooled Reactors."

Careful evaluation of these online monitoring techniques must be performed to determine their effectiveness and practicality. Loose-parts monitoring may not be feasible in steam generators, which are an inherently noisy system; however, the potential benefits from continuous monitoring of the steam generators for loose parts and vibration is sufficient to merit immediate investigation. Consequently, the staff should review and recommend improvements in utility QA procedures, related to secondary-system inspection, repair, and maintenance, and study the effectiveness and practicality of continuous loose-parts monitoring of the steam generators. If loose-parts monitoring of the secondary side of the steam generator can be shown to be practical and effective, it may be recommended that each PWR be required to conduct such monitoring.

5.1.3.2 Conclusions

In general, it is advisable that any piece of mechanical equipment be designed to facilitate periodic ISI. General Design Criterion 32, "Inspection of Reactor Coolant Pressure Boundary" (Appendix A to 10 CFR Part 50), requires that components that are part of the reactor coolant pressure boundary be designed to permit periodic inspection of critical areas to assess their structural and leaktight integrity. Access ports located between the tube sheet and first tube support plate have proved to be essential and effective for removing sludge and evaluating the integrity of the secondary side of steam generators. However, with no upper inspection ports, the upper portion of the steam generator secondary side can only be inspected to a limited degree, or not at all. In addition to being a proven necessity in some units, with and without denting, periodic visual inspection of the upper portion of the steam generator secondary side could have possibly avoided the U-bend tube rupture at the Surry Unit 2 steam generator in 1976. Other unanticipated modes of degradation could possibly be detected by this type of inspection.

Installation of inspection ports in operating steam generators can result in extended outages and additional exposure of personnel to radiation. Therefore, for those plants not yet in operation, upper ports should be installed before the operating license is issued. These ports should be located so that inspection of the upper support plate and inner row U-bend tubes can be performed.

A significant reduction in the frequency of steam generator tube failures could be accomplished by the effective control of secondary-side loose parts. Methods for accomplishing this objective include improved QA procedures, secondary-side ISI, and continuous loose-parts monitoring.

5.2 Inservice Inspection Programs

5.2.1 Current Criteria

The current criteria for frequency and scope of inservice inspection of steam generators are specified in the technical specifications of each operating

Considering the small number of tolerable tube failures determined by the systems analyses presented in this report, Tables 5.2 and 5.3 indicate that on a statistical basis the current inspection criteria in the STS or RG 1.83 are not statistically sufficient to ensure the desired level of protection.

Any sampling plan, no matter what its basis, offers some level of protection defined by its operating characteristics. It is important to know these characteristics. To obtain the operating characteristics of the STS or RG 1.83 plan would require an extensive analysis. The joint probability distribution of the number of degraded, pluggable, and defective tubes would have to be considered and one would need to consider a variety of such distributions. Tracing the calculations through three stages and compounding the problem with measurement error yields an intractable problem and no clear picture at the end, even if all the calculations could be accomplished. In contrast, the operating characteristics of the one- and two-stage sampling plans, such as those given in the preceding section, can be readily obtained and plans which offer a specified level of protection can be derived. Furthermore, it can be shown that very little efficiency is gained by using a three-stage rather than a two-stage plan.

5.2.3 Inservice Inspection Criteria

The need to link ISI plans directly to a specified level of protection, provided motivation for considering alternative plans to those given in the STS or RG 1.83.

Results of the systems analyses presented in Section 4.0 and the statistical analysis of ISI plans in Section 5.2 indicate that current ISI requirements should be revised to provide greater confidence that an intolerable number of tubes will not fail during a postulated MSLB or LOCA. Section 5.2.3.1 presents the recommended revised ISI requirements and Section 5.2.3.2 provides the basis for and a discussion of the proposed requirements.

5.2.3.1 Proposed Revised Inservice Inspection Requirements

A program for inservice inspection of steam generator tubing should be established and included in the technical specifications of each pressurized water reactor. The program should include the following requirements:

(1) Access for Inspection

- (a) Steam generators of pressurized water reactors should be designed to facilitate inspection of all tubes and the secondary side support structures and internals.

