STEAM GENERATOR TUBE PRIMARY-TO-SECONDARY LEAKAGE

A. PURPOSE

The purpose of this document is to provide guidance to inspectors on overseeing PWRs with known steam generator tube primary-to-secondary leakage.

B. BACKGROUND

Steam generator (SG) tubes often leak before they fail or burst. This is not always the case, and the possibility exists for burst with little or no observed leakage. For the many cases where primary-to-secondary leakage can be detected, the licensees have an opportunity to prevent tube burst by early detection of primary-to-secondary leakage and to take corrective action. Routine leakage monitoring with adequate shutdown limits can afford early detection and response to increasing leakage and, thereby, serve as an effective means for minimizing the incidence of steam generator tube rupture. This can be achieved by having near real-time leakage information available to control room operators. Use of such monitoring capability, along with appropriate alarm set points and corresponding action levels, can help operators respond appropriately to a developing situation in a timely manner.

C. DISCUSSION

1. Sources of Primary-to-Secondary Leakage

Primary-to-secondary leakage is ordinarily caused by degraded tubes, leaking plugs, leaking sleeves, or leak-limiting sleeves. To determine possible sources of leakage, it is important to review what is known about the component materials and condition of the steam generator. Reviewing the licensee's report from their last steam generator tube examination should provide details regarding the condition of the steam generator and active degradation processes. Although operating experience may provide insights as to possible sources of degradation, sources of leakage cannot be reliably identified while the reactor is in operation. Therefore, leakage should be treated in accordance with available guidance.

In older plants, it's more likely that leakage is due to some environmentally assisted corrosion process (e.g.,outer diameter stress corrosion cracking (ODSCC) and primary water stress corrosion cracking (PWSCC)) or from a repair process that exhibits some leaks (e.g., leak-limiting sleeves, leaking plugs). Mechanical degradation due to wear, fatigue cracks from vibration, and damage from loose parts are the most likely cause of leakage in newer plants and can also contribute to leakage in the older SGs.

Components fabricated from mill-annealed Alloy 600 have been found to be highly susceptible to environmentally-assisted degradation processes, such as ODSCC and PWSCC. The in-service experience with thermally treated (TT) Alloy 600 and Alloy 690 components has been uniformly good, especially with regard to environmentally assisted degradation.

Cracking has been reported for some Westinghouse plugs manufactured out of Alloy 600. Industry experience with flawed plugs is discussed in NRC Information Notice 94-87 and NRC Bulletin 89-01. Most licensees have replaced the Alloy 600 plugs with Alloy 690 plugs. It is also possible to have flaws in the welds that are used to install the tube sleeves, and some sleeve designs are leak-limiting rather than leak-tight.

2. Leakage Detection Methods

Most plants have radiation monitoring systems that monitor condenser off-gas, steam generator blowdown, and the main steam lines. The condenser off gas is monitored to identify the presence of radioactive gases removed from steam condensate. The steam generator blowdown is monitored to identify non-volatile radioactive species in the steam generator bulk water (excluding OTSGs). The main steam is monitored to detect volatile gases, and in some cases N-16, carried from the steam generator via the main steam lines.

Grab samples are also commonly used, such as reactor coolant samples to quantify the source term, steam generator blowdown to detect non-volatile radioactive species in liquid and condenser off gas to detect noble gas and other volatile species removed from steam condensate. In addition, other common grab samples include condensed main steam to detect noble gas and other volatile species carried over with main steam and condensate to detect soluble species such as tritium and iodine. Also, blowdown filters and ion exchanger columns are used to detect particulates and ionic species from liquid streams.

Although no single monitor should be expected to fulfill all monitoring roles, some monitoring methods have demonstrated particular value in certain situations. Continuous control room display of key radiation monitor trends (e.g., blowdown, condenser exhaust, Nitrogen-16 monitor of leakage rates and change in leak rate over time) gives operators real-time information that can be used to safely respond to the full range of primary-to-secondary leakage.

Use of N-16 monitors installed on or near steam lines has become increasingly common in the industry as a supplemental means of monitoring leakage. These

monitors exhibit short time response to changes in leak rate and are very useful to operators, provided their limitations are understood. However, the short half-life for N-16 presents some problems in the ability of the detector to measure leak rate. Changes in power level and characteristics of the leak itself (location and type of leak) will affect the N-16 concentration reaching the detector. Once the reactor trips, N-16 quickly decays away and no longer provides a measure to measure tube leakage. Also, due to the high energy of the gamma ray emitted by N-16, detectors may be affected by nearby steam lines in addition to the one they are mounted to. This can make it difficult to estimate total leakage or apportion leakage among the generators on the basis of N-16 alone.

