ACTUAL PLANT EXPERIENCE RESULTS OF AN ACOUSTIC MONITORING SYSTEM (AMS) FOR HRSG'S EARLY TUBE LEAK DETECTION

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By

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TOPICS DISCUSSED

1. BACKGROUND INFORMATION ON WHY ACOUSTIC MONITORING SYSTEM (AMS) WAS INSTALLED
   - The Plant Information
   - The Plant's HP Economizer 2-1 Tube Leak Events
   - Root Cause Analysis Results for the Tube Leak Events and Recommended Modifications to Eliminate the Tube Leaks
   - Plant's Decision to Cost Effectively Manage the Tube Leak Events Through Early Detection of the Tube Leak
2. AMS DESCRIPTION & ITS INSTALLATION AT THE PLANT
3. AMS PERFORMANCE RESULTS
   - AMS detected every "Tube Leak Incidence" as soon as the Tube Leak Started

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THE PLANT INFORMATION

- The Plant started commercial operation on December 15, 2009
- Siemens SCC5-4000F 2x1 (V94.3A) Gas Turbine with SST5-5000 Steam Turbine/ 50 Hz Frequency Generator
- Total Combined Electrical Output = 770 MW
- The Unit designed for firing natural gas at base load and limited No.2 oil firing, but ended up firing No.2 oil for 4 to 6 months period continuously
- Natural Circulation Drum Type Triple Pressure HRSGs, Units: 11 and 12

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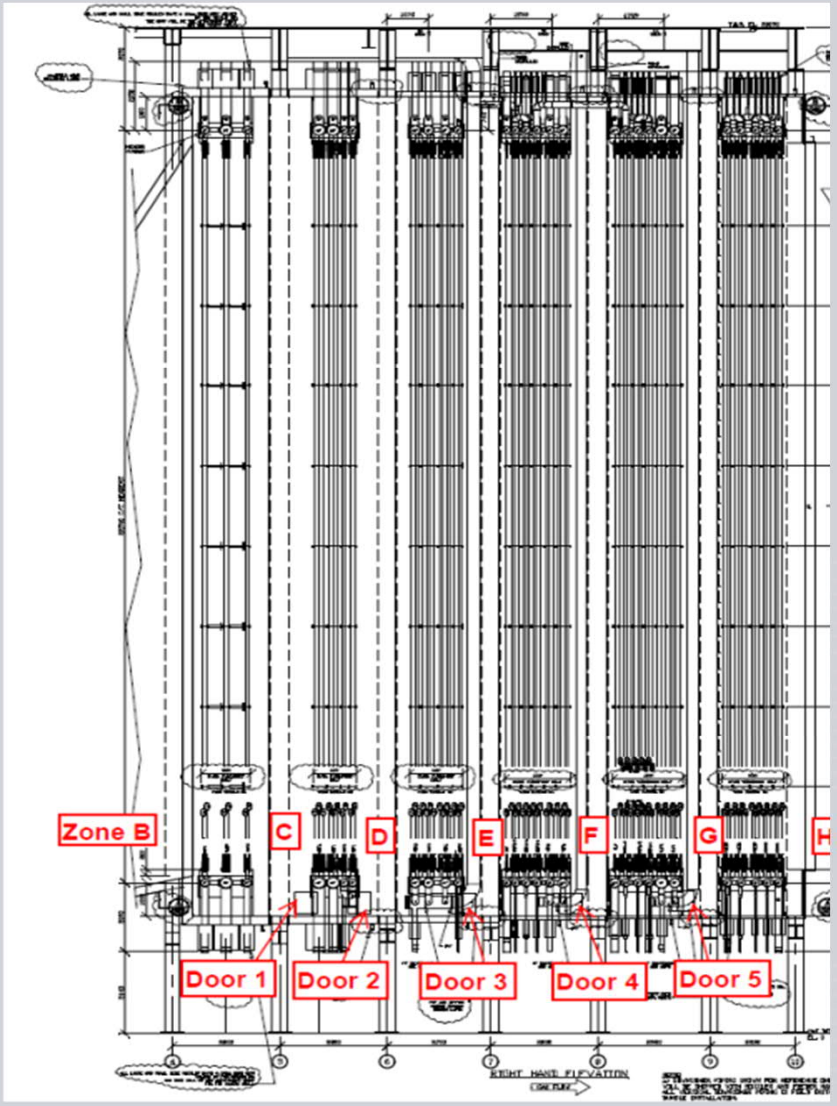
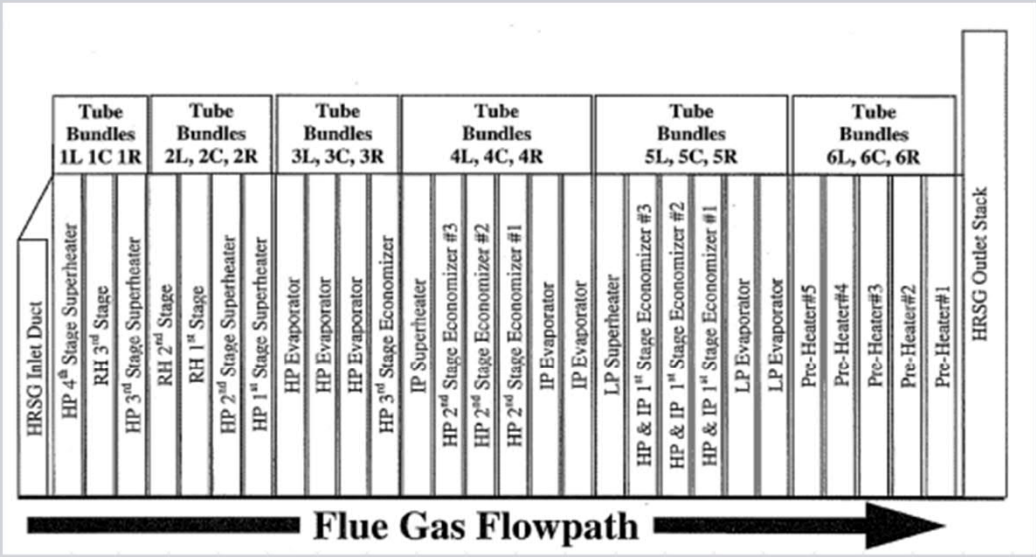
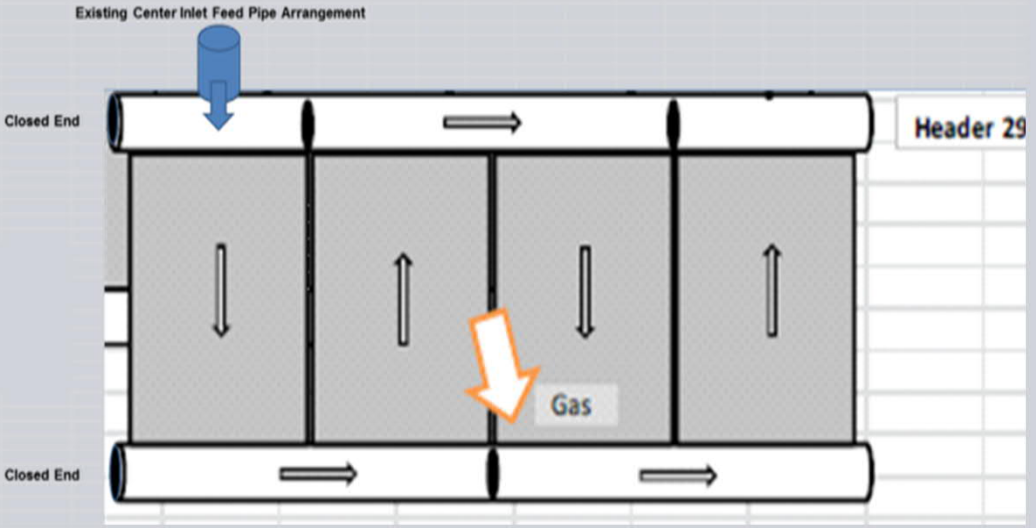
HRSG TUBE SECTIONS ARRANGEMENT







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THE TUBE LEAK EVENTS & IMPORTANCE OF EARLY DETECTION OF TUBE LEAKS

- **Boiler tube leak factor is one of the major causes of loss of generation in the Power Industry**
- **Undetected leaks can cause secondary damage and extend forced outages**
- **Small undetected leaks at inaccessible locations can go unrepaired during shutdowns, further grow in leak jet size and potentially cause further secondary damage to the adjacent tube rows and forced shutdowns**
- **At the subject plant, repeat tube leaks occurred in HP Economizer 2-1 tube Nos: 1-6, at right section of the top header from the water inlet feed pipe connection, indicated by the increase in the demineralized water usage**
- **At the subject plant, initial undetected leaks with continued plant operation created secondary damages to the adjacent tube rows, that lead to extensive tube repairs**
- **Acoustic Monitoring System (AMS) can help detecting the tube leaks as soon as they start occurring in the boiler systems**

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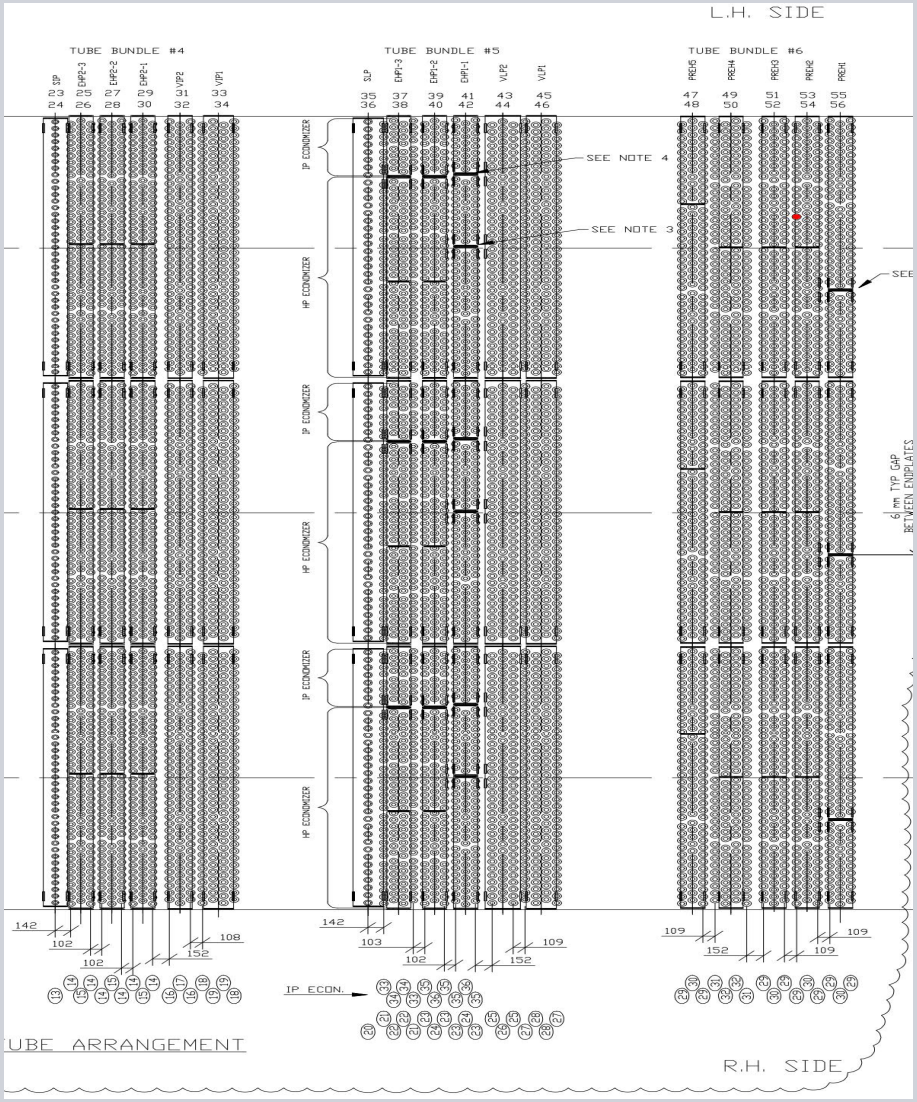
PLAY THE VIDEO OF A TYPICAL TUBE LEAK

(VIEDIO SHOWS THE LEAK BY FAC AT CONDENSATE PREHEATER 2 LHS MODULE – OCCURRED DURING OCTOBER 2016 – SEE THE RED DOT)



Take Away Message From the Video is:

- High Sound Level of the Leak
- How the Leak Jet impinges to the adjacent tube row causing erosion & corrosion (see the discoloration at bottom 3 tubes due to wide spray angle water jet impingement during HRSG operation)

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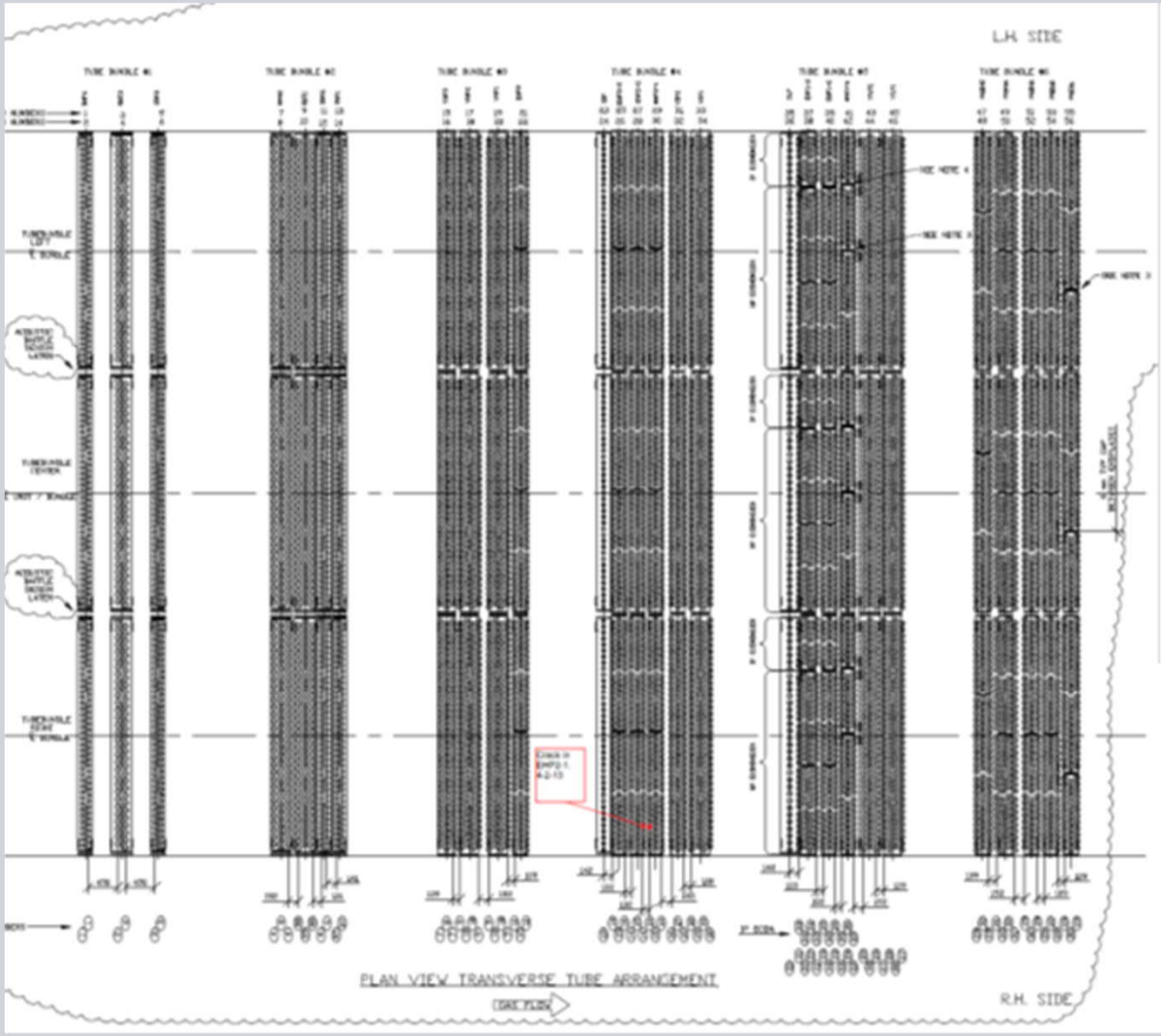
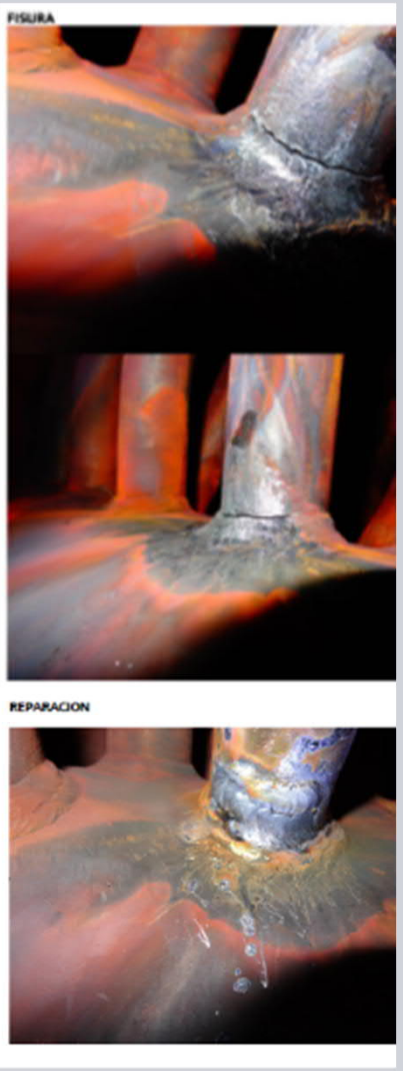
UNIT 12 HRSG's FIRST TUBE LEAK EVENT (FEB. 4, 2013) INDICATED BY HIGH MAKE-UP WATER USE AT HP ECON 2-1 AFTER ABOUT 3 YEARS FROM COMMERCIAL OPERATION & ITS IMMEDIATE SHUT DOWN & REPAIR





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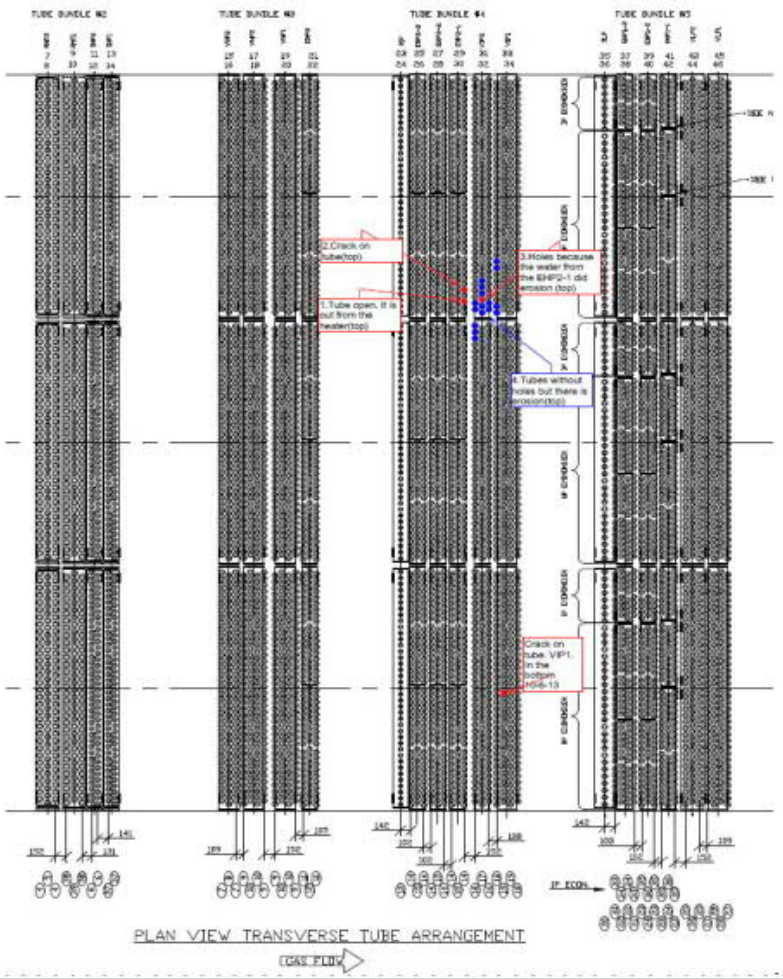
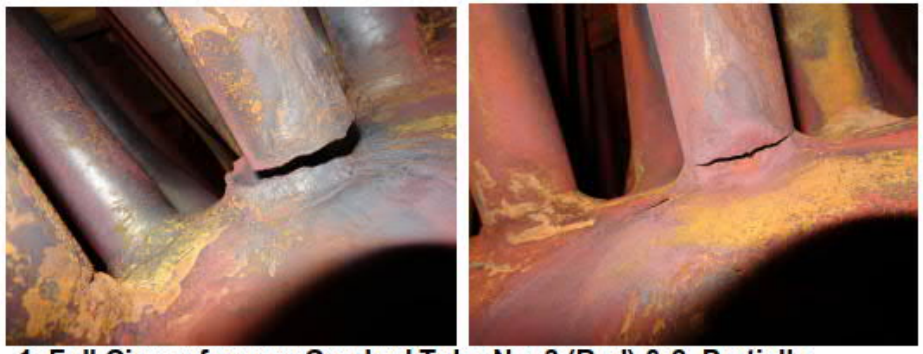
UNIT 12 HRSG's ADDITIONAL TUBE LEAKS DUE TO FEW MONTHS OF CONTINUED OPERATION WITH LEAK (FOUND ON 6/10/2013) - PRIMARY TUBE LEAK CRACKS & SECONDARY WATER JET EROSION & CORROSION DAMAGE TO ADJACENT ROW TUBES





1. Full Circumference Cracked Tube No. 3 (Red) & 2. Partially Cracked Tube No.5 (Red) at Tube Joint on Header 29 as Primary Source of Water Jet Leak

3. Hole on VIP2 tube (Red) Due to HP2-1 Tube Leak Water Jet Erosion

4. Erosion & Corrosion Damage on VIP2 Tubes (Blue) Due to HP2-1 Tube Water Jet Leak

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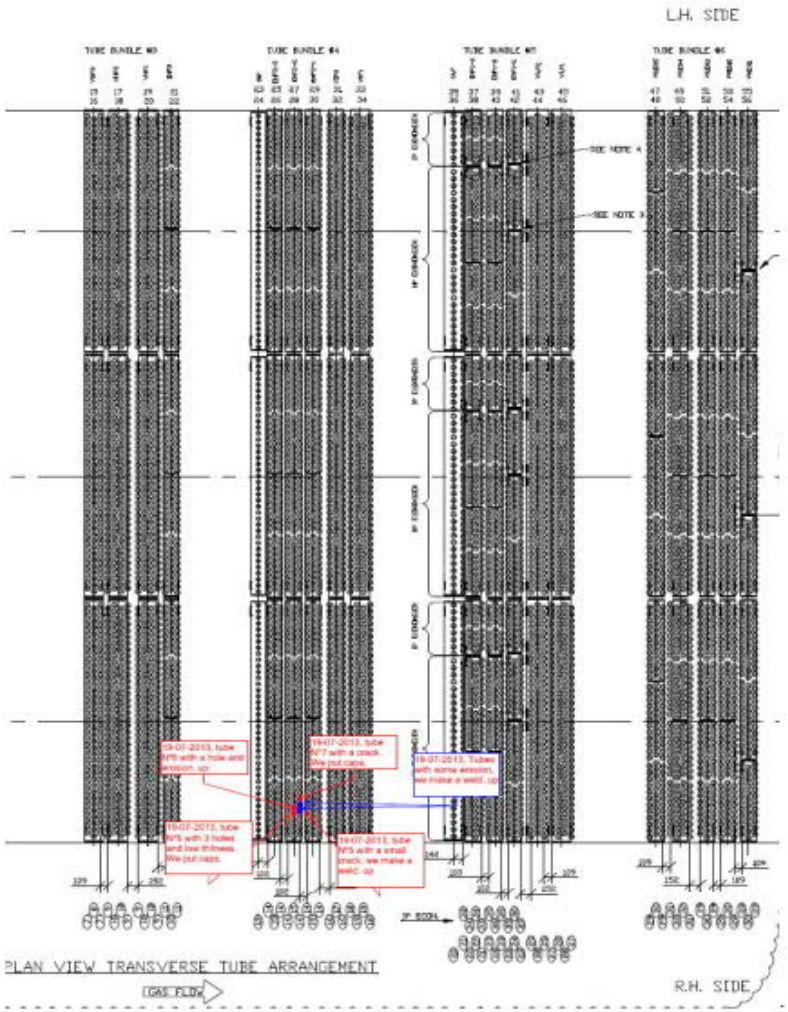
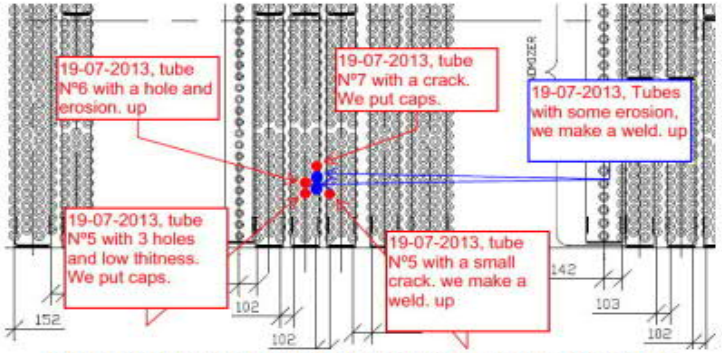
UNIT 11 HRSG's PRIMARY & SECONDARY TUBE LEAKS FOUND ON JULY 19, 2013, AFTER FINDING PRIMARY & SECONDARY TUBE DAMAGES IN UNIT 12.