- (b) Sufficient access should be provided to perform these inspections and to plug tubes as required.

- (c) Prejob planning should be undertaken to make provisions for inspections that ensure that personnel radiation exposure is maintained as low as is reasonably achievable.

(2) Inspection Equipment and Procedures

(a) Inservice inspection should include nondestructive examination by eddy-current testing or equivalent techniques. The equipment should be capable of locating and identifying stress-corrosion cracks and tube wall thinning by chemical wastage, mechanical damage, or other causes. The equipment or data evaluation technique should be capable of eliminating interference from tube-support plates, tube sheets, and other extraneous signals.

(b) The inspection equipment should be sensitive enough to detect imperfections 20% or more through the tube wall.

(c) A suitable eddy-current inspection system could consist of (i) an internal sensing probe, (ii) a two-or-more-channel eddy-current tester, (iii) a viewing oscilloscope, (iv) a conventional two-channel strip chart recorder, and (v) a magnetic tape data recorder.

(d) Examination results and reports should be stored and maintained for the operating life of the facility.

(e) Standards consisting of similar as-manufactured steam generator tubing with known imperfections should be used to establish sensitivity and to calibrate the equipment. Where practical, these standards should include reference flaws that simulate the length, depth, and shape of actual imperfections that are characteristic of past experience.

(f) The equipment should be capable of examining the entire length of the tubes.

(g) The equipment used for eddy-current testing should be designed so that operators may be shielded or the equipment may be operated remotely to limit operator exposure to radiation.

(h) Personnel engaged in taking data and interpreting the results of the eddy-current inspection should be tested and qualified in accordance with American Society for Nondestructive Testing Standard SNT-TC-IA and supplements.

(i) The examinations should be performed according to written procedures.

(3) Baseline Inspection

(a) The full length of all tubes in all steam generators should be inspected by eddy-current or alternative techniques before service to establish a baseline condition of the tubing. This inspection should be performed after the field hydrostatic test and before initial power operation using the equipment and techniques expected to be used during subsequent inservice inspections.

(b) For operating plants without an initial baseline inspection, the first inservice inspection performed according to requirements 4 and 5, below, will define the baseline condition for subsequent inspections.

(c) Operating plants instituting a major change in their secondary water chemistry (for example, phosphate to all volatile treatment) should conduct a baseline inspection before power operation is resumed.

(4) Sample Selection and Testing

Selection and testing of steam generator tubes should be made on the following basis:

(a) The preservice inspection should include the full length of all tubes in all the steam generators.

(b) For the inspection of operating plants, tubes should be selected on a random basis except where experience in similar plants with similar secondary water chemistry indicates critical areas to be inspected.

(c) All of the steam generators in a given plant should be inspected at the first inservice inspection. If the results of the first inspection indicate that all steam generators are performing in a like manner, subsequent inspections may be limited to one or more steam generators on a rotating schedule. The total number of tubes inspected must be at least equal to 3% of the total tubes of the steam generators in the plant. If a steam generator is selected for inspection, then at least 3% of its tubes must be inspected. Each steam generator in the plant must be inspected at least every 48 calendar months.

(d) Every inspection subsequent to the preservice inspection should include all nonplugged tubes that previously had detectable wall penetrations (>20%) and should also include tubes in those areas where experience has indicated potential problems.

(e) Subsets of tubes which are experiencing degradation in well-defined areas because of a unique mechanical or structural design may be identified as a special group and treated separately from the general tube inspection. In this situation, 100% of the identified tubes should be inspected. No credit will be taken for this inspection in meeting the minimum sample size requirements but the results of the inspection of the special group will not be used in classifying the results of the general inspection.

(f) Visual and photographic inspection of the steam generator secondary-side support structures and internals should be performed as part of the inservice inspection of each steam generator.

