HIGH PRESSURE FEEDWATER HEATER REPAIR

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Abstract

In late 1988 and early 1989, two of the four high pressure feedwater heaters at each of the three generating units at the Tennessee Valley Authority's (TVA) Thomas H. Allen Fossil Plant were replaced. In the Fall of 1997, after 8 1/2 years of service, a significant number of tubes failed suddenly in the two Allen unit 3 replacement heaters. Within a 14 month period, one of the unit 3 replacement heaters had 97 tube failures and the other had 171 failures. The mode of these tube failures was determined to be stress corrosion cracking (SCC) initiated at a tube roll transition located within the tubesheet. In order to prevent continued progression of tubing damage and to restore failed tubes to service, TVA employed CTI Industries to install stainless steel inserts in the inlet and outlet ends of each tube in the affected heaters.

This paper discusses the failures, investigative techniques, probable root causes, and corrective measures evaluated and implemented to extend the service life of high pressure feedwater heaters at TVA's Allen Fossil Plant.

Introduction

TVA is a federally owned and operated electric power company serving the Tennessee Valley. TVA's total net electric power generating capability is approximately 28,000 megawatts from a combination of fossil-fired, nuclear, hydroelectric, combustion turbine, and pumped storage plants.

TVA's Allen Fossil Plant, located in Memphis Tennessee, was designed and constructed by Burns and Row Inc. for Memphis Light Gas and Water. The plant was placed into service in 1956, was purchased by TVA in 1984 and is an integral part of the TVA system. The Allen plant has three identical subcritical generating units. Each unit has a B&W coal fired wet bottom steam generator which produces 2,000,000 pounds of steam per hour to drive a Westinghouse tandem compound triple exhaust 'turbogenerator set at a rated capacity of 250,000 kW. Figure 1 depicts the steam/water cycle.

The feedwater heating system for the Allen units includes a single string of three low pressure heaters, one deareating heater, and four high pressure heaters. The heaters are numbered #1 through #8. Heaters #1 through #3 are low pressure, heater #4 is a deaerator, and #5 through #8 are high pressure heaters with # 8 being the highest pressure. The system design includes capability to isolate each high pressure heater individually from extraction steam and to bypass feedwater around each heater individually. However, as with many facilities of this vintage, good isolation is not always achievable and depends on the condition of isolation equipment at any given time.

The original #5 and #6 heaters, manufactured by the American Locomotive Co., were replaced on all 3 units between December 1988 and June1989, with replacement heaters designed and manufactured by Southwestern Engineering Company. The replacement heaters are closed, horizontal U tube, three zone, (desuperheating, condensing, and subcooling) heaters with full access channels. The U-tubes are SB-168-400 drawn and stress relieved Monel , 5/8" OD x .060" wall tubing. The tubesheets are 10" thick carbon steel with Monel overlay machined to 1/4" thickness. The tubes are roller expanded inside the tubesheets and welded to the Monel overlay. Table 1 is a technical specification sheet for feedwater heaters #5 and #6.

Chronology of Tube Failures and Diagnostic Efforts

In October 1997 plant maintenance personnel plugged 28 leaking tubes in the Allen unit 3 feedwater heater #6. Prior to that date and since the initial operation of the replacement heaters in March 1989, there had been a total of 5 tube failures.

During a planned unit 3 maintenance outage in November 1997, pressure testing, eddy current examination, and borescope inspections revealed that tubes in both the #5 and #6 feedwater heaters had failed and were leaking at locations inside the tube sheets. The leaking tubes appeared to be randomly distributed throughout the tube bundle with inlet and outlet tube ends affected. In each of the 12 failed tubes in the #5 heater and in 3 tubes that had been plugged the month before in the #6 heater, the leaks were located with a borescope. This was accomplished by pressurizing the heater (to approximately 100 psig), applying soap solution to the inside of the tubes, and observing the bubble formations with the borescope.

A special eddy current probe, designed to detect circumferential cracks and to minimize the response to conditions that are radially symmetrical, was used to inspect the tubes. Since no calibration standards were available for the conditions encountered, an eddy current pattern recognition scheme was developed based on comparisons between tubes where leaks could be observed with the borescope and others believed not to be damaged. By use of this method the leaks in all 12 failed tubes in the #5 heater and in the three unplugged failed tubes in the #6 heater were detected. Similar damage that had not progressed through wall in other tubes in both heaters was also detected using the procedure. The special probes were obtained from the EPRI NDE Center in Charlotte, North Carolina and are described briefly in figure 2.

A number of Inlet and outlet tube ends from various locations within the tube bundle were inspected in both the #5 and # 6 heaters using the developed eddy current procedure. Eight percent of the nonleaking tube ends inspected in the #5 heater and five percent of those in the #6 heater exhibited eddy current signals characteristic of the damage observed in the tubes which were known to have failed. All damage detected was at precisely the same location in each tube.

Upon completion of the inspections a failed section of one of the #5 heater tubes was removed for laboratory examination. Microscopic examination of the sample revealed the damage to be SCC at a tube roll transition.

As indicated in figures 3 and 4, tube failure rates in both the #5 and #6 heaters increased during the months following the initial failures. Figures 3 and 4 are tube sheet plots showing the location of failed tubes in each heater.

