ELECTRIC POWER RESEARCH INSTITUTE

Field Evaluation of Pulsed Eddy Current

1019558

Field Evaluation of Pulsed Eddy Current

1019558

Technical Update, September 2009

EPRI Project Manager

S. Walker

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Electric Power Research Institute (EPRI)

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

CITATIONS

This document was prepared by

Electric Power Research Institute (EPRI)
1300 West W.T. Harris Blvd.
Charlotte, NC 28262

Principal Investigator
K. Krzywosz

This document describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Field Evaluation of Pulsed Eddy Current. EPRI, Palo Alto, CA: 2009. 1019558.

PRODUCT DESCRIPTION

This report documents the field application of the pulsed eddy current nondestructive evaluation (NDE) technique to assess pipe wall integrity through insulation for detection and characterization of flow-accelerated corrosion (FAC). Specifically, it addresses the technology from Röntgen Technische Dienst (RTD) as an NDE method for FAC that was applied to several 6-inch (152.4-mm) diameter insulated heater drain elbows while the plant was online. The on-site demonstration and evaluation involved application of pulsed eddy current technology known as RTD-INCOTEST® to evaluate wall thickness reduction through insulation and compare its performance to traditional ultrasonic thickness measurements without insulation. Additional validation was performed by examining the insulated Electric Power Research Institute (EPRI) pipe mockup that contained known simulated FAC wall losses.

Results and Findings

Even with the small database used during this project for comparison, the evaluated RTD-INCOTEST® results showed that it can serve as an effective screening tool to identify the areas affected by FAC and can also serve as a reliable analysis tool for estimating the remaining wall thickness.

Challenges and Objectives

Because the pulsed eddy current technology was new to the utility, EPRI was asked to provide necessary support during the on-site examination with the following objectives:

- Use the EPRI mockup to evaluate and validate the performance of the RTD-INCOTEST® pulsed eddy current technology that was utilized by APTECH Engineering Services.
- Compare RTD-INCOTEST® pipe wall thickness estimates through insulation to traditional ultrasonic thickness measurements obtained with insulation removed.
- Observe the ease of using the RTD-INCOTEST® system online, and assess the daily production rate in terms of components examined in an 8-hour shift.
- Prepare an EPRI report.

Applications, Value, and Use

As with the remote-field eddy current technique, this technique (by controlling its pulse amplitude and duration) operates in a very low frequency regime to allow volumetric pipe wall measurements and evaluation of remaining wall loss from damage mechanisms such as FAC. RTD-INCOTEST® is used more as a survey/screening tool and is not intended to be used to scan for localized flaw detection and characterization.

EPRI Perspective

Because several member utilities have requested that EPRI conduct an evaluation of this technology for the detection of FAC, it was appropriate that EPRI staff participate in a plant examination that was held between outages. EPRI conducted an independent evaluation and provides this report as unbiased documentation of the capability of the technology.

Approach

EPRI assisted with on-site support by evaluating and observing examination activities performed by APTECH Engineering Services during the online pulsed eddy current examination of heater drain line elbows through insulation at a domestic power plant.

Keywords

Flow-accelerated corrosion
Nondestructive evaluation
Pulsed eddy current

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1
BACKGROUND AND OBJECTIVES

The Electric Power Research Institute (EPRI) assisted with on-site support by evaluating and observing examination activities performed by APTECH Engineering Services during the online pulsed eddy current examination of heater drain line elbows through insulation at a domestic power plant.

Because the pulsed eddy current technology was new to the utility, EPRI was asked to provide necessary support during the on-site examination with the following objectives:

- Using the EPRI mockup [1], evaluate and validate performance of the pulsed eddy current technology that was used by APTECH Engineering Services
- Compare the pulsed eddy current pipe wall thickness estimates through insulation to traditional ultrasonic thickness measurements obtained with insulation removed
- Observe the ease of using the system online and assess the daily production rate in terms of components examined in an eight-hour shift
- Prepare an EPRI report.

This report details the technology and the subsequent examination results obtained during the in-plant application. Although additional examinations were performed on various components, this report focuses on components with comparable ultrasonic data and three test elbows in the EPRI mockup.

2
RTD-INCOTEST®

INsulated COmponent TEST (INCOTEST®) system was refined and developed after an original pulsed eddy current system known as Transient Electromagnetic Probing (TEMP) was introduced by ARCO, an American oil company. After receiving an exclusive license to further develop and apply this technology from ARCO, Röntgen Technische Dienst (RTD) Quality Services of Rotterdam, the Netherlands, developed the current RTD-INCOTEST® system. APTECH Engineering Services had an exclusive license to apply the RTD-INCOTEST® system in the U.S. power industry sector. This license, however, expired in 2008, leading to other vendors employing the same technology in the U.S. market.

Pulsed Eddy Current System Description

As the name implies, this nondestructive eddy current technique employs a series of excitation pulses rather than continuous wave to interrogate the remaining wall thickness of ferromagnetic piping components. This wall thickness evaluation is performed by measuring the decay time of induced eddy currents in the test material. This section is not intended to provide exhaustive details of the RTD-INCOTEST® system, but rather to provide enough details to support the on-site examination results. More RTD-INCOTEST® details can be found in the RTD training course manual [2].

As with the remote-field eddy current technique, this technique (by controlling its pulse amplitude and duration) operates in a very low frequency regime to allow volumetric pipe wall measurements and evaluation of remaining wall loss from damage mechanisms such as flow-accelerated corrosion (FAC). RTD-INCOTEST® is used more as a survey/screening tool and is not intended to be used for scanning for localized flaw detection and characterization.

Unlike the continuous wave eddy current case, the induced eddy currents in the material are generated by changing field of excitation pulses through a circular transmitting coil. The resultant diffusion field is detected as time-dependent voltage output using separate receiver coils. By relying on the excitation pulse as a driving current, the received voltage is a multiple frequency rather than a single frequency output. In general, the upper frequency limit of the signal is defined by the ratio of $1/T_{0,}$ where T_0 is the pulse width. The pulse width will, therefore, increase as material thickness increases. Typical values range from 200 millisecond (5 Hz) for 0.236 inch (6 mm) wall thickness to 2 seconds (0.5 Hz) for 1.575 inch (40 mm) wall thickness. For thicker components with thicker insulation, the duration of one measurement can extend from 4 to 10 seconds. The following RTD-INCOTEST® system performances were reported by RTD:

- Wall thickness measurement range of 0.12 to 2.6 inch (3 to 65 mm)
- Insulation thickness tolerance of up to 7.875 inch (200 mm)
- Operating temperature range of -238ºF to 932ºF (-150ºC to 500ºC)
- Measurement accuracy of ± 5%
- Repeatability of ± 2%

As with traditional eddy current examination, the signal amplitudes of the induced eddy currents are inversely proportional to the square of the distance between the sensors and the test material surface, which is known as lift-off distance. The signal amplitude will, therefore, decrease rapidly with an increasing lift-off distance. Based on the low frequency nature of this system, the lift-off distance of 2 inches (50.8 mm) is easily handled with an upper limit of around 7.875 inches (200 mm). This lift-off tolerance is helpful in surveying various piping components through insulation to examine those components affected by FAC.