(5) Supplementary Sampling Requirements

If eddy-current inspection pursuant to requirement 4 indicates that (a) one or more tubes are defective (have defects exceeding the plugging limit), (b) 5% or more of the tubes inspected are degraded (have a previously undetected defect of 20% or greater depth or exhibit greater than 10% further wall penetration), or (c) 1% or more of the tubes are defective (exceed the plant Technical Specification tube plugging limit), additional inspection should be performed as follows:

- In each steam generator where the above limits were exceeded, additional tubes should be inspected. The sample size for this inspection should be based on the limiting number of tolerable tube failures as defined by the systems analyses presented in this report (if applicable) or in plant-specific analyses approved by the NRC and by using the statistical methods described in Section 5.2.2.1 of this report and detailed in NUREG/CR-1282.

  This supplementary inspection may be limited to a partial inspection of each tube, concentrating on those portions of the tubes where imperfections were previously found. Furthermore, this supplementary inspection may be limited to subsets of tubes if it can be shown from previous inspection results or from unique structural or mechanical design that the degradation is limited to well-defined areas of the steam generator tube bundle.

- Notwithstanding any inspection rotation schedule, any additional steam generators not yet inspected during the current inspection should be inspected in accordance with requirement 4.

(6) Gauging Inspections

In the event that tubes will not allow passage of the standard diameter eddy-current testing probe, sufficient gauging inspection should be performed to quantify the magnitude and extent of tube denting. The range of probe sizes or the range of the instrument used to perform gauging should have an upper value equal to the diameter of the standard probe size used for ECT inspection of the steam generator tubes at the particular unit. The lower range limit should be small enough to allow passage through the dent restriction or at least 0.235 inch less than the original inside diameter of the tube. Gauging should be continued to the lower limit stated above, in order to assure adequate ISI information. Furthermore, the increment in probe diameters used for gauging should not exceed 0.070 inch. Each inspection should include gauging of all tubes in the steam generator which exhibited denting in a previous inspection.

(7) Inspection Intervals

(a) The first inservice inspection of steam generators should be performed after 6 months of effective full power but before 24 calendar months.

(b) Subsequent inservice inspection should take place not less than 12 nor more than 24 calendar months after the previous inspection.

(c) Inspections may be made to coincide with refueling outages or any shutdown for plant repair and maintenance in accordance with the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section XI.

(d) Unscheduled inspections should be conducted in the event of primary-to-secondary leaks exceeding technical specifications, plant shutdown increasing primary to secondary leak rate (unless the leakage is through a tube plug), a seismic occurrence greater than an operating basis earthquake (NUREG-0571), a loss-of-coolant accident requiring actuation of engineered safeguards, or a major steamline or feedwater line break.

(8) Acceptance Limits

(a) As used in these requirements:

(i) Imperfection means an exception to the dimensions, finish, or contour required by drawing or specification.

(ii) Defect means an imperfection of such severity that the tube is unacceptable for continued service.

(iii) Plugging limit means that imperfection depth at or beyond which plugging of the tube must be performed. (The plugging limit includes allowances for general corrosion and ECT measurement error.)

(iv) Plugging criteria mean those calculational and analytical procedures used to arrive at the plugging limit. These currently may be submitted by a licensee for approval by NRC.

(b) If, in the inspection performed under requirement 4, less than 5% of the tubes inspected are degraded (have previously undetected defects of 20% or greater depth or exhibit greater than 10% further wall penetration) and no tube has imperfections that exceed the plugging limit, plant operation may resume.

(c) If, as a result of the inspections performed under requirement 4, supplemental inspection is required, the situation should be immediately reported to the NRC. Furthermore, the results of the supplemental inspection should be reported to the NRC before power operation is resumed. The NRC may require additional inspection.

(d) If abnormal conditions in the secondary-side support structures and internals (for example, support plate deformation or cracking or tube deformation) are observed, any change from previously reported conditions shall be reported to the NRC before power operation is resumed, and the NRC may require additional inspections.

5.2.3.2 Discussion

Requirement 1 of the proposed revised ISI requirements is essentially the same as Regulatory Position C.1 of RG 1.83. The main difference is in Part a which has been expanded to require access for inspection of secondary-side support structures and intervals. This new requirement is included to facilitate the new Requirement 4.g which requires visual and photographic inspection of the secondary side of the steam generators. This requirement primarily allows inspection for monitoring tube denting and the associated secondary-side degradation. It is recommended that plants in the CP and OL stages install upper inspection ports, as discussed in Section 5.1.3.