Description of Failures, Failure Mechanisms and Root Causes

All the tube damage identified in the Allen unit 3 heaters #5 and #6 was located within the tube sheet at precisely 8 $^7/_8$ inches from the clad face of the tubesheet. Figure 7 is a sketch of the tube and tube sheet cross section depicting the location of failures and cracks. Microscopic examination of the retrieved failed section of tube revealed the damage to be longitudinal SCC at a tube roll transition. Borescope examinations performed after the initial discovery of the problem revealed that the failed tubes each had from one to three longitudinal cracks, all located precisely at the roll transition 8 $^7/_8$ inches from the clad face of the tubesheet.

SCC can occur when a susceptible material with high tinsel stress levels is subjected to a corrosive chemical environment. One of the specific primary causes of the Allen feedwater heater tube wall SCC is believed to be high residual stress levels at the channel end transitions of the tube rolls located at the shell side face of the tubesheets.

The tube rolls in these heaters are unique to those in other high pressure heaters in the TVA Fossil System. Most TVA heater tubes are step rolled inside the tubesheets with the first roll starting near the feedwater side face of the tubesheet. As depicted by figure 7, the tube ends in the Allen #5 and #6 heaters have two distinct rolled areas separated by approximately 6 inches of tubing that is not rolled. It appears that when the smaller of the two rolls in each tube end was made the tubing may have been overly stressed by the operator end of the expander rolls.

Most roller expanders available for installing tubes inside thick tubesheets are designed to step roll the tubes. This means that the operator or back end of the expander rolls are not typically tapered as much as the front ends. When tubes are step rolled care must be taken to overlap each roll so the operator ends of the tube expander rolls don’t leave the tube wall deform and with high levels of residual stress. Overlapping successive rolls inside thick tubesheets ensures that the back ends of the expander rolls do not stress portions of the tube which have already been expanded by the previous roll step.

Another primary cause of any SCC problem, given a susceptible material and sufficient tinsel stresses, is a conducive chemical environment. Inspection of the heater venting systems and a review of venting and feedwater treatment practices at the Allen plant provided no specific indication that heater shell side or waterside chemistry would have contributed to the problem. Ammonia, that can cause SCC in Monel, is present in the feedwater, but chemistry records indicate no unusually high concentrations. There was no evidence that concentrations of chlorides or other chemical species conducive to SCC of Monel had been introduced.

Evaluation of Options for Restoring Heater Reliability and Function

If the root causes of the tube failures could be eliminated or controlled and the failed and damaged tubes recovered or repaired, heater reliability and function could be restored.

Elimination or reduction of the contributing tensile stresses would require that the tube ends be stress relieved. Options considered where:

- Use of high temperature steam from one of the Allen generating units
- Application of heat from electric resistance heating devices similar to those used for weld pre and post heat treatment
- Peening the tube IDs with grit or beads
- Re-expansion of the tubes at the tube roll transition where the SCC was occurring inside the tubesheets,

After careful consideration it was concluded that none of these methods would eliminate problems resulting from small undetected cracks in the tube. For this reason stress relieving was not considered a viable option for mitigation of the cracking problem.

Elimination of the corrosive chemical environment was also not considered an endeavor likely to have an appreciable affect on the tube failures. Even though water chemistry was properly controlled, tubes continued to fail over a considerable period of time. It was thought likely that whatever constituents were causing the damage were concentrated inside many already developed cracks from which it would not be possible to effectively remove them.

Damage Repair and Prevention

While reasonable measures would be taken to prevent future detrimental chemical contamination of the feedwater heaters, none of the failure causes could be sufficiently eliminated or reduced to prevent continuing tube failures. Neither could the elimination of causes restore function to failed tubes or prevent premature failure of already badly damaged tubes.

A number of alternatives for prevention of additional tube failures and restoration of function to failed tubes were evaluated. These included weld repair of failed and cracked tubes and installation of tube inserts by hydraulic or explosive expansion.

Weld repair of failed and cracked tubes was investigated as an option. It was learned that tooling with which weld repairs could be made inside tubing with inside diameters of only 0.5 inch was not commercially available. While it appeared possible to have such tooling developed it clearly would not be a cost effective option because of the considerable expense for such development.

Installation of tube inserts by hydraulic expansion was also evaluated as an option for restoration of tube function and reliability. This restoration technique was developed in the mid 1970’s to restore service life to heat exchanger tubes with various types of damage near the tube ends. Inlet end erosion and SCC are damage mechanisms which can be countered with this technique as are localized pitting, crevice corrosion, impingement and grooving which might occur near tube ends. The technique makes use of thin-walled metallic inserts, fabricated with a flair at one end and I.D. chamfer at the other end, which are expanded into the existing tube ends. Such inserts are also variously referred to as I.D. tube shields, or sleeves.

Figure 8 is a cross section sketch of a tube insert and figure 9 is a cross section sketch of an installed insert, tube, and tubesheet. The intent of insert installation in the Allen heaters would be to bridge degraded sections of the original tubes with a material which would preserve or restore the integrity of the tubes and tube to tube sheet joints. It would also be necessary that the insert installation not lead to other problems such as SCC of the original tube at or near the insert.