Various size sensors were used based on the combined material thickness and lift-off distance (insulation thickness) to be considered. The following probe types were brought on-site for use by APTECH.

- Testing sensor for nominal 0.250 inch (6.4 mm) thick wall with direct contact having:
    - Wall thickness range of 0.118 to 0.630 inch (3 to16 mm)
    - Insulation range of 0 to 0.472 inch (0 to 12 mm)
    - Application to minimum pipe diameter of 2 inches (50 mm)
    - Footprint size of 1.75 to 2.36 inches (45 to 60 mm)
    - Focused mode
- Testing sensor for nominal 0.5-inch (12.7-mm) thick wall with nominal 1 inch (25.4 mm) of insulation having:
    - Wall thickness range of 0.157 to 1 inch (4 to 25 mm)
    - Insulation range of 0.236 to 2 inches (6 to 50 mm)
    - Application to minimum pipe diameter of 2 inches (50 mm)
    - Footprint size of 1.77 to 4.13 inches (45 to 105 mm)
    - Focused and non-focused mode
- Testing sensor for nominal 1-inch (25.4-mm) thick wall with nominal 2 inches (50.8 mm) of insulation having:
    - Wall thickness range of 0.236 to 1.378 inch (6 to 35 mm)
    - Insulation range of 1 to 4 inches (25 to 100 mm)
    - Application to minimum pipe diameter of 2 inches (50 mm)
    - Footprint size of 3 to 5.3 inches (75 to 135 mm)
    - Focused and non-focused mode

- Testing sensor for nominal 1.5 inch (38.1 mm) wall with nominal 4 inches (101.6 mm) of insulation having:
    - Wall thickness range of 0.394 to 2.556 inch (10 to 65 mm)
    - Insulation range of 2 to 8 inches (50 to 200 mm)
    - Application to minimum pipe diameter of 4 inches (100 mm)
    - Footprint size of 6 to 12 inches (150 to 300 mm)
    - Focused and non-focused mode

Figure 2-1 shows four different sensor types which were available for use.

It should be noted that some sensors can be operated in non-focused or focused modes. If deeper eddy current penetration is desired to allow thicker components to be examined, sensors are operated in the non-focused mode to allow expansion of eddy currents as they diffuse into the pipe wall. If more accurate thickness resolution is desired, the focused mode is used. By switching to the focused mode, a driver compensation coil is energized so that opposing eddy currents are induced to cancel out the outer fringes of the induced eddy currents to allow more focusing at the expense of penetration depth.

Figure 2-1
Four Different Pulsed Eddy Current Sensors Tailored to Examine Different Material and Insulation Thickness

The outlined pulsed eddy current sensors can be powered with a dual (20-24 volt) battery pack that is connected to the battery charger which can be connected to 110/240 volt AC source. A third battery in the battery pack is used to power a laptop and two-way communication headsets. Figure 2-2 shows the heart of the INCOTEST system known as MKII, which operates the selected sensor and receives the measured signal for further signal conditioning (amplification, filtering, analog-to-digital signal conversions, etc.).

Actual coil excitation and data acquisition are performed by an instrument operator using a personal laptop computer. By the time the operator sees the received signal, it has already been amplified, filtered, digitized, processed, and displayed as shown in Figure 2-3. The main computer screen is divided into the following quadrants:

- The top left screen provides the measured value expressed in percentages, mm or inches, along with any applicable error message.
- The top right screen provides both system settings and validation numbers to indicate the closeness of the fitted curve.
- The bottom left screen shows a color map of the inspection grid.
- The bottom right screen provides the measured points and the associated fitted curve, allowing an operator to assess the measured curve in reference to the stored reference curve.

Figure 2-2
RTD-INCOTEST® Tester – MKII

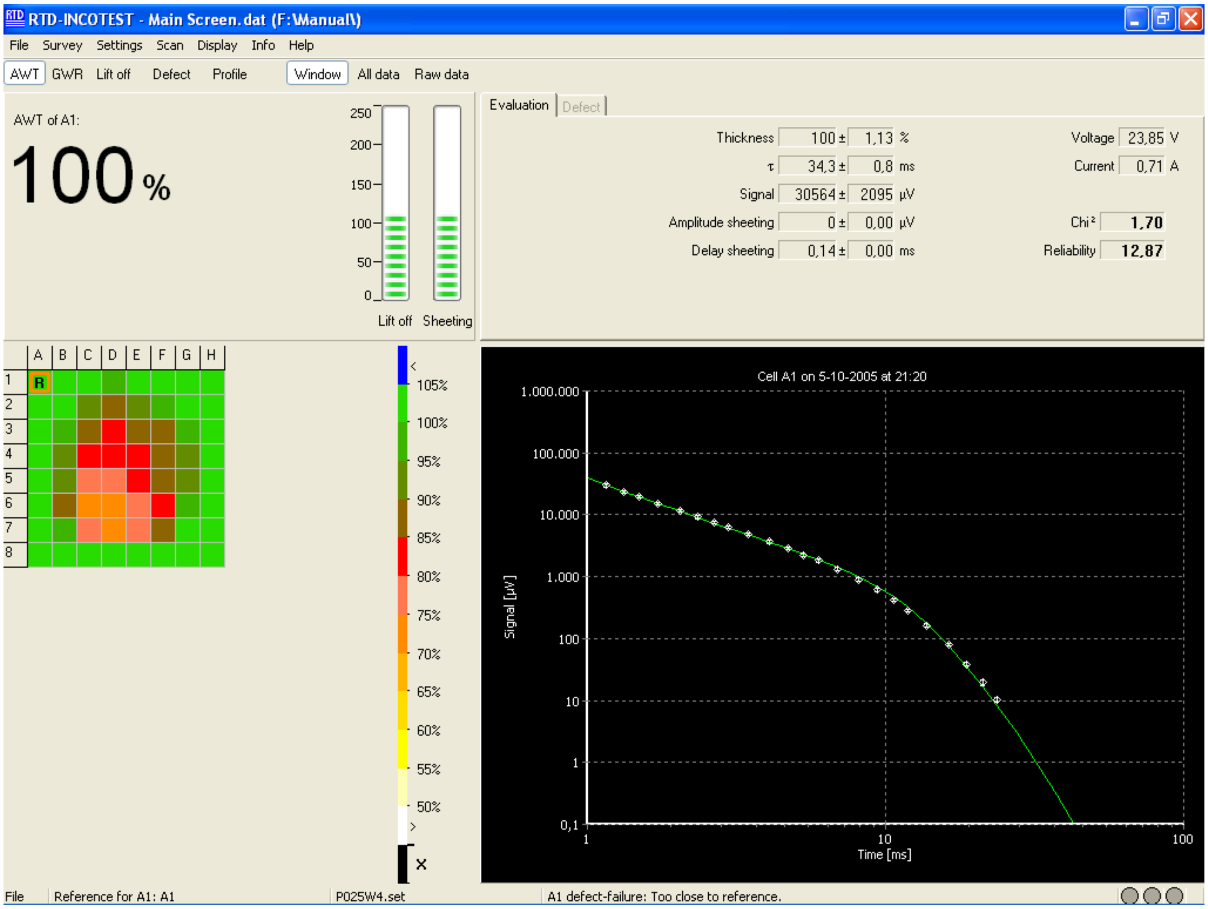


Figure 2-3
RTD-INCOTEST® Screen Capture Showing a Fitted Reference Curve

The reference curve indicating the nominal wall thickness will be shown as a green line, while the measured line will be shown as a yellow line. As will be discussed later, the displayed measured points represent the eddy current decay curve obtained from one grid point and not from multiple grid points. These individual measured points represent different frequency contents with higher frequency contents on the upper left and lower frequency contents on the bottom right.