B&W has developed steam generator tube sleeves intended to stiffen the tubes, thereby reducing dynamic stresses resulting from flow-induced vibration. These sleeves are not intended to perform as part of the primary coolant boundary and are not used for repairing degraded tubes. The tube sleeves vary in length from approximately 1 foot to 1-1/2 feet and are secured inside the generator tube by an expanded region at each end of the sleeve. One or more sleeves can be installed in a given tube to achieve the desired vibration characteristics. The tube sleeves were qualified analytically and experimentally and demonstration programs were approved for the Oconee Units 1, 2, and 3 and for Three Mile Island Unit 2.

6.2.2 Conclusions and Requirements

On a limited basis, sleeving is a viable tube repair procedure. Recently, tube sleeving has been used on a much greater scale in the repair of the San Onofre steam generators. The effectiveness of this repair is being carefully monitored and will be factored into future NRC actions regarding sleeving procedures.

There are currently no regulations governing the design, installation, or inspection of tube sleeves. Because of the potential benefits and increased usage of tube sleeves, a set of standards should be developed to ensure acceptable and uniform tube-sleeving design, installation, and inspection. These standards could be included in updated versions of existing regulatory guides (Regulatory Guides 1.83 and 1.121) or in a new, separate regulatory guide. At a minimum, the standards should include the following:

I. Sleeves Intended To Repair Defective Tubes

A. Sleeves should be designed in accordance with ASME Code requirements to act as the primary pressure boundary, assuming the original defect has penetrated completely through the wall of the tube.

B. Criteria for inspection of sleeved tubes should be no less stringent than those of Regulatory Guide 1.89 for unsleeved tubes.

C. Criteria for plugging tubes with degraded sleeves should provide the same margins of structural and mechanical integrity as those of Regulatory Guide 1.121 for unsleeved tubes.

D. Potential leakage from all installed steam generator tube sleeves under normal operation, transient, and postulated accident conditions should be limited to the rate set in the technical specifications for normal operation.

E. Potential for wear and/or accelerated corrosion at the joints of tubes and tube sleeves should be considered in the design and evaluation of tube sleeves.

II. Tube Stiffening Sleeves

A. Criteria for inspection of sleeved tubes should be no less than those of Regulatory Guide 1.89 for unsleeved tubes.

B. Potential for wear and/or accelerated corrosion at joints between tubes and tube sleeves should be considered in the design and evaluation of tube sleeves.

Item I.D., above, deserves some discussion. The steam generator leak rate limits set by the technical specifications are established for normal operating conditions and are intended to ensure that under postulated accident conditions, offsite dose limits (10 CFR Part 100) will not be exceeded and that steam generator tubes will not rupture or collapse (see Section 6.3 for further discussion). The systems and environmental analysis presented in Sections 4.2 and 4.3 establish the total tolerable leak rate under postulated MSLB and LOCA conditions, with accompanying steam generator tube failures. The contribution of the primary to secondary leak rate limits set by the technical specifications is negligible under both these postulated accident conditions. However, tube sleeves are not considered as a leak source in the accident evaluations nor in the proposed procedures for developing a statistically based inservice inspection program. Since the tolerable leak rate through the steam generators is the basis for defining the acceptance criteria in the inservice inspection program, the potential leakage through the steam generator tube sleeves must be limited to a small amount in order not to invalidate the bases of the inspection program. Therefore, it is proposed that the leak rate limit set for normal operating conditions be applicable to the tube sleeves under all conditions, including postulated accidents. An alternative approach would be to conservatively assume the leak rate through the sleeves during postulated accident conditions and adjust the tolerable number of tube failures and inservice inspection criteria accordingly. But this would require modification of the inspection program as additional sleeves were installed and is hence considered impractical.

6.3 Primary to Secondary Leak Rate Limits

As stated in the introduction, ISI, preventive tube plugging, and primary to secondary leakage rate limits act together to ensure integrity of steam generator tubes. Primary to secondary leakage rate limits are essential to ensuring such integrity and minimizing potential offsite doses.

