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NRC Technical Issues Papers and Fact Sheets

EXHIBIT SG TUBE ISSUES FACT SHEET

STEAM GENERATOR TUBE ISSUES

Background

Pressurized water reactors use steam generators to transfer heat from the reactor to the plant's turbine to make electricity. There are approximately 3,000 to 16,000 tubes in a steam generator that, when operating, receive heated water under pressure from the reactor so that it does not boil. A second system of water entering the steam generator flows over the heated tubes and, in turn, becomes steam which is carried away by pipes to spin the turbine generator blades to make electricity.

These tubes play an important safety role because they stand between the radioactive and non-nuclear sides of the plant. The integrity of the tubing is instrumental in minimizing the leakage of water between the two sides. There is the potential that if reactor fuel is damaged and several tubes were to burst at once, it could lead to a fairly significant release of radioactive steam.

NRC Regulations

The NRC applies a defense-in-depth approach toward protecting public health and safety from the potential consequences of events involving the rupture of steam generator tubes. Steam generator tube degradation is managed through a combination of inservice inspections, tube repair criteria, primary-to-secondary system leak rate monitoring, water chemistry, and analyses to ensure safety objectives are met.

NRC regulations establish requirements for steam generator tube integrity. Tubes must have an extremely low probability of abnormal leakage and must be periodically inspected and tested.

To obtain an operating license, applicants must show that the consequences of a steam generator tube rupture would not exceed the limits for offsite radiological doses (in 10 CFR, Part 100 of the NRC's regulations). In addition, licenses are required to have emergency procedures for mitigating steam generator tube ruptures and leaks.

Once a plant is in operation, licensees are required to inspect and repair or remove from service all tubes found to contain flaws exceeding the acceptance limit, termed the "tube repair limit". A plant's Technical Specifications identify the frequency and scope of these inspections and repair limits. There are also operational leakage limits specified to ensure that if the tubes leak, the plant will be shut down quickly.

Although there are shortcomings, the existing regulatory framework has been effective in providing reasonable assurance of protecting public health and safety. This has been accomplished through evaluations of individual plants experiencing significant amounts of tube degradation. These evaluations have, in some instances, resulted in more frequent inspections at mid-operating cycle and/or permitted the use of alternate tube repair limits to minimize unnecessary tube repairs.

Steam generator tubes made of a particular metal alloy, know as alloy 600, have exhibited widespread degradation by a variety of corrosion and mechanical mechanisms. These problems have caused seven steam generator tube rupture events, numerous forced reactor shutdowns because of steam generator tube leakage, extensive tube repairs and outage extensions, steam generator replacement at 15 plants, and significant radioactive exposure of personnel. This situation has also resulted in approximately eight plants planning to replace their steam generators over the next four years. Steam generator tube degradation also contributed to the decision to permanently shut down two nuclear power plants: San Onofre Unit 1 and Trojan. It is expected that several other plants with alloy 600 steam generator tubes

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Onofre Unit 1 and Trojan. It is expected that several other plants with alloy 600 steam generator tubes will be evaluating the economic feasibility of replacing their steam generators over the next few years.

Different kinds of tube degradation experienced and improvements in inspection and tube repair technology have made regulatory requirements and guidance, developed in the 1970s, difficult to implement. Furthermore, the current regulatory approach for ensuring steam generator tube integrity, is highly prescriptive rather than performance-based. Operating experience indicates that current requirements in some areas should be more stringent, while in other areas they are overly conservative.

A generic approach (i.e., rulemaking) for dealing with steam generator issues is being pursued in order to improve the current regulatory framework and allow appropriate improvements to be more readily implemented across the industry.

Tube Degradation

In the early to mid 1970s, thinning of steam generator tube walls from water chemistry was the dominant form of tube degradation. All plants have changed their water chemistry control programs virtually eliminating the problem with tube thinning.

After tube thinning, tube denting became the primary degradation concern. Denting results from the corrosion of tube support structures and their products impacting the tubes. The mechanical damage to the tube has in some instances resulted in the development of stress-corrosion cracking (SCC). Measures have been taken to control denting; however, during the past five years, cracking not necessarily associated with dented locations has been the major cause of tube repairs, plugging and leakage incidents.

Stress-corrosion cracking has occurred at a number of facilities to varying degrees. It has resulted in mid-cycle tube inspections, the occurrence of unscheduled outages to plug or repair leaking tubes, and steam generator tube ruptures. This cracking has been observed to start from both inside and outside the tube and can be either around the circumference of the tube or along the length of the tube.