INCOTEST Data Review

The decay curve represents the multi-frequency data containing both amplitude and decay time of the received signals from a given grid location. Basically, each point on the curve represents a different frequency signal content of given amplitude and decay time. For remaining wall thickness estimates, more useful information is obtained from the lower frequency points represented by the trailing end of the decay curve. More traditionally, the zero-crossover point of the received pulsed eddy current signal represented the thickness boundary [3]. The RTD-INCOTEST® displays this received signal in a double logarithmic scale, thus accentuating the bending point representing the zero-crossover point. The resultant amplitude signal is also processed internally by subtracting the empty coil signal in air from the measured raw signal obtained from the test object.

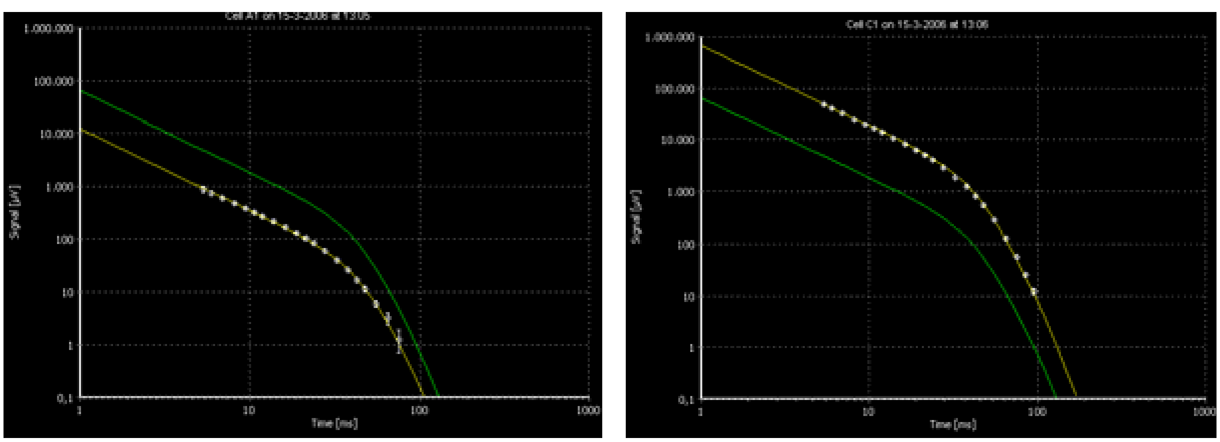
Figure 2-4 shows signal amplitude variations due to changing lift-off conditions. In general, the reference signal shown in the green curve will have nominal wall thickness with a pre-determined lift-off value (for example, a known insulation thickness). If the insulation thickness increases, the resultant amplitude will decrease as shown in Figure 2-4a. Conversely, if the insulation thickness decreases, the resultant signal amplitude would increase due to increased eddy currents induced from the transmitter coil being closer to the test object as in Figure 2-4b.

To perform the actual wall thickness evaluation, the reference signal is cropped on both high and low frequency ends to minimize noise while focusing on the part of the signal that is relevant to the overall examination. This is accomplished by positioning the minimum/maximum red lines and opening the appropriate window size to include those relevant bending points as shown in Figure 2-5. The selected window and the resultant reference curve will then be used to compare the acquired data.

During the course of the examination, it is entirely possible for an operator to reduce or increase the selected reference window width in order to attain better fit and more reliable evaluation results. To aid in the comparative data analysis, the following two statistical terms are closely monitored: Chi^2 and reliability.

Any algorithm difference between the established reference curve and the derived data curve is expressed in terms of the statistically derived Chi^2 factor. A perfect fitting of two curves will result in a value of 1. For calibration and signal validation, the value must be in the range of 0 and 2. The following ranges are provided as guidelines by RTD:

- $0 < Chi^2 < 2$ • good
- $0 < Chi^2 < 10$ • acceptable
- $Chi^2 >> 10$ • not acceptable



a) Thicker Insulation or Increased Lift-Off **b) Thinner Insulation or Reduced Lift-Off**

