INPO® Institute of Nuclear Power Operations

Issue Date: April 30, 2013

Main Condenser Cooling Water Inleakage

Summary

The prevention and mitigation of main condenser cooling water leakage from condenser tube and plug failures are key contributors to long-term preservation of important plant assets such as reactor vessels and steam generators and to protecting nuclear fuel from corrosion. It is important that station personnel be proactive to monitor, detect, and anticipate tube degradation and be prepared to identify and repair condenser leaks promptly.

Since January 2011, 49 events[1] have been reported in which condenser cooling water inleakage affected power generation. These events, encompassing 20 stations, consisted of three scrams, one forced shutdown, two outage extensions, two delayed startups, one delayed power ascension, and 40 power reductions, resulting in 1.9 million MWe-hours of lost generation.

In addition to impacts on power generation, the introduction of sodium, chlorides, sulfates, and other contaminants contributed to out-of-specification reactor water and steam generator chemistry, requiring operations personnel to enter abnormal operating procedures more frequently. Actions taken to identify and address condenser tube leaks also resulted in unplanned dose, premature exhaustion of demineralizer resin, and increased wastewater and radioactive waste. At BWRs, emergent condenser repair operations typically result in 0.5 – 1.0 rem of collective worker dose, depending on the difficulties of locating and repairing a leak.

Many of the events were the result of insufficient actions taken to prevent and detect tube leaks and tube plug failures. Examples are aging and inadequate life cycle management of the main condenser, insufficient foreign material exclusion control in the main condenser during outages, and inadequate assessment of potential erosion of tubes introduced by power uprates or other system modifications that interface with the condenser. Other contributors included missed

[1] Events reported to INPO Consolidated Event System (ICES) and/or shown on power history curves presented on the INPO Plant Information Center (PIC) as of March 20, 2013

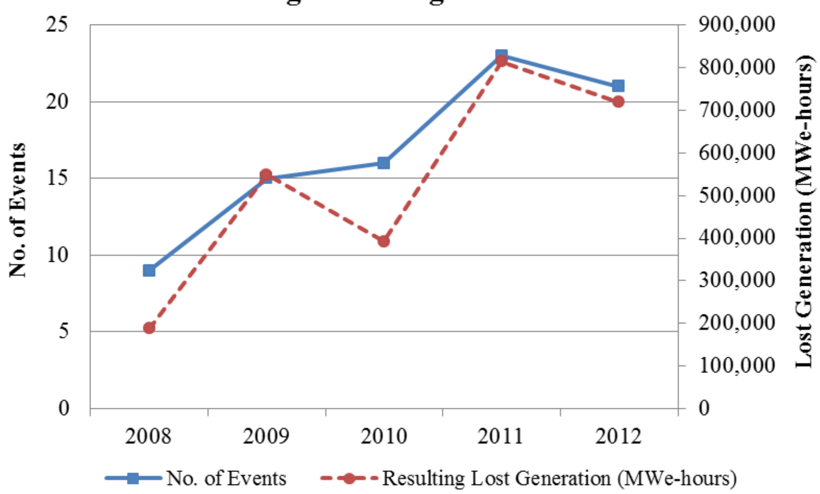
opportunities to identify wall thinning during eddy current testing; extended use of temporary tube plugs; and unsatisfactory workmanship and work practices related to work inside the condenser, including installation of new tubes and tube plugs.

Data Review

From January 2008 through December 2012, 84 events[2] were reported that involved main condenser cooling water inleakage that adversely affected power generation, resulting in 2.6 million MWe-hours[3] of lost generation. Seventy-one events involved downpowers. The remaining events included two scrams, two forced shutdowns, three outage extensions, two delayed startups, and four delayed power ascensions. In addition, five events occurred in 2013 as of March 20, including one scram.

Figure 1 presents the trends for the number of total events and associated generation loss in recent calendar years. Although the values fluctuated during the period, both trends reflect worsening performance over the 2008 through 2012 period.

Figure 1
Events Involving Main Condenser Water Inleakage Affecting Power Generation



One unit was responsible for 21 percent of the 84 events. Figure 2 presents the same data as Figure 1 excluding that outlier. Although the absolute values decreased, the overall trends remain similar to those in Figure 1, indicating that industry performance in this area is worsening.

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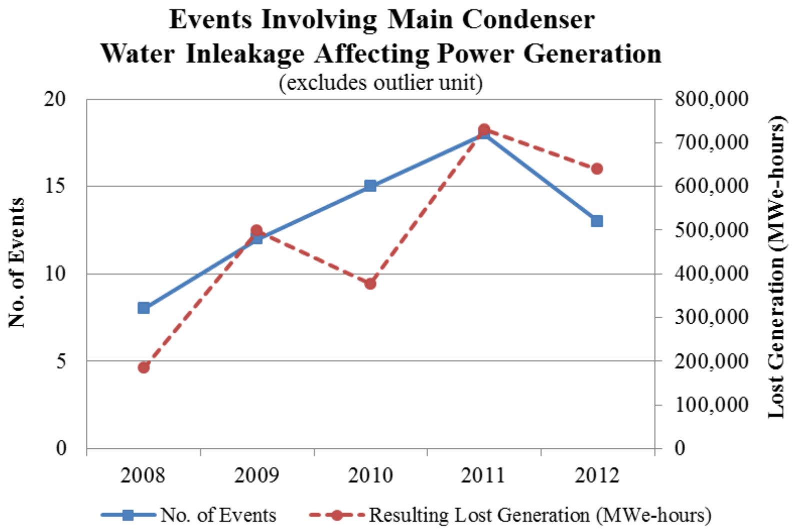
[2] Reported as of March 15, 2013
[3] Lost generation is equivalent to a 900 MWe unit being off line for four months.

Figure 2



Figures 3 and 4 present the quarterly average of events and lost generation, respectively, for each year since 2008. The quarterly averages were compiled to provide a reference for the first quarter of 2013. The number of events during the first quarter of 2013 is less than quarterly averages in 2011 and 2012 but is high compared to 2008 through 2010. More notably, the resulting lost generation during the first quarter of 2013 is much higher than any quarterly average during the prior years.