Some of the newer steam generators have features which make the tubes less susceptible to corrosion-related damage. These features include using stainless steel tube support plates which use a lattice design (to minimize the likelihood of denting), hydraulically expanding the tubes (to minimize stress at the expansion), and using more corrosion-resistant tube materials (such as thermally treated 600 or alloy 690).

Tube Repair Criteria

Traditional tube repair criteria are based on a minimum wall thickness requirement. Typically degradation is allowed to penetrate 40 percent of the tube wall thickness before the tube must be repaired. This allows an adequate margin against leakage and bursting. This criterion can be overly conservative for other flaws such as SCC cracks encountered in operating plants. As a result, use of the 40 percent through-wall repair criterion may result in tubes being unnecessarily removed from service although the they would continue to satisfy the existing regulatory guidance for adequate structural and leakage integrity.

Utilities have proposed various flaw-specific repair limits that do not incorporate a minimum wall thickness requirement. These "alternate repair criteria" permit tubes with up to 100 percent through-wall cracks to remain in service, subject to certain restrictions which are intended to ensure that the tubes retain adequate integrity. These alternate repair criteria provide (1) improved scope and methods for steam generator inspection, (2) incentives to continue to improve inspection methods, and (3) elimination of unnecessary conservatism in plugging and repair criteria.

The NRC issued Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking" on August 3, 1995. The methodology described in this generic letter is intended to ensure adequate structural and leakage integrity of the steam generator tubing throughout the operating cycle without taking credit for the tube

support plates at minimizing the likelihood of tube burst or tube leakage under postulated accident conditions.

With respect to voltage-based limits, the NRC approved an amendment with a methodology similar to that documented in Generic Letter 95-05. It gives credit for tube support plates to minimize the likelihood of tube burst and tube leakage under postulated accident conditions. This amendment, approved on an interim basis for two plants, permits the use of higher voltage limits.

Inspection Issues

The performance of inservice inspections is a critical element in maintaining steam generator tube integrity. The scope and frequency of these inspections vary from plant to plant based on the extent of the degradation. For plants with extensive amounts of degradation, 100% of the tubes are inspected at every outage.

Traditional methods for performing inservice inspection, in the late 1970s proved inadequate for the reliable detection and sizing of cracks. As a result, the industry has developed improved inservice inspection methods capable of detecting cracks before tube integrity is potentially impaired. However, use of these improved inspection methods has varied significantly from plant to plant.

In addition, inspection data analysis procedures and data analyst training have, in a number of instances, proven inadequate. This has the potential for significant tubing flaws to be missed. As a result, the staff issued a generic letter (Generic Letter 95-03 "Circumferential Cracking of Steam Generator Tubes") that emphasizes the importance of performing comprehensive examinations of steam generator tubes using appropriate inspection techniques and equipment capable of reliably detecting steam generator tube degradation.

Current Status - Rulemaking

As a result of shortcomings in the existing regulatory framework, NRC is developing a rule to address steam generator tube integrity issues. The objective is to provide continued assurance that steam generator tubes will remain capable of performing their intended safety function, yet it should accommodate changes in operating experience and technology and give incentives for the industry to continue to improve tube inspection and repair methods.

Under the rule, licensees would be expected to develop and put in place a steam generator program that balances preventive and mitigative measures that reflect operating experience and risk considerations. The steam generator rule would provide broad performance objectives, while an associated regulatory guide would provide more detailed performance criteria with guidance as necessary to ensure that these performance goals are met.

It is believed that a performance-based rule can achieve the desired goals without being unduly prescriptive in nature. The major challenge is to establish parameters to monitor the performance of the steam generators to ensure that the goals of the steam generator rule are continuing to be met. Another major challenge is to ensure that the rule establishes clear, enforceable criteria with which licensees can comply. The rule needs The final rule and regulatory guidance are scheduled to be provided to the Commission in February 1997.

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HIGHLIGHTS OF STEAM GENERATOR TUBE ISSUES

Steam generator (SG) tubing constitutes a large part of reactor coolant boundary in pressurized water reactor plants. There are about 3,000 to 16,000 tubes per SG.

Steam generator tube degradation is managed through a combination of several different elements, including inservice inspection, tube repair criteria, primary-to-secondary system leak rate monitoring, and water chemistry analyses.

