Advanced Ultrasupercritical (AUSC) Tube Membrane Panel Development

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April 20, 2016

Imagination at work

AUSC Tube Membrane Panel Development Agenda

Project Objective and Background

Project Approach

Project Selections and Decisions

Project Current Status and Going Forward

Tube Membrane Panel Development
Statement of Objective

The objective of this Project is to develop and prove the manufacturability of welded tube membrane panels made from high performance materials suitable for the AUSC steam cycles of a fossil-fired boiler. (ex. T92, HR6W, IN617…)

Straight flat panels in shop

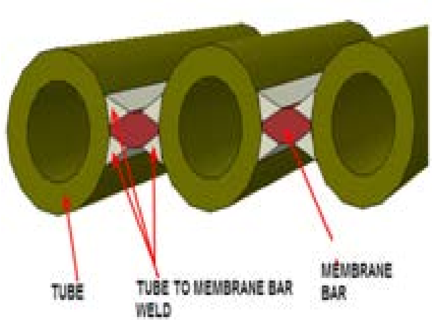
Project Kick-Off Nov. 2014 Project Complete Sept. 2016.

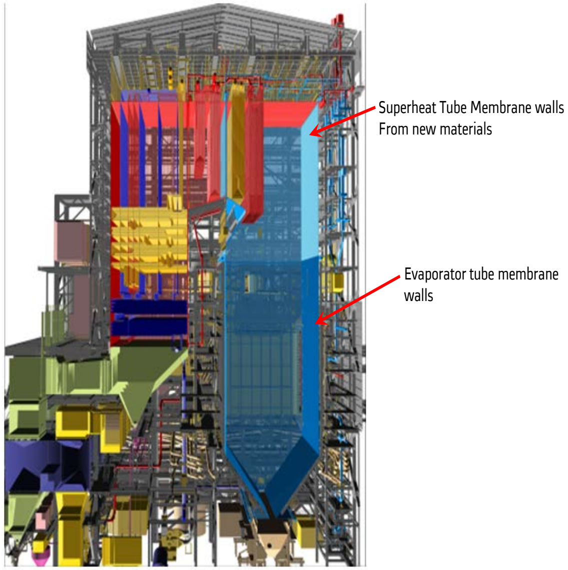
Tube Membrane Panel Development Definitions

- AUSC Steam cycle- Outlet steam temperatures and pressures greater than 700°C (1300°-) / 4000 psi. NETL Target 760°C (1400° F/ 3500-5200 psi.)

- Welded furnace walls, which are frequently referred to as waterwalls, provide the enclosure around a combustion chamber. The upper section of the combustion chamber of an AUSC boiler, **Membrane Panels**.

- Membrane/Fin- Bars, usually rectangular in shape, that are welded to the tube. These bars perform several functions
  1. Along with the tubes form the gas seal of the gas chamber
  2. provide heat transfer surface
  3. provide structural support





Tube Membrane Panel Development
Technical Background

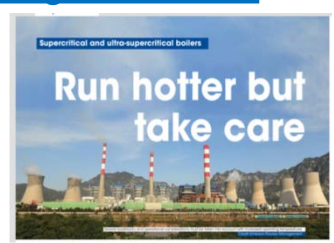
A U.S. industry consortium led the development of materials to enable the use of advanced steam cycles in coal-based power plants since 2001 and with co-funding by the U.S. Department of Energy - NETL and the Ohio Coal Development Office.

Gap Identified: February 2003 Topical Report, "Boiler Materials for Ultra Supercritical Coal Power Plants", written by Alstom:

- "Application of T92 alloy for the construction of waterwalls is technically challenging and requires advanced manufacturing techniques that need to be fully developed yet. Nevertheless, implementation of this alloy or similar alternate is **necessary** to enable higher pressure cycle designs".

- From Power Engineering June 2014 publication:

  From this article the challenge remains to identify candidates and prove manufacturability.



For boilers operating in the 650°C to 700°C range, materials with a higher allowable stress will be required. Potential candidate materials include T91, T92 and T122. The use of these materials for membrane water walls will be a challenge since they require post-weld heat treatment (PWHT).