Figure 3

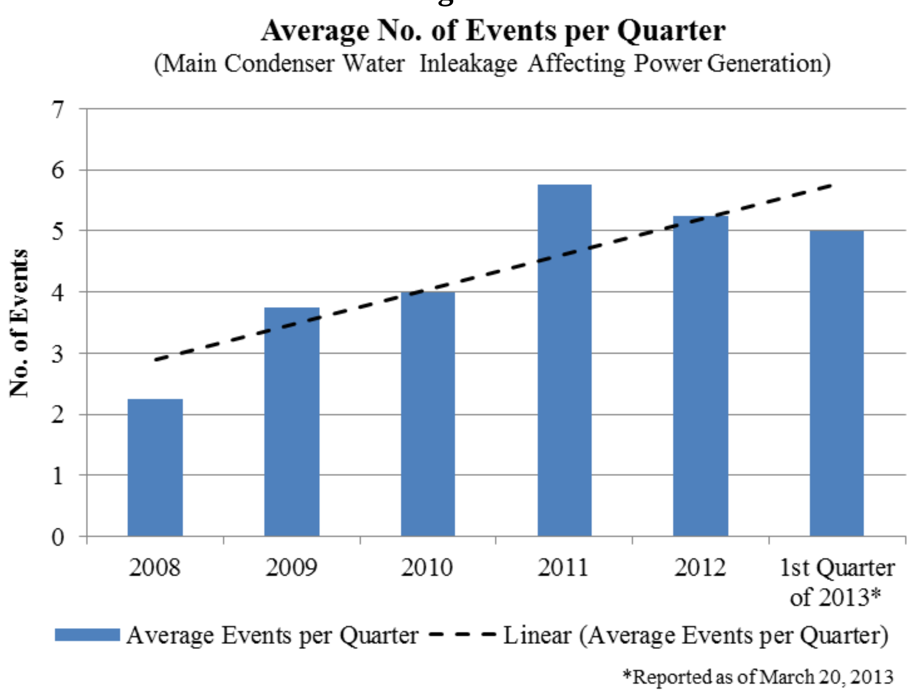
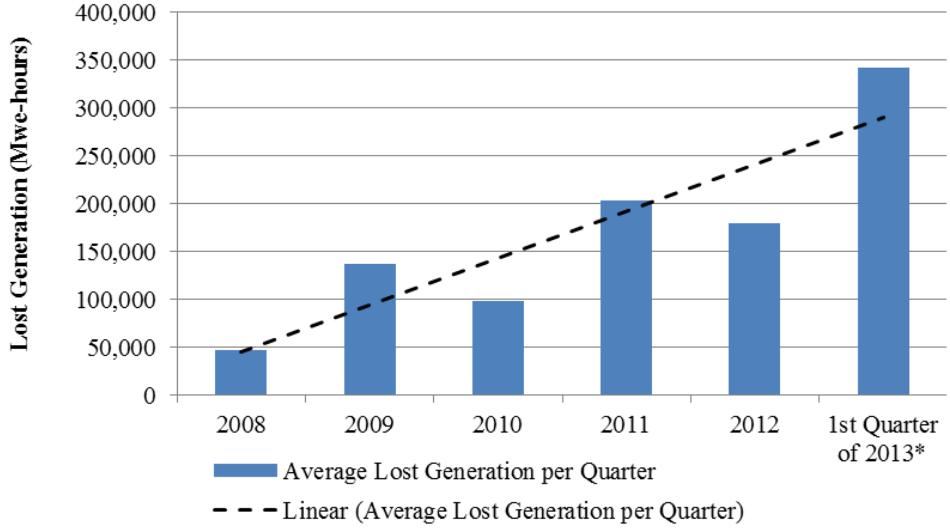


Figure 4
Average Lost Power Generation per Quarter
(Main Condenser Water Inleakage Affecting Power Generation)



*Reported as of March 20, 2013

The problem with condenser cooling water inleakage is also reflected in the industry's 2015 chemistry effectiveness indicator (CEI). Of the five conditions measured in CEI, chronic contamination (condition 4) was identified most often. Nearly two-thirds of U.S. units reported chronic contamination during the last two years, many attributed to main condenser water inleakage. Forty-seven of 65 PWRs and 22 of 35 BWRs reported chronic contamination during their most recent and/or prior cycle. In many cases, main condenser water inleakage also affected other conditions included in the station CEI.

Based on CEI data, about a dozen stations experienced condenser water tube leaks since January 2011 that are not documented in ICES or indicated on history power curves. In these cases, station personnel were able to manage the effects of the intrusion or perform repairs using additional measures without affecting power generation. These incidents, however, indicate that the frequency of cooling water inleakage is actually a little higher than reflected in ICES and the power history curves.

Figures 5 and 6 present a breakdown of direct and general causes of condenser water inleakage events reported in ICES. Little or no causal information was provided in about 20 percent of the reports. For the remaining events, the most frequent causes identified included aging, insufficient life cycle management, erosion, corrosion, surface defects, vibration, and foreign material.

Figure 5

Direct Causes of Main Condenser Water Inleakage Events Affecting Power Generation (ICES/2011-2012)

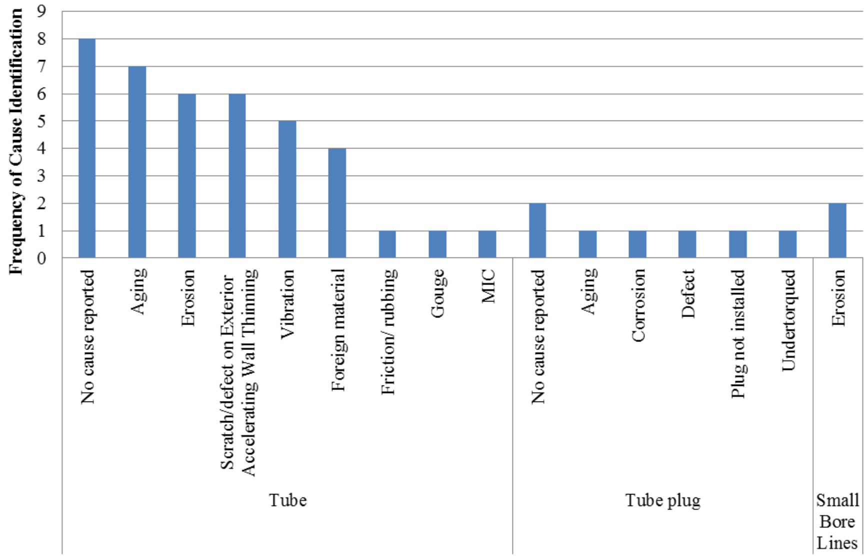
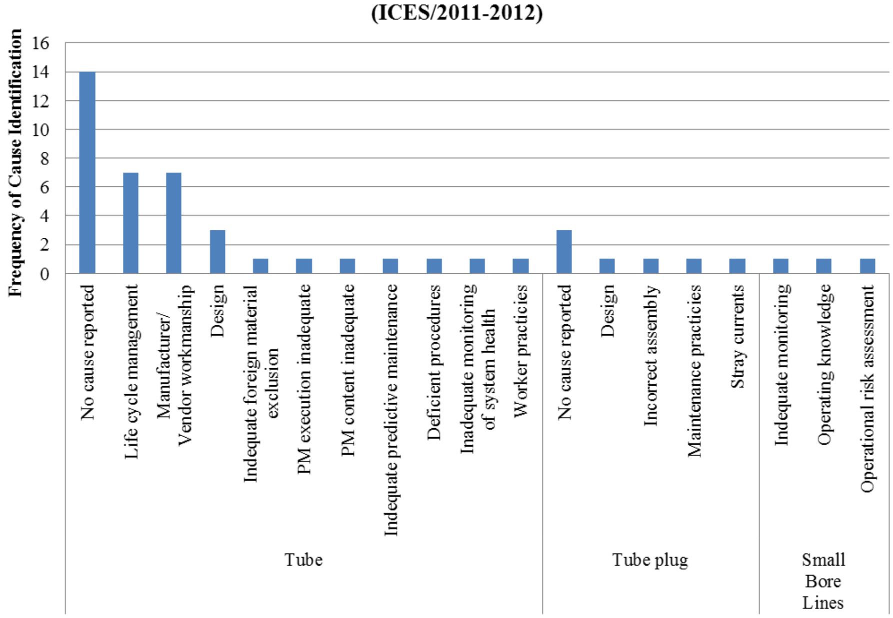