Enlarged View of the Damaged Tubes Section

FOTOGRAFIA 4

Primary Leak Source - Crack Facing Header 27 at Front Row Tube No. 5 Joint of Header 29 – See Water Jet Leak Area Marks

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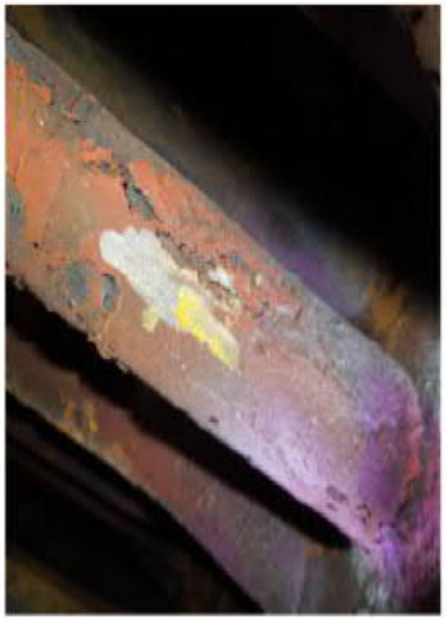
UNIT 11 HRSG's PRIMARY & SECONDARY TUBE LEAKS FOUND ON JULY 19, 2013 & REPAIRS PERFORMED PHOTOS

FOTOGRAFIA 2



Tube No: 5 & 6 on Header 27 with Holes & Low Thickness Due to Erosion & Corrosion

FOTOGRAFIA 3

FOTOGRAFIA 1

Tube No: 7 on Header 27 with a Crack & Tube Plug with Header Window Cutting Method

FOTOGRAFIA 5

Erosion & Corrosion Damage (Blue) on Header 27 Due to HP2-1 Tube No: 5 Water Jet Leak

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PRIMARY & SECONDARY TUBE DAMAGES RESULTED IN EXPENSIVE & EXTENSIVE MULTIPLE ROWS OF TUBE CUTTING FOR ACCESS AND REPAIR WELDING WITH NEW REPLACEMENT PLAIN TUBE SECTIONS (SPENT >$1.5 MILLION US$ FOR TWO MODULES REPAIR, ONE IN EACH UNIT)

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ROOT CAUSE FOR THE HP ECONOMIZER 2-1 REPEAT TUBE LEAK EVENTS & RECOMMENDED MODIFICATIONS TO ELIMINATE THE HP 2-1 TUBE LEAKS

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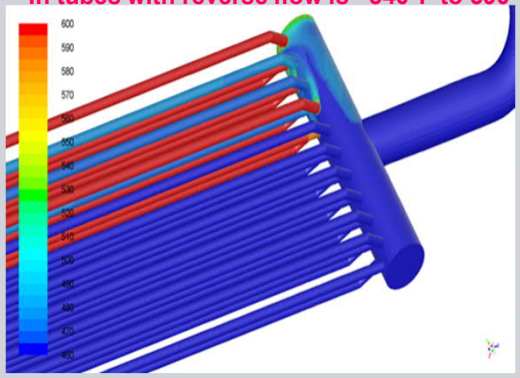
Siemens Energy, Inc. (SEI) Measured Extensive Tube Metal Temperatures & Performed 3D Plexiglass Physical & CFD Flow Modeling Studies. Based on these Studies, the Primary Root Cause Result: "Reverse Flow" in downward water flow pass from insufficient pressure head to overcome the "Upward Buoyancy Forces" created by "Water Density Differences". Recommended Modifications to Eliminate HP Econ 2-1 Tube Leaks: Modify "Feed Pipes" for upward flow in all 4 passes of the same row header.

Measured Temperature Data Calibrated CFD Model's Predicted Temperature Distribution in Existing Arrangement:
In tubes with reverse flow is ~540°F to 590°F near inlet header; Water Outlet Temperature: 480°F



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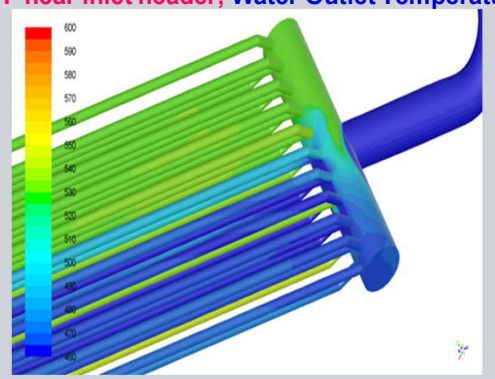

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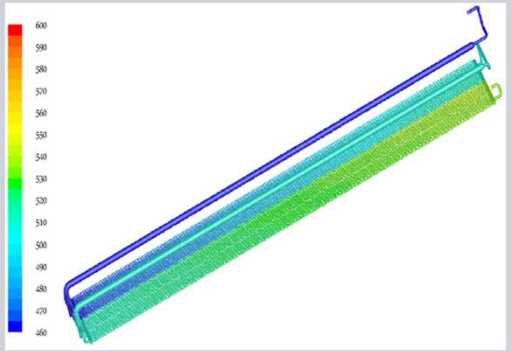
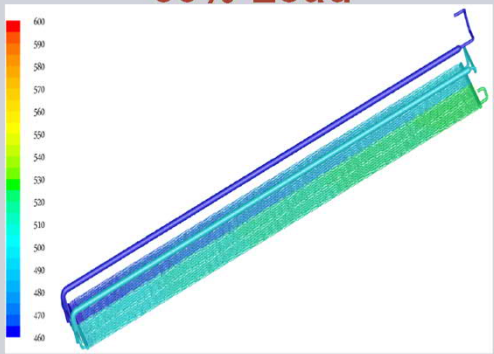
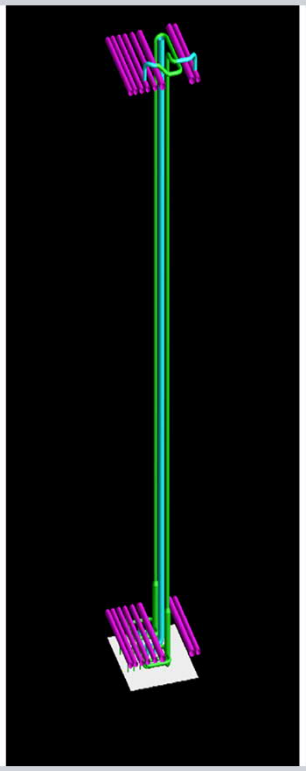
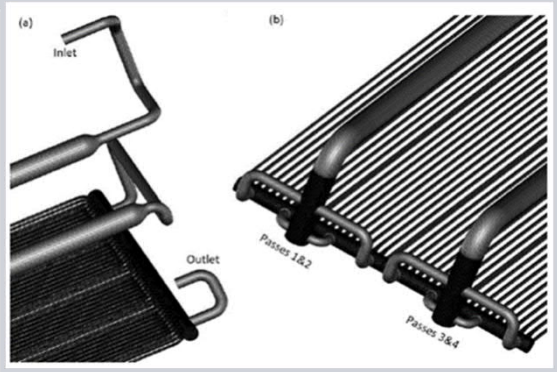
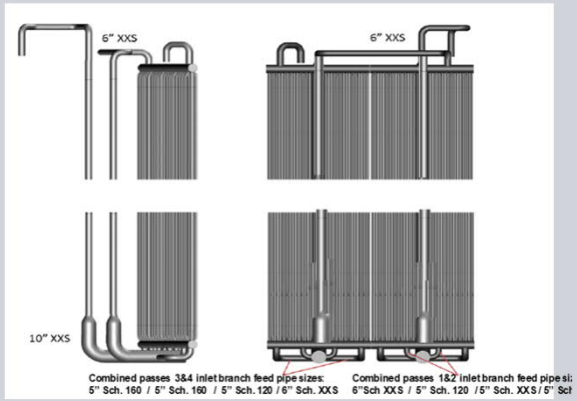




CFD Model Predicted Temperature Distribution in Modified feed Pipe Arrangement







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INTRODUCTION TO ACOUSTIC MONITORING SYSTEM TO DETECT TUBE LEAKS & ITS GENERIC DIFFERENTIATING FEATURES FROM TRADITIONAL METHODS

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- **Traditional methods of tube leak detection are:**
  1. **Sudden or slow increase in the demineralized makeup water usage**
  2. **High moisture content in HRSG exit flue gas**
  3. **Steam in the stack plume**
  4. **Wet spots at the bottom of the HRSG**
- **Traditional methods do not typically locate the specific area of tube failure**
- **Latest technology is the use of Acoustic Monitoring System (AMS)**
- **The AMS detects leaks earlier than traditional methods, and it is an on-line real time tube leak detection (24-7 real time monitoring, with local and network alarming)**
- **It provides an early primary tube leak detection, and the immediate repair of primary leak-tube-crack reduces secondary tube damages**
- **It locates area of leak(s) before unit comes offline, and it trends the severity and progression of the leak with real time data**
- **Depending on the severity of tube leak, it helps managing market exposure and risk, and allows planning the tube leak repair during planned outage or period of low MW demand**
- **It has Non-intrusive sensors & After-market install**
- **It can be installed to provide total HRSG tubes area coverage or in areas of most concern**

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INSTALLED EQUIPMENT AT THE SUBJECT PLANT TO HELP MANAGE THE TUBE LEAK EVENTS BETTER

- The estimated capital budget needed for the subject plant's HRSG HP Econ 2-1 recommended feed & exit pipes modification to eliminate HP Econ 2-1 repeat tube leak events was significant (about US$3.5 million for the two HRSGs)
- The plant looked for ideas to manage the tube leak problem better and minimize the repair costs
- SEI recommended the AMS System which is intended to help with an early detection of primary tube leak, to minimize secondary water jet impingement damages, and to minimize expensive repair cost of both the primary leak and secondary leak damaged tubes
- The reason for recommending Mistras/Triple 5 AMS was the following Installations & Monitoring Experience they had:
  - 21 HRSG's
  - 375+ Power Boilers
  - 500+ Feedwater Heaters
  - 21 Recovery Boilers
  - 2500+ leaks cataloged in Triple 5's database since 2004
  - 100+ Boilers in Surveillance Program
  - 170+ Sites
  - 65+ Companies
  - 9900+ Total sensors
- The plant decided to implement the AMS System to detect the primary tube leaks early
- Mistras/Triple 5 provided the AMS
- Even though the AMS installation started during April 2016, after the plant had a tube leak repair incidence at HP Econ 2-1 bottom header 30 on June 12, 2016 (a forced outage), it escalated the importance of completing the installation and it was completed during July 2016.

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MISTRAS/TRIPLE 5 - ACOUSTIC MONITORING SYSTEM (AMS) FOR SUBJECT PLANT

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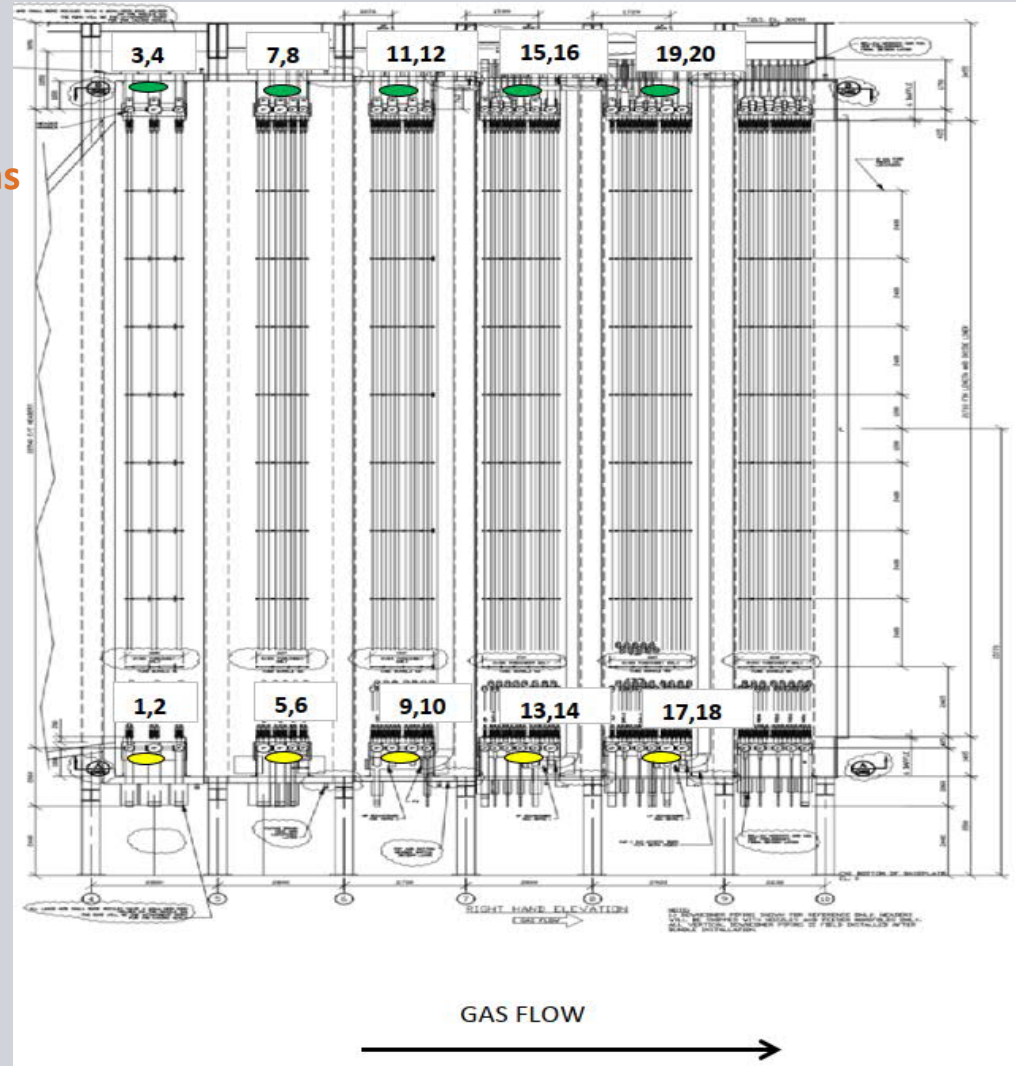
Factors Affecting Waveguide Locations

- **Sensitivity of the sensor is 20 to 30 feet radius**
- **Coverage in areas of the boilers where leaks most expected**
- **Accessibility at each desired location**
- **Economics**



HRSG 11 & 12

20 Sensor Locations
Each ⬭ indicates 2 sensors on Top
Each ⬭ indicates 2 sensors on sidewalls

Even # on Right Side
Odd # on Left Side

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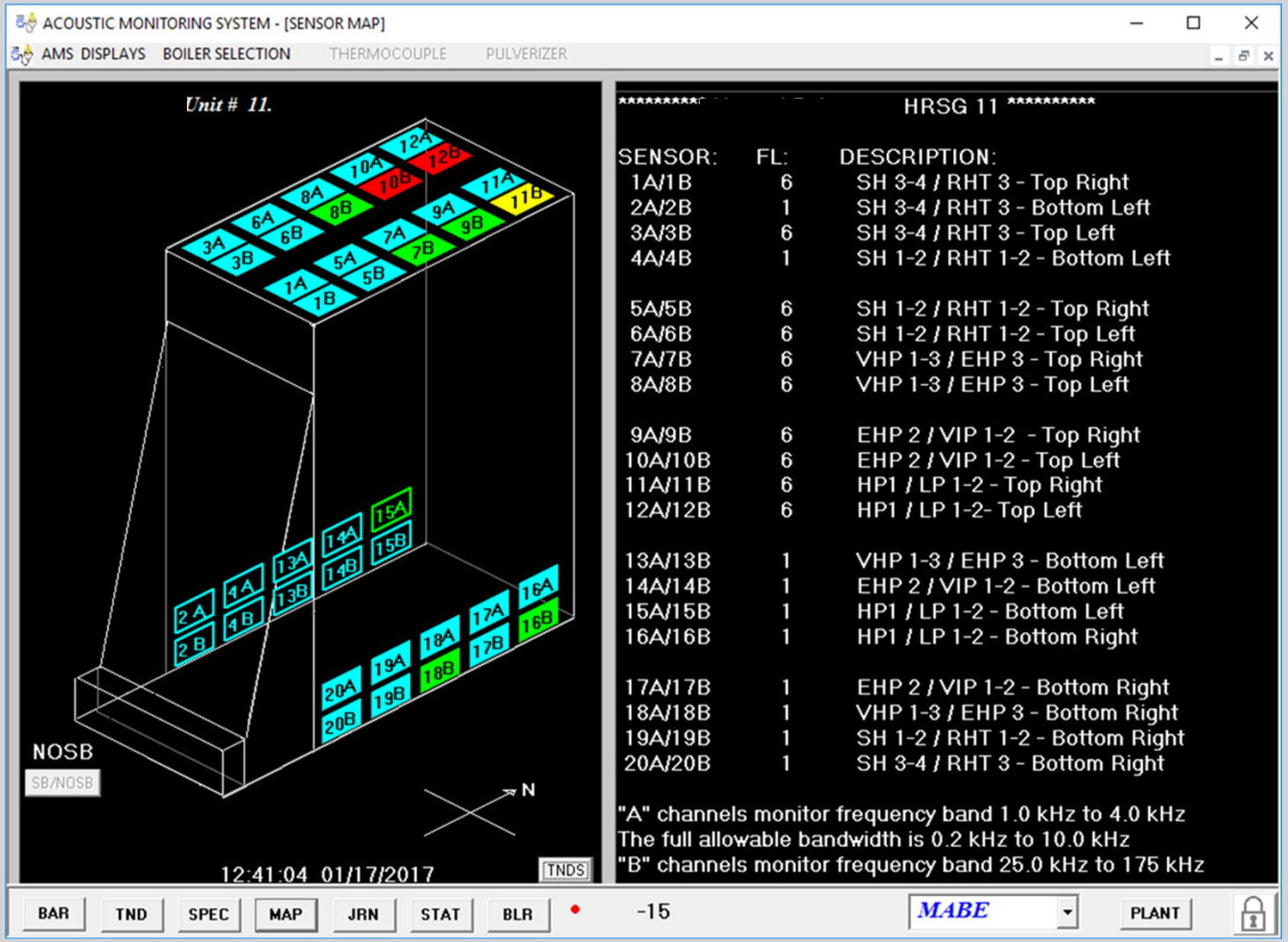
SUBJECT PLANT'S HRSG SENSORS LOCATION ID DISPLAY MAP