6.3.1 Discussion

The technical specifications of each PWR specify limits for the amount of primary to secondary leakage through the steam generators. The leakage rate through the steam generators is continuously monitored by the radiation alarm of the condenser air ejector. This alarm provides an early indication of a steam generator tube leak. The air ejectors remove noncondensible gases from the condenser. Therefore, the radioactive gases transported by the RCS liquid through the leaking steam generator tube into the secondary system are first detected in the discharge from the condenser air ejector. The discharge path is monitored with radiation detectors, and this alarm provides a unique indication of primary-to-secondary system leak. Leakage from steam generator tubes can also be quantified by chemical analyses of bulk samples of secondary water removed from steam generator blowdown. This technique provides a more accurate quantification of small leak rates and is generally performed routinely when a steam generator tube is known to leak.

' .rease in condensate conductivity of 0.1 to 0.2 mho/cm is considered an indication of recirculation-water inleakage.

6.4.2 Secondary Water Chemistry Monitoring Recommendations

In lieu of technical specification requirements, it has been suggested that a more effective approach would be to impose license conditions requiring a secondary water chemistry monitoring and control program containing appropriate procedures and administrative controls.

An August 1979 generic letter requested PWR licensees to submit within 60 days a proposed license amendment incorporating a secondary water chemistry monitoring program. Responses received to this request have not been satisfactory, indicating that there are some misinterpretations about the extent of the requirements requested. The responses, in most cases, did not discuss a program under conditions other than normal power operation. Many of the licensees were negative to the license condition, principally regarding NRC's approval on changes, procedures, limits on parameters established, and requirements for licensee amendment fees whenever a change was necessary in the monitoring and control program.

A properly run secondary water chemistry control program should be capable of detecting off-chemistry conditions under all modes of operation. It should be sufficiently flexible so that corrections of adjustments in control limits can be achieved satisfactorily before tube degradation of any significance can occur between steam generator inspection periods. This capability for the licensee should be provided without unnecessary delays, inhibition, or prior approval.

Although secondary water chemistry control specifications have been deleted from the existing Standard Technical Specifications, this document will still retain primary to secondary leakage rate limits, steam generator tube surveillance, and plugging criteria to ensure that tube integrity is not reduced below an acceptable level for adequate margins of safety.

The recommended approach for implementing a secondary water chemistry monitoring and control program is to require each licensee to make licensing amendments that incorporate an administrative control. Any plant that required changes to the program and procedures, such as changes to the limits of water chemistry parameters, or frequency of sampling, would be handled under the terms of 10 CFR Section 50.59. Normally, this requires that any changes in plant procedures or operating conditions be submitted to NRC as part of the annual report

Because of the complexity of the corrosion phenomena involved and the changing state of the art for steam generator water chemistry control, in the view of the staff, a license condition would provide assurance that licensees have an acceptable control. Moreover, allowing any changes to the program or procedures to be handled under the terms of 10 CFR Section 50.59 will keep NRC informed, yet allow each licensee the needed flexibility to deal more effectively with any off-normal conditions under all modes of operation.

The applicant/licensee should implement a secondary water chemistry monitoring and control program to inhibit steam generator corrosion and tube degradation. This program should cover the following operational modes:

(1) power operation (normal)

(2) startup

(3) hot standby

(4) hot shutdown

(5) cold shutdown/cold wet layup

Each of the above modes of operation should be defined regarding percent rated thermal power and approximate primary coolant temperature range, °F.

The secondary water chemistry monitoring and control program should include the following:

(1) Identification of a sampling schedule for the critical parameters during each mode of operation and of acceptance control criteria for these parameters. The program should include, as a minimum, the control of pH, cation conductivity, free hydroxide or sodium, and dissolved oxygen. However, other parameters, such as specific conductivity, chlorine, fluorine, suspended solids, silica, total iron, copper, ammonia, and residual hydrazine, merit consideration.

(2) Identification of the procedures used to measure the value of each of the critical parameters. Provide the procedure title, the applicant/licensee' procedure number, and the basis for using the procedure (that is, ASTM No.).

(3) Concurrence with Branch Technical Position MTEB 5-3, "Monitoring of Secondary Side Water Chemistry in PWR Steam Generators," attached as Appendix B.