The primary means for assessing SG tube degradation is through periodic inservice inspections required by the plant's technical specifications. Any tubes with identified degradation in excess of the repair criteria are repaired or removed from service.

Tubes fabricated from mill annealed alloy 600 are susceptible to many forms of degradation. Plants with extensive SG tube degradation typically inspect 100% of the tubes.

Extensive degradation has resulted in SG replacements at 15 plants and SG replacements planned for 8 plants over the next 4 years. SG tube degradation contributed to the decision to permanently shut down Sa Onofre 1 and Trojan. Several other plants will be evaluating SG replacement versus plant shutdown over the next few years.

Dominant forms of degraded alloy 600 have changed over time due to improvements in design and changes in water chemistry.

Newer steam generators with thermally treated allow 600 and alloy 690 have exhibited little or no corrosion-related degradation. Inspection technology has also significantly advanced resulting in the detection of degradation at an earlier stage.

In April 1995, the NRC issued GL 95-03, "Circumferential Cracking of SG Tubes," alerting licensees about the importance of performing comprehensive examinations of SG tubes using appropriate inspection techniques and equipment capable of reliably detecting SG tube degradation.

Traditional tube repair criteria, developed in 1970s for uniform thinning of the tube wall, limited degradation to approximately 40% through the wall. Due to the emergence of other degradation mechanisms, the current regulatory framework is out-of-date, difficult to implement, and in some cases overly conservative.

The NRC issued Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking" on August 3, 1995. This methodology provides an alternative to traditional tube repair limits. It requires improved inspection of SG tubes and more restrictive operational leakage limits.

Industry is proposing various forms of alternate SG tube repair criteria to the traditional depth-based limit.

The staff is developing a risk informed, performance-based rule to address numerous shortcomings with the current regulatory framework. The rule will not permit alternate inspection and repair criteria unless there is an adequate data base and technical basis to support such a criteria. The final rule and regulatory guidance are scheduled to be provided to the Commission in February 1997.

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Background

Pressurized-water reactors use steam generators, large components which convert water into steam from heat produced in the reactor core. These devices can measure up to 70 feet in height and weigh as much as 800 tons. Inside the steam generators, hot radioactive water is pumped through thousands of feet of tubing -- each steam generator can contain anywhere from 3,000 to 16,000 tubes, each about three-quarters of an inch in diameter -- under high pressure to prevent it from boiling. That water flowing through the inside of the tubes then heats non-radioactive water on the outside of the tubes. This produces steam that turns the blades of turbines to make electricity. The steam is subsequently condensed into water and returned to the steam generator to be heated once again.

These tubes have an important safety role because they constitute one of the primary barriers between the radioactive and non-radioactive sides of the plant. For this reason, the integrity of the tubing is essential in minimizing the leakage of water between the two "sides" of the plant. There is the potential that if a tube bursts while a plant is operating, radioactivity from the primary coolant system -- the system that pumps water through the reactor core -- could escape directly to the atmosphere in the form of steam. However, such a rupture has not occurred since March 14, 1993, when a tube burst at Palo Verde 2 plant in Arizona.

NRC Regulations

The NRC places a high priority on ensuring that steam generator tube degradation is carefully monitored through inspections, strict repair criteria and the monitoring of water chemistry to detect radiation leaking from the primary to the secondary side of the plant. In addition, NRC regulations establish requirements for steam generator tube integrity. Tubes must have an extremely low probability of abnormal leakage and must be periodically inspected and tested.

To obtain an operating license, applicants must show that the consequences of a steam generator tube rupture would not exceed the NRC's conservative limits for offsite radiological doses (described in 10 CFR, Part 100 of the agency's regulations). Plant operators also are required to have emergency procedures for mitigating steam generator tube ruptures and leaks.

Once a plant is in service, its operator is required to inspect and repair or remove from use all tubes found to contain flaws exceeding certain limits. Each plant's technical specifications describe the frequency and scope of these inspections and tube repair limits. There are also operational leakage limits to ensure that if any of the tubes leak, the plant will be shut down quickly. Existing regulations have been effective in providing reasonable assurance of protecting public health and safety. This has been accomplished through evaluations of individual plants experiencing significant amounts of tube degradation. These evaluations have, in some instances, resulted in more frequent inspections at mid-operating cycle.