- Color Coded For Signal Strength
- Customized To Subject Plant's Nomenclature



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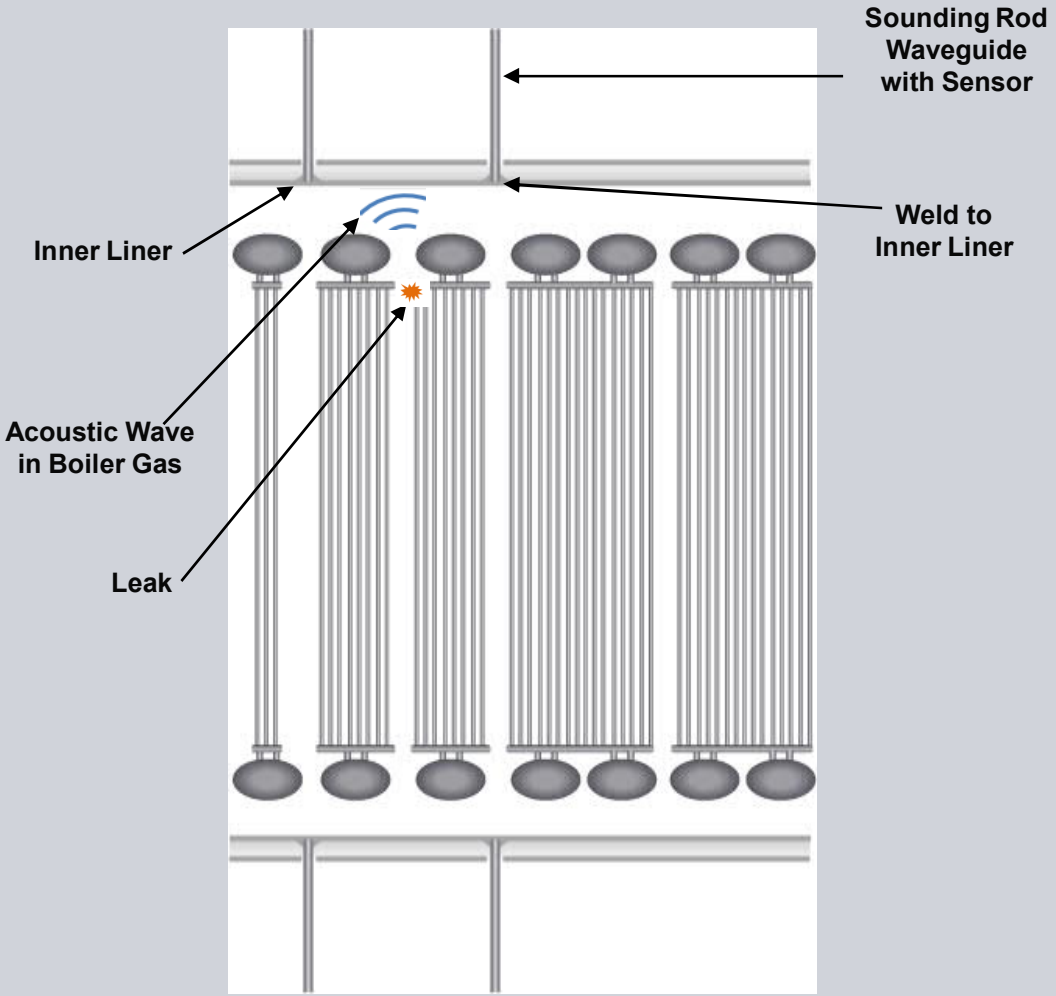
HOW ACOUSTIC MONITORING WORKS

- AMS involves continuous measurement of sounds from within the HRSG
- Tube leaks create noise that travels through the boiler gasses
- Leak noise travels until it “hits” the inner liner
- Leak noise also travels through fused metal pathways, such as the inner liner
- This noise causes the inner liner, sounding rod and sensor to vibrate
- Sensor converts vibration to electrical energy that is trended and alarmed in the monitoring system



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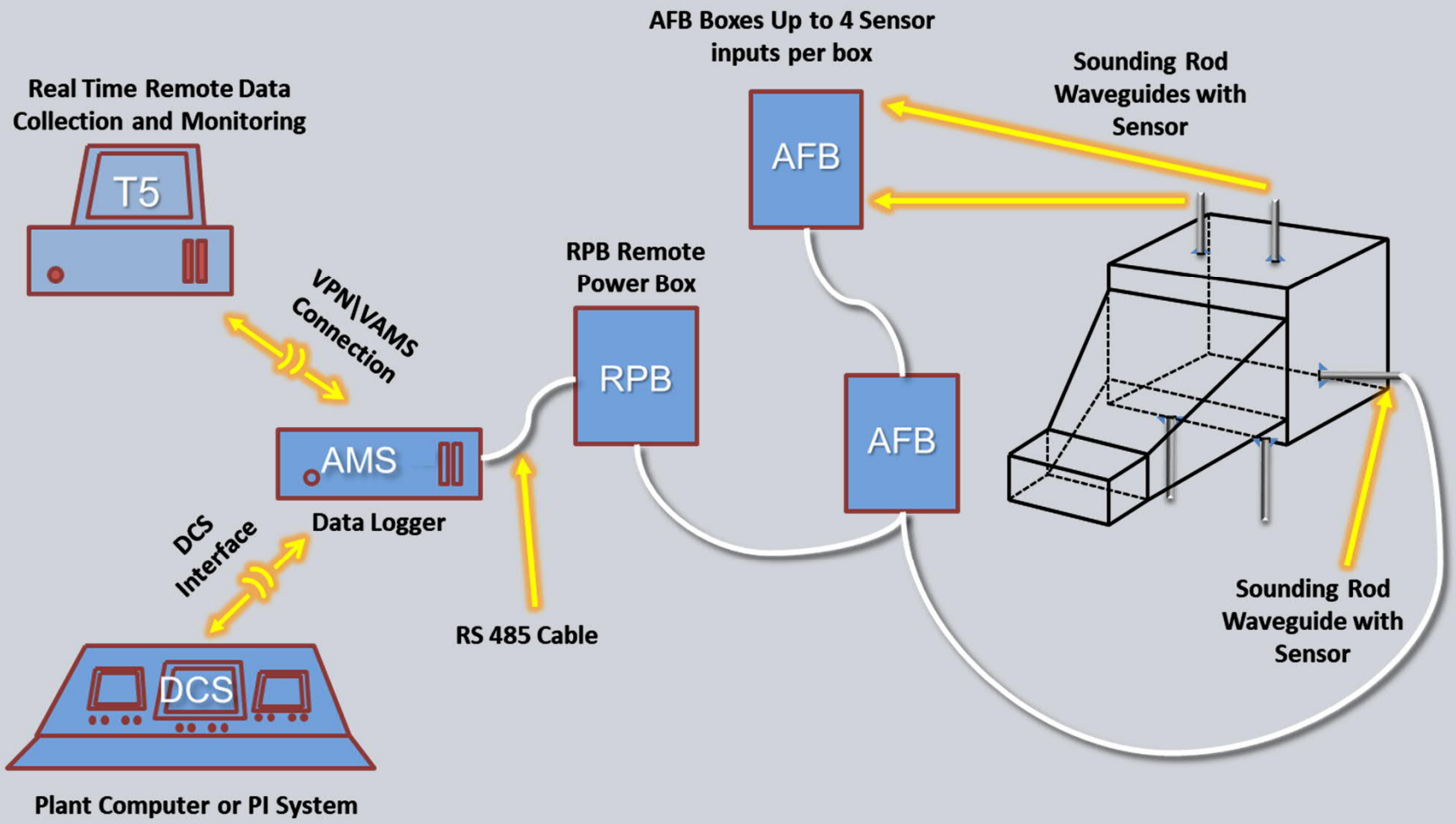
ACOUSTIC MONITORING SYSTEM COMPONENTS



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HRSG ACOUSTIC MONITORING SYSTEM INSTALLED COMPONENTS

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SM-2 Sounding Rod

- Noninvasive rods welded to inner liner
- Sensor mounted on end
- Covered with sensor box for protection

Amplifier Box

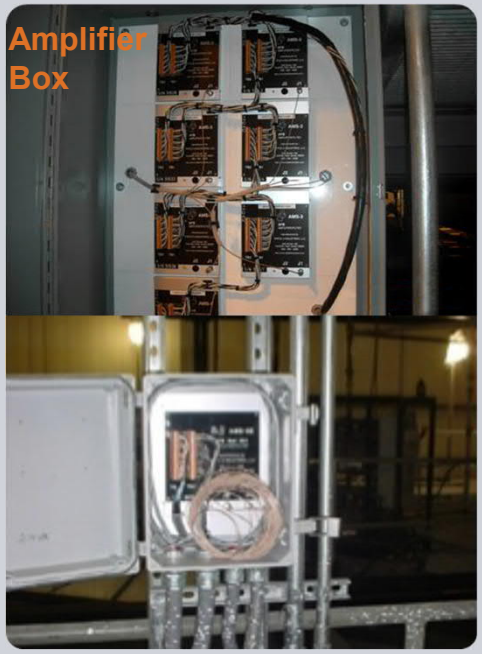
- Accepts input from 2 sensors
- Daisy chained to minimize cable runs
- AFB's can be contained in large NEMA's located on top and bottom elevations

Drilled Hole on Subject HRSG Casing Plate

Sounding Rod & Sleeve Attachment

Typical Sensor Box With Signal Cable at Subject Plant

Amplifier Box

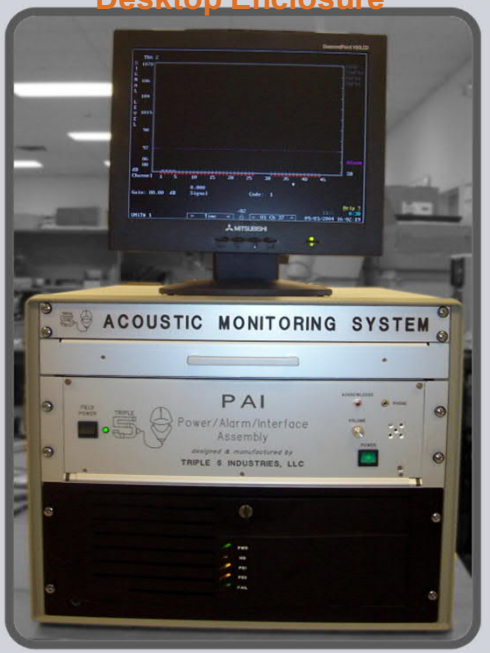


Remote Power Box

- Accepts 120 / 240 VAC
- Powers the field with 24 VDC

Cabinet Enclosure

Desktop Enclosure



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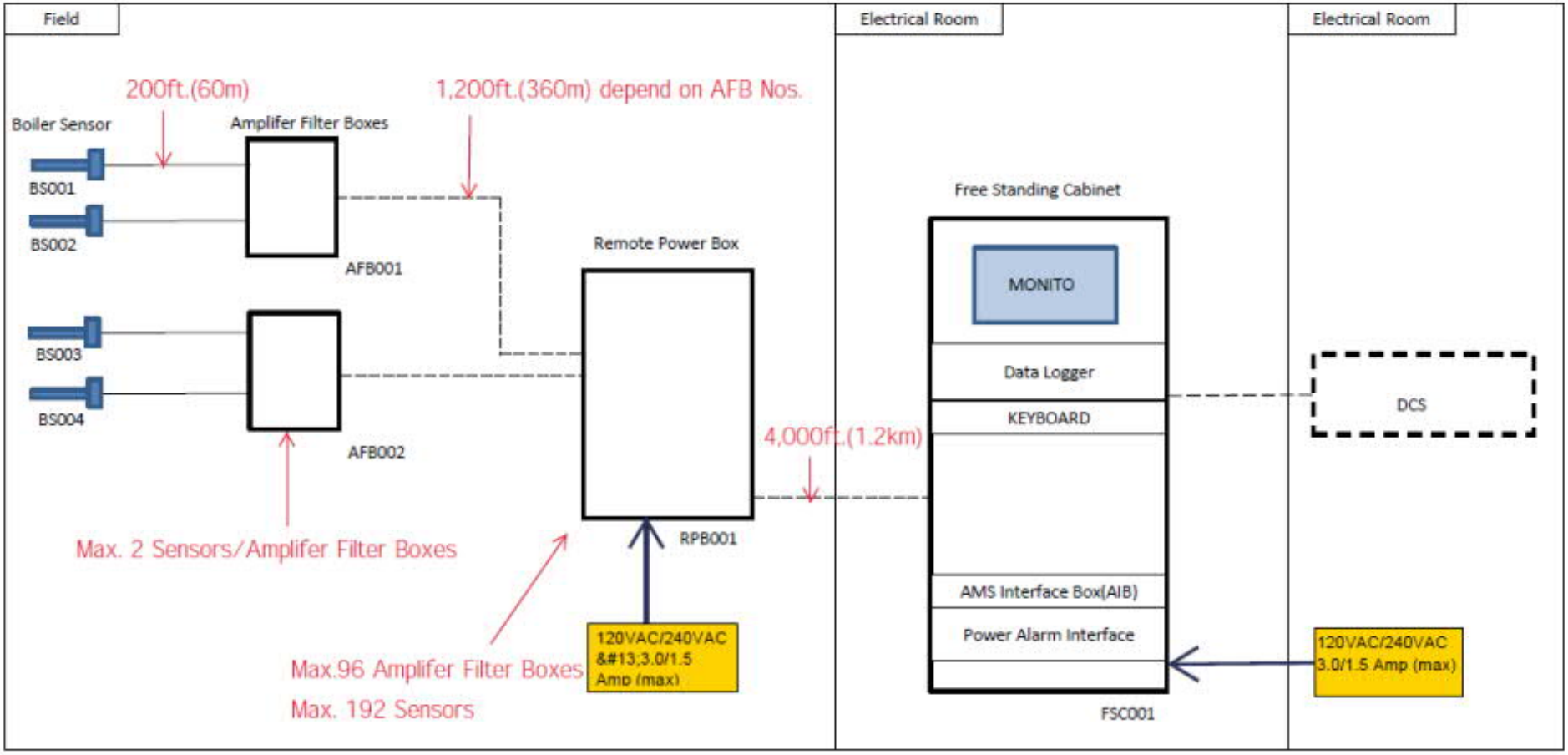
ACOUSTIC MONITORING SYSTEM – RELATIVE DISTANCE BETWEEN COMPONENTS



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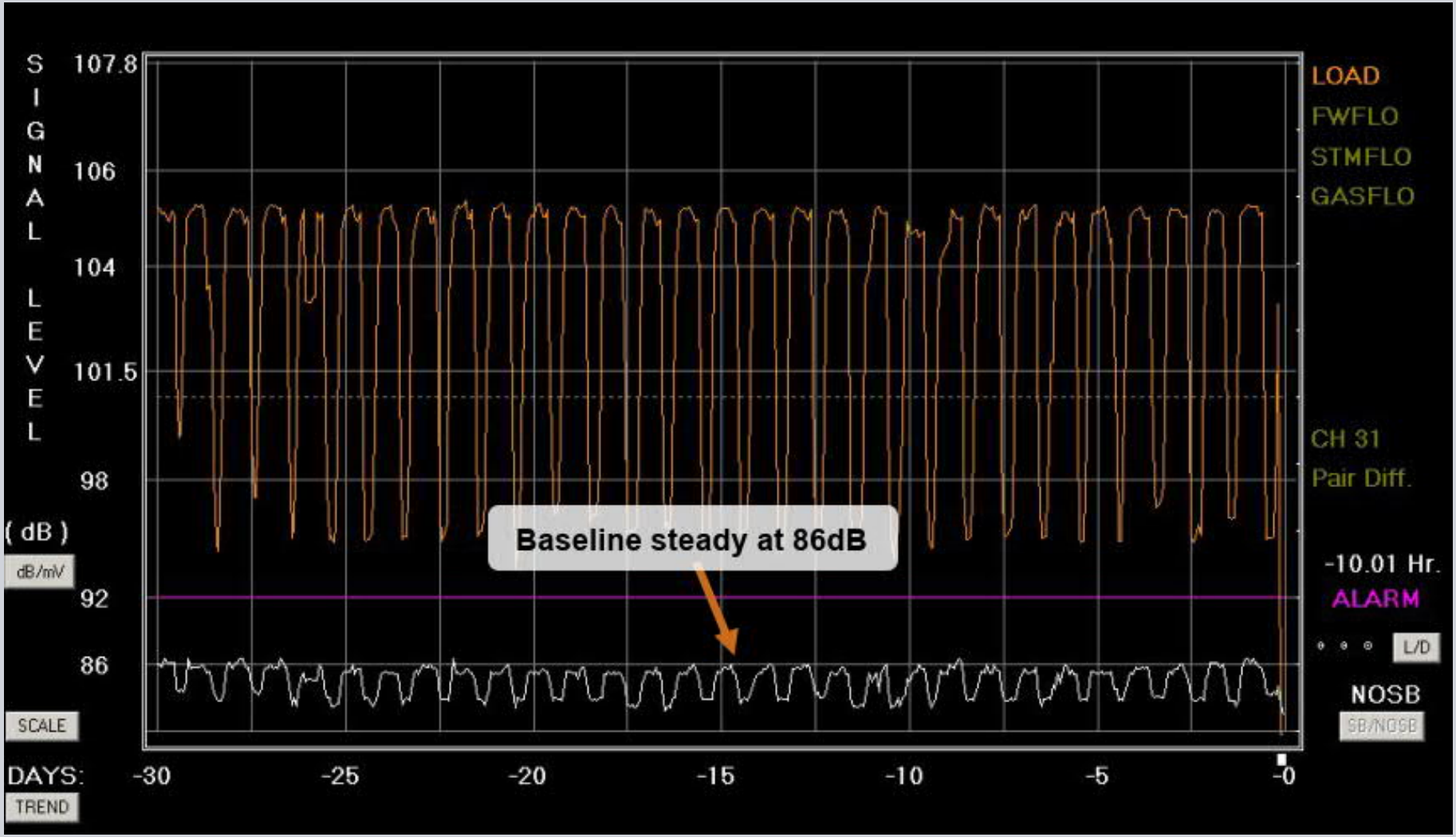
EXAMPLE NORMAL BACKGROUND NOISE OF AMS



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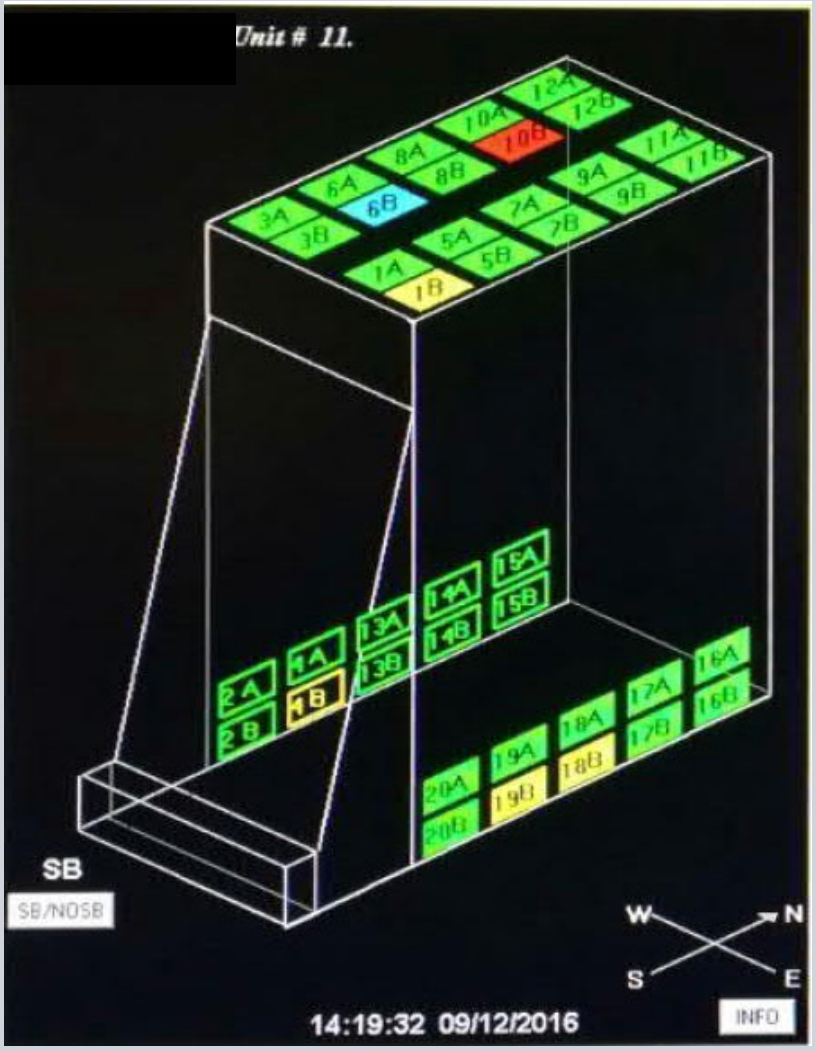
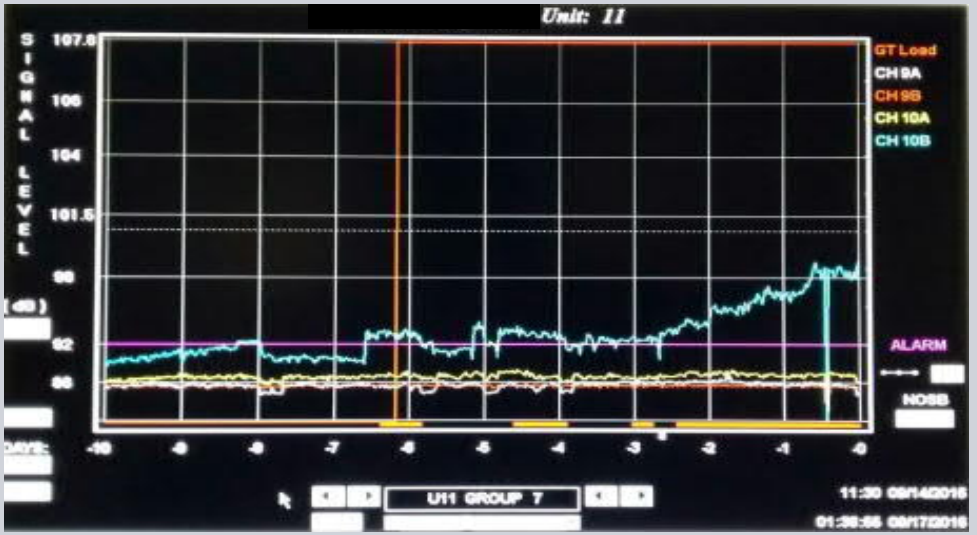
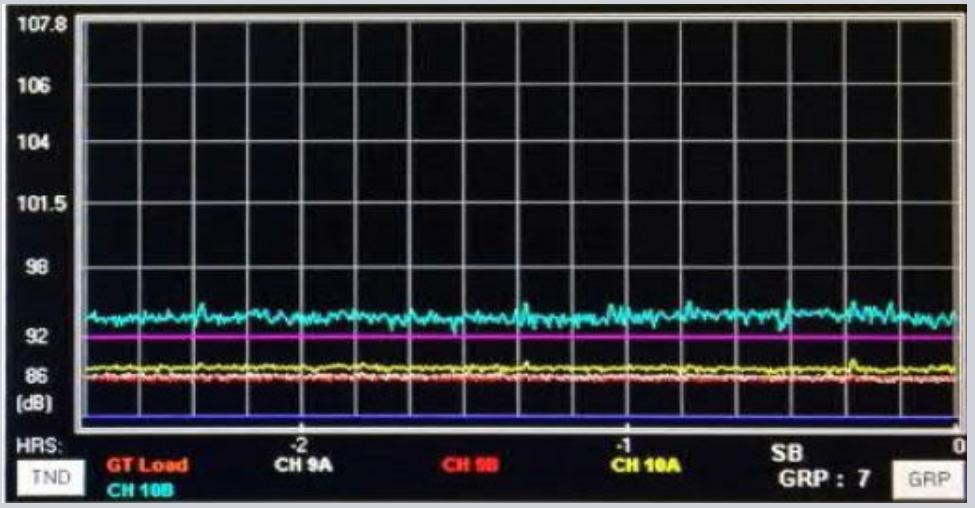
1ST TUBE LEAK DETECTION BY AMS AFTER 2 MONTHS OF ITS INSTALLATION AT SUBJECT PLANT (9/12/2016 HP ECON 2-1 TUBE NO. 5 FRONT ROW ON TOP HEADER 29 – LEAKED FOR 57 HOURS ABOVE ALARM LEVEL)