Figure 6

General Causes of Main Condenser Water Inleakage Events Affecting Power Generation (ICES/2011-2012)



Discussion

In addition to the information available in ICES (see Attachment 1), causal information was obtained from INPO areas for improvement (see Attachment 2) and subject-matter experts. Based on these collective inputs, the predominant reasons for cooling water leaks inside main condensers include the following:

Prevention

1. Preventive maintenance and life cycle management of main condensers did not effectively address the effects of general aging and wear and did not predict condenser tube and plug life. In some cases, ownership of the main condenser performance was not always clear because responsibilities were spread across several organizations, thereby diluting accountability.

2. Foreign material exclusion control during outages was inadequate, resulting in falling objects striking tubes during the outage and foreign material being left behind that damaged tubes after the condenser was put into service. In some cases, supplemental personnel disassembling turbines above the condenser dropped debris into the condenser. Also, debris originating from cooling towers or other water sources entered the condenser water boxes, damaging tube-to-tube-sheet joints, tube sheet coatings, and tubes, resulting in leaks.

3. Permanent tube plugs were installed without appropriate follow-up inspections to ensure they were not experiencing galvanic corrosion, deformation, and loosening. In other cases, temporary plugs (rubber/polymer) that were being used instead of permanent plugs were not replaced in a timely manner. Temporary plugs are particularly vulnerable to ejection during power excursions as rubber/polymer loses elasticity after several temperature cycles.

4. The effects of steam erosion and liquid drop impingement were not fully considered or assessed after operational changes such as power uprates or modifications to systems that discharge into the condenser. In several cases, tube inspections during refueling outages after these operational changes were not thorough.

5. Tube-to-tube-sheet joints weakened as the result of aging or poor workmanship. The joints leaked after hydraulic pulsing or water hammer transients. In several cases, tube sheet coatings hid early indications of joint leaks that became visible after the coating started to delaminate.

6. Mechanical damage occurred during maintenance or retubing activities in the main condenser as the result of poor workmanship. This resulted in tube exteriors being scratched, dented, or gouged, which accelerated failures as the tubes started to approach their end of life.

Leak Detection

7. Some on-line chemical monitoring systems were not being maintained and, thus, were either unavailable or unreliable. This hindered the ability of personnel to quickly detect a small leak or a leak at its infancy.

8. Potential failure locations were missed during initial reviews of eddy current test data. In several cases after a failure, the potential failure location was identified during a re-review of the prior test data.

9. An incorrect detection method was used after a leak was suspected, resulting in personnel initially entering the incorrect water box. By the time the correct water box was identified, significants amount of contaminants were introduced into the plant water systems.

Attachment 3 provides details on these topics.

Corrective Actions for Consideration

The following corrective actions for consideration reflect information provided in ICEs reports, INPO areas for improvement, and input from subject-matter experts.

Prevention

1. Ensure that equipment used to clean tubes and tube sheets is maintained in a manner that results in high reliability and availability (for example, ball cleaning systems and cathodic protection).

2. Periodically evaluate and revise the condenser preventive maintenance strategy as condenser performance decreases. Adjustments are needed if tube degradation measures such as wall thinning, pitting, or the number of leaks are increasing.

   a. Measure and trend tube wall thinning in a systematic way. Condenser tube wall thinning is a known phenomenon that is predictable based on inspection data. Make use of prediction techniques to forecast service life based on inspection results. Develop a retest schedule for and monitor degraded tubes that do not meet plugging criteria. For tubes that show advanced wear, consider reinspecting every outage or plugging. Ensure that tube inspection frequencies are adjusted to account for the effects of power uprates on wall thinning as the result of increased flow.

   b. Appropriately adjust the frequency and scope of preventive maintenance activities when the number of degraded tube and plug conditions increases. For example, consider increasing the tube percentage of inspections and the frequency of eddy current testing as the condenser ages.

c. Develop a preventive maintenance strategy for inspecting main condenser tube plugs during outages. This may include visual inspections and plug replacement at a predetermined frequency. Verify that no tube plugs are missing and that all plugs are in their correct locations. This is particularly important after the condenser water box experiences an extreme pressure transient.

d. Perform eddy current testing or an equivalent inspection method on all tubes within a given time period—preferably every 8 to 10 years. Follow up unusual probe indications with an advanced, slower-moving probe to detect pits and circumferential cracks. Ensure that the correct types of eddy current testing probes and equipment are used based on materials, dimensions, and plant conditions (references 1, 3, and 4). In some cases, different types of probes are used in conjunction to ensure proper measurements. Consider validating indications with another method, such as a visual inspection using a boroscope.

e. Verify that main condenser tubes are leak tight when coming out of a refueling outage. One approach is to use dimple plugs as soon as condenser vacuum can be established. Ensure that compensatory actions are in place as part of the startup strategy in case a leak develops. If properly planned, those actions can be performed without becoming critical path for startup.

3. Evaluate current strategies regarding chemical treatment of circulating cooling water. Ensure strategies address microbial-induced attacks, general corrosion, and wear from mussel and clam shells. The effectiveness of chemical treatments should be routinely monitored.