- Why the Gap still exists? Efforts of the various international developments have focused only on the Nickel alloy research.

Tube Membrane Panel Development Roadmap to AUSC Demo

2000	2005	2010	2015	2020	2025

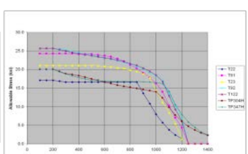
Materials Development
Laboratory TRL 2 to 3

Component Mockup
Proof of Concept TRL 4

Steam Loop at Plant Barry
Component Test TRL 4 to 5

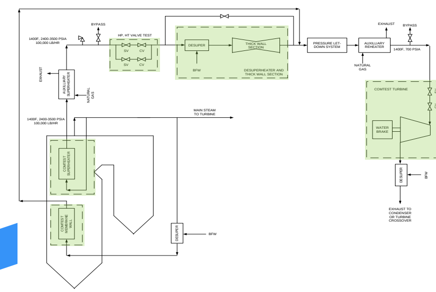
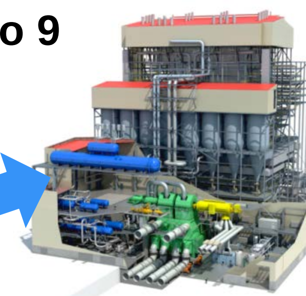
AUSC-COMTEST
System TRL 6 to 8

AUSC Demonstration
Overall TRL to 9





components	TRL
Tube Membrane Panel	4
Superheater	5
Turbine	4
Desuperheater	4
Header	4
Valves	4

Current DOE-sponsored programs designed to bring components to TRL 5;
AUSC-COMTEST will bring system to TRL 7 or 8

Tube Membrane Panel Development Potential Significance

Using today's "traditional" alloys (T12,T22, T23, T24…) for abusive conditions, whether during manufacturing or during service, has contributed significantly to the favorable service experience of the boiler fleet.

Boiler wall layout in Shop

AUSC membrane panel may not have the same tolerance for these abusive conditions. The panels constructed from advanced materials require special care during fabrication to retain obtain their superior properties and characteristic microstructures.

For this reason it is imperative that issues associated with the fabrication of membrane-welded panels fabricated using advanced alloys be investigated and manufacturing verified so that potentially disruptive problems can be identified and technically feasible resolutions of those problems developed as part of the effort.