It is prudent for the monitoring program to also include provisions for detection of primary-to-secondary leakage during low power or plant shutdown conditions. This program should ensure that means are available to detect tube leakage whenever primary pressure is greater than secondary system pressure. This includes hot shutdown conditions and plant startup situations, when normal means of detecting leakage might be limited or unavailable. For instance, the radionuclide mix is altered following a period of plant shutdown so that condenser off-gas monitor indications may be questionable during startup since they are calibrated for a specific radionuclide mix based on power operation. Also, N-16 monitoring is not considered reliable at low power since lower levels of N-16 are available to trigger detector response during a tube leak.

Plants spend a relatively small fraction of time in low power or hot shutdown. However, it is prudent to have techniques and procedures available to detect a rapidly developing leak under those circumstances. In the event a tube failure develops, operators should have reasonable time to respond to the situation before the plant reaches full power operation, when the consequences of a tube failure would be magnified.

The technical specifications (TS) include a limiting condition for operation (LCO) limit with respect to the allowable primary-to-secondary leakage rate, beyond which prompt and controlled shutdown must be initiated. As discussed in the next section, the acceptable LCO limit will become 150 gallons per day as the licensees change their TS to be consistent with a generic TS change package associated with an industry SG initiative.

As discussed in the next section, guidance to the industry is provided by EPRI Report TR-104788, "PWR Primary-to-Secondary Leak Guidelines" (Ref. 11). Detection capability and measurement uncertainties are discussed in the guidance, as well as the characteristics of certain monitoring methods. This is useful to licensees in determining the adequacy of specific parts of their monitoring system and the effectiveness of the combination of methods used.

3. Guidance from Industry SG Initiative

The industry currently relies on industry-developed guidelines to evaluate the significance of primary-to-secondary steam generator tube leakage. In the fall of 1997 the Nuclear Strategic Issues Advisory Committee, a committee consisting of

the chief nuclear officers from the nuclear utilities, voted to adopt the NEI 97-06, "Steam Generator Program Guidelines," industry initiative. This commitment is in the form of an industry initiative and is an internal commitment between NEI members to take the agreed upon position. The industry informed the NRC by letter dated December 16, 1997, from the Nuclear Energy Institute, of their commitment to implement the industry steam generator initiative described in NEI 97-06. Each licensee committed to evaluate its existing SG program and where necessary, revise and strengthen program attributes to meet NEI 97-06 by no later than the first refueling outage starting after January 1, 1999.

In accordance with the industry commitment to NEI 97-06, the utility SG management programs should explicitly provide direction on monitoring primary-to-secondary leakage in SG tubes. NEI 97-06 references a guidance document prepared by the Electric Power Research Institute (EPRI), "PWR Primary-To-Secondary Leak Guidelines," TR-104788-R2, to assist the industry in developing plant-specific procedures to manage small amounts of leakage within the context of their SG management program. The guidelines address management considerations, monitoring methods and equipment, leak rate calculations, operational response and data evaluation. The guidelines were developed consistent with industry's observed field experience with leakage, and where possible, are intended to ensure the propagation of flaws to tube rupture is minimized under normal and faulted conditions.

Revision 2 to the guidelines was implemented October 14, 2000. The guidelines direct the licensee to implement a monitoring program that accounts for plant design, steam generator tube degradation, and previous leakage experience. In addition, the EPRI guidelines recommend action levels defined by limits on the leak rate and the rate of change of the leak rate. The action levels provide a framework that licensees can use to formulate preplanned operator actions based on specified leakage indications. The objective for the normal operating leak rate limit or rate of change limit is to establish a reasonable likelihood that the plant is shut down before the tube could rupture under either normal or faulted conditions. The operating leakage experience together with the analytically based burst pressure versus normal operating leak rate trends provide the bases for a recommended leakage limit.

There is a generic TS change package under review by the NRC staff that is part of the NEI 97-06 industry initiative. In the current TSs, the LCO limits can vary from plant to plant with respect to the allowable primary-to-secondary leakage rate through any one SG, beyond which prompt and controlled shutdown must be initiated. The TS LCO limits in operating plants vary from 150 to 500 gallons per day (gpd). The NEI 97-06 generic license change package will standardize that value to 150 gpd for all PWRs.