4. Maintain a robust foreign material exclusion program for main condenser entries, ensuring that all tools and other objects taken into the condenser are accounted for and removed before closure. The foreign material exclusion program also applies to work performed on the turbines above the condenser. Do not leave partially disassembled systems inside a main condenser; instead, remove everything associated with a subsystem that is not being used. Parts left in the condenser that may be attached to it can eventually fail or break away and become foreign objects that damage tubes (for example, leaving pipe hangers in place after the piping was removed).

5. Avoid the use of temporary rubber/polymer plugs. Polymer plugs and plugs that have rubber components are easy to install but are meant to be temporary and should be replaced with a permanent plug at the first opportunity, typically within one cycle.

6. Verify that an adequate supply of tube plugs is available in inventory.

7. Ensure that modifications made to systems that discharge into the condenser address all potential effects on components inside the condenser, such as accelerated erosion of tube exteriors that could result when a normally closed line is allowed to discharge continuously.

8. Ensure all relevant information has been reviewed and evaluated when different tube sheet coating applications are assessed, including the following:

    a. potential impacts of coatings on condenser thermal performance
    b. possibility of additional biological growth, which may require additional demand for biocide treatment within the condenser

9. Inspect for tube sheet coating delamination and defects as well as leaks underneath the coating.

<u>Leak Identification</u>

10. Review leak detection strategies to ensure that monitors and equipment used to identify and diagnose condenser water inleakage are the most appropriate for the application. Ensure that leak detection monitors and equipment are accurate and available.

11. Develop decision trees with corrective actions for repairing leaks inside the main condenser and document in procedures and processes. Key decision points should consider negative impacts on protected assets. At BWRs, dose, resin replacement, and additional liquid radwaste also need to be considered in the decision process.

12. Ensure the leak detection process/procedure provides clear instructions for identifying the size and location of a leak. Important aspects include the following:

    a. Validate that initial indications of a leak are the result of cooling water inleakage and not the result of contaminates from other sources.
    b. Quantify the leak rate.
    c. Use a leak detection method that has the lowest detection limit necessary to find the leak location.
    d. Verify that all prospective cleanup systems are maximized with the most effective media and that equipment is reliable and available.
    e. Monitor the capacity and predict the exhaustion of the media in the cleanup systems being used to mitigate the leak, and proactively change out the media prior to impurity breakthrough. Cleanup systems typically used are condensate demineralizers, blowdown cleanup demineralizers, and reactor water cleanup.

13. Verify that operations, engineering, and chemistry personnel have been trained on abnormal operating procedures for condenser leak detection and mitigation. Perform follow-up training when condenser conditions change as the result of aging.

References

1. EPRI 1003088, *Condenser Application and Maintenance Guide*, Final Report 2001
2. EPRI 1007309, *Condenser Performance Monitoring Practices*, September 2002
3. EPRI TR-112819, *Condenser In-Leakage Guideline*, Final Report, January 2000
4. EPRI 1004116, Condenser Technology, Seminar and Conference, Proceedings, September 2002

Attachment 1

Main Condenser Cooling Water Inleakage Resulting in Lost Generation (ICES/2011 - 2013[4])

(in order by unit effect, then date)

	Unit	Unit Effect	Date of Unit Effect	ICES Report No.	Event Title	Component	Primary Problem Area(s): Prevention	Primary Problem Area(s): Detection	Primary Problem Area(s): Repairs
1	Hatch 1	Manual scram	02/10/13	302697	Manual scram from 47% caused by rising water chemistry conductivity - enter forced outage	Tube	X		
2	Comanche Peak 2	Manual scram	05/19/11	249248	Main Condenser Tube Leak Due to Falling Object	Tube	X		X
3	Turkey Pt. 3	Manual scram	03/06/11	247888	Manual reactor scram and AP-913 failure event due to failure of tube in Main Condenser.	Tube		X	
4	Dresden 2	Forced shutdown	08/31/12	300739	Forced Outage Resulting From Main Condenser Center Water Box Vent Line Perforation	Vent line	X		
5	Palo Verde 2	Outage extension	11/10/12	302476	During Power Ascension After A Refueling Outage Power was Held at 40% for Condenser Tube Leak Repair	Tube	X		
6	St. Lucie 1	Outage extension	04/07/12	No ICES report issued Event identified on power history curve	Forced Outage to Repair Condenser Tube Leaks (7 days)	Tube			
7	Salem 2	Delayed startup	11/13/12	302143	Elevated Conductivity/Sodium Levels In Condenser Hotwells During Start Up From Refueling Outage	Tube plug			X
8	Fermi 2	Delayed startup	02/11/11	247489	System Trip of Circulating Water System Causes Tube Plug Ejection	Tube plug			X

[4] Reported as of March 20, 2013.

	Unit	Unit Effect	Date of Unit Effect	ICES Report No.	Event Title	Component	Primary Problem Area(s) Prevention	Detection	Repairs
9	St. Lucie 1	Delayed power ascension	04/04/11	248418	Failure Of Bolt(S)/Stud(S)/Screw(S) and Tube Plugs in Subcomponent Condenser of Main Condenser	Tube plug			X
10	Fitzpatrick	Power reduction	03/19/13	No ICES report issued Event identified on power history curve	Forced power reduction [50%] to repair a main condenser tube leak	Tube	X		
11	Fitzpatrick	Power reduction	02/24/13	No ICES report issued Event identified on power history curve	Forced power reduction [50%] because of condenser leakage	Tube	X		
12	Fitzpatrick	Power reduction	02/02/13	No ICES report issued Event identified on power history curve	Reduced power [51%] for condenser tube leak repair	Tube	X		
13	Palo Verde 3	Power reduction	01/08/13	302505	Reduced power [40%] to repair a condenser tube leak	Tube	X		
14	Fitzpatrick	Power reduction	12/21/12	302215	Plant had a planned power reduction greater than 20% due to increased conductivity indicating a tube leak.	Tube	X		
15	Cooper	Power reduction	12/10/12	302325	Condenser B1 Tube Leak Resulting in an Unexpected Reduction of Power Greater than 20%	Tube	X		
16	Fitzpatrick	Power reduction	11/09/12	302202	Plant downpower due to increased condenser conductivity.	Tube	X		