Figure 2-4
Effect of Insulation Thickness on Received Signal Amplitude

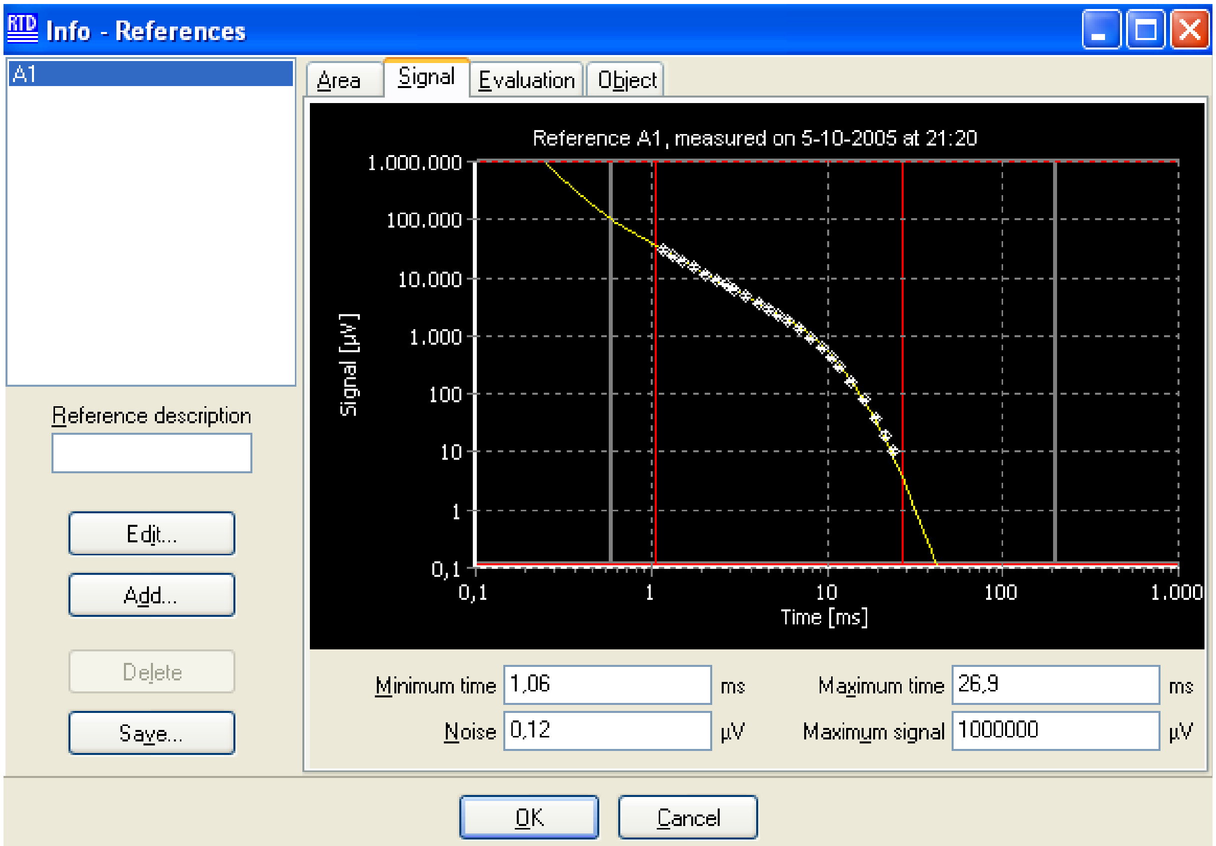


Figure 2-5
Cropped Reference Signal to Include Relevant Bending Points

The term “reliability” is defined by RTD as a signal-to-noise ratio from the bending point. Obviously, the higher number indicates better estimates of an average wall thickness. The following guidelines are provided:

- Reliability >> 1 • good (In general, 10 or higher is good.)
- Reliability > 1 • acceptable (In general, 1-10 are acceptable.)
- Reliability < 1 • not acceptable

As indicated earlier, all estimates provided are averaged wall thickness estimates expressed in terms of percentages, mm or inche, in comparison to the measured reference thickness value. Based on the operator experience, sometimes a minimum wall thickness value is reported instead of the averaged wall thickness. This reporting takes place when a localized wall loss is observed within the general wall loss. This “defect” mode of presenting a minimum wall thickness is shown in Figure 2-6.

According to the APTECH representative, the wall loss estimates shown were tightly grouped with a good Chi^2 value and an acceptable defect wall thickness quality number.

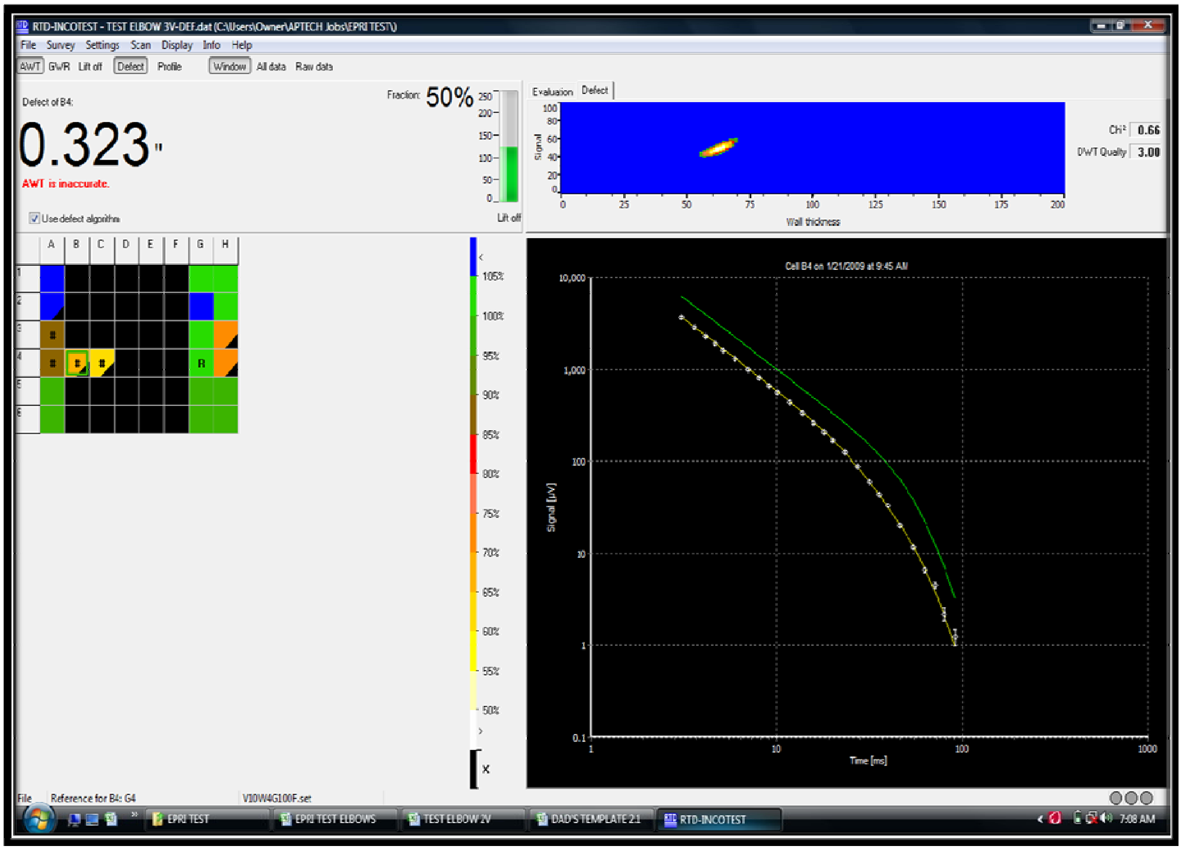


Figure 2-6
Screen Capture of Displaying Minimum Wall Thickness Value in Defect Mode

3
COMPONENTS TESTED

For the purpose of evaluating the RTD-INCOTEST® technology by comparing its analysis results with the traditional ultrasonic thickness measurements, three #2 heater drain to #3 heater drain pipe elbows were examined. In addition, three insulated pipe elbows from the EPRI mockup were examined and the results compared with the ultrasonic-based thickness measurements.

Heater to Heater Drain Line Components

The following three components were examined – they were all 6-inch (152.4-mm) diameter piping having 0.28-inch (7.112-mm) nominal wall thickness with an estimated insulation thickness of around 1 inch (25.4 mm).

- Identified as 2-23AHD-Loc 1
- Identified as 2-23AHD-Loc 2
- Identified as 2-23AHD-Loc 3

For ultrasonic thickness measurements, a 1 inch x 1 inch (25.4 mm x 25.4 mm) grid spacing was used to obtain both minimum and averaged wall thickness readings from the elbow and next to the weld regions. In the circumferential orientation, letters A through K were used in the clockwise orientation starting with A at the extrados of the elbow, while numbers increased from 1 to 10 at 1 inch (25.4 mm) increments from the upstream side to the downstream side of the elbow. The FAC damage, if present, will more likely be located at the extrados side of the elbow. Figure 3-1 and the associated table show the elbow location and three associated ultrasonic thickness readings. The minimum thickness reading from the elbow region is presented along with the averaged readings from the upstream and downstream sides of the pipe welds.

Similarly, Figures 3-2 and 3-3 show both elbow locations and the associated ultrasonic thickness readings from the #2 heater drain to #3 heater drain pipe elbows.

In Figure 3-3, rather than showing the average readings from the upstream or downstream sides of the pipe welds, minimum measured readings from the specified circumferential locations are provided.