Steam generator tubes made of a particular metal alloy, known as Alloy 600, have exhibited widespread degradation as a result of a variety of corrosion and mechanical factors. This has contributed to seven steam generator tube rupture events, numerous forced reactor shutdowns, extensive tube repairs and outage extensions, significant occupational exposure of personnel to radiation and steam generator replacement at

22 plants. Eleven plants are planning to replace their steam generators in the next five years. Steam generator tube degradation also contributed to the decision to permanently shut down the Trojan nuclear power plant in Oregon, and other licensees may choose to close plants in cases where repair or replacement of the components proves economically prohibitive.

Different kinds of tube degradation and improvements in inspection and tube repair technology have made regulatory requirements and guidance, developed in the 1970s, difficult to implement. Moreover, operating experience indicates that current requirements in some areas should be more stringent, while in other areas they are overly conservative.

Tube Degradation

In the early to mid-1970s, thinning of steam generator tube walls due to the chemistry of water flowing through them was the dominant cause of tube degradation. However, all plants have changed their water chemistry control programs since then, virtually eliminating the problem with tube thinning.

After tube thinning, tube denting became a primary concern. Denting results from the buildup of corrosion products in the crevices between tubes and the tube support plate. Measures have been taken to control denting, including changes in the chemistry of the secondary, in the non-radioactive side of the plant. But other phenomena continue to cause tube cracking.

Some of the newer steam generators have features which make the tubes less susceptible to corrosion-related damage. These include using stainless-steel tube support plates, which use a lattice design to minimize the likelihood of denting; new fabrication techniques to minimize mechanical stress on tubes; and the use of more corrosion-resistant tube materials, such as thermally treated Alloy 600 and Alloy 690.

Tube Repair Criteria

Traditional tube repair criteria are based on a minimum wall thickness requirement. Typically, the tube wall thickness may be degraded by up to 40 percent before the tube must be repaired. This allows an adequate margin against leakage and bursting. This criteria can be overly conservative for other flaws, such as stress corrosion cracks, encountered in operating plants. As a result, use of the 40-percent through-wall repair guideline may result in tubes being unnecessarily removed from service even though they would continue to satisfy the existing regulatory guidance for adequate structural and leakage integrity.

In 1995, NRC issued Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking." This report describes the methodology to be used to ensure adequate structural and leakage integrity of the steam generator tubing throughout the plant's operating cycle without taking credit for use of tube support plates. These plates minimize the likelihood of tube burst or tube leakage under postulated accident conditions. The alternate repair criteria specified in the generic letter differ from the minimum wall thickness requirements in that tube integrity is ensured through the application of voltage-based (via electrical testing) rather than depth-based repair limits.

Inspection Issues

In-service inspections are critical in maintaining steam generator tube integrity. The scope and frequency of these inspections vary from plant to plant based on each facility's operating experience. For plants with extensive tube degradation, 100 percent of the tubes are inspected at every outage.

Traditional methods for performing in-service inspections were inadequate for identifying and precisely measuring the size of cracks. In 1995, the NRC issued Generic Letter 95-03, "Circumferential Cracking of Steam Generator Tubes," alerting plant operators about the importance of performing comprehensive examinations of tubes using appropriate inspection techniques and equipment capable of reliably detecting degradation. During the past decade, the industry has developed better methods of detecting cracks before tube integrity is potentially impaired. However, use of these new inspection techniques differs from plant to plant and there continue to be significant difficulties in precisely measuring the size of cracks.

In December 1997, NRC issued Generic Letter 97-05, "Steam Generator Tube Inspection Techniques," to address measuring the size of steam generator tube flaws. Additionally, in December 1997, NRC issued Generic Letter 97-06, "Degradation of Steam Generator Internals," which emphasizes the importance of performing comprehensive examinations of steam generator internals to ensure that tube structural integrity is maintained in accordance with 10 CFR 50, Appendix B. The generic letter was issued as a result of foreign and U.S. operating experience indicating the potential for degradation to damage tube supports and tube bundle wrappers.

Current Status - Revision to the Current Regulatory Framework

To address various steam generator problems, NRC is currently examining ways of modifying its requirements. Although NRC initially believed that a new steam generator rule might be necessary, regulatory analyses led NRC to conclude that a better regulatory instrument for addressing the problems is a generic letter. In late 1997, the industry, through the Nuclear Energy Institute (NEI), adopted an initiative entitled NEI 97-06, "Steam Generator Program Guidelines." The chief objective of the initiative is for pressurized-water reactor operators to evaluate their existing steam generator programs and, where necessary, revise or strengthen program attributes to meet the intent of the NEI guidelines. The guidelines are intended to improve both the quality and consistency of steam generator programs throughout the industry.