TVA had two primary concerns regarding the installation of inserts in heat exchanger tubing. One was that the expansion of inserts into the existing tubing might induce additional excessive stresses and thereby promote further SCC. The other was that leak paths might develop between the OD of the inserts and the I.D.'s of the existing tubing and that very small leaks through these paths might grow over time to unacceptable rates.

Review of the application of this technique for rehabilitating feedwater heaters at other utilities indicated that function and reliability of the Allen feedwater heater tubes could be restored by the hydraulic expansion of inserts.

In addition to having been demonstrated to be a successful option, installation of tube inserts by hydraulic expansion was also determined to be the most cost effective. Explosively expanded inserts was evaluated and also considered to be a viable option for recovering tube function and reliability. This method is considerably more expensive than hydraulic expansion and for the Allen feedwater heaters it was not considered to provided any significant advantage over hydraulic expansion. For TVA the decisive difference between the two methods was cost. According to budgetary estimates received, the explosive expansion method would have been approximately five (5) times the cost of hydraulic method.

Implementation of solution

Upon evaluation of the various alternatives considered it was TVA's decision to have metallic tube inserts fabricated and install by hydraulic expansion in the Allen unit 3 feedwater heater #5 & #6 tube ends. CTI Industries was contracted to fabricate and install the inserts and the installation was performed in September 1999, during a scheduled maintenance outage. The inserts were fabricated from 304 Stainless Steel seamless tubing, 0.485 inch OD, 0.020 inch wall thickness. Figures 9 depivts the as installed insert, tube, and tubesheet.

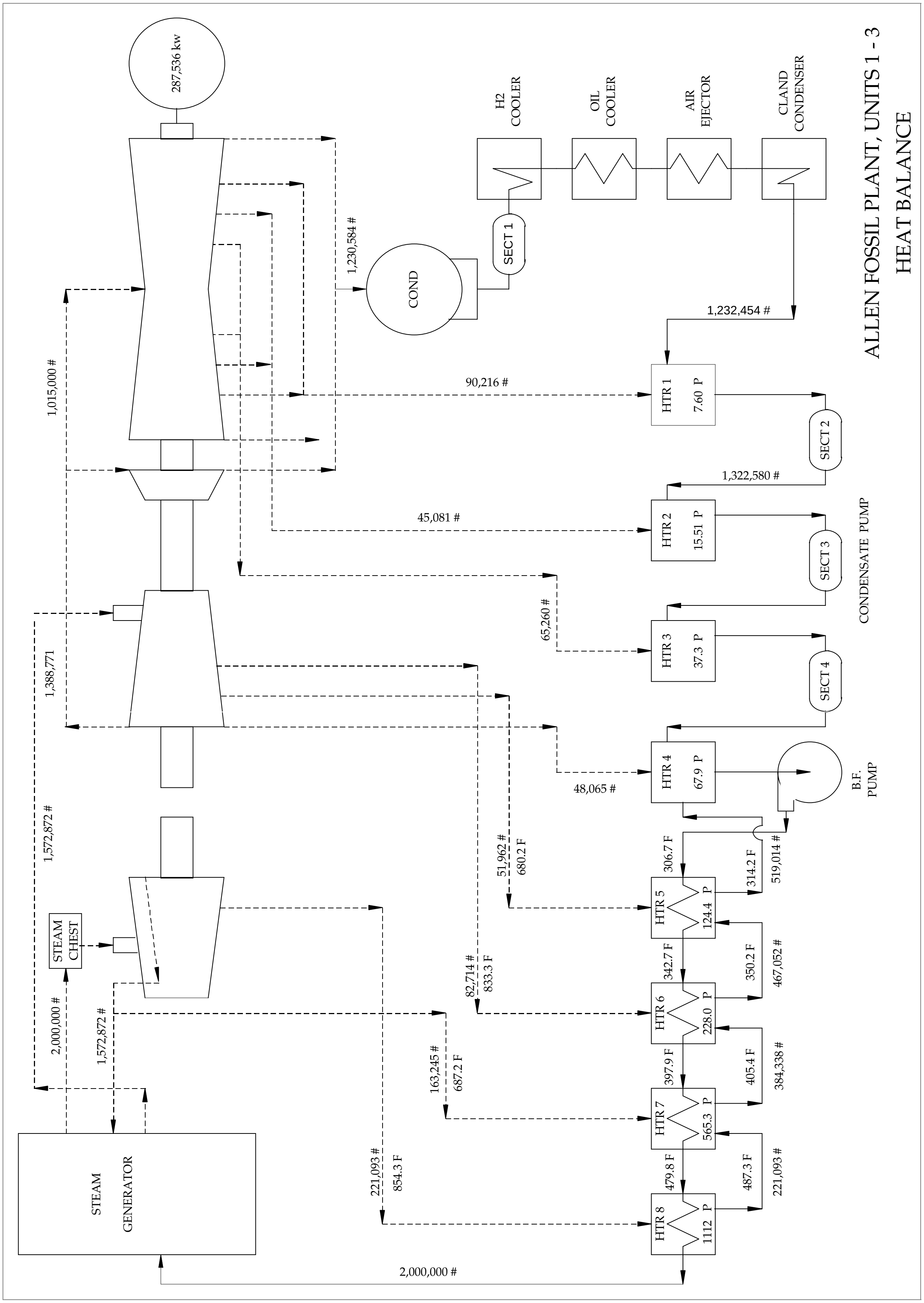
In preparation for installation the heaters were opened and checked for additional tube failures which were documented. All the tube plugs were removed from previously failed tubes. To ensure reasonable cleanliness at the tube ID and insert interface, TVA cleaned each tube end to a depth of two feet using a portable pressure washer and blew each tube dry with station service air. At that point CTI Industries arrived on site to install the inserts. CTI wire brushed each tube end I.D., blew each end clear with compressed air, took ID measurements to determine expansion requirements, and placed inserts into each tube end.