Typical USC 1000MW USC Boiler furnace 200' tall, 100' wide, 50' deep

AUSC Tube Membrane Panel Development
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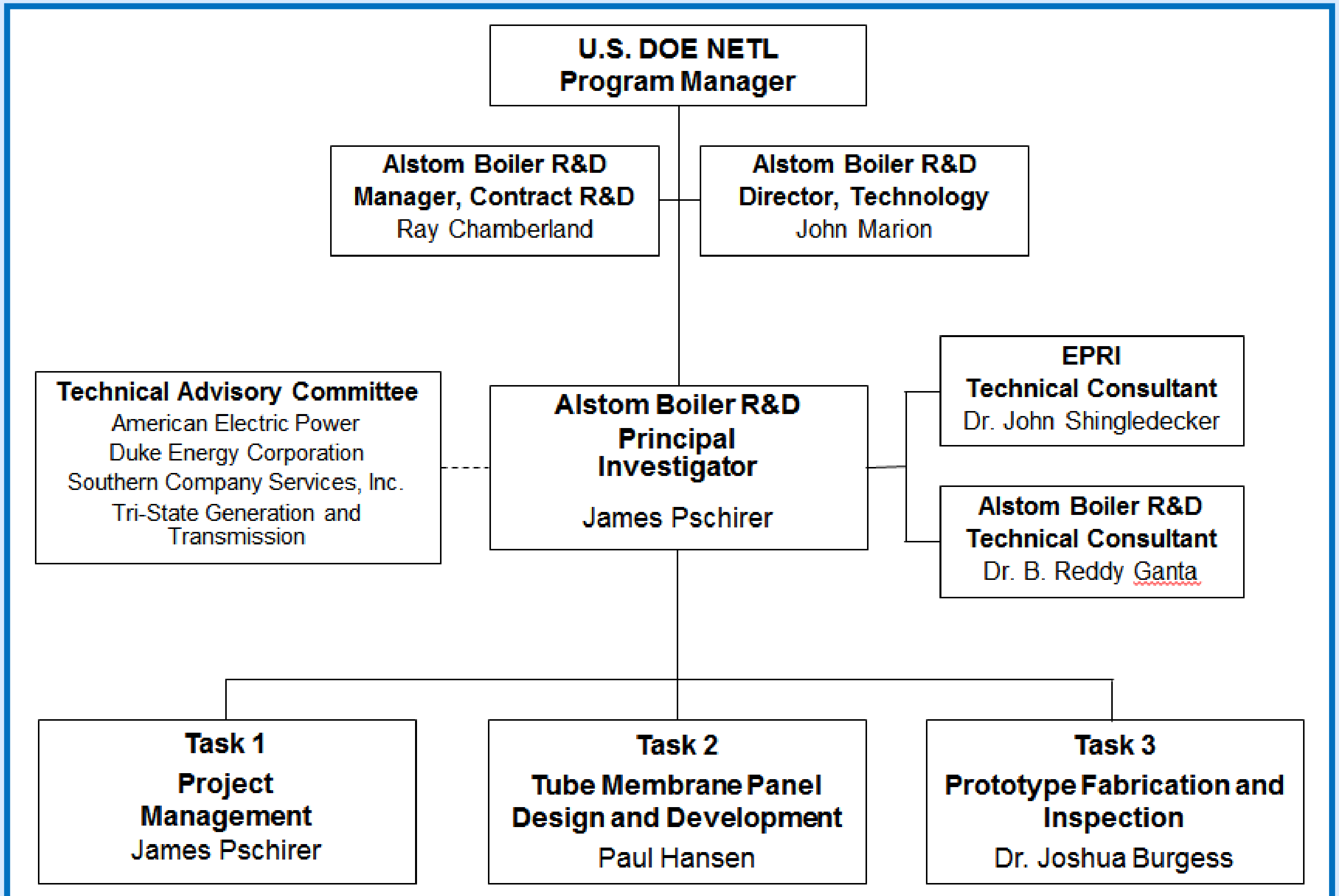
Project Current Status and Going Forward

Tube Membrane Panel Development Project Team



- GE team comprised of members of Boiler R&D in Windsor Ct. and the Met Lab in Chattanooga Tn.
- Manufacturing of the Panels GE Manufacturing Plant in Chattanooga Tn.

Tube Membrane Panel Development
Technical Approach

Alstom has divided the tube membrane panel development Project into three major Tasks with a number of Subtasks