As a consequence, the generic letter is on hold while NRC meets with industry representatives to determine if the NEI initiative eliminates the need for a generic letter. Under either regulatory approach (NEI initiative or NRC generic letter), licensees would improve existing steam generator programs to ensure that the inspection, monitoring and assessment of steam generator tubes is sufficient to maintain their integrity from one operating cycle of the plant to the next (12 to 24 months). The industry initiative calls for implementation of the NEI guidelines during the first refueling outage after January 1, 1999.

The NRC has issued, for public comment, draft regulatory guide DG-1074, "Steam Generator Tube Integrity," to provide guidance to PWR licensees on an acceptable approach for monitoring and maintaining steam generator tube integrity. The public comment period has ended and the staff is in the process of reviewing the comments.

Differing Professional Opinion

Throughout the process to revise the regulatory framework governing steam generator tube integrity, the NRC has carefully considered a differing professional opinion (DPO) written by a colleague, Joram Hopenfeld. (DPOs allow NRC staff members to express views that are markedly different from those that gain staff acceptance.) The DPO issues apply primarily to the approach and methodology on steam generator repair criteria. As part of the request for public comment on draft regulatory guide DG-1074, the Commission agreed to issue the DPO document describing how each issue was considered, along with a memorandum by Hopenfeld to the Commission dated September 25, 1998, detailing the author's

continuing concerns with the regulatory approach for steam generators.

The NRC continues to conclude that in considering all the DPO issues, steam generators in pressurized-water reactor plants are safe. These issues are also part of the ongoing technical dialogue with industry. No new repair criteria will be approved unless they satisfy all applicable regulations and ensure that plant risk remains acceptable.

HIGHLIGHTS OF STEAM GENERATOR TUBE ISSUES

Steam generator tubes provide one of the primary barriers between the radioactive and non-radioactive sides of a nuclear power plant. There are about 3,000 to 16,000 tubes per steam generator. The number of steam generators used in pressurized-water reactors varies, depending on the design of the individual plant.

Steam generator tube degradation is managed through inspection, tube repair, primary-to-secondary system leak rate monitoring and water chemistry control.

NRC regulations establish requirements for tube integrity. Tubes must have an extremely low probability of abnormal leakage and must be periodically inspected and tested.

Tubes fabricated from Alloy 600 metal have exhibited many forms of degradation. Plants with extensive steam generator tube degradation typically inspect 100 percent of the tubes.

Extensive degradation has resulted in steam generator replacements at 22 plants. Replacements are planned for 11 additional plants over the next five years. Tube degradation contributed to the decision to permanently shut down the Trojan nuclear plant in Oregon.

Several other plants will be evaluating replacement versus plant shutdown over the next few years.

Dominant forms of degradation have changed over time. Reports of tube thinning and tube denting have decreased significantly due to improvements in design and fabrication of new steam generators and changes in water chemistry.

Some of the newer steam generators have features which make the tubes less susceptible to corrosion-related damage.

Tube repair criteria, developed in the 1970s, limited degradation to approximately 40 percent through-wall. Due to other kinds of emerging tube problems, the current regulatory framework is out of date, difficult to implement and, in some cases, overly conservative.

Inspection technology has also significantly advanced, resulting in the detection of degradation at an earlier stage.

In 1995, NRC issued Generic Letter 95-05, "Voltage-Based Repair Criteria for Westinghouse Steam Generator Tubes Affected by Outside Diameter Stress Corrosion Cracking." This alternative methodology to traditional tube repair limits requires improved inspection of steam generator tubes and more restrictive operational leakage limits.

To address various steam generator problems, NRC has decided to use a generic letter approach.. Recently, the generic letter effort was put on hold to determine if an industry initiative would be an effective substitute.

Under either an industry or NRC generic letter approach, licensees would improve steam generator programs to ensure that licensees maintain sufficient steam generator tube integrity from one operating cycle to the next (12 to 24 months). The industry is implementing the industry initiative during the first refueling outage after January 1, 1999.

NRC is seeking public comment on a regulatory guide on how to monitor and maintain steam generator tube integrity along with a Differing Professional Opinion from an NRC employee regarding the approach and methodology being used for steam generator repair criteria.

NOTE: The issue of electrosleeving has also arisen in this area. SECY 99-199 was written to document issues raised during the review of a license amendment that would allow electrosleeve repair of steam generator tubes at Callaway.

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