The inserts were expanded with a hydroswage mandrel. The mandrel was coupled to a strain volume control hydroswage pump which was preset to achieve full length expansion of the insert. A hybrid expansion was then accomplished by roller expanding each insert at two areas within the tubesheet to torque controlled settings and also at the shell side end by mechanical settings. Finally the insert ends were flared to conform to the contour of the flared end of each tube. Upon completion of the installation the heater shells were pressurized to 100 psig and a leak check was made at the tube sheets using a soap solution.

Conclusion

During a short planned maintenance outage in March of 2000, the Allen unit 3 high pressure heater #5 was opened because of suspected tube leaks. Upon pressurizing the heater, to 100 psig, eight (8) tubes were found to be leaking. Seven of the leaks were determined to be from locations at the U bends. One tube was observed to have a very small leak from the shell side end of one of the inserts. This leak would not have been detected had the heater not been inspected because of the significant leaks found in the tubes which had failed at the U bends.

By the installation of inserts TVA was successful in recovering 310 tubes in the #5 and #6 high pressure heaters at Allen unit 3. After the SCC problems were initially encountered with these two heaters, the same problem began to plague the #5 and #6 heaters at Allen unit 1. During a maintenance outage in March of 2000, CTI Industries installed inserts in all the tube ends of the unit 1 heater #6. Current plans are to have CTI install inserts in the #5 heater on that unit at the next available opportunity.



ALLEN FOSSIL PLANT, UNITS 1 - 3
HEAT BALANCE
287,536 kw
H2 COOLER
OIL COOLER
AIR EJECTOR
CLAND CONDENSER
SECT 1
COND
1,230,584 #
1,232,454 #
1,015,000 #
90,216 #
HTR 1 7.60 P
SECT 2
1,322,580 #
HTR 2 15.51 P
45,081 #
SECT 3
CONDENSATE PUMP
65,260 #
HTR 3 37.3 P
SECT 4
1,388,771
48,065 #
HTR 4 67.9 P
B.F. PUMP
1,572,872 #
51,962 # 680.2 F
306.7 F
314.2 F
519,014 #
HTR 5 124.4 P
342.7 F
350.2 F
467,052 #
82,714 # 833.3 F
HTR 6 228.0 P
STEAM CHEST
2,000,000 #
1,572,872 #
163,245 # 687.2 F
397.9 F
405.4 F
384,338 #
HTR 7 565.3 P
221,093 # 854.3 F
479.8 F
487.3 F
221,093 #
HTR 8 1112 P
STEAM GENERATOR
2,000,000 #

Figure 1.

TVA Allen Fossil Plant - Unit 3

High Pressure Feedwater Heater Specifications		Feedwater Heaters	
		No. 5	**No. 6**
Manufacturer :		Southwestern Engineering Co.	
Type :		Horizontal U-Tubes	
Design Operating Steam Inlet Temperature :	F	680	833
Design Operating Drain Inlet Temperature :	F	350	405
Design Operating Feedwater Inlet Temperature :	F	307	343
Design Operating Drain Outlet Temperature :	F	314	350
Design Operating Feedwater Outlet Temperature :	F	343	398
Design Operating Shell Pressure :	psia	122	228
Design Temperature, Shell Side Skirt :	F	750	890
Design Temperature, Shell :	F	400	450
Design Temperature, Tube Side :	F	400	450
Design Shell Pressure :	psig	150	300
Test Shell Pressure :	psig	225	450
Design Tube Side Pressure :	psig	3,700	
Test Tube Side Pressure :	psig	5,550	
Design Operating Tube Side Velocity :	ft. / sec	8.25	7.67
Number of "U" tubes :		765	824
Tube Material :		Monel SB-163-400 DSR	
Tube OD :	in.	0.625	
Average Tube Wall :	in.	0.060	
Average Tube Wall - Three Inner Rows	in.	0.063	0.064
Tube pitch :	in.	0.8438	
Tube straight Length :	in.	391	450
Tube sheet material :		SA-350-LF2	
Tube sheet thickness :	in.	10 1/4	
Tube to Tube Sheet Joint :		Welded & Rolled	
Tube Sheet Overlay :		Monel 1/4 in. after machining	
Date of Heater Manufacture :		10/87	

Table 1.