(4) Identification of sampling points. The program should consider sampling the steam generator blowdown, the hot well pump discharge, the feedwater, and demineralizer effluent as a minimum of sampling points.

(5) Procedure for recording and managing data.

(6) Procedures defining corrective action for various out-of-specification parameters. The procedure should conform to the allowable time outlined in NUREG-75/087 for correction of "out-of-spectrum" chemistry.

(7) Identification of (a) the authority responsible for interpreting the data, and (b) the sequence and timing of administrative events required to initiate corrective action.

(8) Identification of major components of the secondary water system and materials in contact with secondary water coolant.

6.4.3 Condenser Inservice Inspection Program

As discussed in Section 6.2.1, secondary water chemistry control is essential to maintaining steam generator integrity. Many undesirable contaminants enter the secondary system through condenser leaks and condenser integrity is essential to maintaining good water chemistry. An inservice inspection program to provide improved condenser performance should be required of all plants.

The inservice inspection program should include the following features:

(1) Access for Inspection

The condenser shall be designed for personnel access to perform the examinations and to repair and maintain the equipment as required.

(2) Examination Procedures

(a) The internal surface of the condenser tubing on the recirculation water side shall be cleaned and free from foulants prior to examination.

(b) Visual examination shall be performed on both the steam/condensate side and the recirculation water side of the condenser. Evidence of abnormal pitting, erosion, and/or corrosion on the interior walls, structural supports, and condenser tubing shall be noted and compared to either the as-manufactured appearance or the appearance during the previous examination.

(c) A hydrostatic test shall be performed to identify and locate through-wall condenser leakage.

(d) Other leak-detection procedures may be used in lieu of the hydrostatic test procedure to determine through-wall tube leakage between the steam/condensate side and the recirculation-water side of the condenser. The applicant/licensee should identify in writing the leak-detection procedure to be used.

(e) Nondestructive examination by eddy-current testing or other equivalent techniques shall be used to indicate and locate condenser tube defects resulting from stress-corrosion cracking and tube-wall thinning resulting from mechanical damage, chemical wastage, or other causes. The examination technique should provide a sensitivity that will detect penetration of 20% or more of the minimum allowable as-manufactured tube-wall thickness. No fewer than 3% of the total number of condenser tubes should undergo this procedure in the baseline (preservice) examination.

(3) Baseline (Preservice) Inspection

The baseline (preservice) inspection should be performed after the field hydrostatic test and before initial plant operation. The baseline (preservice) inspection should consist of visual examination, hydrostatic test procedure, and random nondestructive examination of 3% of the condenser tubes.

In the event defective tubes are found or a degradation mechanism is identified, the nondestructive examination shall be increased from 3% of the tubes to all the tubes in the degraded sections of the condenser. Tube leakage will be identified, and the tube leakers either repaired or plugged.

(4) Inservice Inspection

The inservice inspection should consist of visual examination, hydrostatic test procedures, and random nondestructive examination of 3% of the condenser tubes.

A rate of tube degradation shall be determined by comparing the as-manufactured tube-wall thickness with the measured tube-wall thickness. If the tubes in the condenser are manufactured from ammonia-sensitive materials (copper alloys), the random nondestructive examination of 3% of the condenser tubes shall be increased to 100%.

In the event defective tubes are found or a degradation mechanism is identified, the nondestructive examination shall be increased from 3% of the tube to 100% of the tubes in the degraded sections of the condenser. Tube leakage will be identified, and tube leakers will be repaired or plugged.

(5) Inspection Interval

Examination procedures can be made coincident with either refueling outages or any planned shutdown for plant repair and maintenance. However, they should be performed at intervals of not less than 12 nor more than 40 calendar months.

(6) Corrective Measures

All tubes found to contain unacceptable defects should be repaired or plugged. In the event leakage is found in condenser tubes, those tubes that leak will be identified and repaired or plugged. In the event tube degradation is found and the rate of degradation determined, no corrective measure need be taken if it is reasonably expected that penetration will not occur before the next inspection, considering accident or unusual operating occurrences, such as high-pressure flow surges or waterhammers. On the other hand, degraded condenser tubes should be either repaired or plugged if penetration is likely to occur before the next inspection.