	Unit	Unit Effect	Date of Unit Effect	ICES Report No.	Event Title	Component	Primary Problem Area(s) Prevention	Detection	Repairs
17	Vogtle 1	Power reduction	10/22/12	No ICES report issuedEvent identified on power history curve	Power reduction caused by a condenser tube leak (drop to 83% power)	Tube			
18	Oyster Creek	Power reduction	09/29/12	301577	Leak in the main condenser cooling water piping was identified during a condenser backwashing evolution.	Pipe	X		X
19	Fitzpatrick	Power reduction	09/05/12	300943	Forced downpower >20% scheduled <10 days ahead due to failure of condenser tube in "A" Main Condenser	Tube	X		
20	Fitzpatrick	Power reduction	07/25/12	300942	Forced downpower >20% scheduled <10 days ahead due to failure of condenser tube in "A" Main Condenser 33C-10A	Tube	X		
21	Fitzpatrick	Power reduction	06/19/12	No ICES report issued Event identified on power history curve	Reduced Power to 50 Percent for Main Condenser Tube Repair	Tube	X		
22	Fitzpatrick	Power reduction	06/14/12	300940	Forced down power >20% scheduled <10 days ahead due to failure of tube in The 'B' Main Condenser.	Tube	X		
23	Vermont Yankee	Power reduction	04/09/12	253444	Forced down power >20% scheduled >=10 days ahead due to failure of tube in Main Condenser.	Tube		X	
24	Robinson 2	Power reduction	03/26/12	253532	Forced down power >20% scheduled <10 days ahead due to preliminary report of failure of Heat Rejection System centrifugal - axial pump CW-PMP-A.	Tube		X	
25	Palo Verde 1	Power reduction	02/22/12	253108	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube in Main Condenser 1MCDNE05A.	Tube	X		

	Unit	Unit Effect	Date of Unit Effect	ICES Report No.	Event Title	Component	Primary Problem Area(s) Prevention	Detection	Repairs
26	Fitzpatrick	Power reduction	01/25/12	252726	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube in Main Condenser 33C-10B.	Tube	X		
27	Oyster Creek	Power reduction	01/21/12	No ICES report issued Event identified on power history curve	Power Reduced to 60 Percent to Perform Condenser Tube Repairs	Tube			
28	Fitzpatrick	Power reduction	01/15/12	252575	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube in Main Condenser 33C-10B.	Tube	X		
29	Oyster Creek	Power reduction	01/11/12	252530	Forced down power <=20% and AP-913 failure event due to failure of tube and tube plugs in Condenser System piping that supports Main Condenser CD-2-001C.	Tube and Tube plugs	X		X
30	San Onofre 3	Power reduction	01/08/12	252488	Forced down power <=20% due to failure of tube in Main Condenser S31314ME085.	Tube	X		
31	Fitzpatrick	Power reduction	12/27/11	252353	Forced down power >20% scheduled <10 days ahead due to failure of tube in Main Condenser 33C-10A.	Tube	X		
32	ANO 2	Power reduction	12/19/11	252288	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube in Main Condenser 2E11B and Subsequent Sodium Excursion Result in a Unit Down Power to 47% Power (OE35202)	Tube	X		
33	Fitzpatrick	Power reduction	12/02/11	252021	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube in Main Condenser 33C-10B.	Tube	X		

	Unit	Unit Effect	Date of Unit Effect	ICES Report No.	Event Title	Component	Primary Problem Area(s): Prevention	Detection	Repairs
34	Catawba 2	Power reduction	10/12/11	251256	Forced down power >20% scheduled >=10 days ahead due to failure of tube in Main Condenser 2CMCDC.	Tube		X	
35	St. Lucie 1	Power reduction	10/03/11	No ICES report issued Event identified on power history curve	Planned load reduction for maintenance to locate waterbox tube leak [16 days]	Tube			
36	Palo Verde 1	Power reduction	09/28/11	251098	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube in Main Condenser 1MCDNE05C.	Tube plug			X
37	Oyster Creek	Power reduction	09/21/11	251003	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tubing in Condenser System piping that supports Main Condenser CD-2-001B.	Tube	X		
38	Three Mile Island 1	Power reduction	09/02/11	250752	Planned/scheduled unit power reduction due to failure of tube in Main Condenser CO-C-1A.	Tube		X	
39	Susquehanna 1	Power reduction	07/05/11	249966	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube in Condenser System condenser 1E108C.	Tube	X		
40	St. Lucie 1	Power reduction	07/05/11	249962	Forced down power <=20% and AP-913 failure event due to failure of tube plugs in subcomponent condenser of Main Condenser CNDSR 1A.	Tube plug		X	X
41	St. Lucie 1	Power reduction	05/30/11	249420	Forced down power <=20% and AP-913 failure event due to failure of tube sheet in Main Condenser CNDSR 1A.	Tube plug	X		X

	Unit	Unit Effect	Date of Unit Effect	ICES Report No.	Event Title	Component	Primary Problem Area(s) Prevention	Detection	Repairs
42	Fitzpatrick	Power reduction	05/06/11	249036	Forced down power >20% scheduled <10 days ahead due to failure of tube in Main Condenser 33C-10A.	Tube			
43	Fitzpatrick	Power reduction	04/30/11	248923	Forced down power >20% scheduled <10 days ahead due to failure of tube in Main Condenser 33C-10A.	Tube	X	X	
44	Beaver Valley 1	Power reduction	04/17/11	248675	Unit Power Reduction Due to Preventive Maintenance of Tubing/Fittings In Main Condenser	Tube	X		
45	Beaver Valley 1	Power reduction	04/07/11	248487	Unit Power Reduction Due to Preventive Maintenance of Tubing/Fittings In Main Condenser	Tube	X		
46	Clinton	Power reduction	04/02/11	248057	Forced down power >20% scheduled >=10 days ahead and AP-913 failure event due to failure of tube in Main Condenser 1CD01A.	Tube		X	
47	Palo Verde 3	Power reduction	03/04/11	247777	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube in Main Condenser 3MCDNE05A.	Tube	X		X
48	Palo Verde 3	Power reduction	01/15/11	247082	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube plugs in Main Condenser 3MCDNE05C.	Tube plug			X
49	Fitzpatrick	Power reduction	01/11/11	247019	Forced down power >20% scheduled <10 days ahead and AP-913 failure event due to failure of tube in Main Condenser 33C-10B.	Tube		X	

Attachment 2
Excerpts From INPO Areas for Improvement Referencing Main Condensers[5] (2011-2012)