EDDY CURRENT CALIBRATION & INSTRUMENT SETTINGS

COMPANY, SITE, UNIT: TVA, Allen Fossil Plant, Unit 3

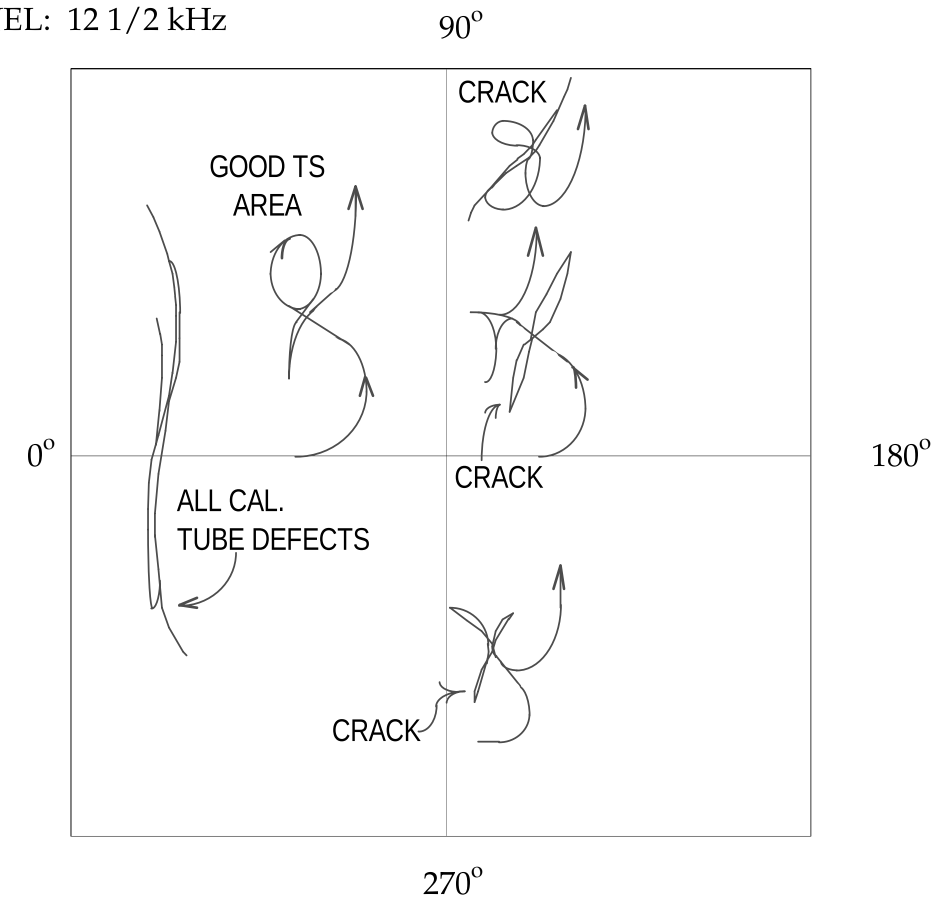
COMPONENTS: High Press Feedwater Heaters 5 & 6, TUBES: 5/8 x .060" Monel

INSPECTOR: Allen Gallaher, E.T. Level III DATE: 11/14/97

MIZ- 17	Channel	
	F1	F2
Frequency (KhZ)	50	12.5
Diff. / Abs.	C1	C1
Phase	240	195
Gain	FO	FF

INSPECTION PROBE	
Size	0.46
Frequency (KhZ)	20 - 200
Type	C1
Manufacturer	AECL

CHANNEL: 12 1/2 kHz



The Carter C1 eddy current probe is designed to detect circumferential cracks and to minimize response to conditions that are radially symmetrical such as tubesheet presence and the change in ID at tube expansion rolls. With no calibration standards available for these conditions a pattern recondition procedure was developed by comparing signals from failed tubes where leaks where observed visually with those from other tubes where no leaks were evident. The probe was obtained from the EPRI NDE Center in Charlotte, North Carolina.