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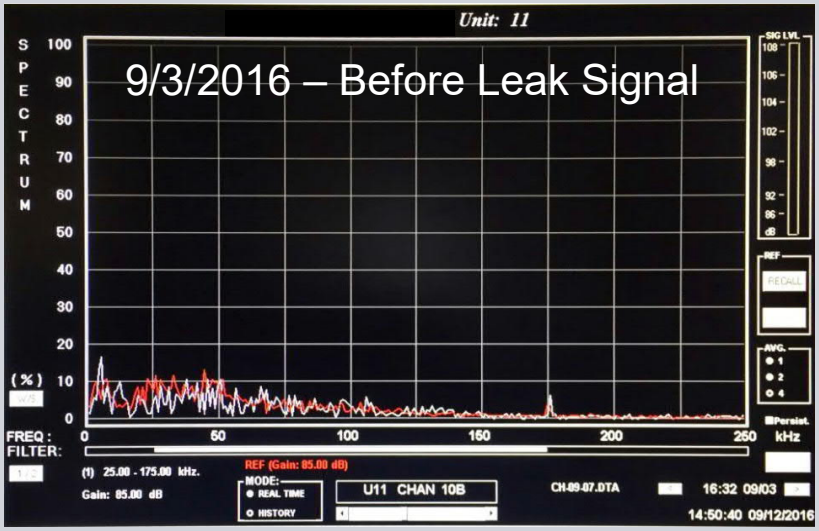
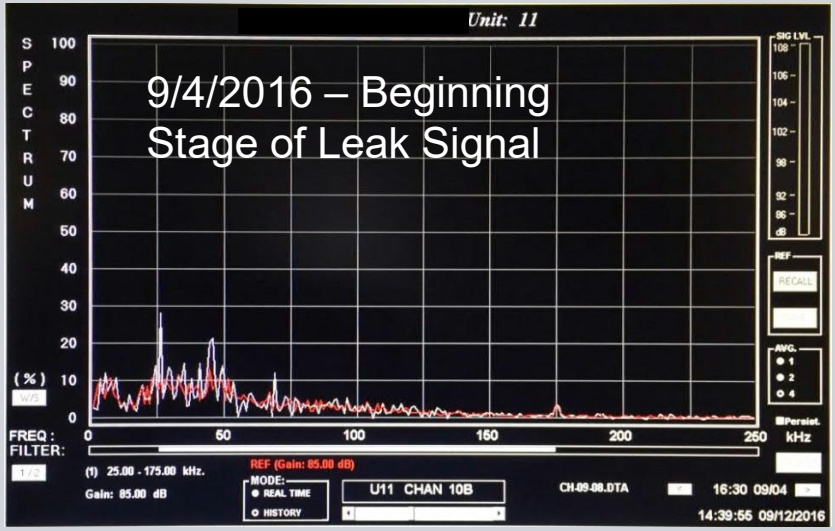
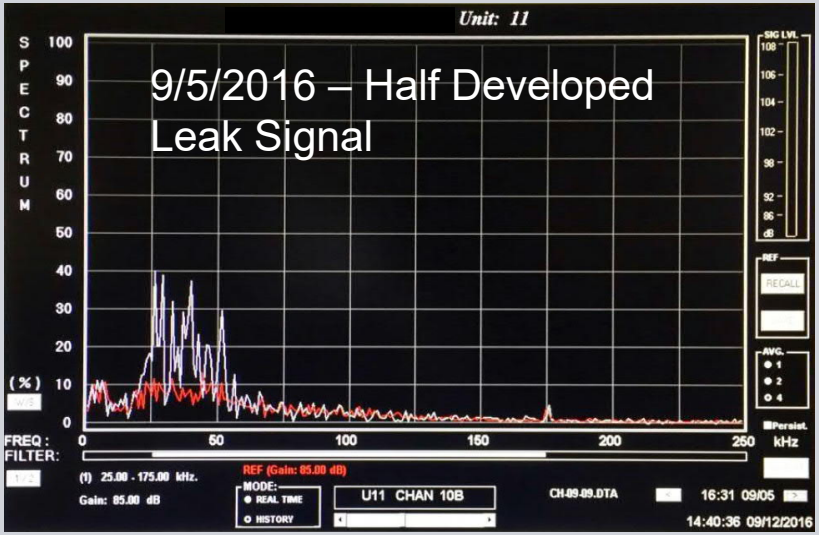
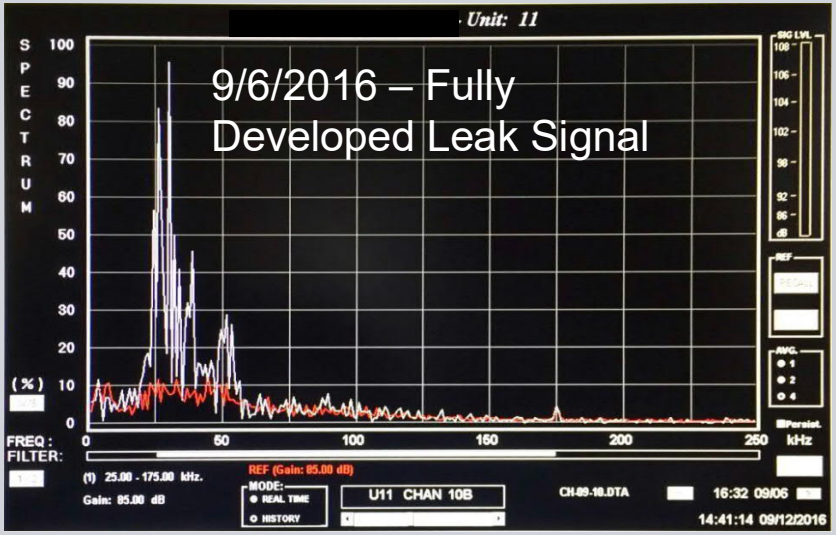
FREQUENCY DISTRIBUTION OF THE ENERGY FOR BEFORE & AFTER THE LEAK EVENT SIGNALS (9/12/2016 HP ECON 2-1 TUBE NO: 5 LEAK REPAIR EVENT) - TRENDS SEVERITY AND PROGRESSION OF LEAK









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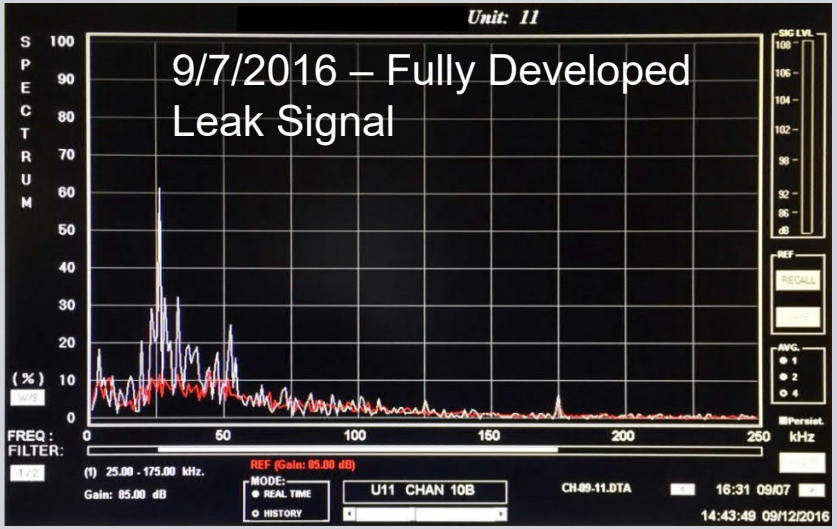
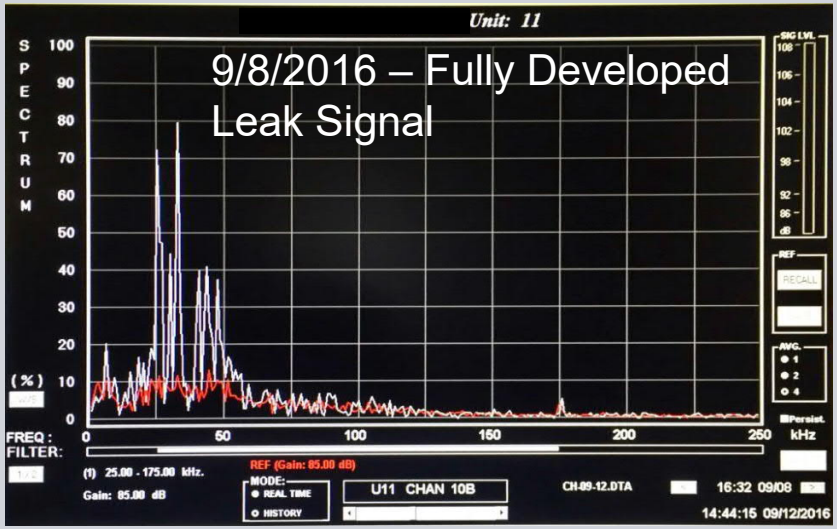
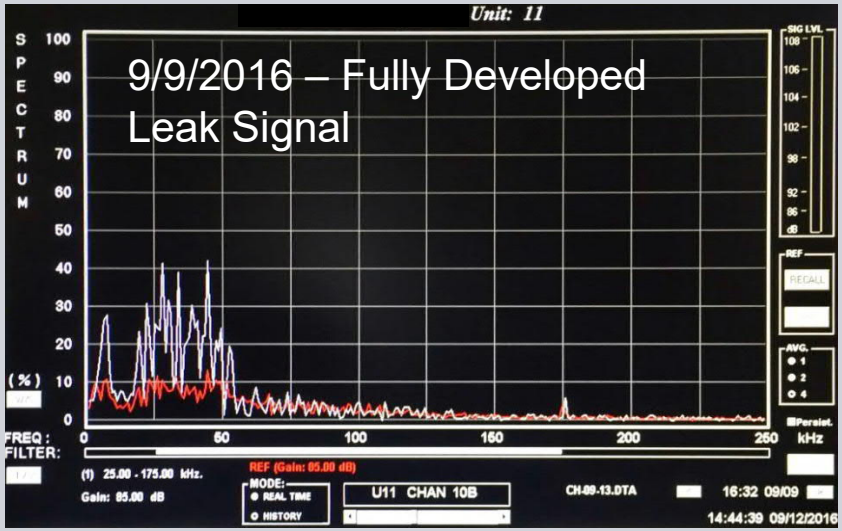
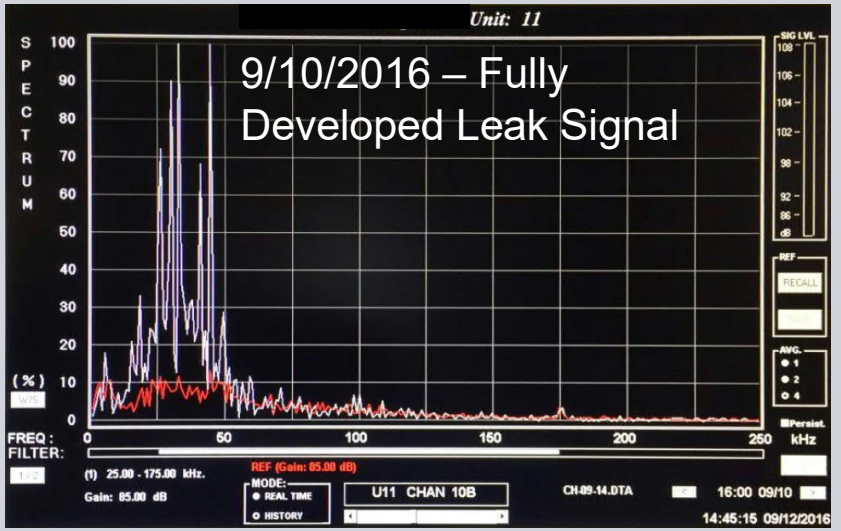
FREQUENCY DISTRIBUTION OF THE ENERGY FOR FULLY DEVELOPED LEAK SIGNALS ON DIFFERENT DAYS (9/12/2016 HP ECON 2-1 TUBE LEAK REPAIR EVENT)









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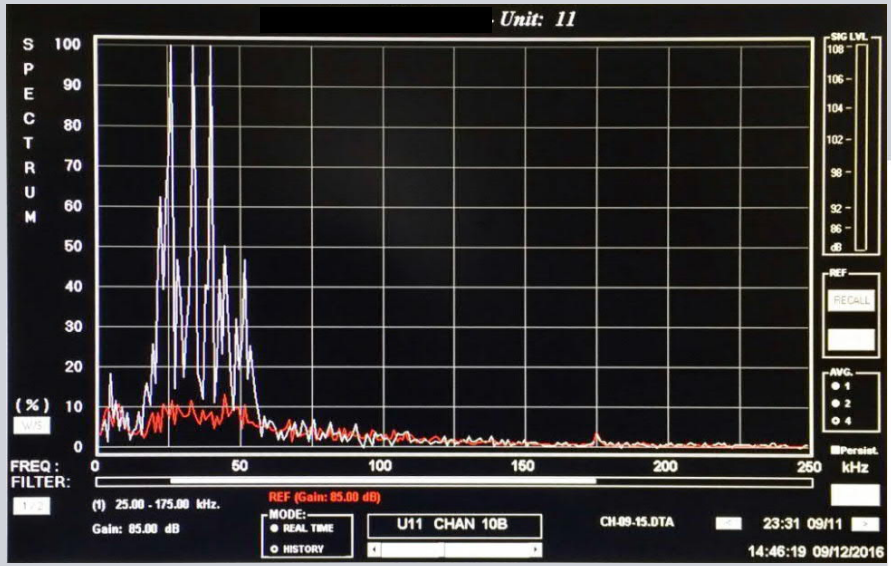
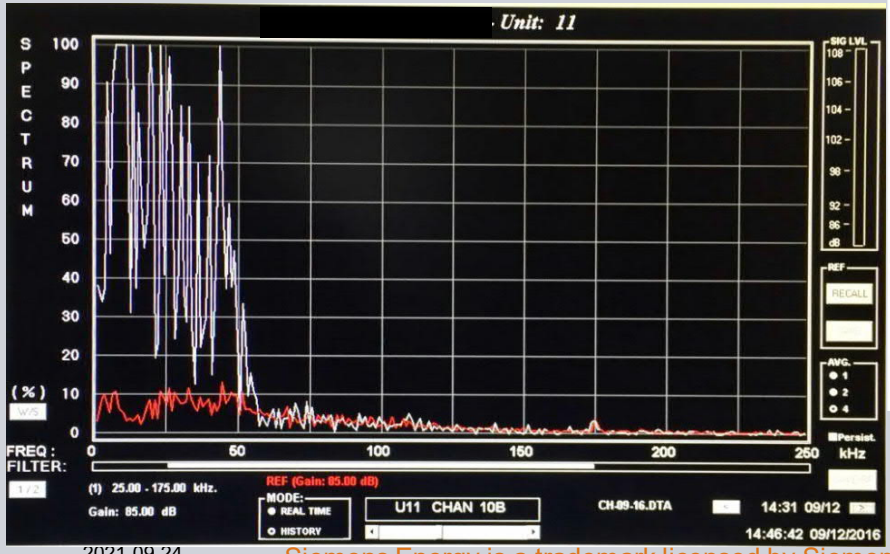
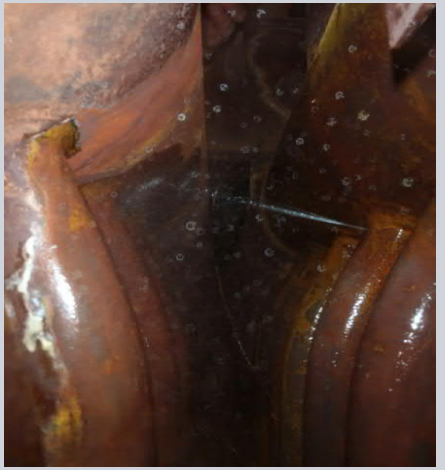
FREQUENCY DISTRIBUTION OF THE ENERGY FOR AFTER THE LEAK SIGNALS (9/12/2016 HP ECON 2-1 ACTIVE TUBE LEAK LOCATION PHOTO)





9/12/2016 – Found Leak Jets at HP Econ 2-1 Tube No. 5 Front Row of Top Header 29 - LHS Module - Channel 10 B Area



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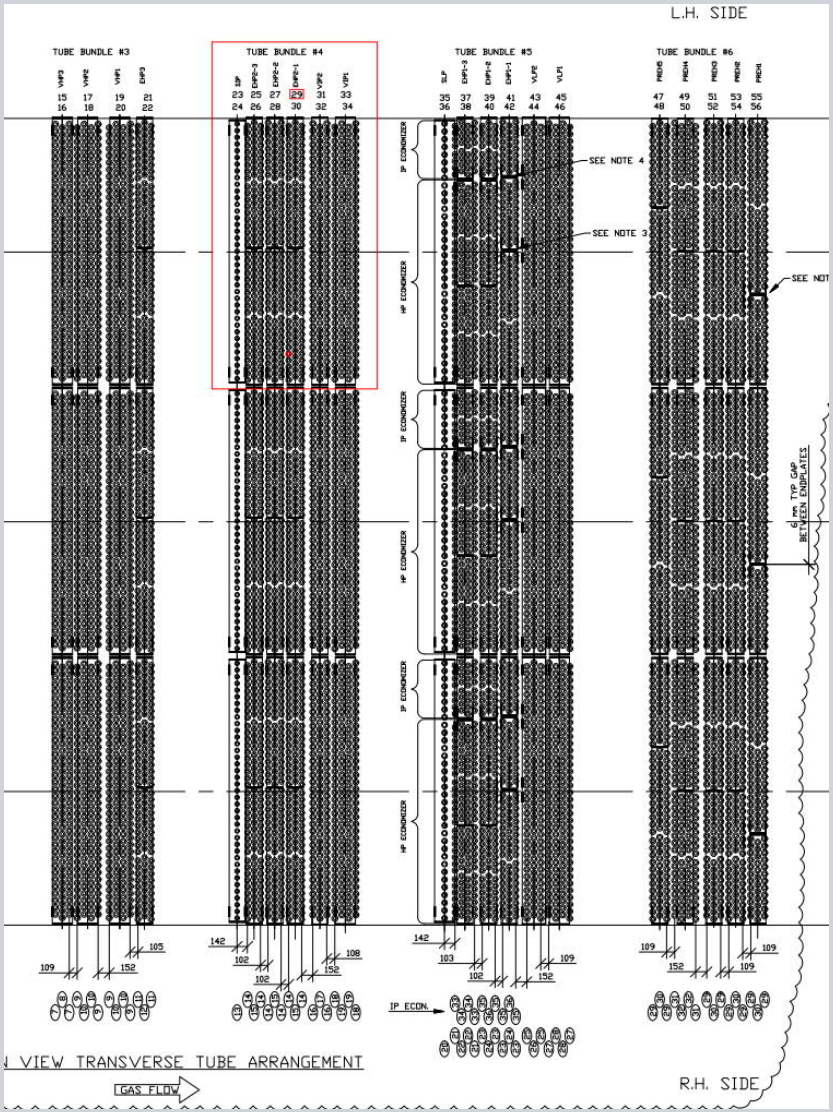
1ST TUBE LEAK DETECTION BY AMS AFTER 2 MONTHS OF ITS INSTALLATION AT SUBJECT PLANT (9/12/2016 HP ECON 2-1 TUBE NO. 5 FRONT ROW ON TOP HEADER 29 LOCATION & PHOTO OF NARROW AVAILABLE PENTHOUSE AREA SPACE FOR WELDING ACCESS)



Narrow Space in Penthouse Area for Welding the Tubes.