Task 1.0 Project Management and Reporting

Task 2.0 Tube Membrane Panel Design and Fabrication Development

Task 3.0 Prototype Fabrication and Inspection

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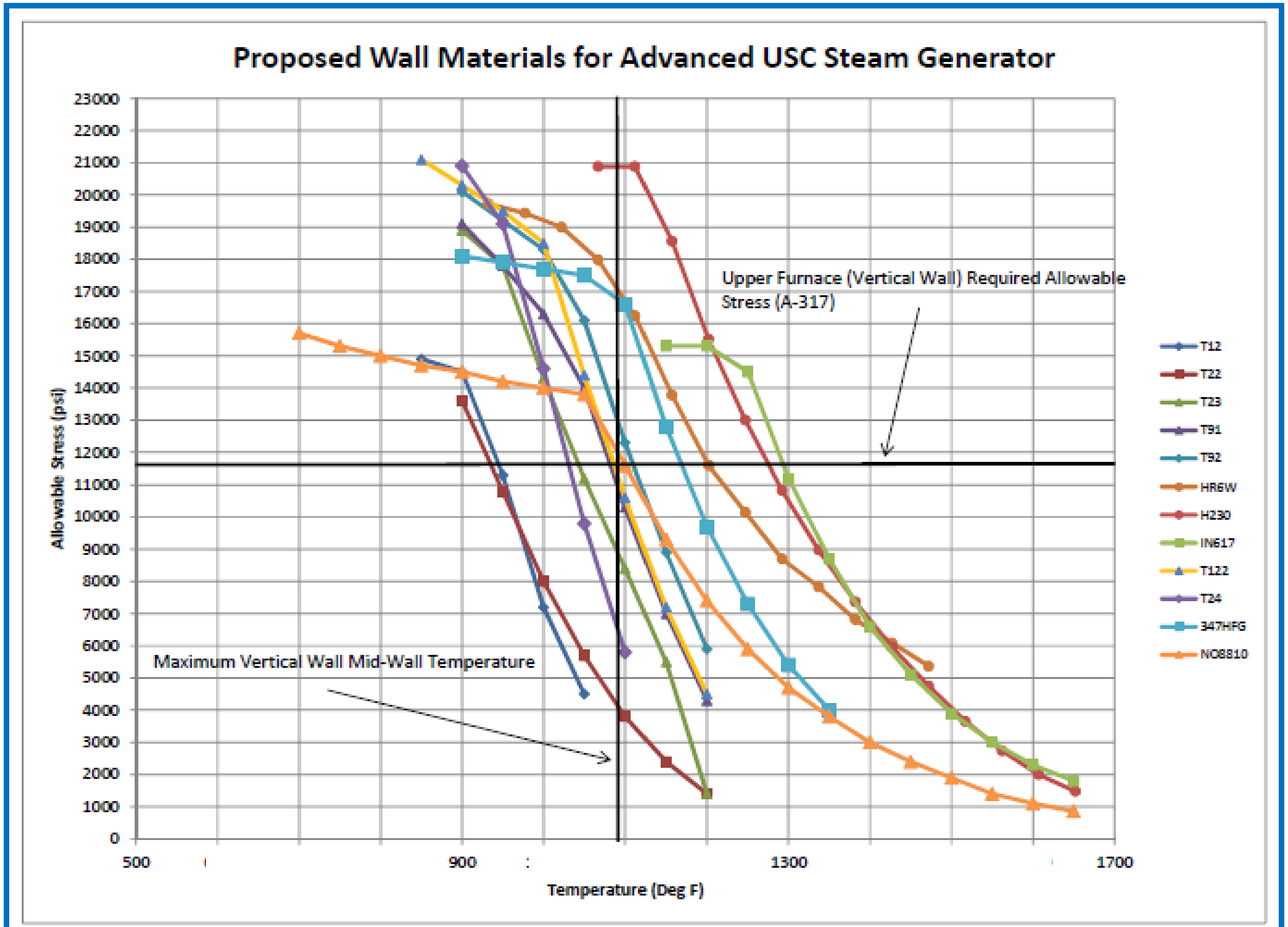
Tube Membrane Panel Development
Material Selection



AUSC Tube Membrane Panel Development Project Decisions To Date

Tubing Selection:

- Two materials selected, T92 and HR6W.
  - **T92** in-line with the Topical Report, "Boiler Materials for Ultra Supercritical Coal Power Plants" as well as other published papers.
  - 2nd material, **HR6W**. Chosen for several reasons
    - » In ASME.
    - » Choosing another CSEF material was not truly giving the designer a choice, the materials are so similar the welding and handling would be basically the same
    - » The design temperature in the region of the boiler could be modified and surface transferred to another location but the choice still remains another CSEF material.
    - » Austenitic materials not in line with Code for "Wetted" service
    - » Use of the HR6W pushes to use of Ni Alloys, which once mastered can provide reference for some of the higher Ni Alloys such as 617.

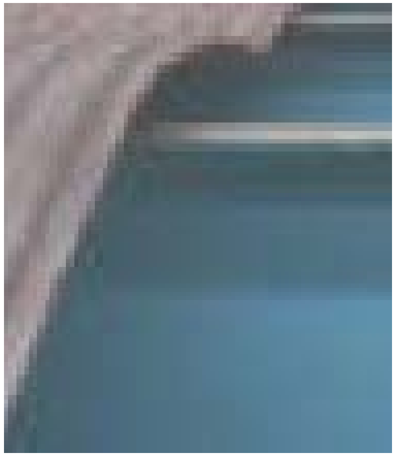
AUSC Tube Membrane Panel Development
What are we looking for?