Figure 2

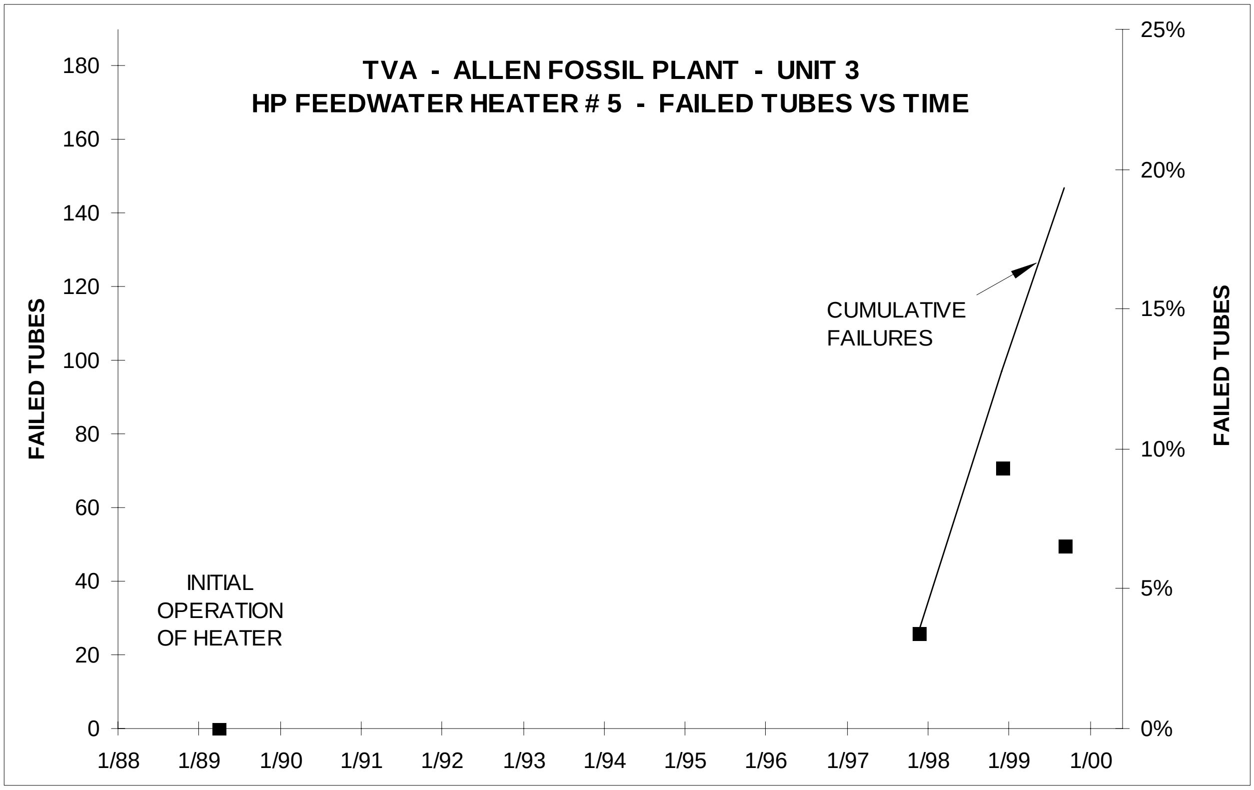


Figure 3.

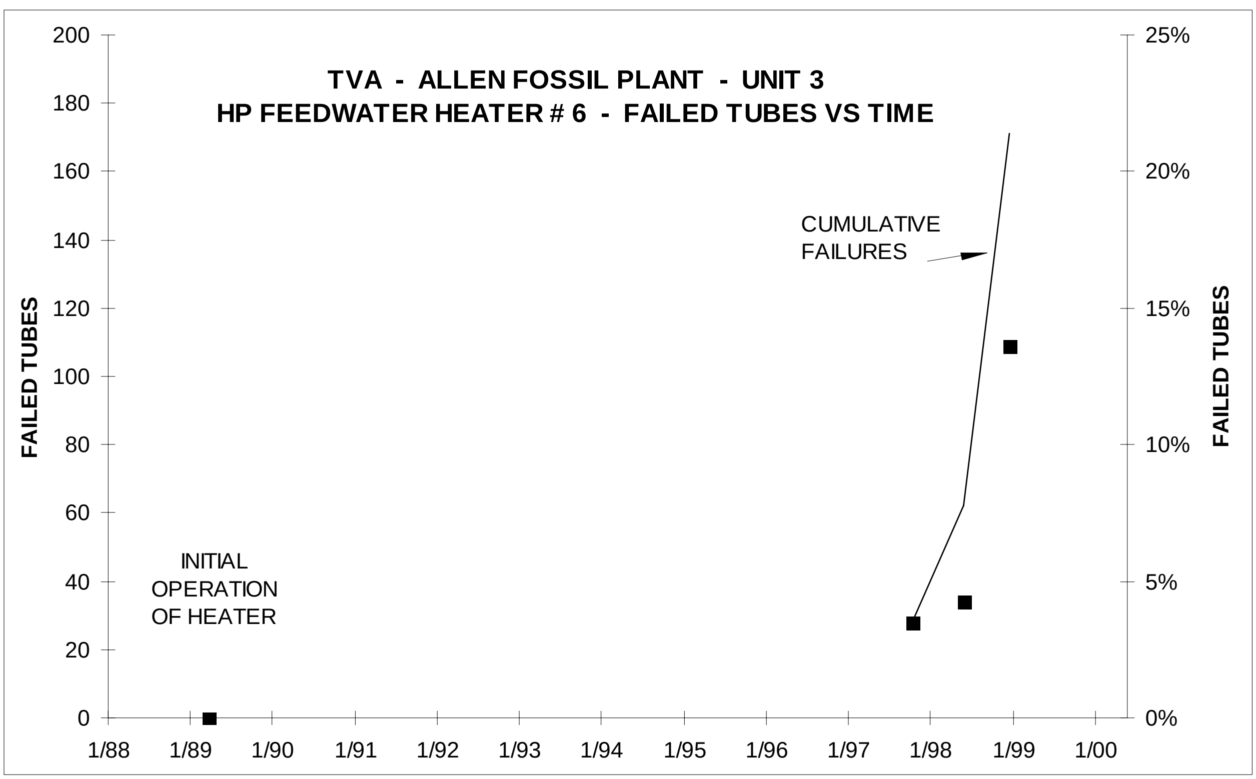


Figure 4.