FIL	Grid No	DIA	Thickness (inch)			Inspect. Type	Comments
	WCF2-HD2-3-EL002		T nom	0.5 T nom	T min	Scan, Base, Initial, Subsequent	Scan based on an axial spacing of one inch.
	Overall Minimum	6	.280	.140		Scan	.312”
	Downstream Toe Scan					Scan	.305”
	Upstream Toe Scan					Scan	.314”

Figure 3-1
Ultrasonic Thickness Readings from 2-23AHD-Loc1 (1 inch = 25.4 mm)

FIL	Grid No	DIA	Thickness (inch)			Inspect. Type	Comments
	WCF2-HD2-3-EL004		T nom	0.5 T nom	T min	Scan, Base, Initial, Subsequent	Scan based on an axial spacing of one inch.
	Overall Minimum	6	.280	.140		Scan	.281”
	Downstream Toe Scan					Scan	.281”
	Upstream Toe Scan					Scan	.304”

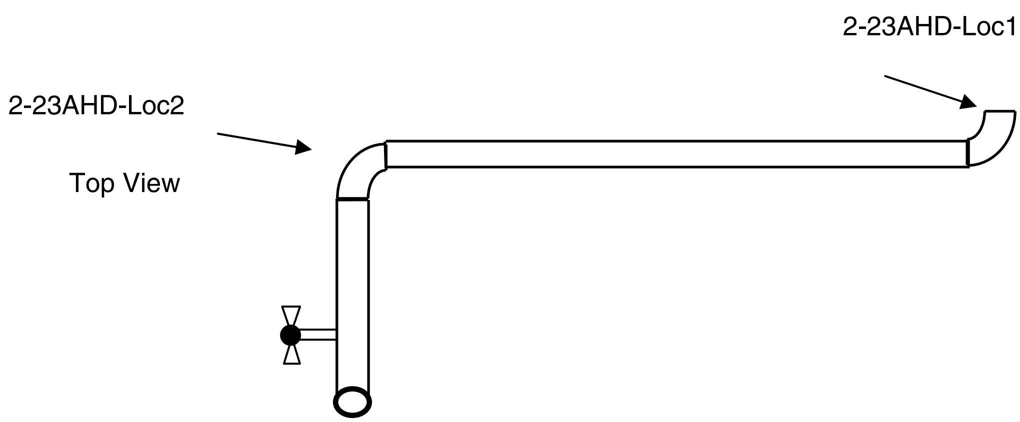


Figure 3-2
Ultrasonic Thickness Readings from 2-23AHD-Loc2 (1 inch = 25.4 mm)

FIL	Grid No	DIA	Thickness (inch)			Inspect. Type	Comments
	WCF2-HD2-3-EL006		T nom	0.5 T nom	T min	Scan, Base, Initial, Subsequent	1X1 INCH GRID
	Overall Minimum	6	.280	.140		Initial A1-K10	.246”
	Downstream Toe Scan					Scan	.261” @ A
	Upstream Toe Scan					Scan	.260” @ K

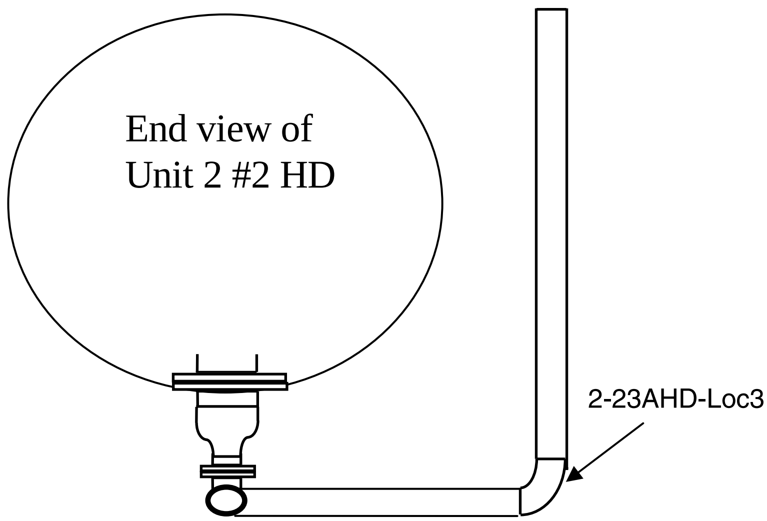


Figure 3-3
Ultrasonic Thickness Readings from 2-23AHD-Loc3 (1 inch = 25.4 mm)

Gridding the Elbows for INCOTEST

The following gridding procedure has been used to test the 6-inch (152.4-mm) diameter heater drain pipe elbows:

Axial Direction (Rows): The row numbers shall be labeled from the upstream to the downstream side of the elbow at 6-inch (152.4-mm) intervals. Row 1 will start at least one pipe diameter away from the upstream side of the pipe-to-elbow butt weld. This 6-inch (152.4-mm) grid spacing will start on the extrados side of the elbow and continue downstream to at least two pipe diameters away from the downstream elbow-to-pipe butt weld. To maintain the same row number around the pipe circumference, the grid spacing will obviously decrease, especially on the intrados side of the elbow.

Circumferential Direction (Columns): Columns shall be evenly spaced and labeled around the pipe circumference starting with the letter "A". For elbows, Column A is located on the extrados side and labeled sequentially in the clockwise direction every 45º, resulting in eight columns from A to H.

Figure 3-4 shows one of the gridded elbows where RTD-INCOTEST® measurements were being acquired by placing the sensor over individual grid points.

Similarly, three elbows in the EPRI mockup were gridded and tested as shown in Figure 3-5.

Figure 3-4
RTD-INCOTEST® of the Gridded Pipe Elbow

Figure 3-5
Gridded Pipe Elbows from the EPRI Mockup

4

RTD-INCOTEST® RESULTS

The following test results were provided by APTECH Engineering Services by reporting the remaining wall thickness as percent of the reference point and also in inches after determining the reference point wall thickness value.

#2 Heater Drain to #3 Heater Drain Pipe Elbow Results

Initial wall thickness results were presented as a percent of the reference point. For evaluating elbows through insulation, this reference point was generally selected at about half-way between the intrados and extrados of the elbow. Table 4-1 shows the APTECH-reported examination results which indicated most wall loss of 12% from the elbow component, 2-23AHD-Loc 3. The elbow component, 2-23AHD-Loc 1, showed the least amount of wall loss with 9% wall loss, followed by 2-23AHD-Loc 2 with 10% wall loss.

Table 4-1
APTECH RTD-INCOTEST® Results in Remaining Percent Wall Thickness (1 inch = 25.4 mm)

Item Number	File ID Number	Grid Layout (R X C)	Total Readings	Pipe Specifications (NWT)	Examination Results	Wall Thickness Variation
1	2-23AHD-LOC 1	6 X 8	48	6" OD X 0.280" NWT	Lowest AWT 91% of Reference @ G6	Level A
2	2-23AHD-LOC 2	8 X 8	64	6" OD X 0.280" NWT	Lowest AWT 90% of Reference @ A4	Level A
3	2-23AHD-LOC 3	10 X 8	80	6" OD X 0.280" NWT	Lowest AWT 88% of Reference @ E2	Level B
AWT = AVERAGE WALL THICKNESS; NWT = NOMINAL WALL THICKNESS, %NWT = 100%*AWT/NWT, UTTH = ULTRASONIC THICKNESS MEASUREMENT						
Level A Less than 10% of Nominal Wall Thickness Lost		No Action or Cut Hole for UTTH		If the client decides to perform no action, the client is taking the small risk that the component may have been installed with the wrong schedule or is uniformly thinned. This is typically no priority.		
Level B 10% to 13% Wall Thickness Variation		Cut Hole for UTTH may be taken at the lowest thickness measurement location.		The Cut Hole for UTTH may be compared to the specified MWT value. At the discretion of operator and specific INCOTEST results, this is Priority P1 or P2.		