- Control of weld penetration to satisfy mechanical and heat transfer requirements Control of the deformation to acceptable tolerances.

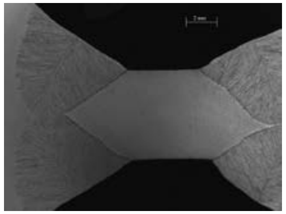
- Panels routinely require straightening in the workshop after welding and heat treatment, the question to be answered is can the shop then meet the required dimensional tolerances for successful site installation?

- Can existing shop handling procedures be used as-is without adding excessive controls that will add cost and schedule.

- The importance of preheating and its maintenance through the welding process could cause a number of handling and shop processing issues that will substantially increase cost.



Camber



Penetration

Bowing

AUSC Tube Membrane Panel Development Inspection

An inspection will be performed recording results for items such as:

- hardness of weld and HAZ
- overall weld shrinkage
- tube ovality
- Tube-to-membrane bar weld to verify that no cracking in the weld, bars, or tube
- distortion of panel prior to and after PWHT
- The panels will be inspected again after "shop handling" for any cracking in welds, bars, or tubes.

AUSC Tube Membrane Panel Development
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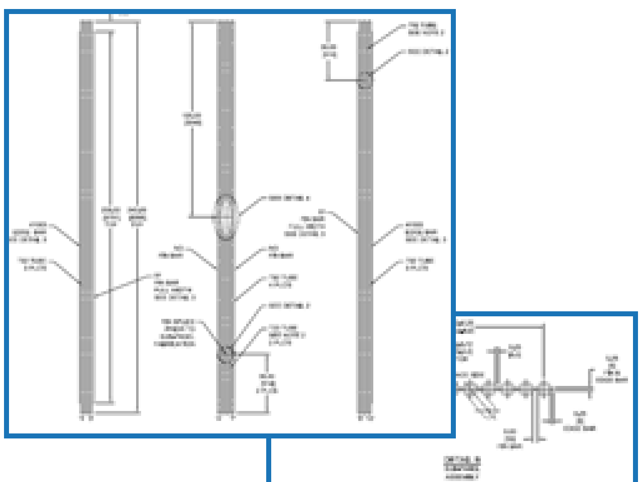
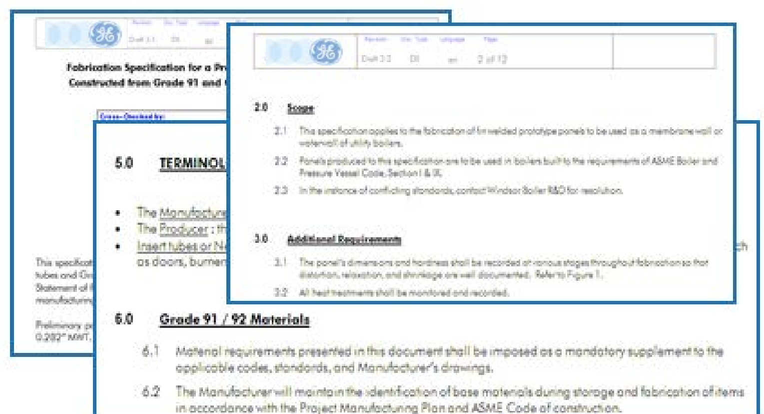
Tube Membrane Panel Development Project Status

- Task 1 – In-progress
- Task 2 - Complete
- Task 3: Progress
  - T92 prototype panel fabrication including PWHT. Complete
  - HR6W panel fabrication. Complete
  - Inspections Complete
- ❖ Ahead of Schedule and below Budget.
- ❖ Additional Scope





Tube Membrane Panel Development Project Status

Sub-Arc of tube to membrane welds in lab size panels

Tube Membrane Panel Development Project Status

Initial runs of Sub-Arc welds in lab mock-ups.