4. Assessing the Significance of the Leakage

The EPRI guidelines developed under NEI 97-06 provide recommendations for plant actions based on observed primary-to-secondary leakage rates. The guidelines recommend increased monitoring at 5 gpd. Below 5 gpd during normal

operation, no specific actions are recommended. The guidelines suggest that the licensee's grab sample program be able to quantify leakage at 5 gpd. At lower leakage levels, the analysis is limited by a lack of analytical certainty at low radiochemical concentrations.

Above 5 gpd, the EPRI Primary-to-Secondary Leak Guidelines (Rev. 2) recommend three action levels:

a. Action Level 1. This action level requires increased attention and monitoring. This action level is entered when:

- leakage greater than or equal to 30 gpd, and
- less than 75 gpd in any SG.

b. Action Level 2. This action level requires that the plant be in Mode 3 within 24 hours. This action level is entered when:

- leakage greater than or equal to 75 gpd in any SG, and
- sustained for greater than or equal to 1 hour, and
- the rate of increase in leakage is <30 gpd/hr in any SG.

c. Action Level 3. This action level requires a prompt and controlled plant shutdown to < 50% power within one hour and in Mode 3 within the next 2 hours. This action level is entered when:

- leakage is increasing by greater than 30 gpd/hr, and
- is greater than or equal to 75 gpd in any steam generator.

In addition, the guidelines recommend an action level at leakage of ≤30 gpd that directs the licensee to increase their use of grab samples when no on-line quantitative monitors are operable.

For additional reporting guidance recommended to the inspectors, see Inspection Procedure 71111.08, "Inservice Inspection Activities." |

5. Questions to Gain Additional Information About the Leakage

Questions should focus on how the licensee is monitoring the leakage, evaluating the potential sources of leakage, and what the past inspection results and in-situ testing information tell them about the condition of their SGs.

It is useful for the inspector to understand how the licensee detected the leakage, and what the leakage history for this unit (and the specific steam generator) was for previous outages. There are various advantages and disadvantages of various monitoring techniques, which can affect the quantity of leakage reported.

After shutdown, the licensee may observe leakage from post-shutdown visual inspections of the tubesheet face. Additional information may be available from secondary side tube leak tests performed early during outages to identify leaking tubes. To conduct these tests, nitrogen pressure is applied to the water inventory in the secondary side of the steam generators and maintained for an extended period (often for days). If the visual inspections reveal any observed dampness or drops of water from the tubesheet face, tubes in that area need to be evaluated carefully with appropriate inspection methods.

Sometimes plants experience very low levels of leakage in current and previous cycles, with no clear cause identified. Small changes in low levels of leakage can be due to changes in monitoring equipment, either putting new equipment in service or recent calibrations of the existing equipment. The staff was recently informed of small changes of observed leakage that directly correlated to putting new detection equipment in service. This led to a step increase in the very small amount of leakage observed. This could also be observed after calibrating equipment, or any other major change that would reset the baseline readings.

The inspector should recognize that although it is not possible to reliably identify the source of leakage while the plant is operating, insights can be obtained by discussing with the licensee the SG tube examination findings from the eddy current testing during the last outage, in situ pressure test results, and the licensee's knowledge of loose parts in the SGs.

The inspector can ascertain information on the degradation modes being experienced by the SGs. For example, AVB wear can have a significant through-wall extent, even for replaced SGs that have not been in service many years. Some of the plants have qualified sizing techniques for AVB wear, so indications of wear are sometimes left in service for the next operating cycle.

For any reported active degradation modes, the inspector can ask about their in-situ pressure test results from previous outages. If the licensee has experienced difficulty satisfying the in-situ pressure test performance criteria, it may indicate that the flaws were deeper than their SG eddy current tests were capable of detecting.

Some plants also have known loose parts in the affected SG that they have not been able to retrieve, that they had identified through techniques such as foreign object search and retrieve (FOSAR). In some cases, the licensees will plug tubes around a loose part that they are unable to retrieve, to reduce the chance of tube rupture from the loose part during the next cycle.

It should also be noted it just is not practical for licensees to shut down plants at low levels of leakage. In fact, sustained leakage below 10 gpd in some older plants is not unusual. As noted above, when plants shut down leakage tests are used to identify leaking tubes. The experience of plants that have shut down with low levels leakage has been that it is very difficult to determine the source of the leakage.

In summary, obtaining background information about operating and inspection experience may provide useful insights regarding the significance of ongoing primary-to-secondary leakage. Accordingly, the staff's ability to influence the actions of licensees with known primary-to-secondary leakage is limited. Because of the inability to reliably identify the source of leakage while the plant is operating, the NRC staff's primary role should be to ensure that the licensee is responding to leakage in a conservative manner by monitoring the leakage and being prepared to implement plant shutdown consistent with EPRI guidelines.