To quantify the initial percentage readings, the utility agreed to make circular insulation cuts over the reference points, allowing APTECH Engineering Services to obtain online ultrasonic thickness measurements for estimating the remaining wall thicknesses by RTD-INCOTEST®.

Table 4-2 provides the detailed remaining wall thickness estimates based on using three ultrasonically-derived reference thickness values for 2-23AHD-Loc 3. Basically, each reference value was applied separately to estimate the remaining wall thickness values over a 3 x 8 inch (76.2 x 203.2 mm) grid area as shown.

Table 4-2
APTECH RTD-INCOTEST® Results for 2-23AHD-Loc 3 - Remaining Wall Thickness in Inches (1 inch = 25.4 mm)

ROW/COL	A	B	C	D	E	F	G	H
1	0.304	0.285	0.283	0.280	0.283	0.296R1	0.305	0.314
2	0.294	0.311	0.293	0.289	0.269	0.291	0.298	0.302
3	0.312	0.318	0.312	0.279	0.270	0.284	0.298	0.312
4	0.345	0.343	0.333				0.339	0.335
5	0.349	0.329	0.333	INTRADOS LIMITATIONS			0.335	0.322
6	0.341	0.329	0.322				0.327R2	0.323
7	0.316	0.315	0.320				0.333	0.332
8	0.278	0.284	0.283	0.277	0.279	0.300	0.300	0.282
9	0.291	0.282	0.291	0.300	0.285	0.294	0.305	0.293
10	0.311	0.299	0.304R3	0.298	0.290	0.293	0.290	0.292

VALUES MEASURED IN INCHES	
Program version 3.03	LOCATION H23D-3
Algorithm version 1.98	ROW 1 STARTS @12 " U/S OF 90/USP BUTT WELD
Number of rows 10	COLUMN A STARTS ON EXTRDOS OF 90
Number of columns 8	JORDAN NORTON, ACCP PROFESIONAL LEVEL III, CHRIS LHERON, ASSISTANT
POSSIBLE WELD INFLUENCE BETWEEN ROWS 3 & 4, POSSIBLY AFFECTING DATA IN BOTH ROWS	

Reference 1			Reference 2			Reference 3	
Row Start	1		Row Start	4		Row Start	8
Row End	3		Row End	7		Row End	10
Location	F1		Location	G6		Location	C10
Value	0.296		Value	0.327		Value	0.304
Lowest AWT	0.269”- 91%		Lowest AWT	0.315” - 96%		Lowest AWT	0.277” - 91%
Location	E2		Location	B7		Location	D8

Similarly, Tables 4-3 and 4-4 provide estimated remaining wall thickness for 2-23AHD-Loc 1 and 2-23AHD-Loc 2 based on the applicable ultrasonic reference thickness measurements.

Table 4-3
APTECH RTD-INCOTEST® Results for 2-23AHD-Loc 1 - Remaining Wall Thickness in Inches (1 inch = 25.4 mm)

ROW/COL	A	B	C	D	E	F	G	H
1	0.336	0.306	0.311	INTRADOS GEOMETRICAL LIMITATIONS			0.312R_1	0.311
2	0.316	0.306	0.305				0.306	0.301
3	0.327	0.342	0.307				0.301	0.314
4	0.339	0.339	0.352	0.318	0.313	0.327	0.338	0.354
5	0.310	0.307	0.315	0.316R_2	G0UGES	0.288	0.303	0.309
6	0.292	0.311	0.317	0.311	0.293	0.299	0.287	0.283
VALUES MEASURED IN INCHES								
Program version 3.03			LOCATION H23D-1					
Algorithm version 1.98			ROW 1 STARTS @ 0" U/S OF 90/USP BUTT WELD					
Number of rows 6			COLUMN A STARTS ON EXTRDOS OF 90					
Number of columns 8			JORDAN NORTON, ACCP PROFESIONAL LEVEL III					
POSSIBLE WELD INFLUENCE ON ROW 4								
Reference 1			Reference 2					
Row Start	1		Row Start	5				
Row End	4		Row End	6				
Location	G1		Location	D5				
Value	0.312		Value	0.316				
Lowest AWT	0.301" – 96%		Lowest AWT	0.287" – 91%				
Location	H2		Location	G6				

Table 4-4
APTECH RTD-INCOTEST® Results for 2-23AHD-Loc 2 - Remaining Wall Thickness in Inches (1 inch = 25.4 mm)

ROW/COL	A	B	C	D	E	F	G	H
1	0.315	0.319	0.322	0.311	0.309	0.317	0.319R1	0.322
2	0.310	0.315	0.325	0.314	0.307	0.304	0.302	0.319
3	0.320	0.335	0.316	0.300	0.307	0.315	0.318	0.329
4	0.322	0.343	0.333	INTRADOS GEOMETRICAL LIMITATIONS			0.340	0.327
5	0.344	0.334	0.340				0.340R2	0.344
6	0.326	0.344	0.337				0.332	0.352
7	0.323	0.320	0.290	0.298	0.305	0.305R3	0.313	0.340
8	I-BEAM		0.299	0.297	0.280	0.294	0.310	I-BEAM
VALUES MEASURED IN INCHES								
Program version 3.03			LOCATION H23D-2					
Algorithm version 1.98			ROW 1 STARTS @12 " U/S OF 90/USP BUTT WELD					
Number of rows 8			COLUMN A STARTS ON EXTRDOS OF 90					
Number of columns 8			JORDAN NORTON, ACCP PROFESIONAL LEVEL III, CHRIS LHERON, ASSISTANT					
POSSIBLE WELD INFLUENCE ON ROW 7								
Reference 1			Reference 2			Reference 3		
Row Start	1		Row Start	4		Row Start	7	
Row End	3		Row End	6		Row End	8	
Location	G1		Location	G5		Location	F7	
Value	0.319		Value	0.340		Value	0.305	
Lowest AWT	0.304” - 95%		Lowest AWT	0.322” - 95%		Lowest AWT	0.280” - 92%	
Location	F2		Location	A4		Location	E8	

EPRI Mockup Results from Three Insulated Pipe Elbows

The following RTD-INCOTEST® results were provided by APTECH Engineering Services. The ultrasonic reference thickness values used to evaluate the three elbows were provided by an earlier EPRI report [1] that documents pulsed eddy current work performed on the same mockup.

Tables 4-5 through 4-7 show both the averaged thickness readings along with the minimum thickness readings based on the defect mode of the RTD-INCOTEST® system.