Tube Membrane Panel Development Project Status

Lab Mock-up Panels

Fit-up of T92 panel before welding

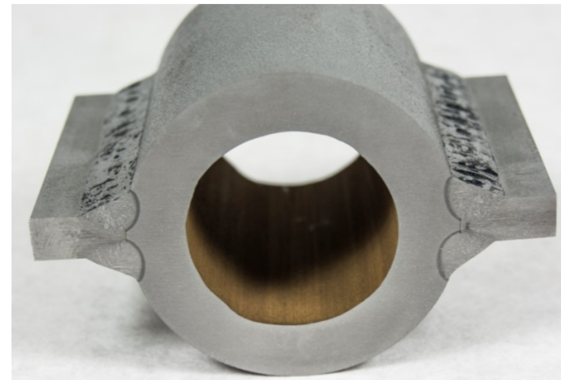
After welding: showing that the slag falls off in some areas without chipping or brushing.

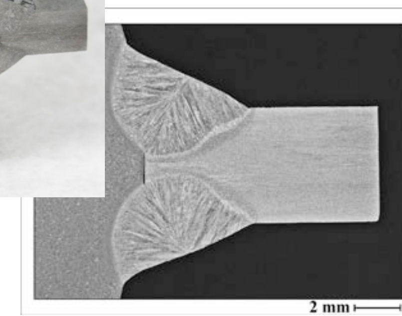
Tube Membrane Panel Development
Project Status

Sub-Arc of tube to membrane welds in lab size panels

Tube Membrane Panel Development
Project Status

T92 with edge bar



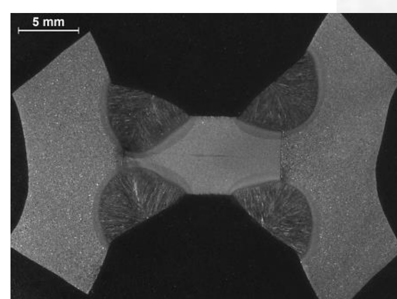


Lab Mock-up Panels

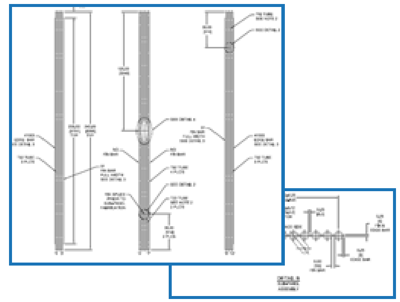
Welds after flux removal before brushing

Varying the wire position and angle

to influence penetration



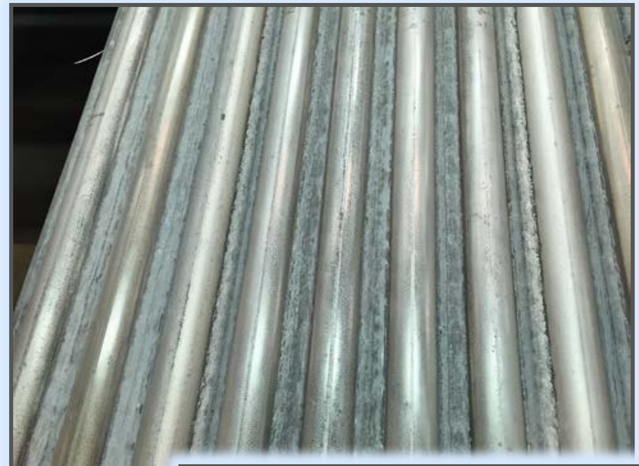
Tube Membrane Panel Development
Project Status