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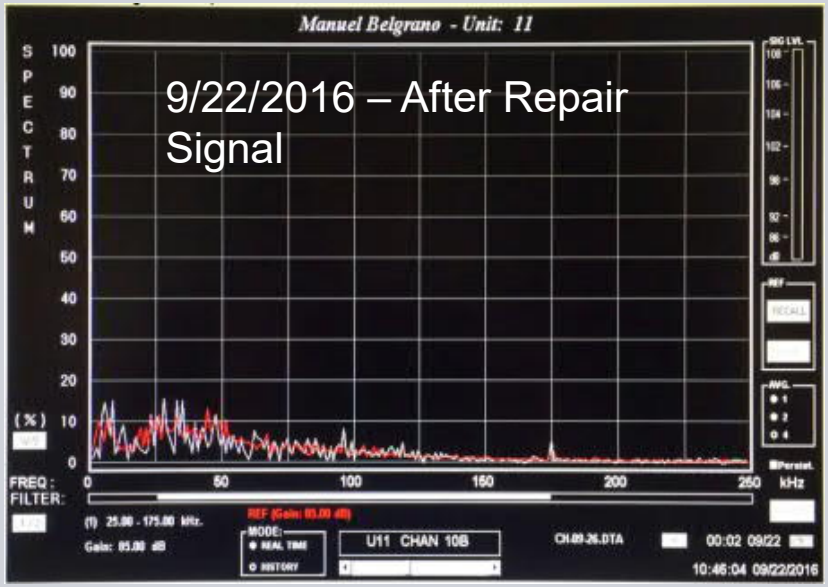
9/12/2016 HP ECON 2-1 TUBE NO. 5 TOP HEADER - AFTER REPAIR WELDING PHOTOS & AFTER REPAIR SIGNALS TREND



After Repair Signals Went Back To Normal Level

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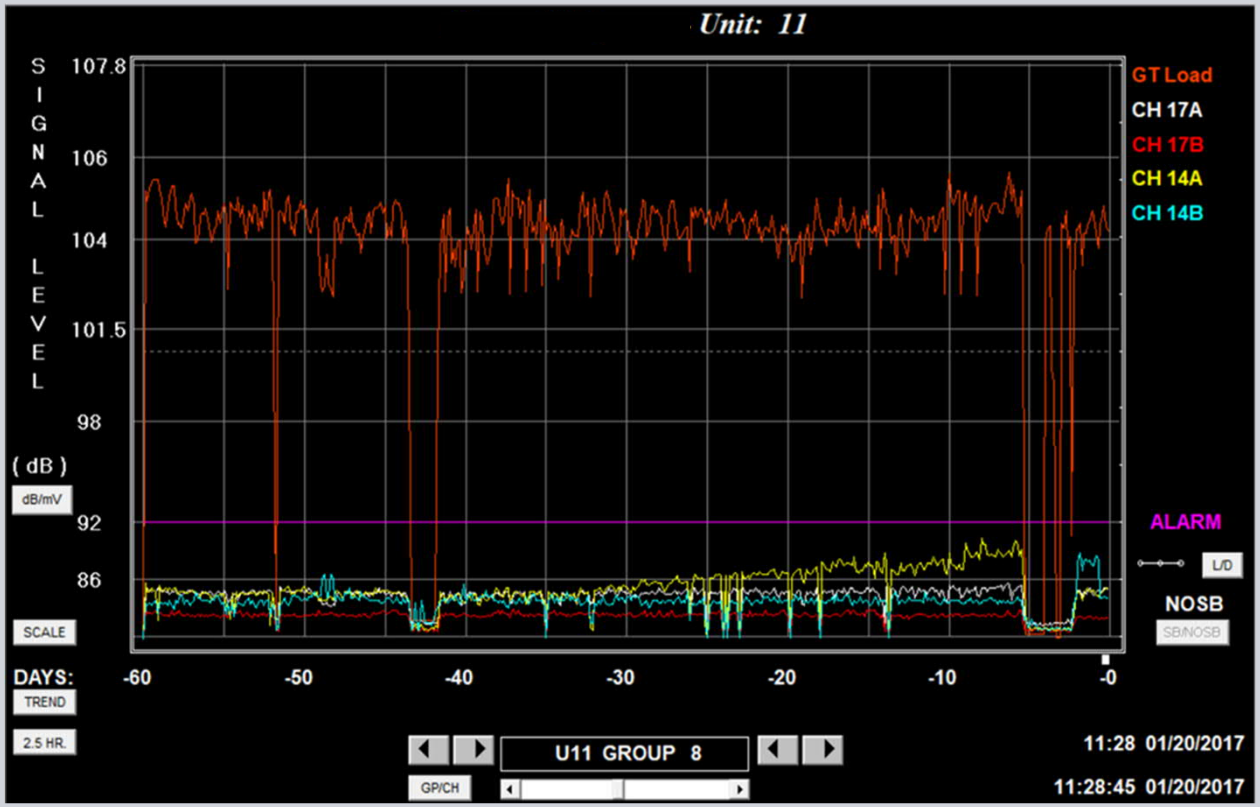
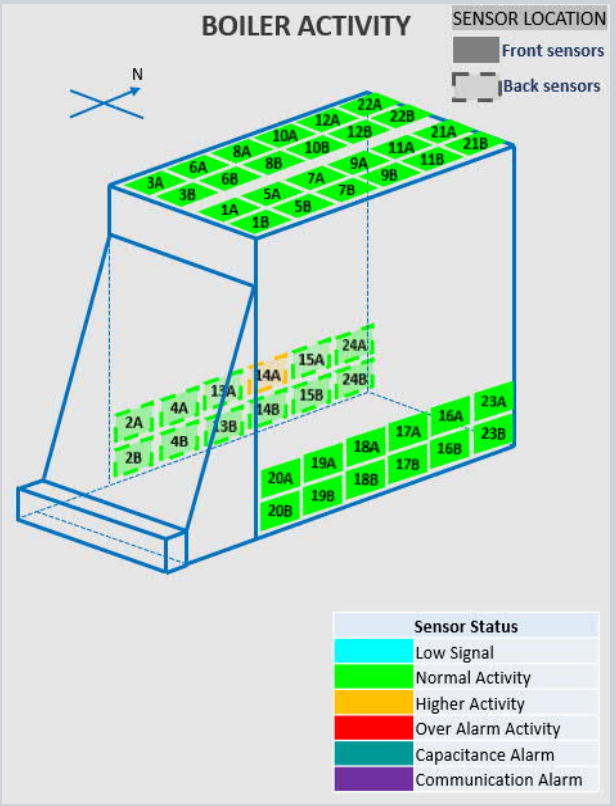
2ND TUBE LEAK DETECTION BY AMS (01/15/2017 HP ECON 2-1 TUBE NO: 5 FRONT ROW AT BOTTOM HEADER 30 LHS MODULE - LEAK SIGNAL TREND)





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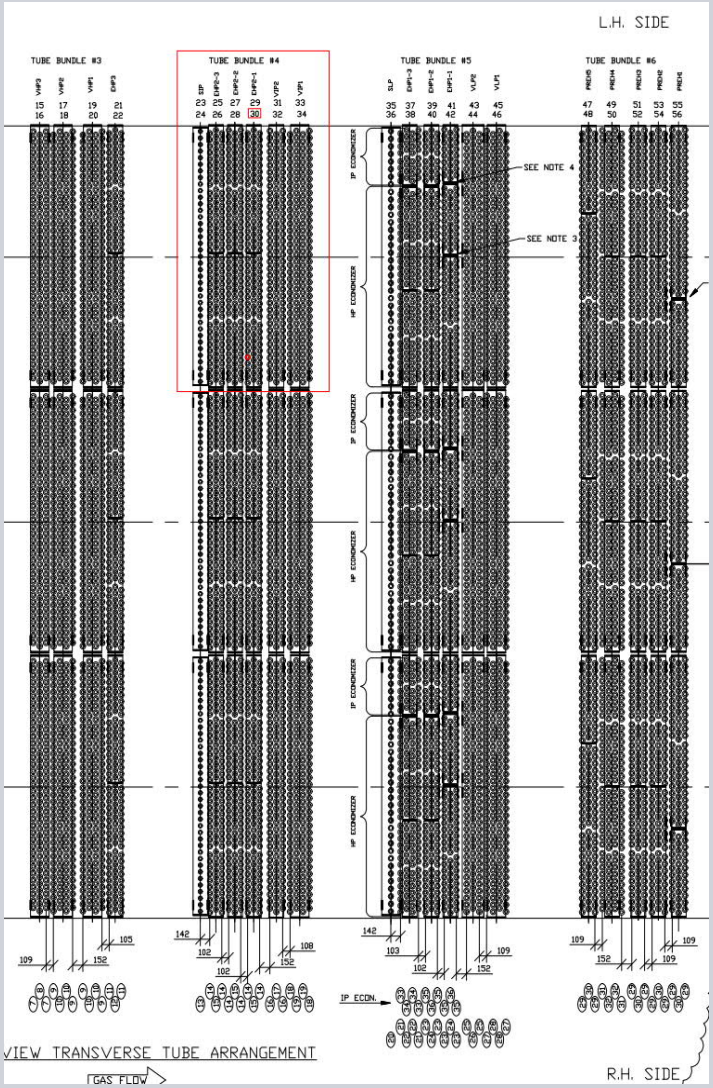
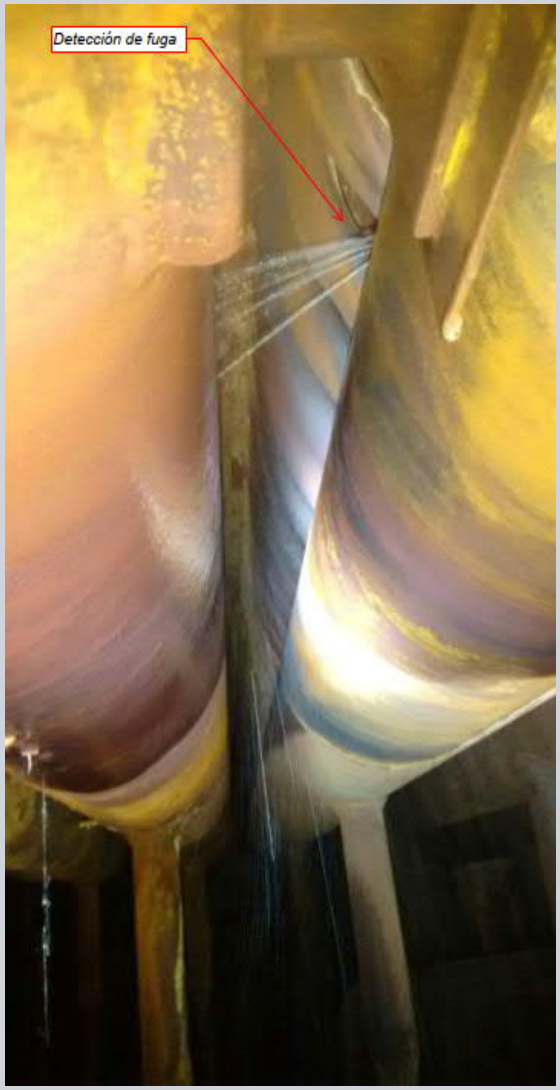
2ND TUBE LEAK DETECTION BY AMS (01/15/2017 HP ECON 2-1 TUBE NO: 5 FRONT ROW AT BOTTOM HEADER 30 LHS MODULE - LEAK LOCATION & REPAIR PHOTO)





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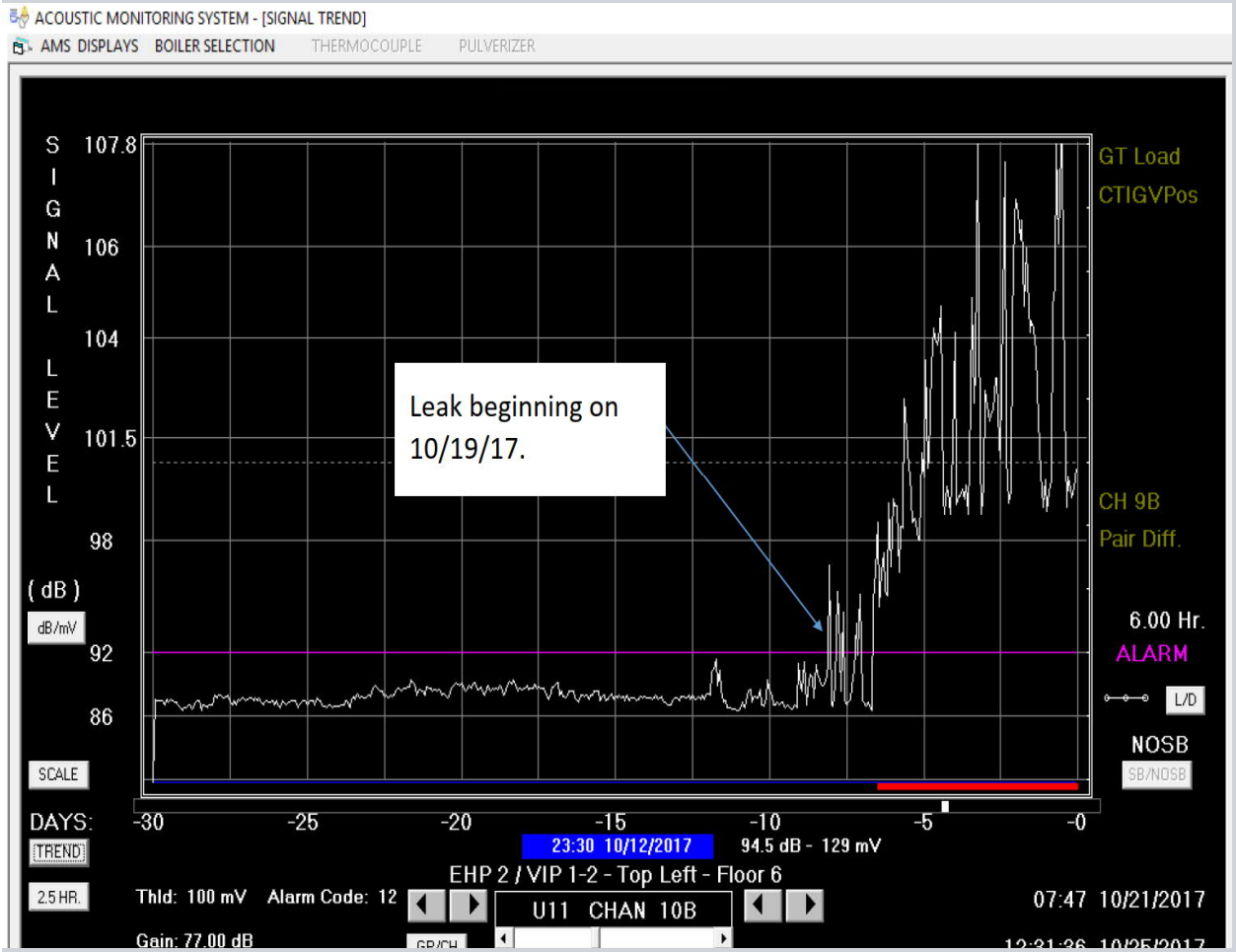
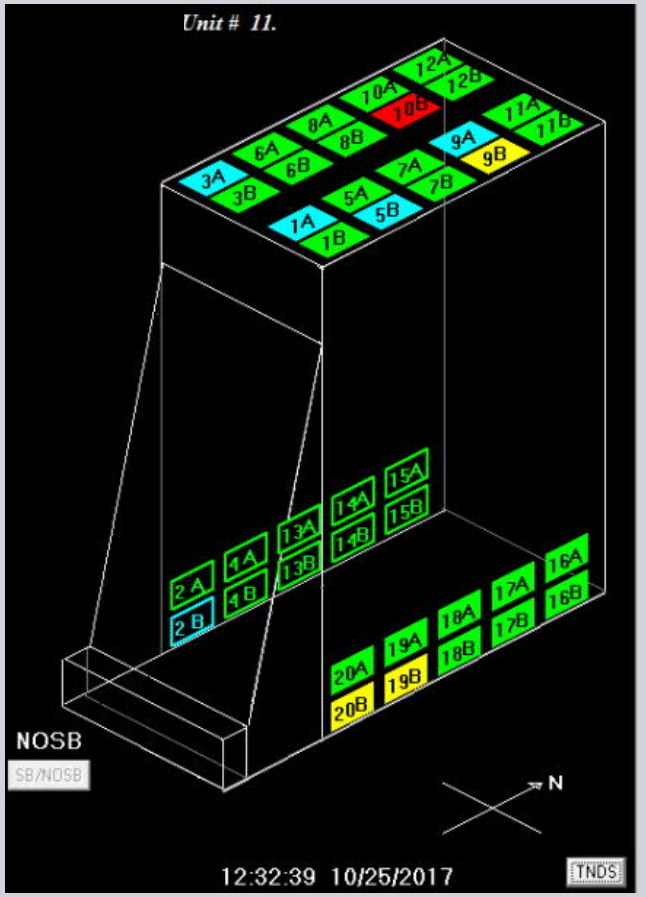
3RD TUBE LEAK DETECTION BY AMS (10/19/2017 HP ECON 2-1 TUBE NO. 4 & 5 FRONT ROW ON TOP HEADER 29 LOCATION – LEAK SIGNAL TREND)





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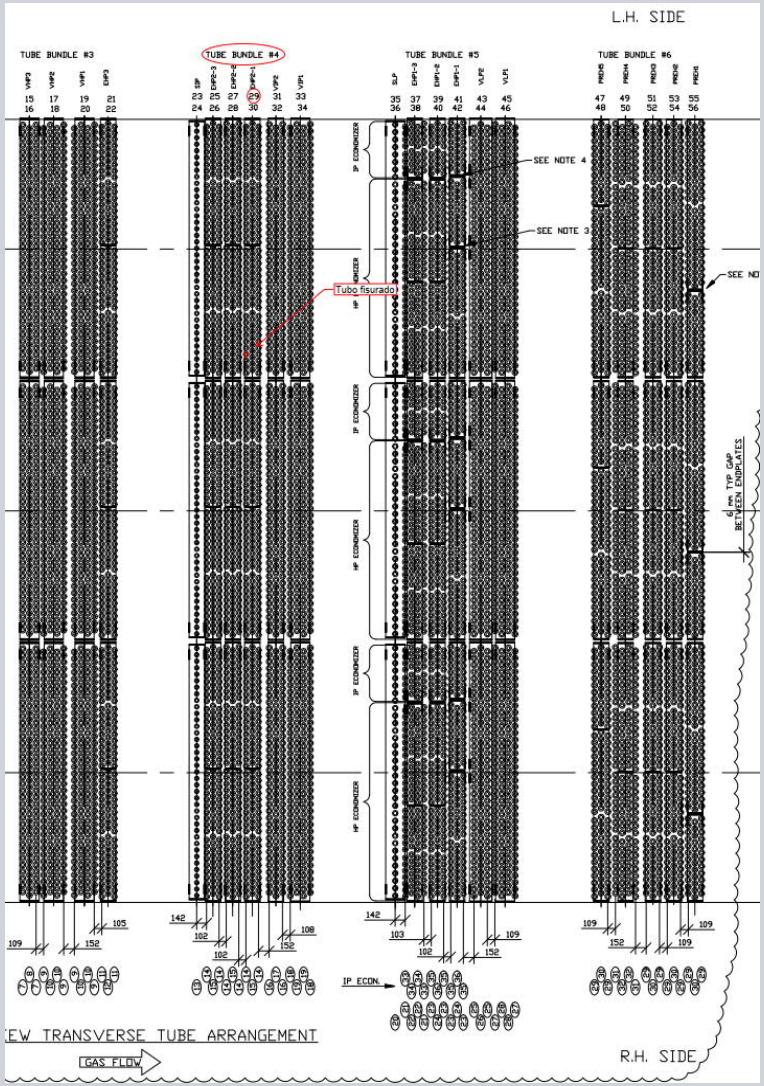
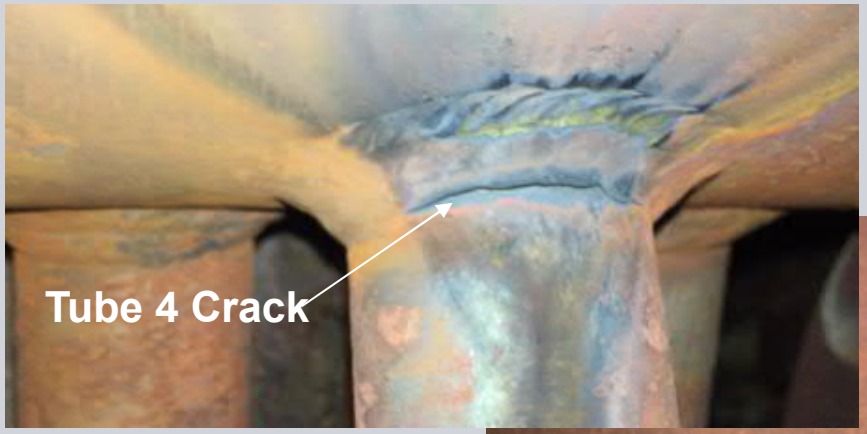
3RD TUBE LEAK DETECTION BY AMS (10/19/2017 HP ECON 2-1 TUBE NO. 4 FRONT ROW ON HEADER 29 LHS MODULE- TUBE LEAK LOCATION & REPAIR PHOTOS)





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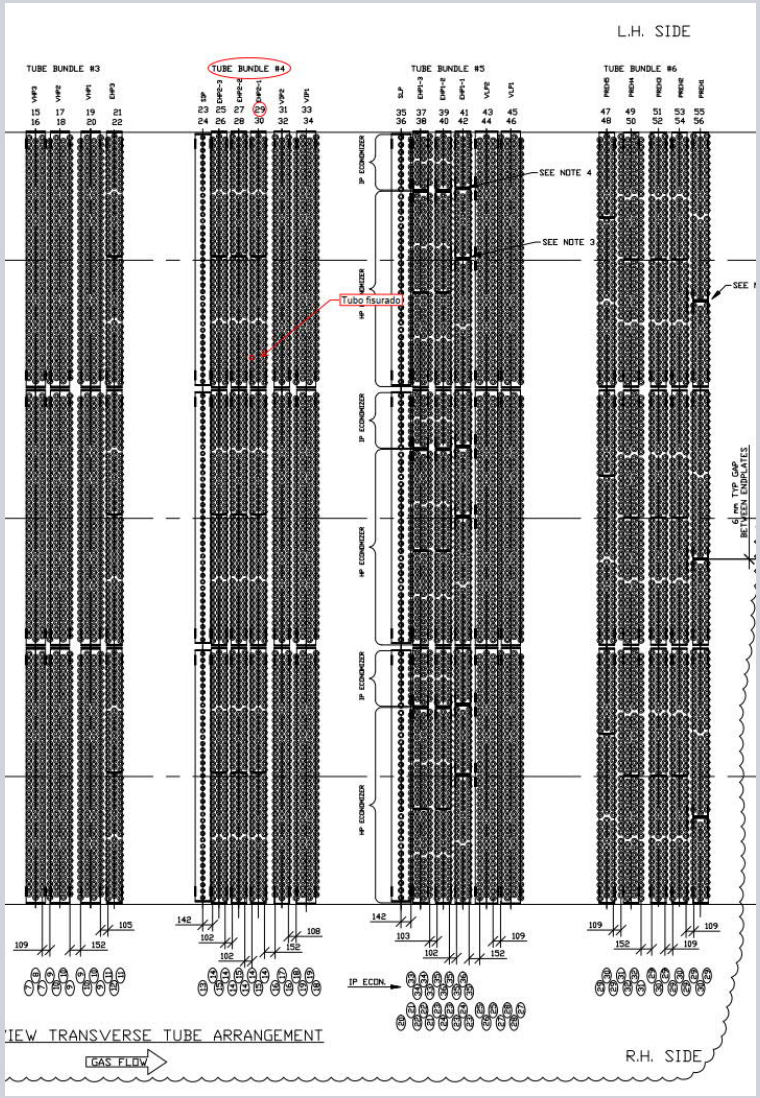
3RD TUBE LEAK DETECTION BY AMS (10/19/2017 HP ECON 2-1 TUBE NO. 5 FRONT ROW ON HEADER 29 LHS MODULE – TUBE LEAK LOCATION & REPAIR PHOTOS – CRACK AT THE SAME WELD OF THE 1ST TUBE LEAK REPAIR)