	Reactor Type	Year AFI	Summary
1	BWR	2012	Deficiencies exist in establishing sufficient foreign material control plans and worker adherence to foreign material exclusion (FME) standards. During condenser repairs the supplemental workforce did not establish the condenser as a high-risk foreign material exclusion area requiring accountability of tools and material brought into the condenser. This resulted in materials such as welding rods, pieces of wire, grinding discs, wire brushes, and wire ties accumulating in the condenser that could result in tube damage during operation. The supplemental workers stated that retrieval of material and debris following the completion of the job would be sufficient to ensure foreign material was removed before closeout. Contributing to the inappropriate FME risk classification was an insufficient level of station management oversight of this supplemental work activity.
2	BWR	2012	Long-standing condenser tube leakage has not been addressed effectively. Recurring condenser tube leaks have degraded reactor water chemistry, increased personnel exposure, and required emergent repairs. Inadequate system engineering benchmarking has resulted in insufficient progress for improving condenser performance. The 1995 retubing installed tubes made from the same material as original construction. The current tubes are exhibiting similar failure rates as the original condenser after 15 years of service. There are opportunities to proactively plug some tubes experiencing wall thinning before the next refueling outage. For example, micrometer measurements found 30 tubes with less than 10 percent of the wall thickness remaining. Site managers decided to not plug these tubes because no leakage existed at the time. Furthermore, the current strategy calls for a go/no-go test in the upper regions of a single water box after an emergent tube leak occurs. Other water boxes and the lower section of the water box removed from service are not part of the current action plan and should be incorporated. Installation of outlet end tube sleeves in the next refueling outage should reduce the frequency of wall thinning failures. Development of the improved eddy current probe should detect the linear splitting locations.
3	BWR	2012	Chemistry management did not recognize the error-likely situations created by not incorporating revisions to important diagnostic data validation procedures and flowcharts. This required chemistry technicians to use their knowledge and experience to compensate for the procedure weaknesses.

[5] Includes AFIs in which main condenser problems were identified as an example of the fundamental overall problem.

	Reactor Type	Year AFI	Summary
			When personnel were subjected to the time pressures of an escalating condenser tube leak, they were unable to apply the appropriate data validation techniques. Although continuing training to identify off normal system chemistry conditions had been recurring since 2003, the laboratory guidance and flowcharts had not been updated since May 2000. The existing diagnostic guidance was event driven and did not contain pertinent information for evaluating the changing conditions. Also contributing to misdiagnosis was that chemistry personnel had not experienced a condenser tube leak at the station since 1984. Training modules to identify the off normal chemistry lacked questioning techniques needed for technicians to validate condenser tube leaks even though they lacked first-hand experience. Instituting a new electrical safety requirement in the chemical addition process did not prompt chemistry leaders to perform a thorough review to ensure that critical steps and consequences were understood by chemistry technicians.
4	PWR	2012	The material condition of the main condenser tubes is not fully resolved. As a result, at least one power reduction was required because condenser water boxes had to be isolated to locate and repair tube leaks. Contributing is that the plan to understand the material condition of the main condensers has not been implemented with the appropriate level of urgency. A plan to examine the main condenser tubes and assess the extent of tube degradation was not timely. This was partly because personnel tend to rely on a robust design of the condensate polisher system to protect the steam generators from the consequences of tube leaks. The plan for examining the main condenser tubes is not monitored effectively to eliminate delays and ensure examinations are timely. One reason is that the method used to track the timeliness of completing actions was not effective. A decision to partner with an industry third-party organization to develop new eddy current probes also caused delays. This is because the third party was not contacted until two months after the failure analysis was completed, and the engineer overseeing the new probe design stated that probe development experienced delays. An opportunity to examine Unit 2 condenser tubes with available conventional technology during the last refuel outage was not taken, despite a recommendation from the condenser tube failure analysis report in 2011 that conventional eddy current testing could identify degraded tubes for plugging. Instead, engineers chose to wait for newly designed probes because those probes would provide more accuracy.
5	BWR	2012	Maintenance and supplemental workers do not consistently apply verification practices, mitigate hazards, or follow work instructions when performing work. This has resulted in a turbine trip, damaged condenser

	Reactor Type	Year AFI	Summary
			tubes, component mispositioning, and rework. Contributing to this, workers sometimes proceed without validating assumptions when faced with a problem. During a refueling outage, supplemental turbine services workers did not verify the diffuser holding bolts was secure before rigging and installation of the low-pressure turbine upper inner casing. As a result, when the inner casing was being lowered, incidental contact with the diffuser knocked a holding bolt out of the keeper, causing the bolt to drop into the condenser, which damaged several condenser tubes. The potential for dropping diffuser bolts was not discussed during the prejob briefing because of assumptions about the bolts' engagement in the inner cylinder.
6	BWR	2011	Chronic condenser tube leaks coupled with degrading tube plugs have allowed the ingress of contaminants into the reactor vessel. The buildup of contaminants forced a plant shutdown, increased the potential for stress corrosion cracking of reactor vessel internals, and caused some entries into chemistry action levels. Contributing to this is that chemistry and engineering managers have elected to manage the impact of contaminant ingress rather than prioritize and repair the faulty equipment. Chemistry and engineering managers chose to manage ongoing condenser tube leakage rather than advocate and drive resolution of the degraded equipment. Chronic leaks have occurred over the last three cycles, and contaminant ingress has typically been managed through resin configuration in the filter demineralizers for condensate and reactor water cleanup. Actions are either slow or are not being taken to resolve the ongoing condenser tube leaks. Tube plugs of limited pressure ratings still exist in the condenser, and foreign material exclusion (FME) controls are not reducing the risk of material in contact with condenser tubes. These materials increase the potential for further condenser tube damage. Managers did not implement some recommendations identified during formal benchmarking. For example, eddy current testing of condenser tubes has not been performed since their replacement in 1991. Managers purchased dimple plugs for condenser leak detection but have not used them. Additionally, managers are aware of industry experience indicating that the older-style tube plugs fail over time based on their material properties; however, they have not championed aggressive replacement. Personnel have not performed a focused assessment on the condenser in approximately five years to look for degrading performance and its impact on system chemistry and corrosion control. Although engineering personnel stated that FME is the likely cause of the tube leaks experienced during the past two cycles, they have not verified the failure mechanism.
7	PWR	2011	Mitigation strategies for condenser leaks have been unsuccessful in preventing recurrence. This has resulted in contaminant ingress to the