Should condenser tube leaks in excess of the limit established by the Chemical Engineering Branch be detected during reactor operation, that section of the condenser containing the leak shall be identified and removed from service. Leaking tubes shall be identified by hydrostatic or other appropriate leak test methods. In addition, 3% of the tubes in that section should be examined by a nondestructive inspection procedure. All leaking tubes, or those containing unacceptable degradation (as defined earlier) shall be repaired or plugged.

6.4.4 Recommendations and Proposed Requirements

The resolution of the operational problems of PWR steam generators is many-faceted and requires the efforts of the designers, vendors, and operators of not only the steam generators but of the entire secondary system. Several of the following recommendations are design improvements and as such are not necessarily subject to NRC requirements and control. Some of these recommendations are based upon incomplete experimental work but represent the staff's best judgment of the direction for improvement. Again, the staff does not find that any single recommended improvement will solve the problem of steam generator tube degradation, but taken together the recommendations will increase the life of the steam generators. Recommendations and proposed requirements are divided into the categories of (1) operating plants, (2) plants in the post-construction-permit, pre-operating-license stage, and (3) plants in the pre-construction-permit stage.

6.4.4.1 Operating Plants

Steam Generator

Recommendations:

(1) Increase frequency of blowdown.

(2) In recirculating-type steam generators, provide extra access and inspection ports. These ports should be located so that the upper support plate and inner-row U-bends and the lower support plate and secondary face of tubesheet can be inspected.

(3) Perform chemical cleaning before excessive sludge builds up on tubesheet and support plate.

(4) When chemical cleaning is impractical, provide extensive lancing for sludge removal.

Proposed Requirement:

Establish a secondary water chemistry monitoring and control program in accordance with Section 6.4.2.

Condensers

Proposed Requirements:

(1) When retubing, use alloys that are not copper based.

(2) Develop a condenser inservice inspection program in accordance with Section 6.4.3.

Other Components

Recommendations:

(1) Install filters at locations downstream of the point where chemicals are added.

(2) Install demineralizers with rigid operating controls, including control of resin bead inleakage to the steam generators.

(3) Retube all feedwater heaters with non-copper-base alloys.

(4) Provide suitable deaeration equipment downstream of the condenser.

6.4.4.2 Post-Construction-Permit, Pre-Operating-License Plants

Steam Generator

Recommendations:

(1) Chemically clean

  (a) before startup,

  (b) at each refueling period,

(2) Provide increased blowdown capacity and optimal location.

Proposed Requirements:

(1) In recirculating-type steam generators, provide extra access and inspection ports. These ports should be located so that inspection of the support plant and inner-row U-bends and the lower support plate and secondary face of tubesheet can be made.

(2) Provide for identification of tube locations for verification of plugged tubes. (Stamped or etched numbers are normally not adequate for visual verification because of presence of deposits.)

(3) Provide tube expansion to the full depth of the tubesheet.

(4) Establish a secondary water chemistry monitoring and control program in accordance with Section 6.4.2.

(5) Provide design modification against water hammer.

(6) Formulate and submit a plan for steam generator/tube bundle replacement.

Condensers

Recommendation:

Retube with non-copper-base alloys.

Proposed Requirement:

Develop a condenser inservice inspection program in accordance with Section 6.4.3.

Other Components

Recommendations:

(1) Install filters at location downstream of the point where chemicals are added.

(2) Install demineralizer with rigid operating controls. (Design and operation should minimize potential for inleakage of resin fines to steam generator.)

(3) Retube all feedwater heaters with non-copper-base alloys.

(4) Provide suitable deaeration equipment after condenser.

6.4.4.3 Pre-Construction-Permit Plants

Steam Generator

Recommendations:

(1) Chemically clean

(a) before startup,

(b) provide connections to permit chemical cleaning.

(2) Consider using alternate tube materials containing low carbon (that is, >0.03%). Use of either Incoloy 800 or Inconel 690 is suggested.

(3) Provide increased blowdown capacity and optimized location.