Table 4-5
EPRI Mockup Elbow #1 – Remaining Wall Thickness Results in Inches and Percentages (1 inch = 25.4 mm)

ROW/COL	A	B	C	D	E	F	G	H
1	0.489	0.479	PALLET	INTRADOS GEOMETRY			0.474	0.484
2	0.491	0.478					0.484	0.485
3	0.491	0.487					0.492	0.492
4	0.504	0.496					0.498R1	0.505
5	0.498	0.505					0.498	0.511
6	0.511	0.494					0.481	0.506
VALUES EXPRESSED IN INCHES								
Program version 3.03		LOCATION 3						
Algorithm version 1.98		ROW 1 STARTS @12 " U/S OF 90/USP BUTT WELD						
Number of rows 6		COLUMN A STARTS ON EXTRDOS OF 90						
Number of columns 8		JORDAN NORTON, ACCP PROFESIONAL LEVEL III, CHRISTOPHER LHERON, ASSISTANT						
REFERENCE LOCATION NOT MEASURED BY UTTH. OBTAINED FROM EPRI REPORT 10 YEARS AGO.								
Reference 1								
Row Start	1							
Row End	6							
Location	G4							
Value	0.498							
Lowest AWT	0.474" – 95%							
Location	G1							

Table 4-6
EPRI Mockup Elbow #2 – Remaining Wall Thickness Results in Inches and Percentages (1 inch = 25.4 mm)

ROW/COL	A	B	C	D	E	F	G	H
1	0.496	PALLET	INTRADOS				0.488	0.485
2	0.563						0.485	0.501
3	0.453						0.498	0.470
4	0.442						0.507R1	0.469
5	0.520						0.500	0.513
6	0.498						0.501	0.491

VALUES EXPRESSED IN INCHES

Program version 3.03

Algorithm version 1.98

Number of rows 6

Number of columns 8

LOCATION 2

ROW 1 STARTS @12 " U/S OF 90/USP BUTT WELD

COLUMN A STARTS ON EXTRDOS OF 90

JORDAN NORTON, ACCP PROFESIONAL LEVEL III, CHRISTOPHER LHERON, ASSISTANT

REFERENCE LOCATION NOT MEASURED BY UTTH. OBTAINED FROM EPRI REPORT 10 YEARS AGO.

Reference 1	
Row Start	1
Row End	6
Location	G4
Value	0.507
Lowest AWT	0.442” – 87%
Location	A4

Lowest AWT in Defect Mode	0.376” – 74%

Table 4-7
EPRI Mockup Elbow #3 - Remaining Thickness Results in Inches and Percentages (1 inch = 25.4 mm)

ROW/COL	A	B	C	D	E	F	G	H
1	0.520	PALLET OBSTRUCTION		INTRADOS			0.503	0.498
2	0.559						0.519	0.508
3	0.401						0.506	0.433
4	0.381						0.490R1	0.450
5	0.485						0.472	0.476
6	0.475						0.480	0.472

VALUES EXPRESSED IN INCHES

Program version 3.03	LOCATION 3
Algorithm version 1.98	ROW 1 STARTS @12 " U/S OF 90/USP BUTT WELD
Number of rows 6	COLUMN A STARTS ON EXTRDOS OF 90
Number of columns 8	JORDAN NORTON, ACCP PROFESIONAL LEVEL III

Reference 1			
Row Start	1		
Row End	6		
Location	G4		
Value	0.490		
Lowest AWT	0.381” – 78%	Lowest AWT in Defect Mode	0.323” – 66%
Location	A4		

5
COMPARATIVE ANALYSIS RESULTS

Table 5-1 shows comparisons of pipe elbow data based on ultrasonic pipe wall thickness measurements to RTD-INCOTEST® estimates in both averaged and minimum wall thickness values.

To make this table's comparisons meaningful, it was necessary to provide two separate thickness readings based on the RTD-INCOTEST® results. The #2 heater drain to #3 heater drain pipe elbow thickness readings provided in Figures 3-1 through 3-3 showed only the minimum wall thickness readings without reference to any specific areas within the elbow. Consequently, it was necessary to identify those minimum thickness readings from the elbow region rather than assuming the worst condition to be at the extrados side. In fact, the minimum RTD-INCOTEST® thickness readings were obtained just outside of the intrados side. The highlighted minimum wall RTD-INCOTEST® readings were found to be within 9% of the ultrasonic thickness readings.

Regarding the EPRI mockup pipe elbows, all of the simulated FAC based on grinding took place only on the extrados. As such, only those RTD-INCOTEST® readings associated to the extrados were comparable. The highlighted RTD-INCOTEST® readings were found to be within 7% of the averaged ultrasonic thickness readings. The averaged extrados ultrasonic thickness value was obtained over the 4 by 1 inch (101.6 x 25.4 mm) area. Additional thickness readings from the extrados of elbows at locations 2 and 3 were obtained in defect mode to compare with the minimum ultrasonic thickness data. This comparison showed an even better matc, to within 3% of the minimum ultrasonic thickness reading. Despite the encouraging results, extra care should be taken to ensure the validity of the minimum wall thickness value in the defect mode as the value is totally dependent on the selected reference point and the associated ultrasonic thickness measurement.

Table 5-1
Comparative Wall Thickness Values and Percent Difference

	Remaining Wall Thickness in Inches (1 inch = 25.4 mm)		
Component	Ultrasonic	INCOTEST	
	Averaged/Minimum Elbow Thickness (Nominal Thickness)	Averaged Wall – Extrados Only / % Difference	Averaged Minimum Wall / % Difference
2-23AHD-Loc 1	-/0.312 (0.280)	0.316@A2/+1%	0.287@G6/-8%
2-23AHD-Loc 2	-/0.281 (0.280)	0.322@A4/+15%	0.280@E8/-0%
2-23AHD-Loc 3	-/0.246 (0.280)	0.316@A7+28%	0.269@E2/+9%
EPRI Pipe Loc 1	0.478/0.472 (0.500)	0.489@A1/+2%	0.474@G1/0%
EPRI Pipe Loc 2	0.412/0.382 (0.500)	0.442@A4/+7%	0.376@A3&4/-2%
EPRI Pipe Loc 3	0.381/0.315 (0.500)	0.381@A4/0%	0.323@A3&4/+3%

6
RTD-INCOTEST® ON-SITE PRODUCTION RATE

The onsite examination was accomplished by a two-man crew – one to operate the RTD-INCOTEST® instrument and to acquire the data and another to place the sensor at the given grid intersection point. All of the necessary hardware was loaded onto a cart for setup and data acquisition. In general, all grid points were already marked on the components to be examined using the grid plan prepared by APTECH Engineering Service.

All of the examinations through insulation were conducted online without interruption to the power plant operation. Based on the control room temperature readings, the inspected components were in the range of 300-315ºF (149-157ºC).

Table 6-1 provides a daily summary of components examined, along with the number of readings obtained based on the grid layout. On average, based on an eight-hour shift per day, eight components can be examined.