6. NRC Generic Communications and Regulatory Guidance

   a. USNRC Information Notice No. 91-43: "Recent Incidents Involving Rapid Increases in Primary-to-Secondary Leak Rate," (July 1991)

   b. USNRC Information Notice No. 94-43: "Determination of Primary-to-Secondary Steam Generator Leak Rate," (June 1994)

   c. USNRC Regulatory Guide 1.45, "Reactor Coolant Pressure Boundary Leakage Detection Systems," (May 1973)

   d. USNRC Regulatory Guide 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident," (December 1980).

7. Operating Experience: Primary-to-Secondary SG Tube Leakage

A summary of information in Table 1 on past forced outages from 1990 to 1998 due to SG tube leaks. References to generic communications are given for many of the events, if more information about the event is needed.

Table 1: Tube Leak Forced Outages at US PWRs

Plant	**Date**	**Leak Rate (gpd)**	**Cause**	**Reference**
St. Lucie 1	Jan. 1990	3	Foreign Object	
TMI 1	Mar. 1990	1440	Fatigue	
Millstone 2	May 1990		Cracked Plug	
North Anna 2	Aug 1990	40	Cracked Plug	
Oconee 2	Nov. 1990	130	Fatigue	
Shearon Harris	Nov. 1990	50	Loose Part	
Maine Yankee	Dec. 1990	1440	PWSCC	
San Onofre 1	Apr. 1991	150	Sleeve Joint	EN 20860
Millstone 2	Apr. 1991	70	U-bend SCC	PN 1-91-030
Millstone 2	May 1991	70	Tube Sheet Circumferential Crack	EN 21077

McGuire 1	Jan. 1992	250	Freespan Crack	PN 2-91-002
ANO 2	Mar. 1992	360	Tube Sheet Circumferential Crack	PN 4-92-018, -081A, EN 22975
Prairie Island 1	Mar. 1992	144	Roll Transition Zone Axial Crack	
McGuire 1	May 1992	5		MR 3-92-0255 PN 23400
Prairie Island 1	Sep. 1992	187		MR 3-92-0255 PN 3-92-048
McGuire 1	Nov. 1992	250		
Trojan	Nov. 1992	200	Sleeve Weld Circumferential Crack	PN 5-92-035 EN 24569
Palo Verde 2	Mar. 1993	240	Upper Bundle Freespan Inter Granular Stress Corrosion Cracking	PN 5-93-009, -009A, -009B, -009C, -009D EN 25255
Kewaunee	Jun. 1993	100	Leaking Plug	MR 3-93-0167
McGuire 1	Aug. 1993	185 (?)	Sleeve Failure	PN 2-93-038 EN 25990
Palo Verde 3	Sept 1993		Freespan crack	MR 5-93-0066 PN 5-93-017
McGuire 1	Oct 1993	185	Circ. crack in sleeved tube	PN 2-93-053
Braidwood 1	Oct. 1993	300	Freespan Cracks	PN 3-93-061
San Onofre 3	Nov. 1993	50	Loose parts degradation and leaking welded plugs	MR 5-93-0081 PN 5-93-020
Farley 2	Nov. 1993			MR 2-93-0132
McGuire 1	Jan. 1994	100	Leaking Sleeve	PN 2-94-003 EN 26665
Oconee 3	Mar. 1994	144	Fatigue	PN 2-94-014 EN 26967
S. Texas	Mar. 1994	160	Leaking Plug	PN 4-94-005A EN 26859
Zion 2	Mar. 1994	1440	Tubesheet Crevice Inter Granular Attack OD	EN 26901
Oconee 2	Jul. 1994	144	Fatigue	PN 2-94040
Maine Yankee	Jul. 1994	50	Circumferential Crack PWSCC	MR 1-94-0079 EN 27587
Zion 1	Feb. 1996		Foreign object	PN 3-96-009
Byron 2	Aug. 1996	120	Loose Part	PN 3-96-049 MR 3-96-0106
Vogtle 1	May 1996		Foreign object	PN 2-96-041 EN 30555
ANO 2	Nov. 1996	65	Axial Crack	PN 4-96-061 EN 31344
McGuire 2	June 1997	66	ODSCC at TSP	PN 2-97-033

Oconee 1	Nov. 1997	400	2 Welded Plugs	PN 2-97-065, -065A EN 33458
Farley 1	Dec. 1998	90	2 Freespan Cracks	

Information from EPRI TR-106365-R14 and NRC documents

END