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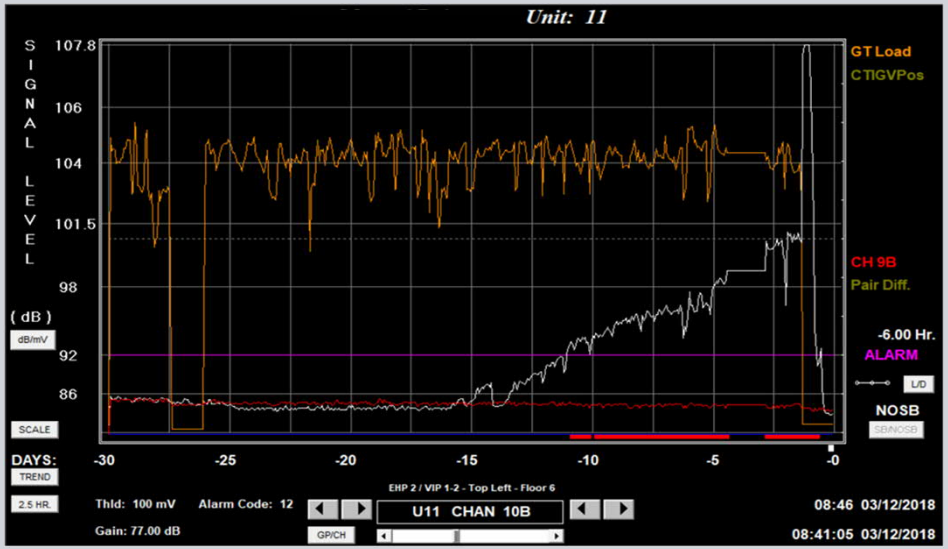
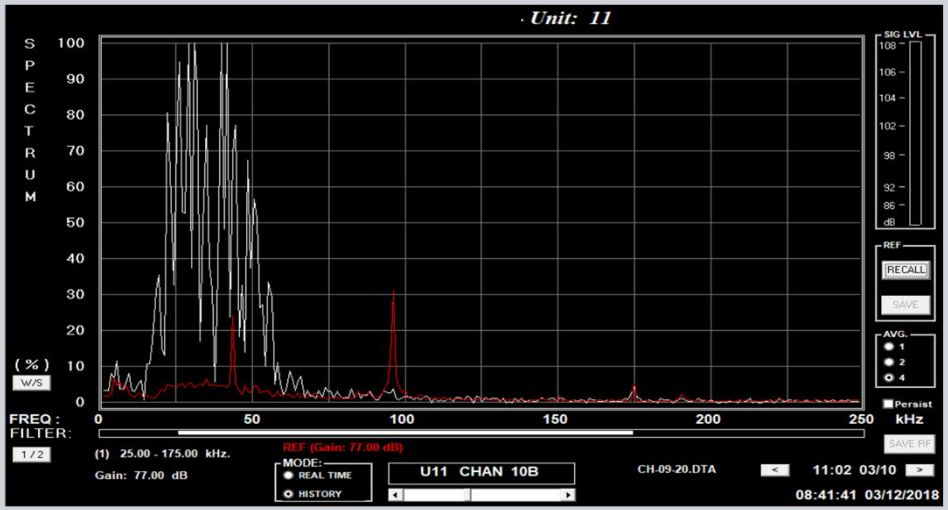
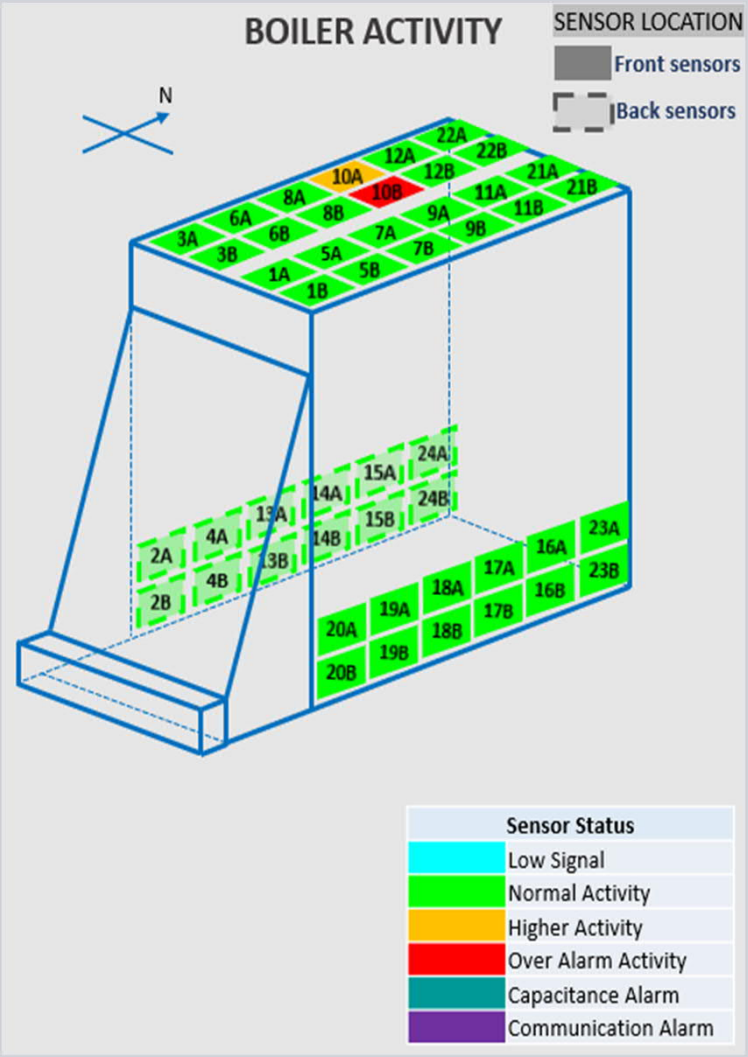
4TH TUBE LEAK DETECTION BY AMS (03/10/2018 HP ECON 2-1 TUBE NO: 6 FRONT ROW ON HEADER 29 LHS MODULE – LEAK SIGNAL TRENDS)







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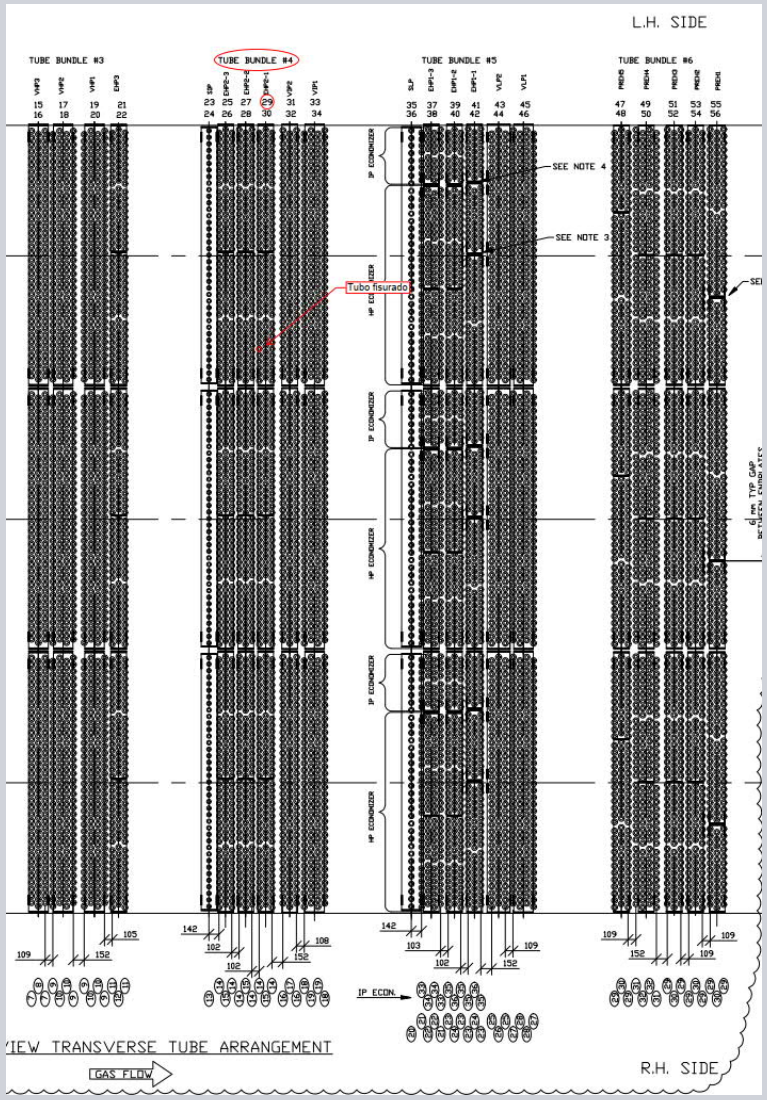
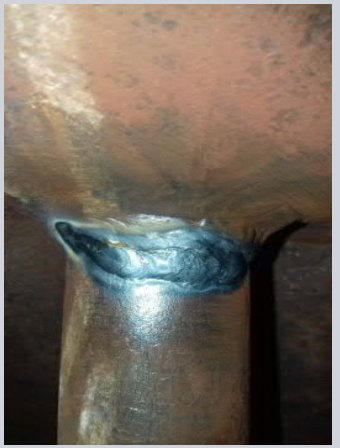
4TH TUBE LEAK DETECTION BY AMS (03/10/2018 HP ECON 2-1 TUBE NO: 6 FRONT ROW ON HEADER 29 LHS MODULE – LEAK LOCATION & REPAIR PHOTOS)





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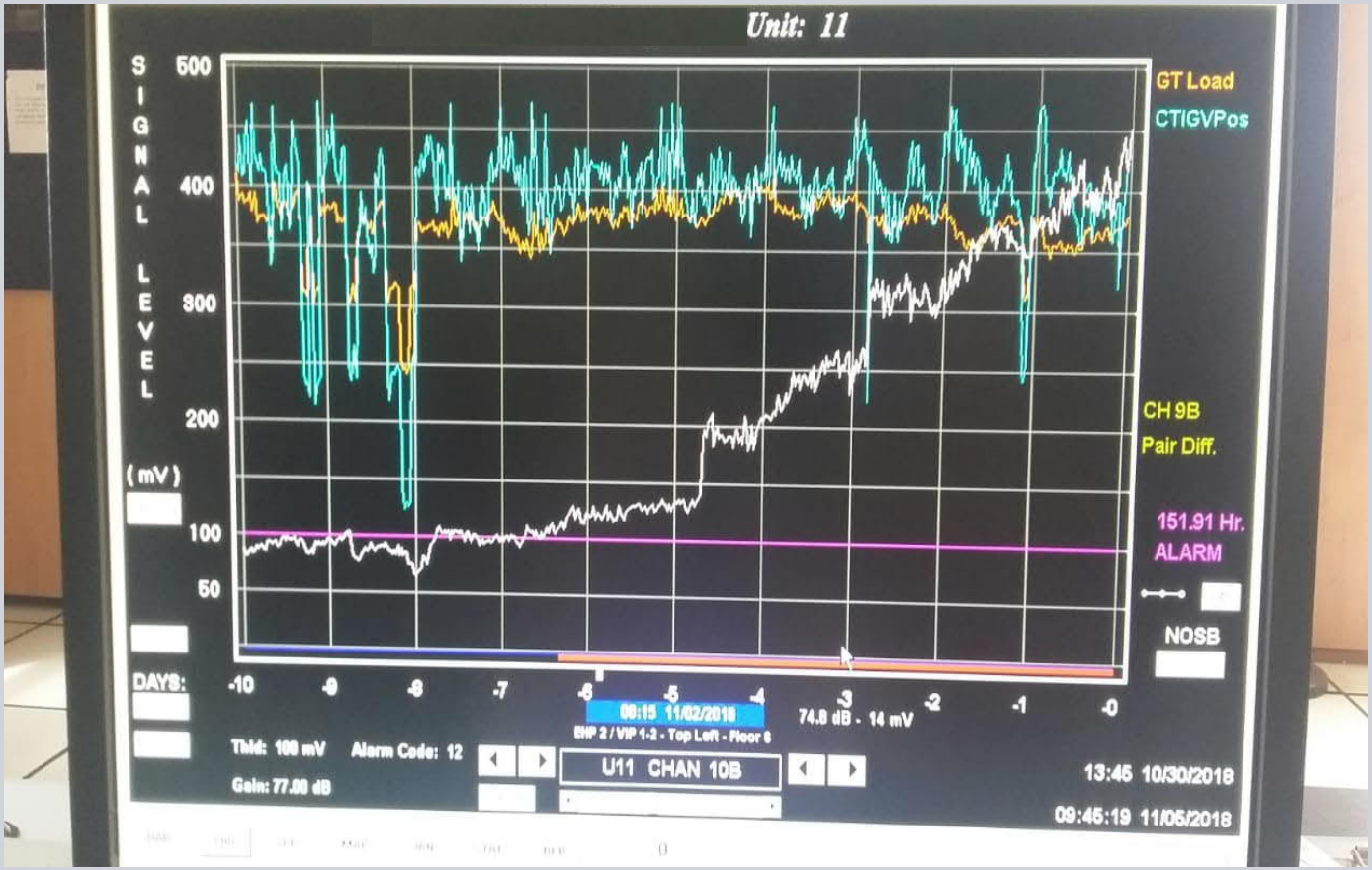
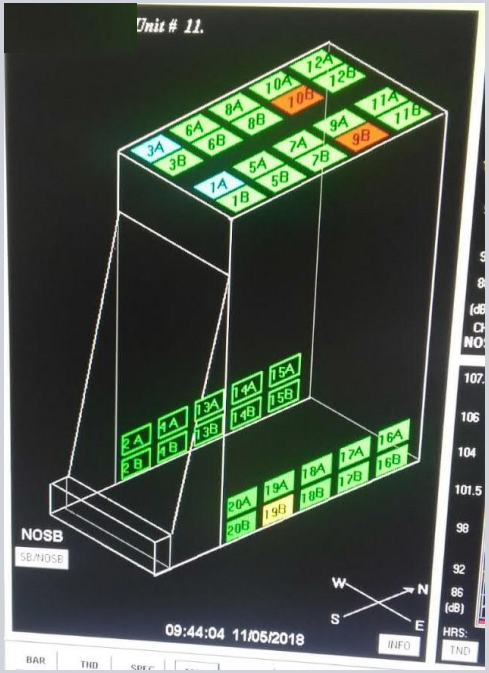
5TH TUBE LEAK DETECTION BY AMS (11/05/2018 IP EVAPORATOR PIN HOLE TUBE LEAK – SIGNAL TRENDS)





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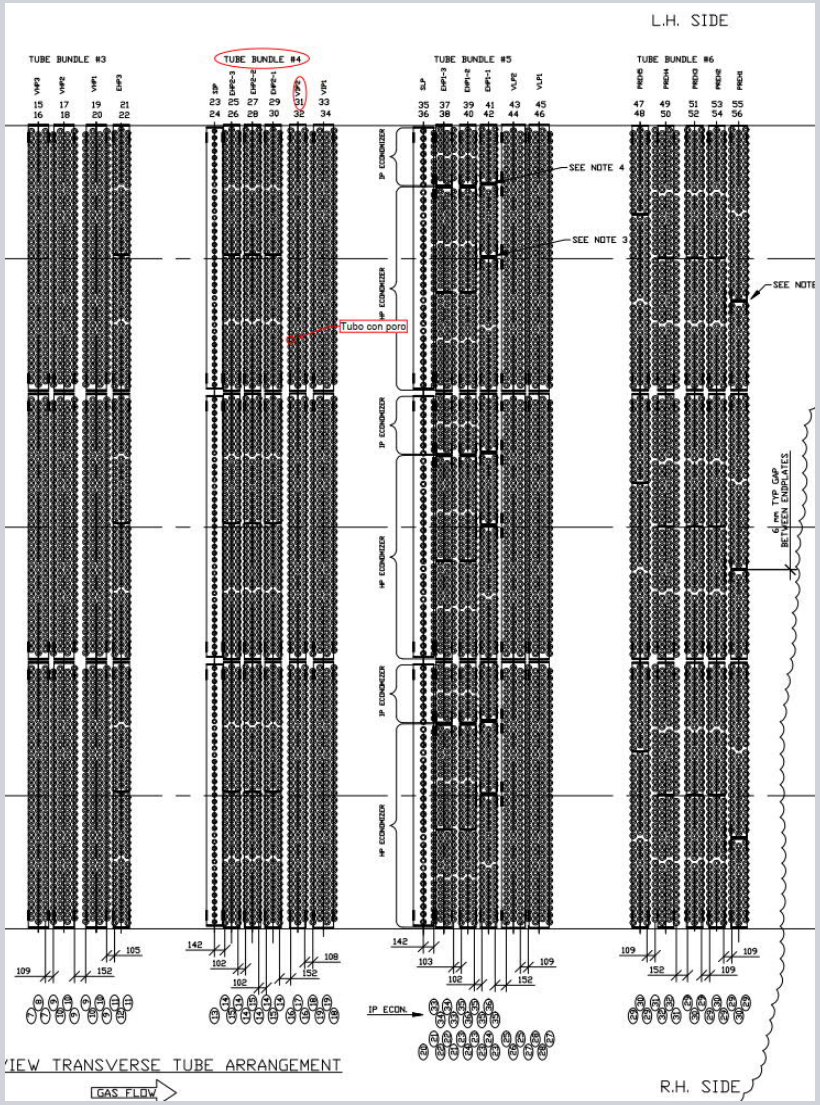
5TH TUBE LEAK DETECTION BY AMS (11/05/2018 IP EVAPORATOR PIN HOLE TUBE LEAK – LEAK LOCATION & AFTER REPAIR PHOTOS)



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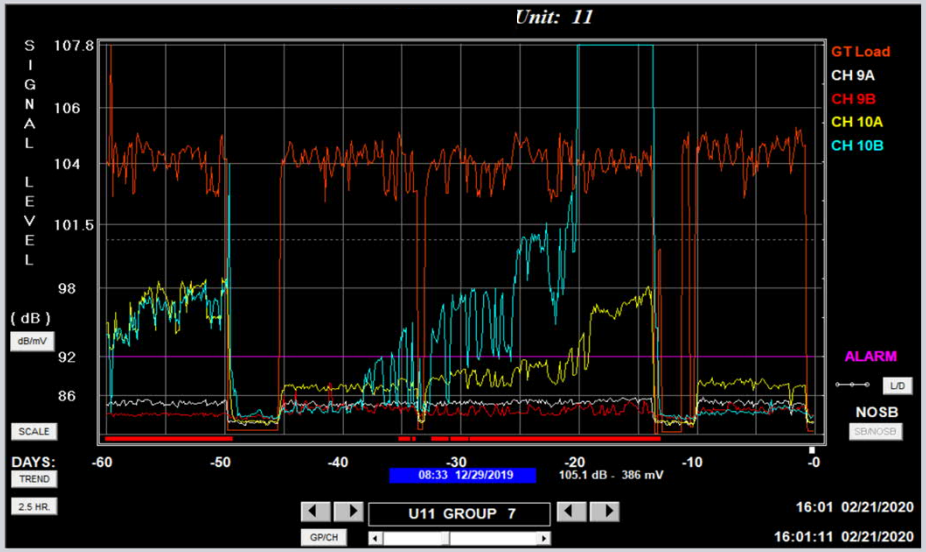
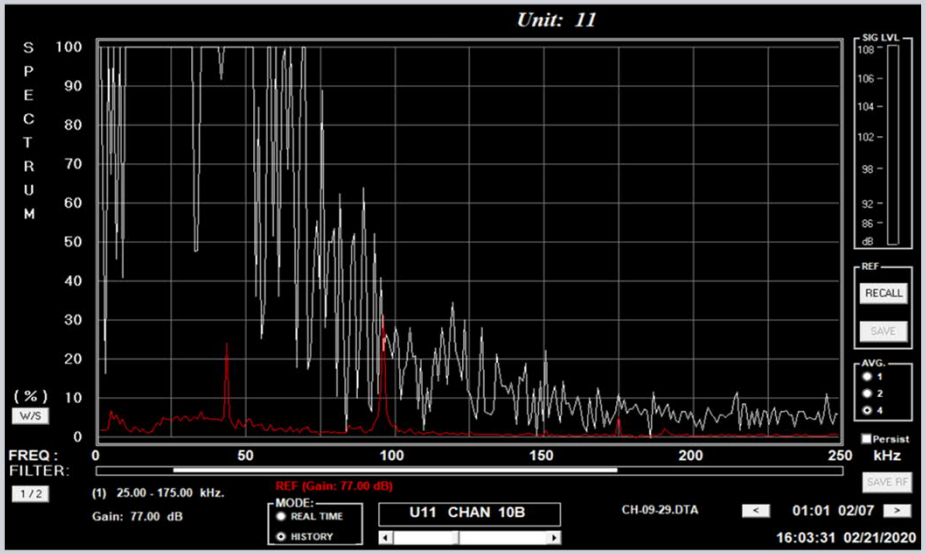
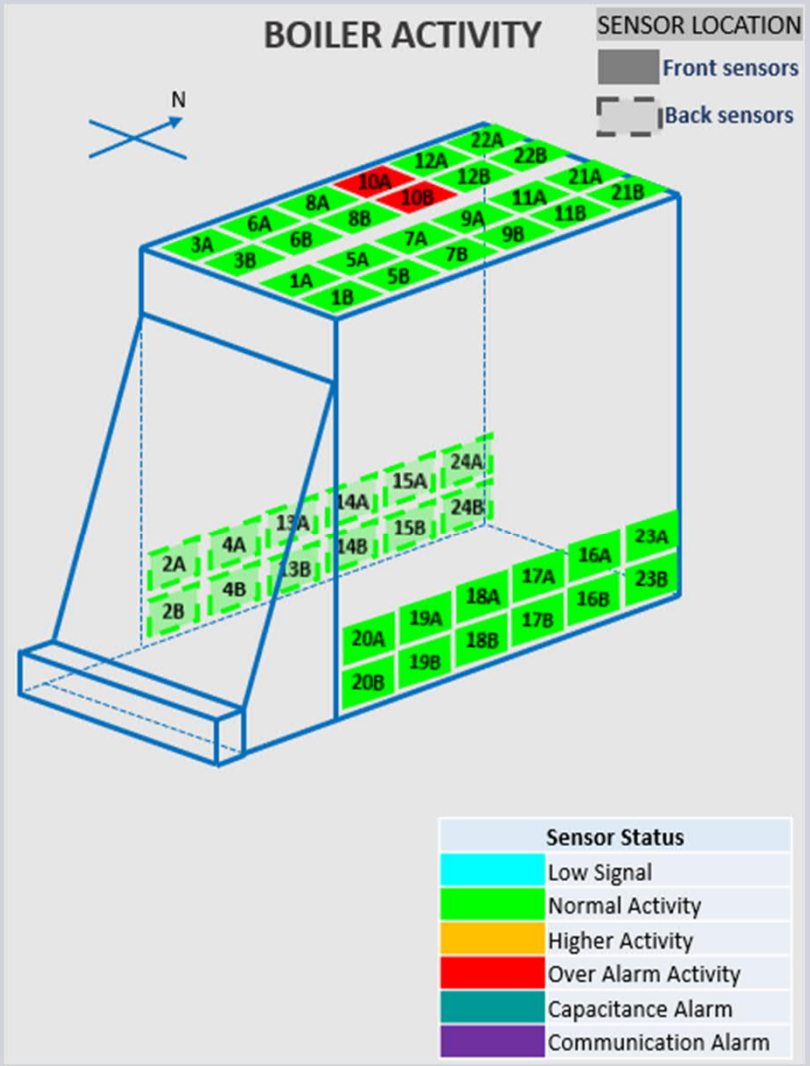
6TH & 7TH TUBE LEAK DETECTION BY AMS (6TH IS FOR HP ECON 2-1 TUBE NO: 5 BOTTOM HEADER NO: 30 & TUBE NO: 37 AT TOP HEADER 29 FRONT ROW TUBES & 7TH IS FOR TUBE NO: 5 & 6 FRONT ROW OF TOP HEADER 29 LHS MODULE – LEAK SIGNAL TRENDS)