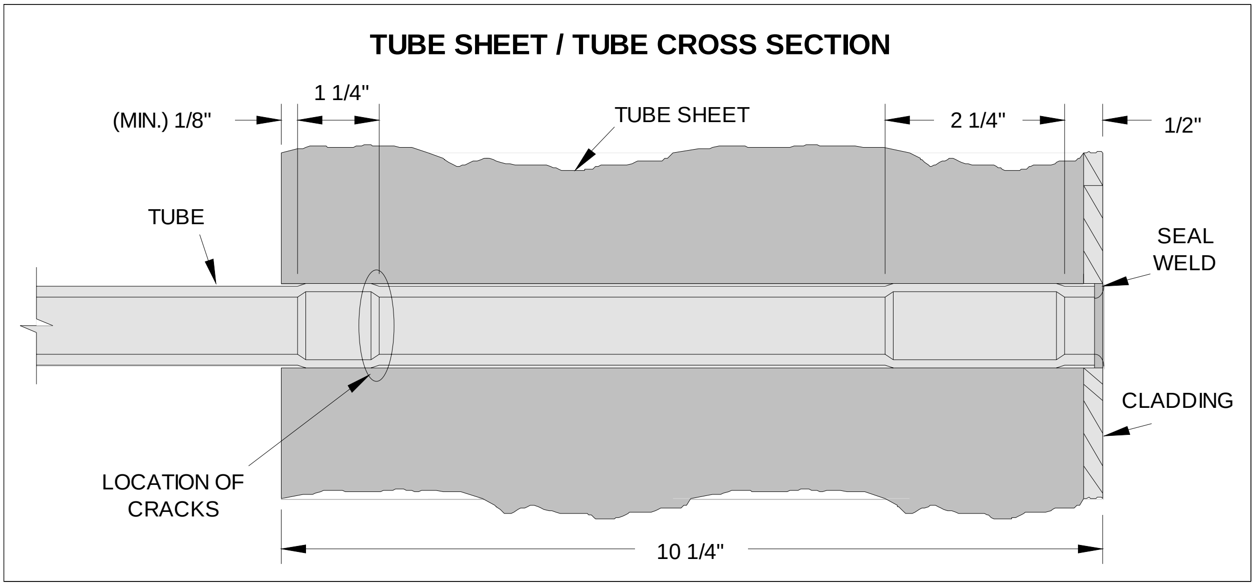


Figure 7.

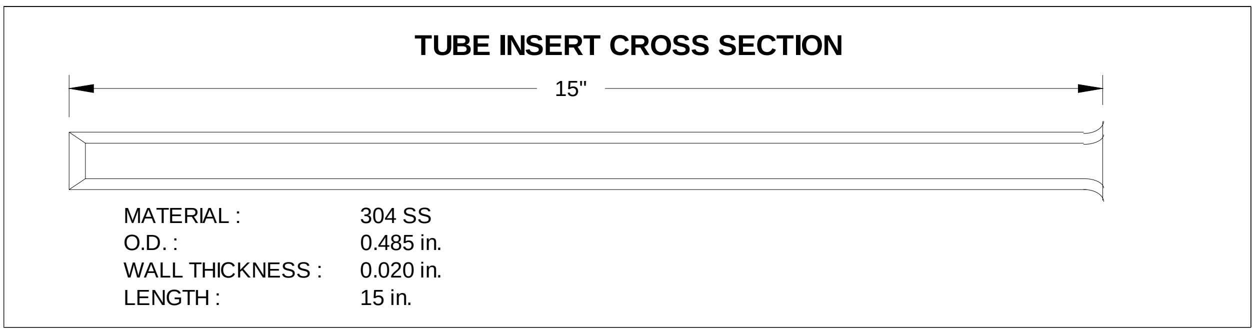


Figure 8.