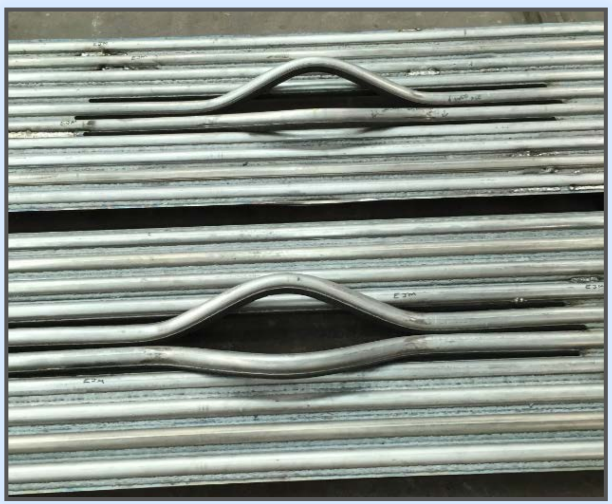


T92 Panels

Tube Membrane Panel Development
Project Status

HR6W Sub Panels

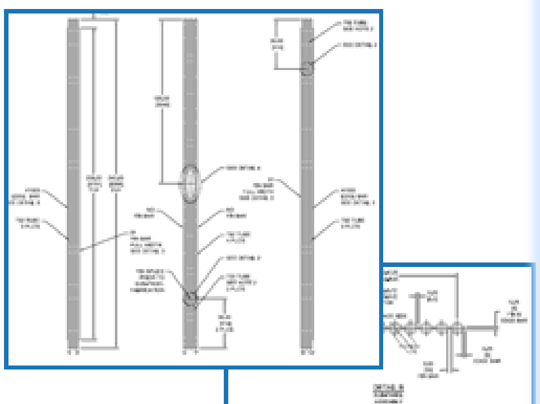


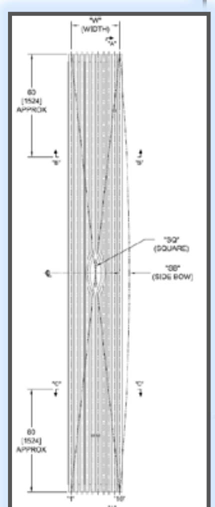


Tube Membrane Panel Development
Project Status

T92

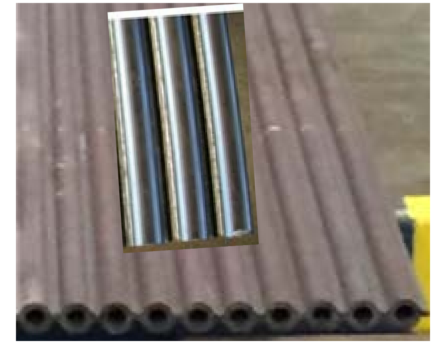
HR6W

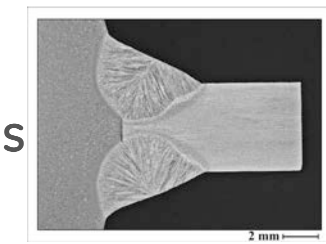




Tube Membrane Panel Development Going Forward

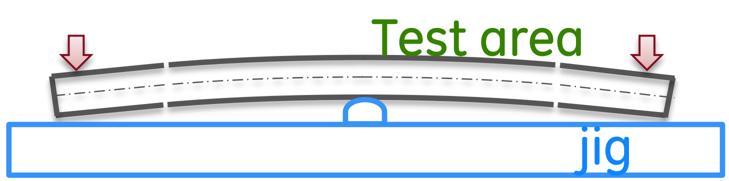
- Simulated Dutchman repair on T92 Panel
  - Cut (3) 12" long pieces of tube out of panel and replace





- Metallography Examination on T-92 Panel Welds
- Metallography Examination on HR6W Panel Welds
- T92 Mock-up Panel with alternate weld Wire

- Crack Test along the tube to membrane welds



- Complete tasks and submit Final Report

We are looking forward to completing a successful Project and thank The DOE NETL for this opportunity.

Technology Readiness Levels for the DOE[8]

Technology Readiness Level	Description
TRL 1.	Scientific research begins translation to applied R&D - Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
TRL 2.	Invention begins - Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
TRL 3.	Active R&D is initiated - Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
TRL 4.	Basic technological components are integrated - Basic technological components are integrated to establish that the pieces will work together.
TRL 5.	Fidelity of breadboard technology improves significantly - The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
TRL 6.	Model/prototype is tested in relevant environment - Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
TRL 7.	Prototype near or at planned operational system - Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment.
TRL 8.	Technology is proven to work - Actual technology completed and qualified through test and demonstration.
TRL 9.	Actual application of technology is in its final form - Technology proven through successful operations.