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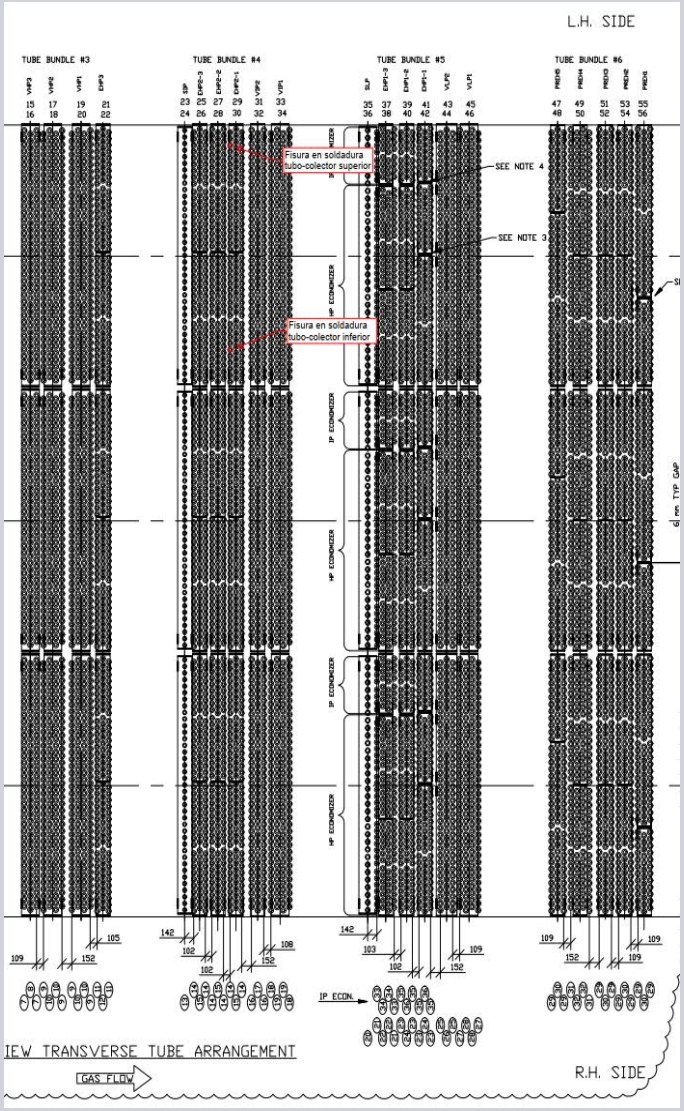
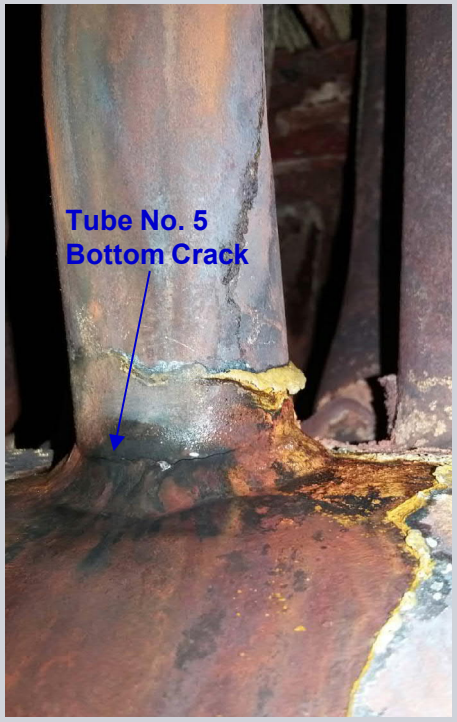
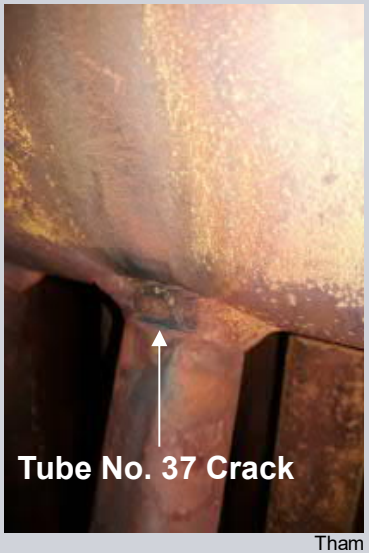
6TH TUBE LEAK DETECTION BY AMS (HP ECON 2-1 TUBE NO: 5 BOTTOM HEADER NO: 30 & TUBE NO: 37 AT TOP HEADER 29 FRONT ROW TUBES – LHS MODULE (01/06/2020) – LEAK LOCATION & REPAIR PHOTOS)







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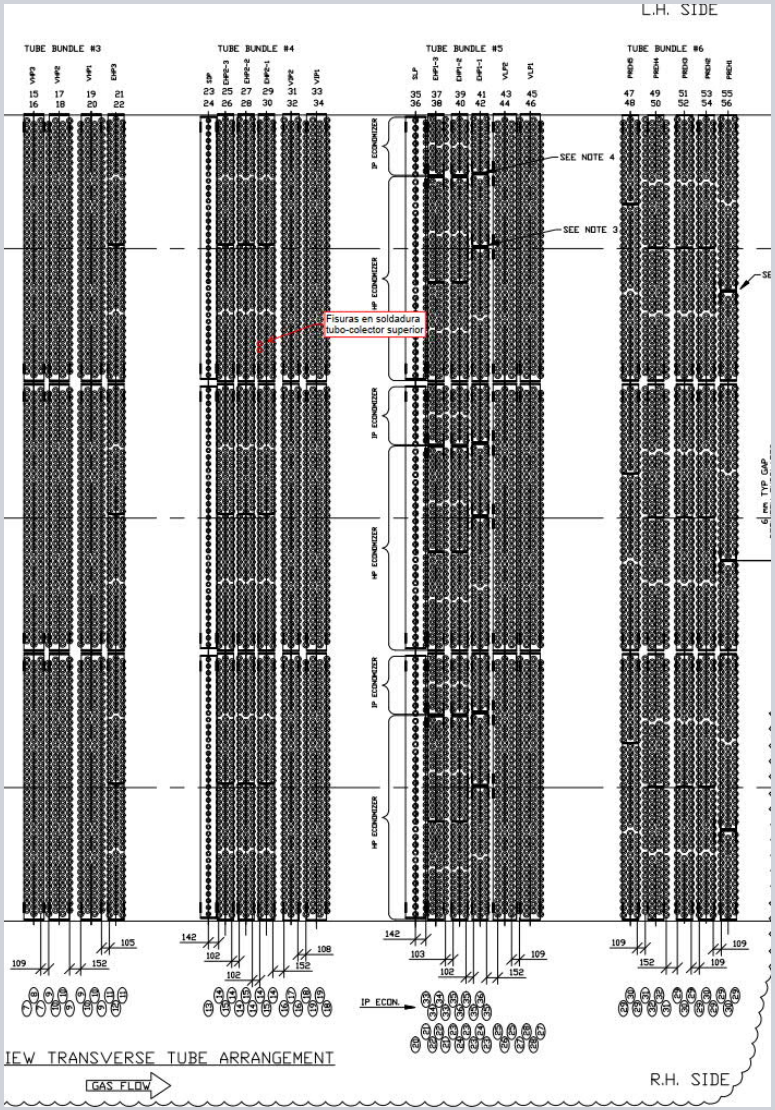
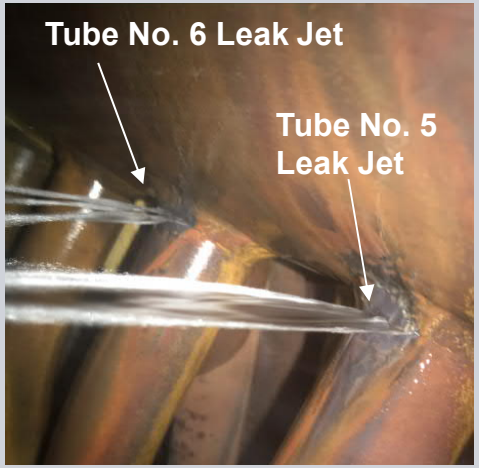
7TH TUBE LEAK DETECTION BY AMS (HP ECON 2-1 TUBE NO: 5 & 6 FRONT ROW OF TOP HEADER 29 LHS MODULE (02/08/2020) – LEAK JET LOCATION & REPAIR PHOTOS – SAME TUBES OF 3RD & 4TH INCIDENCE WELD REPAIRS





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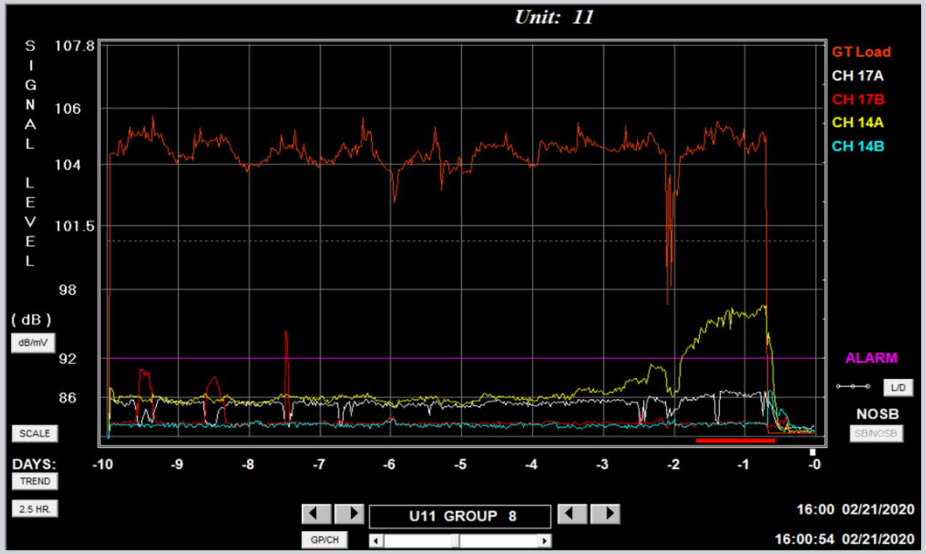
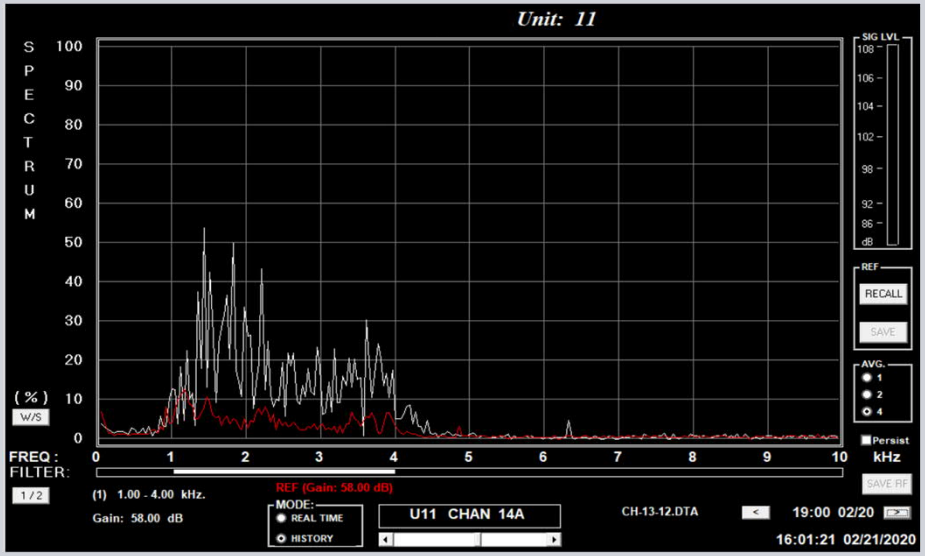
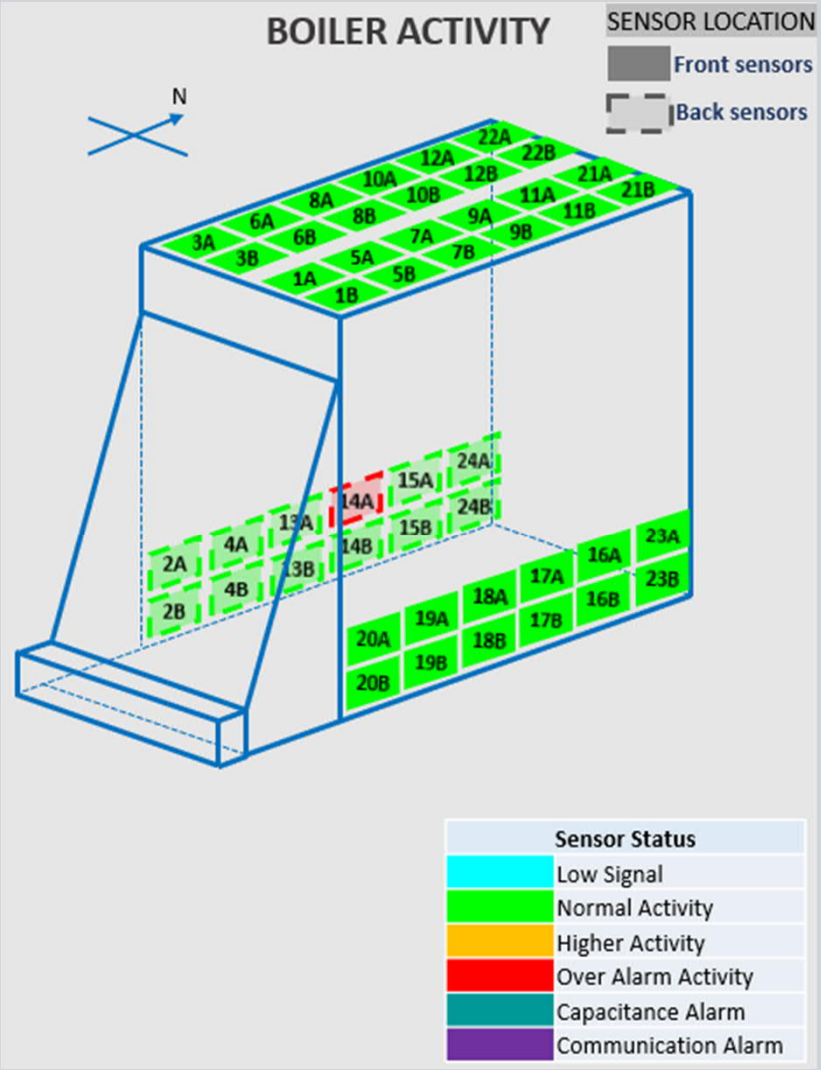
8TH TUBE LEAK DETECTION BY AMS (HP ECON 2-1 TUBE NO: 5 FRONT ROW OF BOTTOM HEADER 30 HAD REPEAT CRACK LEAK ON 02/20/2020 – SAME LOCATION AS THE 2ND INCIDENCE) – LEAK SIGNAL TRENDS)







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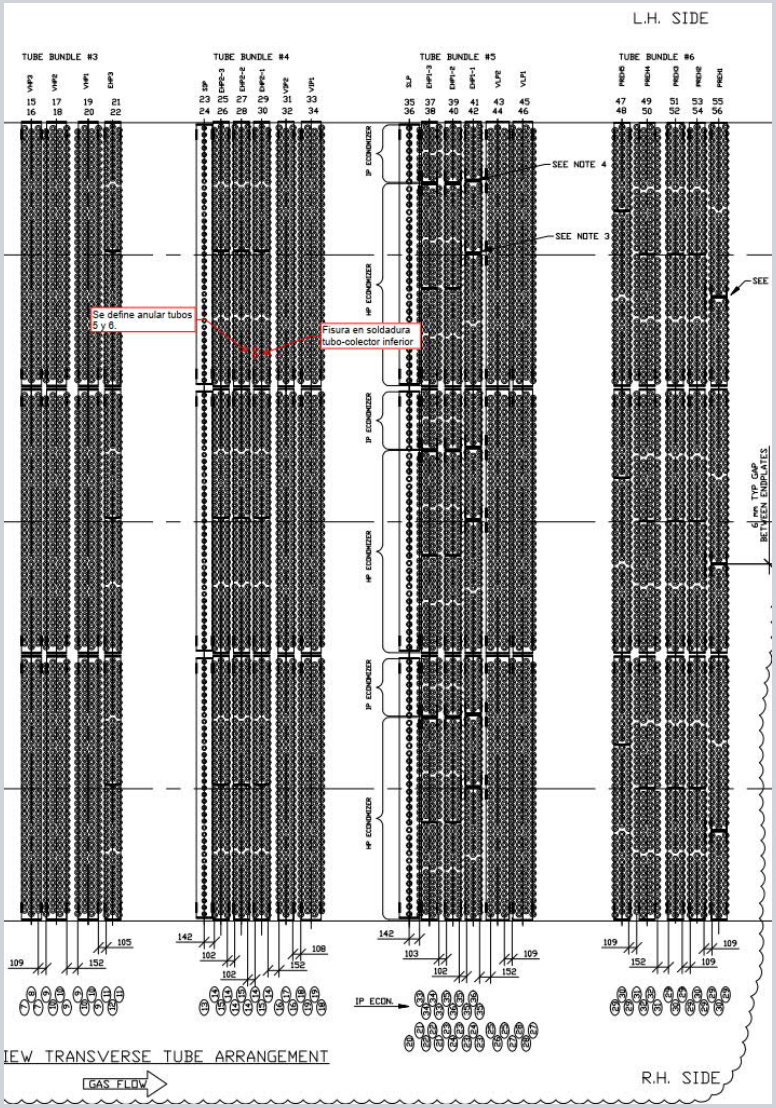
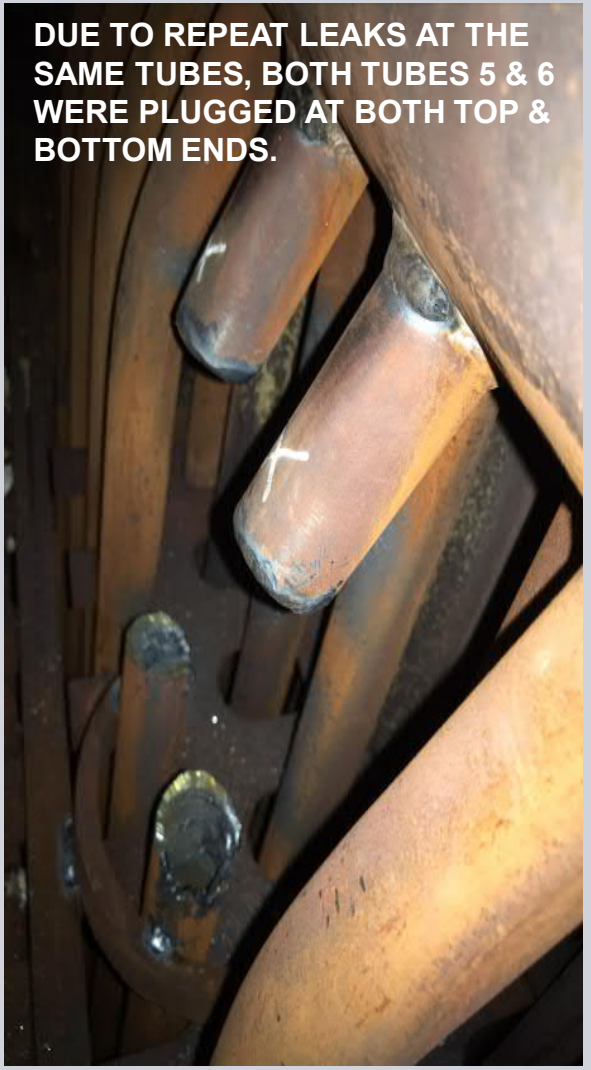
8TH TUBE LEAK DETECTION BY AMS (HP ECON 2-1 TUBE NO: 5 FRONT ROW OF BOTTOM HEADER 30 HAD REPEAT CRACK LEAK ON 02/20/2020 – SAME LOCATION AS THE 2ND INCIDENCE) – LEAK LOCATION & REPAIR PHOTO)





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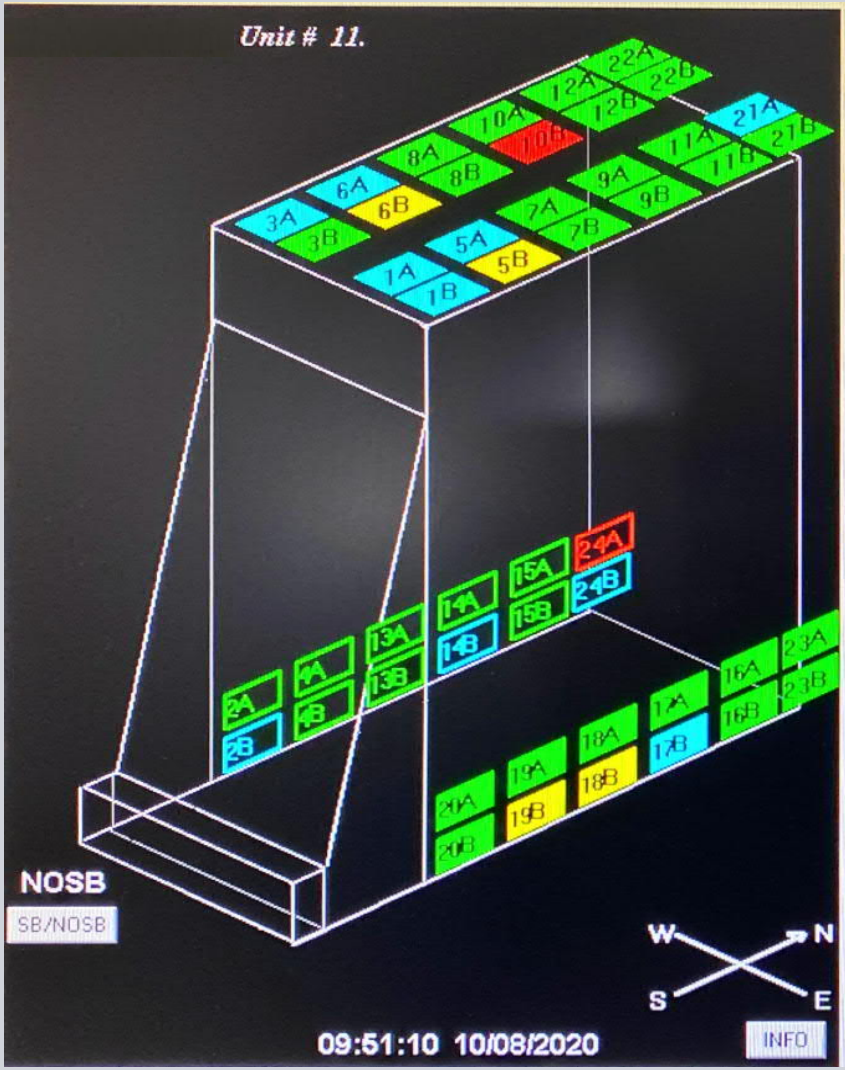
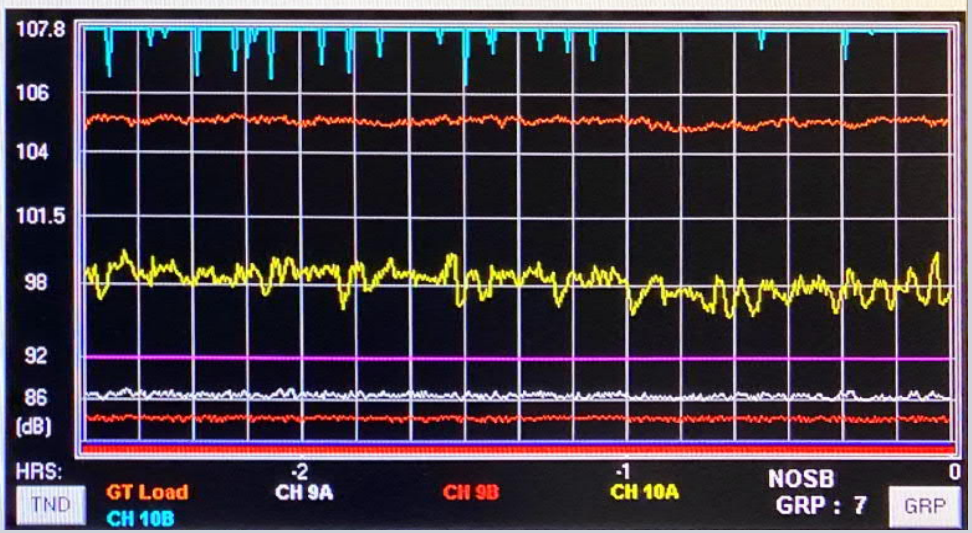
9TH TUBE LEAK DETECTION BY AMS (HP ECON 2-1 TUBE NO: 4 REAR ROW OF TOP HEADER 29 LHS MODULE (10/08/2020) – LEAK SIGNAL TRENDS)