(4) Provide design modifications to ensure that feedwater is properly circulated and is not bypassed into the blowdown exit.

(5) Make provisions to provide optimum sludge lancing efficiency. (Remove 85% or more of deposited sludge if possible.)

Proposed Requirements:

(1) Preassembly--Store and protect all components received at the site in a manner to preclude corrosion.

(2) Identification of tube locations--Provide for identification of tube locations to permit verification of plugged tubes. (Stamped or etched numbers are sometimes inadequate for visual verification because of presence of deposits.)

(3) Provide tube expansion to the full depth of the tubesheet.

(4) All U-bend tubes with less than a 6-inch bend radius shall be in the heat-treated and stress-relieved condition after installation.

(5) Heat treat all Inconel 600 tubing to minimize its susceptibility to primary-side SCC.

(6) Provide design modifications to eliminate waterhammer.

(7) In recirculating-type steam generators provide extra access and inspection ports. These ports should be located so that inspection of (a) the upper support plate and inner row of U-bends and (b) the lower support plate and secondary face of the tubesheet can be made.

(8) Establish a secondary water chemistry monitoring and control program in accordance with Section 6.4.2.

(9) Improve containment layout for access, inspection, repair, and replacement of steam generator components or replacement of entire steam generator/tube bundle. Provide suitable equipment hatch in containment structure for replacement of steam generator or components.

Condensers

Recommendation:

Tubes shall be rolled into grooved or double tubesheets.

Proposed Requirements:

(1) Preassembly--All components received at the site must be stored and protected in a manner to preclude corrosion.

(2) Provide isolatable, sectionalized condensers.

(3) Provide condenser tubing of non-copper-base alloys.

(4) Make special provisions to prevent biofouling.

(5) Develop a condenser inservice inspection program in accordance with Section 6.4.3.

(6) Provide design modification as necessary to ensure that steam dump and drain lines are routed to a single manifold, and not into the condenser shell.

Other Components

Recommendations:

(1) Install filters at locations after chemical addition point.

(2) Install demineralizers with rigid operating controls. (Design must ensure that resin fines are not permitted to escape into the steam generator.)

(3) Provide suitable deaeration equipment downstream of the condenser.

Proposed Requirements:

(1) Preassembly--All components received at the site must be stored and protected in a manner that precludes corrosion.

(2) Provide feedwater heater tubes of non-copper-base alloys.

6.5 Tube Integrity Conclusions and Criteria

This section summarizes the conclusions of the tube integrity evaluations which have been described and recommends requirements and criteria.

6.5.1 Conclusions

(1) Burst and collapse pressure relations were shown to exist which are highly dependent upon exact defect geometry, length as well as depth of defect being the important parameters. Present regulations, as defined in U.S. NRC Regulatory Guide 1.21, do not require the measurement or assessment of defect length in the judgment of a tube's ability to sustain its pressure boundary integrity.

(2) In all cases tested, the collapse of these tubes and the subsequent loss of pressure integrity occurred at pressures considerably higher than could occur under the most credible accident condition, LOCA.

(3) Tests showed that the currently used method for steam generator tube ISI (the single-frequency eddy-current inspection) (a) can measure defects inaccurately and to a significant degree and (b) can often fail to detect small-volume defects in straight-section tubes under optimum test conditions.

(4) The analysis of the burst data has led to a set of formulas which clearly defines the residual strength (margin-to-burst) of defected tubes where the defect geometries are known.

(5) Because of the large margin of safety built into the choice of steam generator tube plugging criteria and the inherent toughness of Inconel 600 material, inspection and plugging criteria are adequate to ensure tube integrity, as evidenced by the high-burst pressures in tubes where defect depth measured by eddy current exceeded the plugging depth. Requirements for multiple-frequency or similar ECI techniques would justify this conclusion in the region of the tube sheet, tube support plates, or other external interferences.

(6) Dented tubes masked by the tube support plate have adequate margins of safety against failure during normal and postulated accident conditions.

(7) Small leak rates are associated with stress-corrosion cracks at dented tube locations so that many dented-tube/tube-support-plate intersections would have to leak during an MSLB or LOCA to violate the allowable leak rate criteria established in Section 4.0.