Table 6-1
Daily RTD-INCOTEST® Production Rate (1 inch = 25.4 mm)

Item Number	File ID Number	Grid (Row X Column)	Total Readings	Pipe Specifications (NWT)	Examination Results
1	2-23AHD-LOC 1	6 X 8	48	6" OD X 0.280" NWT	Lowest AWT 91% of Reference @ G6
2	2-23AHD-LOC 2	8 X 8	64	6" OD X 0.280" NWT	Lowest AWT 90% of Reference @ A4
3	2-23AHD-LOC 3	10 X 8	80	6" OD X 0.280" NWT	Lowest AWT 88% of Reference @ E2
			192	3 Components Completed Today; 3 for the Project to date	
4	23BHD- LOC 1	12 X 7	84	10" OD X 0.365" NWT	Lowest AWT 89% of Reference @ K1
5	23BHD- LOC 2	10 X 8	80	10" OD X 0.365" NWT	Lowest AWT 87% of Reference @ H9
6	23BHD- LOC 3	11 X 8	88	6" OD X 0.280" NWT	Lowest AWT 92% of Reference @ C4
7	23BHD- LOC 4	9 X 8	72	6" OD X 0.280" NWT	Lowest AWT 85% of Reference @ G5
8	23BHD- LOC 5	8 X 8	64	6" OD X 0.280" NWT	Lowest AWT 89% of Reference @ C2
9	23BHD- LOC 6	8 X 4	32	4" OD X 0.237" NWT	Lowest AWT 90% of Reference @ B5
			420	6 Components Completed Today; 9 for the Project to date	
10	23AHD-1	7 X 12	84	10" OD X 0.365" NWT	Lowest AWT 92% of Reference @ J1
11	23AHD-2	10 X 8	80	10" OD X 0.365" NWT	Lowest AWT 89% of Reference @ F8
12	23AHD-3	10 X 8	80	6" OD X 0.280" NWT	Lowest AWT 87% of Reference @ F3, F10
					Lowest Est. MWT 75% of Reference @ F3
13	23AHD-4	10 X 8	80	6" OD X 0.280" NWT	Steam leak nearby prevented access
14	23AHD-5	9 X 8	72	6" OD X 0.280" NWT	Lowest AWT 90% of Reference @ G1 & E7

Item Number	File ID Number	Grid (Row X Column)	Total Readings	Pipe Specifications (NWT)	Examination Results
15	EPRI ELBOW 1	8 X 6	48	8" OD X 0.500" NWT	Wall Thickness ≥ 0.480-inch AWT
16	EPRI ELBOW 2	8 X 6	48	8" OD X 0.500" NWT	0.442" AWT, 0.376" Estimated Minimum
17	EPRI ELBOW 3	8 X 6	48	8" OD X 0.500" NWT	0.382" AWT, 0.323" Estimated Minimum
			540	8 Components Completed Today; 17 for the Project to date	
18	23AHD-6	8 X 6	48	6" OD X 0.280" NWT	Lowest AWT 95% of Reference @ B1 & A5
19	23AHD-7	9 X 8	72	6" OD X 0.280" NWT	Lowest AWT 92% of Reference @ G6
20	23AHD-8	13 X 8	104	6" OD X 0.280" NWT	Lowest AWT 89% of Reference @ B1
21	23AHD-9	6 X 8	48	6" OD X 0.280" NWT	Lowest AWT 90% of Reference @ G3
25	23AHD-13	6 X 4	24	4" OD X 0.237" NWT	Lowest AWT 93% of Reference @ B1
26	23AHD-14	3 X 8	24	6" OD X 0.280" NWT	Lowest AWT 74% of Reference @ A3
					Lowest Est. MWT 65% of Reference @ A3
27	23AHD-15	4 X 8	32	6" OD X 0.280" NWT	Lowest AWT 80% of Reference @ F3
					Lowest Est. MWT 73% of Reference @ F3
28	23BHD-9	6 X 8	48	6" OD X 0.280" NWT	Lowest AWT 88% of Reference @ H6
			400	8 Components Completed Today; 28 for the Project to date	
29	2A4HD-7	8 X 4	32	4" OD X 0.237" NWT	Lowest AWT 88% of Reference @ A7
30	2A4HD-3	10 X 8	80	6" OD X 0.280" NWT	Lowest AWT 88% of Reference @ A9

Item Number	File ID Number	Grid (Row X Column)	Total Readings	Pipe Specifications (NWT)	Examination Results
31	2B4HD-2	10 X 8	80	6" OD X 0.280" NWT	Lowest AWT 91% of Reference @ D8
32	2B4HD-7	10 X 4	40	4" OD X 0.237" NWT	Lowest AWT 89% of Reference @ D4
33	2B4HD-3	10 X 8	80	6" OD X 0.280" NWT	Lowest AWT 92% of Reference @ F10
			312	5 Components Completed Today; 33 for the Project to date	

7
SUMMARY

Even with the limited database for comparison, the evaluated RTD-INCOTEST® results showed that it can serve as an effective screening tool to identify the areas affected by FAC and can also serve as a reliable analysis tool for estimating the remaining wall thickness.

Once the area of interest is identified and gridded, the resultant RTD-INCOTEST® examination can be conducted online and through insulation to quickly identify the FAC area for further investigation. As a qualitative screening tool, RTD-INCOTEST® can be used to screen and identify the affected FAC area in percent wall thickness remaining, based on an assumed reference point being corrosion free with 100% of the wall still intact.

During the screening test, if any wall thickness loss represented by 12% below the reference wall thickness value is encountered, additional investigation is recommended by APTECH to quantify the wall loss. With RTD-INCOTEST®, this involved asking the utility to make circular insulation cuts over the reference points for the purpose of obtaining the ultrasonic thickness measurements. From the measured thickness values, the remaining wall thickness values (in inches or mm) were estimated.

The wall thickness quantification by RTD-INCOTEST® involved providing either the lowest averaged wall thickness or the lowest estimated minimum wall thickness in either percent or inches. For up to 12% change from the nominal 0.28 inch (7.112 mm) wall in the drain pipe elbow, the RTD-INCOTEST® analysis results were found to be within 10% of the minimum ultrasonic thickness readings. For up to 24% averaged change from the nominal 0.5 inch (12.7 mm) wall in the EPRI mockup, the RTD-INCOTEST® results were within 7% of the averaged ultrasonic thickness readings.

If the minimum wall thickness values were compared, this translated to 35% change from the nominal 0.5 inch (12.7 mm) wall and the associated RTD-INCOTEST® reading was found to be within 3% of the minimum ultrasonic thickness reading.

On average, the field RTD-INCOTEST® production rate was found to be around eight components examined within an eight-hour per day shift. This translated to anywhere from 400 to 540 readings.

8
REFERENCES

1. *FAC Wear Rate Assessment Through Insulation.* EPRI , Palo Alto, CA: 2000.TR-1000114.
2. Scottini, R., "RTD-INCOTEST® Training Course," June 2008.
3. Krzywosz, K., et al., "Pulsed eddy Current Flaw Detection and Flaw Characterization," Volume 3: Electromagnetic Methods of Nondestructive Testing, Nondestructive Testing Monographs and Tracts - ISSN:0730-7152, August 1985.

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute Inc., (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass.

Together…Shaping the Future of Electricity

1019558

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com