	Reactor Type	Year AFI	Summary
			steam generators and has required power reductions to repair leaks. Contributing to this are vibration-induced failures in tubes combined with changes in velocity patterns of the condenser following the turbine retrofit project. An apparent cause is vibration-induced failure of long unstaked tubes in high-velocity regions of the condenser. The condensers have a history of vibration-induced failures with corrective actions taken to stake the first 15 rows of condenser tubes. It is suspected that turbine replacement on Unit 2 may have resulted in changes in velocity patterns that are contributing to the degradation beyond the initial areas addressed. Since January 2011, Unit 2 has been above the 10 GPD threshold twice, requiring leak identification. The current short-term mitigations put into place have not prevented further condenser in-leakage. Neither the plugging criteria nor the condenser pressure changes have been effective in preventing the reoccurrence of leaks.
8	PWR	2011	Chronic problems with sodium intrusion from condenser leaks and the resultant need to operate with condensate polishers are resulting in unexpected downpowers, increased feedwater system corrosion, and elevated iron transport to the steam generators. Contributing to this problem is that benchmarking to improve condenser performance was ineffective and did not include some successful industry approaches for improving condenser integrity and reducing iron transport. Early in the evaluation period, chemistry and engineering managers focused on protecting condenser tubes from debris, improving condenser coatings, and enhanced condenser inspections. However, efforts to improve condenser integrity were reactive, and new approaches using industry best practices to correct recurring condenser in-leakage were not pursued. Benchmarking efforts missed some current industry approaches to correct condenser leaks. For example, while condenser dimple plugs are left in place for 12 hours to find low-level leaks, some stations with small condenser leaks leave dimple plugs in place for 18 hours or more to improve the ability to detect small leaks. Other industry-proven techniques for identifying condenser leaks have not been evaluated, including sleeving the first 6 inches of condenser tubes and the use of condenser hydros to find small leaks.
9	PWR	2011	Outage activities are not adequately planned, scheduled, or controlled to ensure secondary chemistry is maintained to maximize steam generator reliability. Consequently, during the spring 2010 refueling outage and subsequent startup, secondary chemistry was outside specifications for steam generator corrosion control for more than 60 days.

	Reactor Type	Year AFI	Summary
			Contingencies to monitor or correct condenser tube tightness were not available before startup from the refueling outage. When the planned method for leak testing the condenser going into the outage was not possible because of a scram, alternative methods such as dimple plugs were not used to ensure condenser tightness before startup.
10	PWR	2011	Managers have not successfully resolved recurring chemical intrusions into secondary systems. As a result, shutdowns and power reductions have been necessary to minimize the effect of chemical impurities on the health of the steam generators. Contributing to this are recurring condenser leaks and the lack of an aggressive secondary chemistry outage strategy to eliminate impurities. Corrective actions have not been effective in eliminating recurring seawater leakage into the condenser hotwell, and inleakage events continue to subject the steam generators to out-of-specification chemistry. Several sources of condenser leakage have been addressed in succession, such as condenser air removal flange leakage, tube stub failure, and tube plug degradation. A high-level evaluation of all possible failure mechanisms reviewed in parallel using cross-functional personnel, including thorough review of operating experiences from other stations with similar failures, was only recently organized to identify the needed corrective actions. There is no identified owner for the condenser. The health of the condenser is shared among the intake cooling water, condensate polisher, cathodic protection, and thermal performance engineers. As a result, measurement of condenser health is not reported to management through the equipment and component health reporting system. By dispersing facets of the condenser within other health reports, the true measurement of the condenser health is being diluted.
11	PWR		Elevated levels of iron and ionic impurities entering the steam generators contribute to the continued buildup of sludge deposits and promote potentially corrosive chemistry conditions. Contributing is that chemistry managers have not pursued methods to maintain steam generator chemistry impurities as low as achievable for all modes of operation. Chronic low-level condenser in-leakage is resulting in incremental increases in sodium and other contaminant ingress into the steam generators. The presence of elevated levels of contaminants can promote steam generator crevice corrosion. As a result, lake water ingress is contributing to average levels of steam generator ionic contaminants that are among the highest in the industry. Chemistry managers have not pursued methods to maintain steam generator chemistry impurities as low as achievable. Specifically, they have focused on startup chemistry control, which has had the largest

	Reactor Type	Year AFI	Summary
			negative impact on the chemistry effectiveness indicator (CEI). Chemistry managers stated that improving steady-state levels of iron was a lower priority than iron transport during unit startup. They also believed that costs to further improve steady-state chemistry levels would not justify the benefit, although no formal cost benefit assessments were made. In addition, some analytical techniques used to monitor impurity ingress are not optimized.
12	PWR	2011	Insufficient startup chemistry controls, condenser in-leakage, and makeup treatment plant impurities are adversely affecting the ability to maintain secondary chemistry parameters within desired limits. Contaminants entering the secondary plant increase the risk of steam generator corrosion. The main cause is a low organizational sensitivity of the need for better impurity control in the secondary system. Small, intermittent condenser water box leaks on both units are contributing to steam generator impurities. Although several actions have been taken to identify the leaks, the most sensitive leak-detection methods were not applied, and the actions have been ineffective. Main condenser tube leak detection investigations and techniques observed at other stations were not performed because the leaks were assumed to be too small to find. Managers stated that the condenser leakage is caused by tube-to-tube sheet leakage and plan to apply a coating to both condensers in an upcoming outage. Because action levels are met during normal operation, tube leakage has not been investigated for several years, and no plans other than for eddy current testing exist. Dimple plugs have not been employed as a standard practice during each refueling outage as seen in the industry. This is often done first to rule out tube failures before other more resource-intensive activities, such as tube sheet coating, are performed. There are plans to apply a plastic coating to the condenser tube sheet to reduce tube-to-tube sheet leakage.
13	PWR	2011	At times, secondary water chemistry has not been controlled effectively to meet chemistry specifications for the feedwater and steam generators. In addition, the secondary on-line chemistry monitoring system has not operated reliably. These problems increase the potential for long-term degradation of the steam generators. Three Unit 2 condenser tube leaks over the evaluation period have delayed the effective implementation of Unit 2 condensate polishers to the amine form, which would improve feedwater iron concentrations.

Attachment 3

Discussion Regarding Causes of Main Condenser Cooling Water Inleakage

Additional discussion regarding prevention and detection of cooling water leaks inside the main condenser is provided below based on information available from events, related INPO areas for improvement, and subject-matter experts.

Prevention

A robust main condenser health program predicts condenser life by considering the effects of aging and wear. Condenser tube health and life expectancy monitoring should consider days of operation, wear data, and other data that could affect operating life. Condenser tube ruptures from normal wear, aging, and wall pitting and thinning need to be considered in condenser performance monitoring.

- Trending of Condenser Performance

  Use proactive monitoring to trend condenser performance and material conditions relative to the predicted life expectancy of the condensers. The long-term asset management plan should consider the appropriate timing for condenser tube bundle replacement to avoid increasingly frequent and repetitive leaks that reduce condenser life, cause complications from downpowers, and challenge operations personnel to maneuver the plant. (references 1, 3, and 4)

- Inspection Program

  A robust inspection problem involves performing a 100% baseline inspection followed by reinspection of all tubes within 8 to 10 years (for example, every four to five refueling outages assuming a two-year fuel cycle). The number of reinspections each outage should be increased if signs of aging or degradation are identified. Among techniques available to inspect condenser tubes, eddy current testing (ECT) is the most widely used inspection method. However, the industry has experienced some problems using ECT (for example, use of the wrong probe for tube material, misinterpretation of indications, fouled tubes, and less conductive tube materials). Stations have discovered that a follow-up ECT using a slower, advanced probe such as point-plus improves the identification of tube flaws.