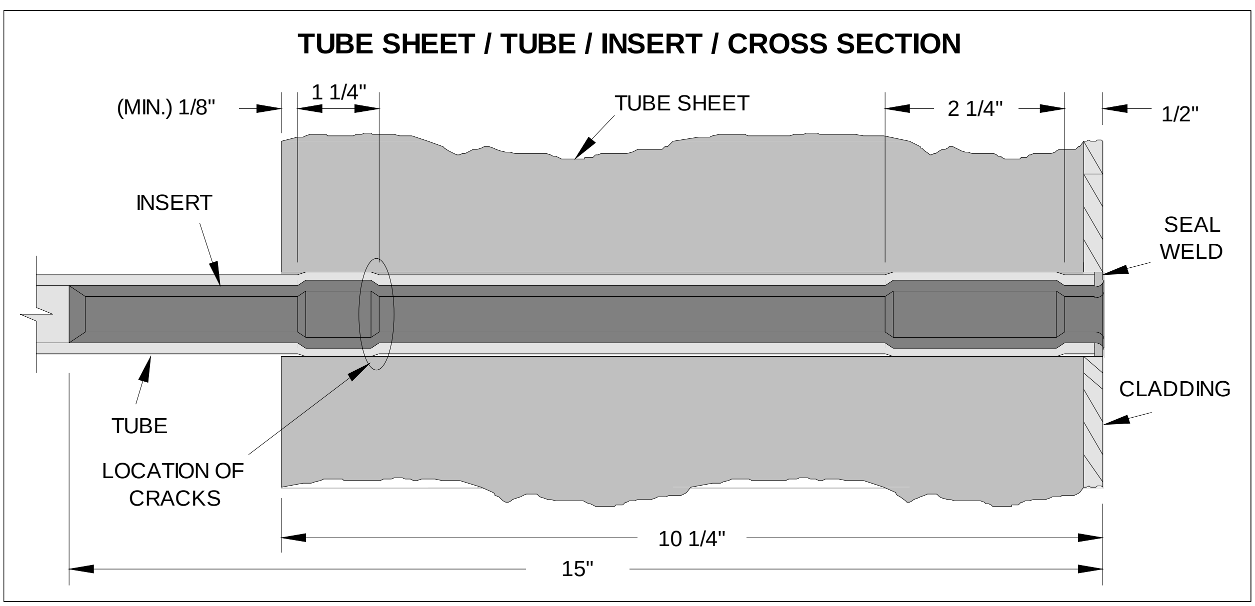
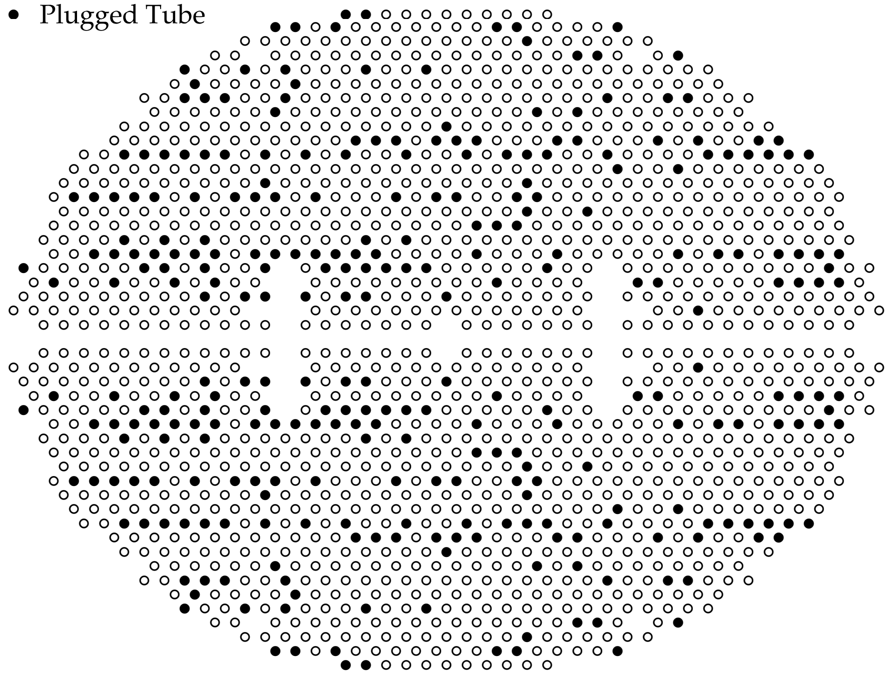
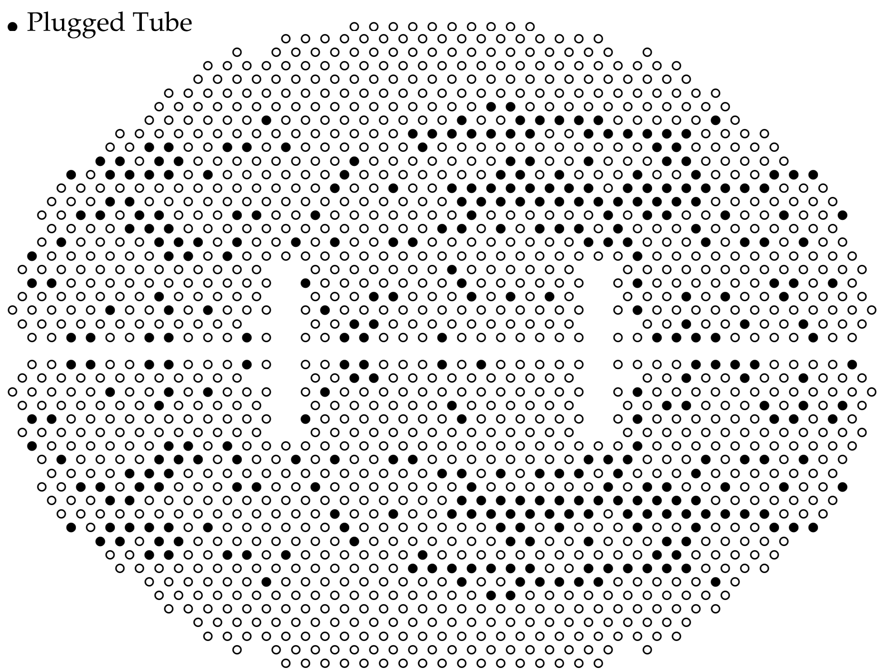


Figure 9.



Allen Fossil Plant Unit 3 HP Feedwater Heater #5,   Sept. 99
Figure 5.



Allen Fossil Plant Unit 3 HP Feedwater Heater #6,   Sept. 99

Figure 6.