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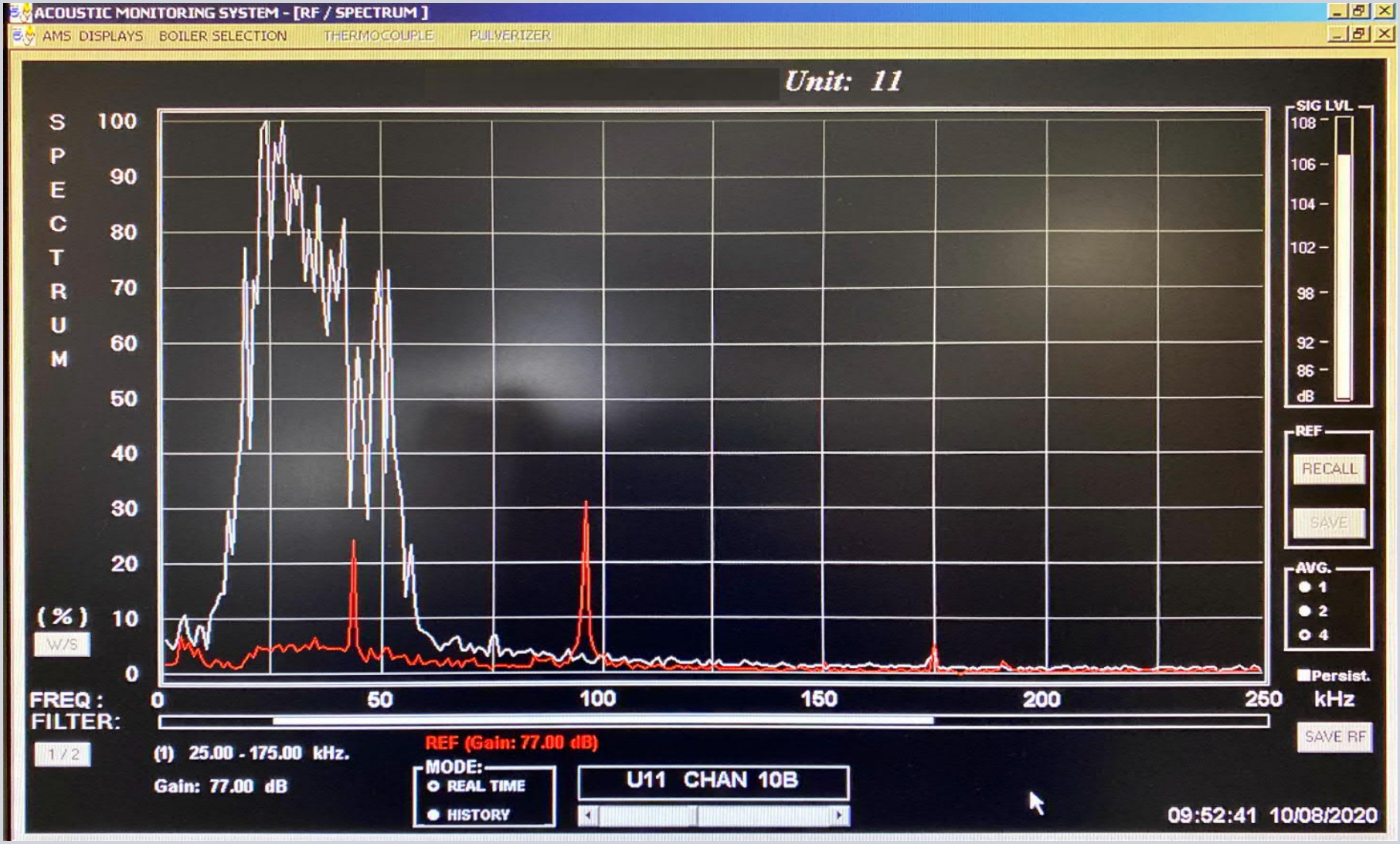
9TH TUBE LEAK DETECTION BY AMS (HP ECON 2-1 TUBE NO: 4 REAR ROW OF TOP HEADER 29 LHS MODULE (10/08/2020) – LEAK SIGNAL TRENDS)



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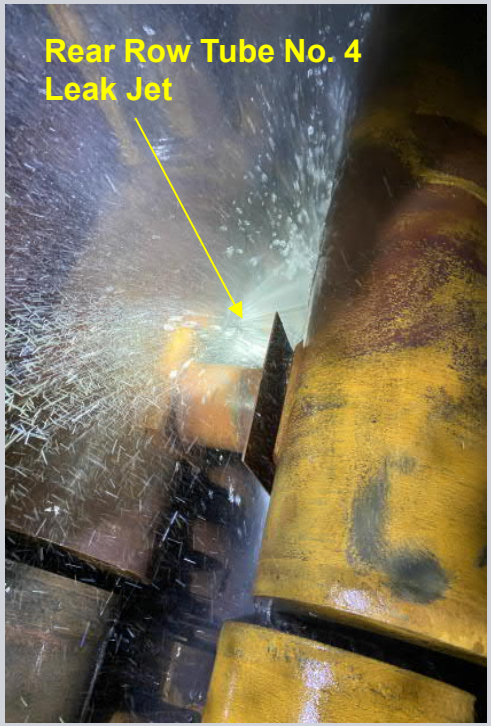
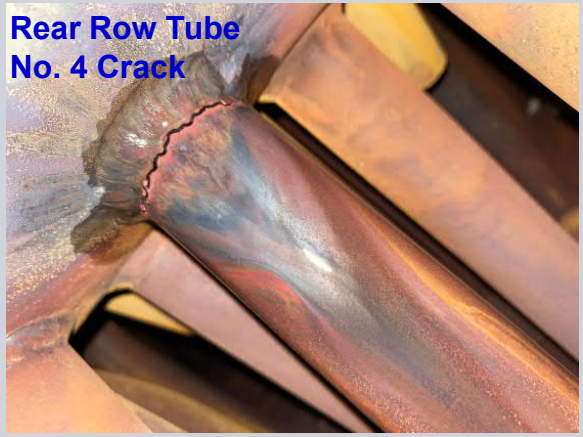
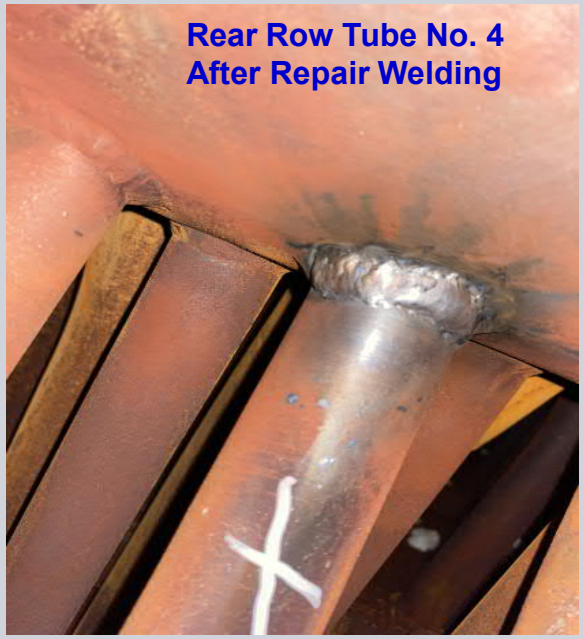
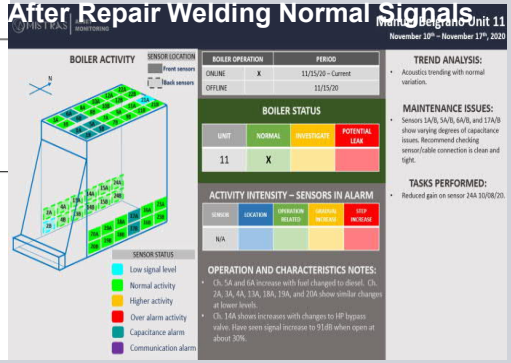
9TH TUBE LEAK DETECTION BY AMS (HP ECON 2-1 TUBE NO: 4 REAR ROW OF TOP HEADER 29 LHS MODULE (10/08/2020) – LEAK LOCATION & REPAIR PHOTOS)









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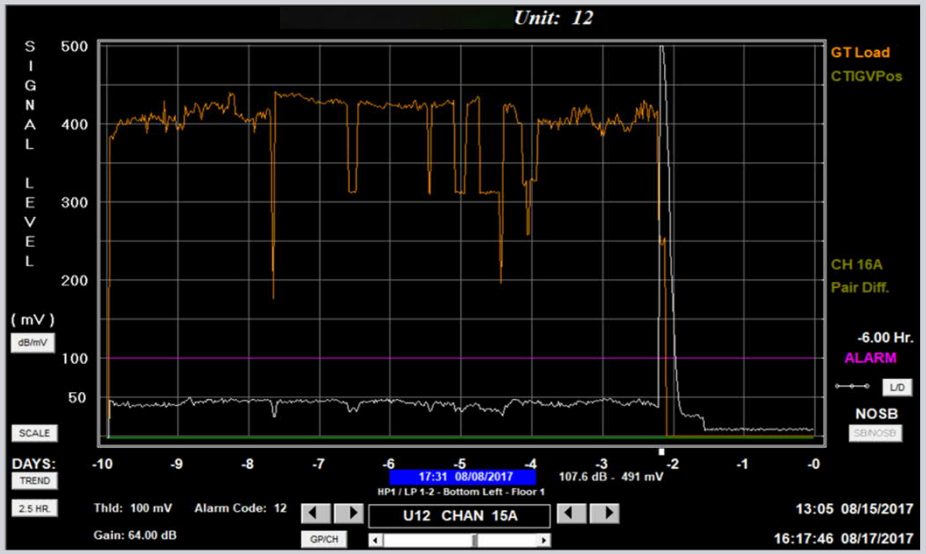
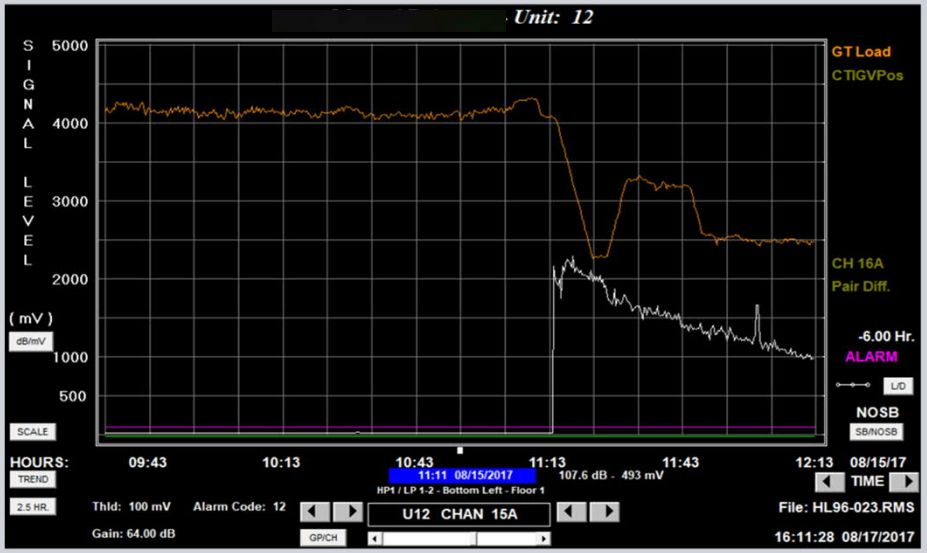
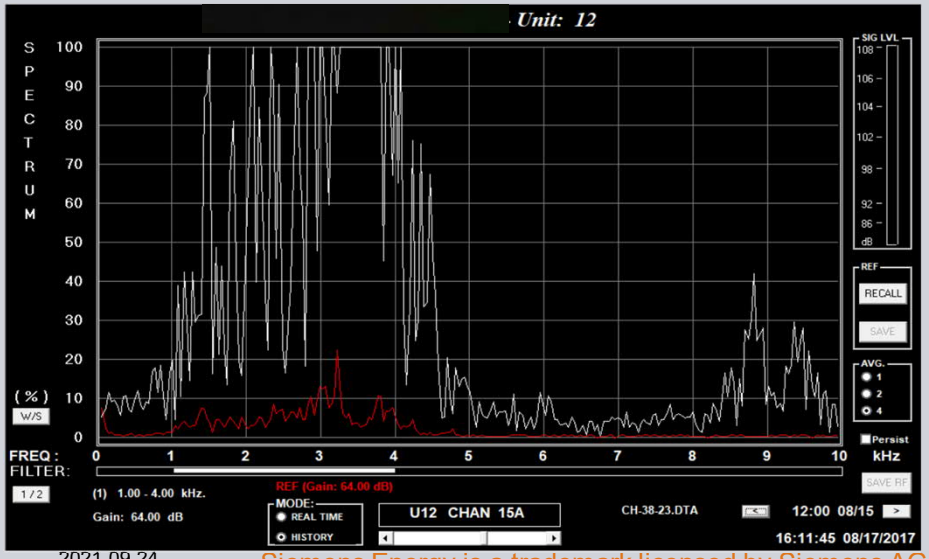
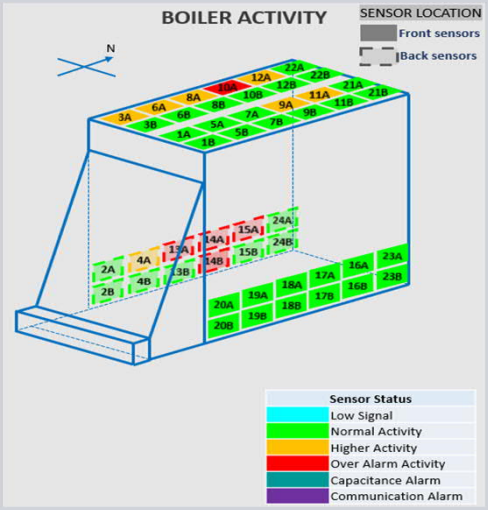
1ST TUBE LEAK DETECTION BY AMS IN UNIT 12 (IP EVAPORATOR 1 TUBE NO:15 FROM RHS OF BOTTOM RHS MODULE HEADER 34 (08/15/2017) – LEAK SIGNAL TRENDS)









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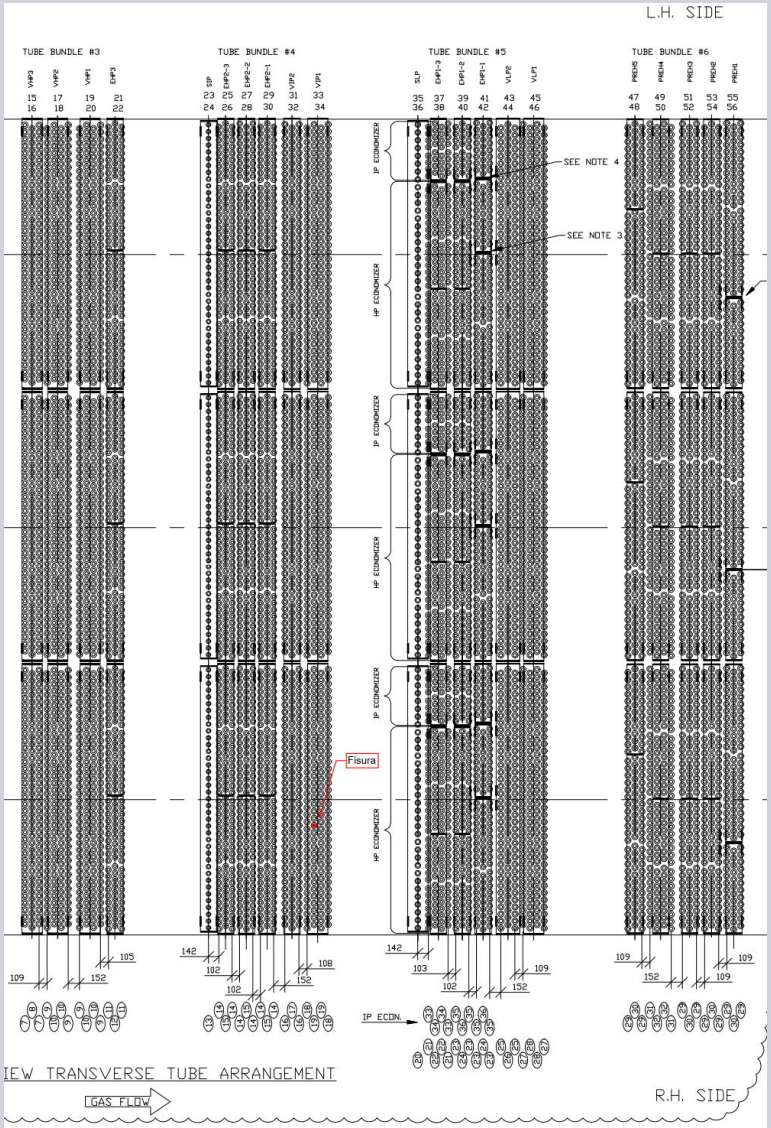
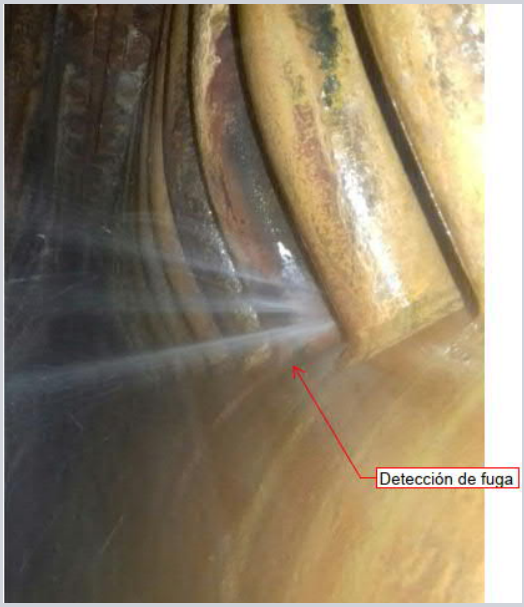
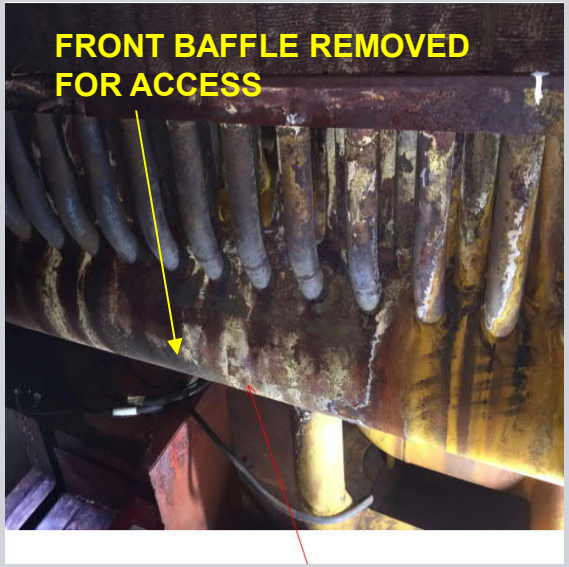
1ST TUBE LEAK DETECTION BY AMS IN UNIT 12 (IP EVAPORATOR 1 TUBE NO:15 FROM RHS OF BOTTOM RHS MODULE HEADER 34 (08/15/2017)– LEAK & REPAIR PHOTOS)







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1ST TUBE LEAK DETECTION BY AMS IN UNIT 12 (IP EVAPORATOR 1 TUBE NO:15 FROM RHS OF BOTTOM RHS MODULE HEADER 34 (08/15/2017)– PIN HOLE & REPAIR PHOTOS)

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SUMMARY

- The subject plant's HRSG HP Econ 2-1 Circuit had a "Reverse Flow" in downward water flow pass from insufficient pressure head to overcome the "Upward Buoyancy Forces" created by "Water Density Differences"
- The above factor resulted in multiple repeat tube leaks at Header 29 RHS end tubes 1 through 6
- To eliminate the repeat tube cracks, SEI recommended to modify the "Feed Pipes & Exit Pipes" for upward flow in all 4 passes of the same row headers: 29 (top header) & 30 (bottom header)
- The plant decided that the feed and exit pipe modification was expensive and decided to manage the repeat tube leak incidences with immediate tube repairs
- For early detection of tube leaks and immediate tube repair, SEI recommended to install AMS system & the subject plant installed it in both HRSG units 11 & 12
- The installed AMS system description and performance results were presented
- The installed AMS system was successfully detecting all the tube leak incidences as soon as the tube leak starts occurring, well before any of the traditional method's indication, and quick tube repairs were performed immediately before they cause secondary damages, and managed effectively
- Unit 11 had a greater number of tube leak events than Unit 12
- The subject plant was very happy on the performance of the installed AMS system

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