Leak Detection

The consequences of condenser leaks vary depending on the plant design and cooling water quality. Some stations are less affected by low levels of inleakage depending on the type of cooling water supply and condensate cleanup capability. A leak involving saltwater is typically more severe than that from a freshwater source. Some stations do not have to downpower to enter a water box for repairs, which allows for a quicker response to the leak. In other cases, some stations have more cleanup capacity that provides them more time before the leak needs to be addressed.

When monitoring and predictive tools do not prevent condenser leakage, be prepared to locate and repair condenser leaks promptly. Have an established strategy and proven methods for locating the water box or tube tray leak location to avoid delays and misidentification of the leak. Managing long-term condenser inleakage by increased blowdown and use of demineralizers could result in elevated impurities in the reactor vessel or steam generator and could increase the potential for stress corrosion cracking.

- On-line Monitors and Equipment

  It is crucial to use on-line chemistry monitors and sampling equipment to enable rapid and accurate identification and location of condenser water inleakage. On-line monitors typically used are specific conductivity, cation conductivity, sodium and similar analyzers, as well as temperature, pressure, and level indicators associated with the main condenser. Regardless of the monitor type, these monitors and support equipment need to be maintained for high reliability and availability. Repairs of this equipment should be prioritized regardless of the safety classification. Equally important is grab sample equipment such as hotwell sample pumps and tube tray samplers. This equipment also needs to be maintained for high reliability and availability. Grab sample points provide data needed to confirm the identification and mitigation of a leak.

- Detection Techniques

  The sensitivity of the leak detection method depends on the plant design and size of the leak. Injecting helium during drain-down of suspected leaking water boxes can provide a quick reference of the vertical location of the leaking tube. A reduction of the secondary side on-line monitor indication(s) upon isolation of the suspected leaking water box provides some assurance that the water box has been isolated.

  — large leaks

    In general, large leaks can be detected using enhanced audible-related techniques, shaving cream, foam, or plastic wrap once the water box is open and the plant condenser is under vacuum. Visual examinations also can detect large leaks. Foam has been used successfully when positive pressures can be applied and is effective at finding tube-to-tube-sheet leaks.

    Hydrostatic testing has been used successfully to detect larger leaks. This is typically performed when the unit is shut down and involves monitoring chemistry parameters as water level in the condenser is raised.

Another approach involves monitoring offgas and chemistry parameters while lowering water box level in both BWRs and PWRs. This is typically performed on line and is used to identify the elevation of the leak in the tube bundle.

— small leaks

Techniques typically used for identifying small leaks include helium, sulfur hexafloride and dimple plugs.

Helium (He) and Sulfur Hexafloride (SF_6)

Helium and SF_6 are typically used to find smaller leaks down to 2-3 gallons per day (GPD). However, one station reported using helium to find leaks less than 1.0 GPD. The appropriate gas to use depends on plant design. In some cases, both gases are used to identify the water box location and tube leak locations once the water box in opened. The SF_6 is injected into the circulating water before it reaches the suspected water box while detecting for the SF_6 gas at the air ejector. A positive indication for SF_6 at the air ejector is an indication that the leak is likely in that specific water box. However, beware of crossover piping providing faulty indications. Because SF_6 is more soluble than helium, it is more easily injected into the circulating water than helium, although some stations have used helium for this as well. Both SF_6 and helium can be used once a water box is open to spray into discrete locations while detecting for the gas at the air ejector. A systematic pattern of injecting helium, typically starting at the top rows of the tube sheet and working downward (because helium is lighter than air and will rise), will provide an indication near the leaking tube(s). In a BWR however, beware when connecting leak detection equipment to offgas systems, because high dose rates can be encountered.

Dimple Plugs

One of the most sensitive detection methods for locating leaks is inserting dimple plugs and visually looking for the dimples created by leaking tubes (less than 1 GPD) under vacuum. Generally, this method is more sensitive than helium or SF_6 leak detection methods and has been used successfully when SF_6 and helium were ineffective in finding leaking tubes. However; this method may not be effective for tube-to-tube-sheet leaks. It is most effective when tubes can be cleaned prior to testing to remove debris that may have plugged a hole during water box draining. During outages, many stations install dimple plugs and establish a vacuum to ensure the condenser is leak tight. Dimple plugs have identified significantly more (greater than100) leaks than determined by 100% eddy current testing.

- False Positive Indications of Leaks

  False positive indications of condenser leaks can cause unnecessary power reductions in the attempt to find phantom leaks. For example, leak-by from a motor-driven main feedwater pump valve looked similar to a condenser leak. Another suspect condenser leak turned out to be a failed fire protection sprinkler head. Plastic coating delamination has caused false tube leak indications or has hidden the leak location during leak detection. Out-of-service condenser monitoring equipment such as hotwell sample pumps and tube trays have resulted in misdiagnosed conditions and led leak detection teams to the wrong water box. Other sources of contaminants such as sodium during startup from an outage when components were replaced have also been mistaken for condenser water inleakage.

Leak Repairs

Typical methods of leak repairs include tube plugs, tube sleeves, tube liners, and coatings. Coatings and sleeves used to fortify aging condensers need to be thoroughly evaluated for heat transfer characteristics because some stations have experienced thermal performance losses after parts of the condenser were coated. Also, procedures for installing coatings should have sufficient details to avoid tube damage during installation.

Plug failures, inappropriate plugs, or missing plugs have led to unexpected or premature leakage from plugged tubes. For example, several degraded rubber-sleeved tube plugs were dislodged and ejected, resulting in a significant transfer of contaminants to the reactor water or steam generator. Brass and fiber tube plugs have been known to corrode under certain conditions, especially when used with dissimilar metals. Stainless steel plugs have degraded and dislodged as the result of galvanic corrosion caused by dissimilar metals. Temporary plugs such as rubber plugs can degrade over time from oxidation and hardening.

Improper installation of tube plugs can result in damage to the condenser or loss of tube plugs at a later time. Plastic coatings used to repair tubes or address tube sheet aging can become delaminated or become the source of condenser thermal performance issues if not prepared properly.

Installation Practices During Tube Replacement

In several cases, leaks were accelerated by linear and axial scoring during tube replacements. The scoring seeded rupture points that revealed themselves prematurely when the tubes were approaching end of life. These events clearly demonstrate the importance of using appropriate techniques when installing new tubes.