

Establishing Modular In-Chamber EB Welding (MIC-EBW) Capability in USA

David Gandy
Sr. Technical Executive
davgandy@epri.com

DOE AMM Technical
Review Webinar

December 18, 2019

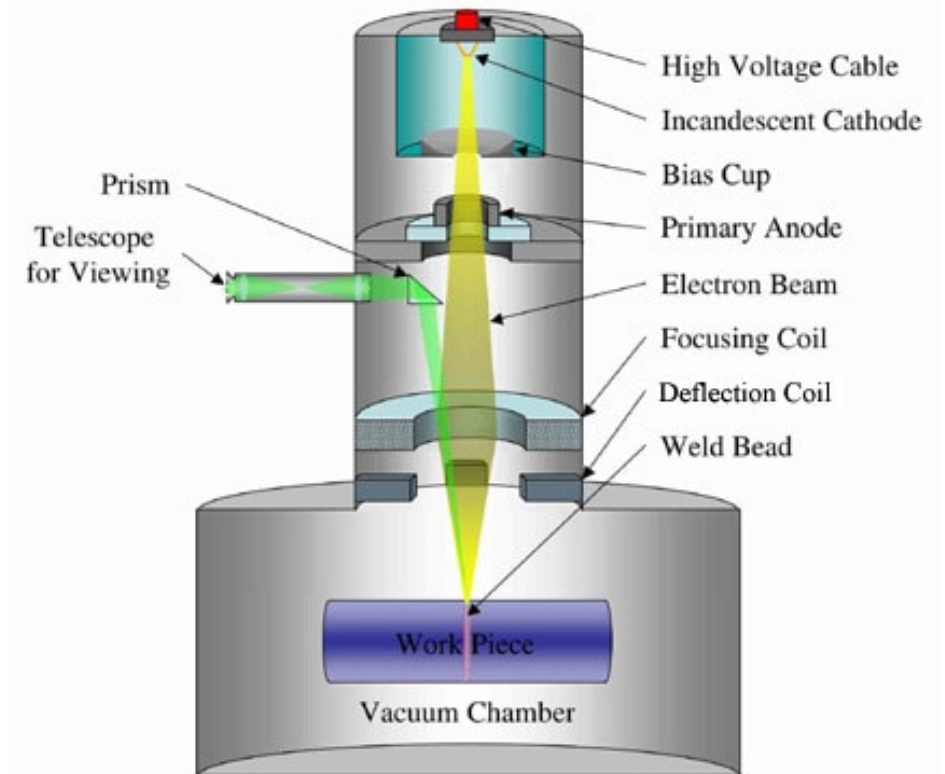
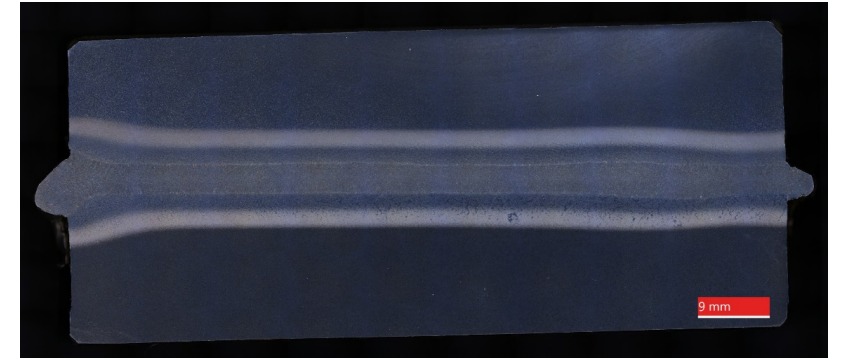


Outline

- Background
- Why Consider Modular In-Chamber Electron Beam Welding?
- DOE Project Objectives
- Project Tasks
- Project Status
- Summary

Background— Electron Beam Welding

- EBW is used extensively in aerospace, aircraft, automotive, food, electronics, medical, and defense industries
- Primarily used for thinner materials; limited use for thick sections
- DOE Project DE-NE0008629 with EPRI/NAMRC has established parameters for thick section (110mm) applications in a vacuum chamber.
- Now need to utilize same parameters and similar equipment in MIC-EBW approach.



Example EBW Equipment



*Photograph provided courtesy:
PTR Precision Technologies*



*Photograph provided courtesy: Nuclear AMRC (UK)
Chamber is 9 x 4 x 5m*

Why Modular In-Chamber Electron Beam Welding?



Three Options Considered

1. Build a **very long chamber – 40+ ft**
 - Fixes one's options and requires high pumping capabilities
 - Locks one in for future
2. Use **local vacuum** (reduced pressure?)
 - Hasn't quite gotten to where it should be even after many years of R&D
3. **Modular approach** ★
 - Many of the welds only require short assemblies
 - Provides options for future/alternative applications
 - Scalable

DOE Project Objectives

- Develop and establish MIC-EBW capability at a major U.S. fabricator
- Reduce overall welding arc time by up to 90% compared to conventional welding technologies used for vessel production.
- Successfully demonstrate a 10-ft (3.05-m) diameter, 4.375-inch (110-mm) thick vessel EB weld in less than 90 minutes of welding time.
- Establish MIC-EBW capability to perform major RPV girth welds for the NuScale Power RPV.
- Develop manufacturing process plans based on the technology and required post-weld inspection/heat treatment.

**DOE Project
DE-NE0008846**

Two-Phase Approach



Phase 1. EBW Equipment Design and Production (**12 months**) -- funded

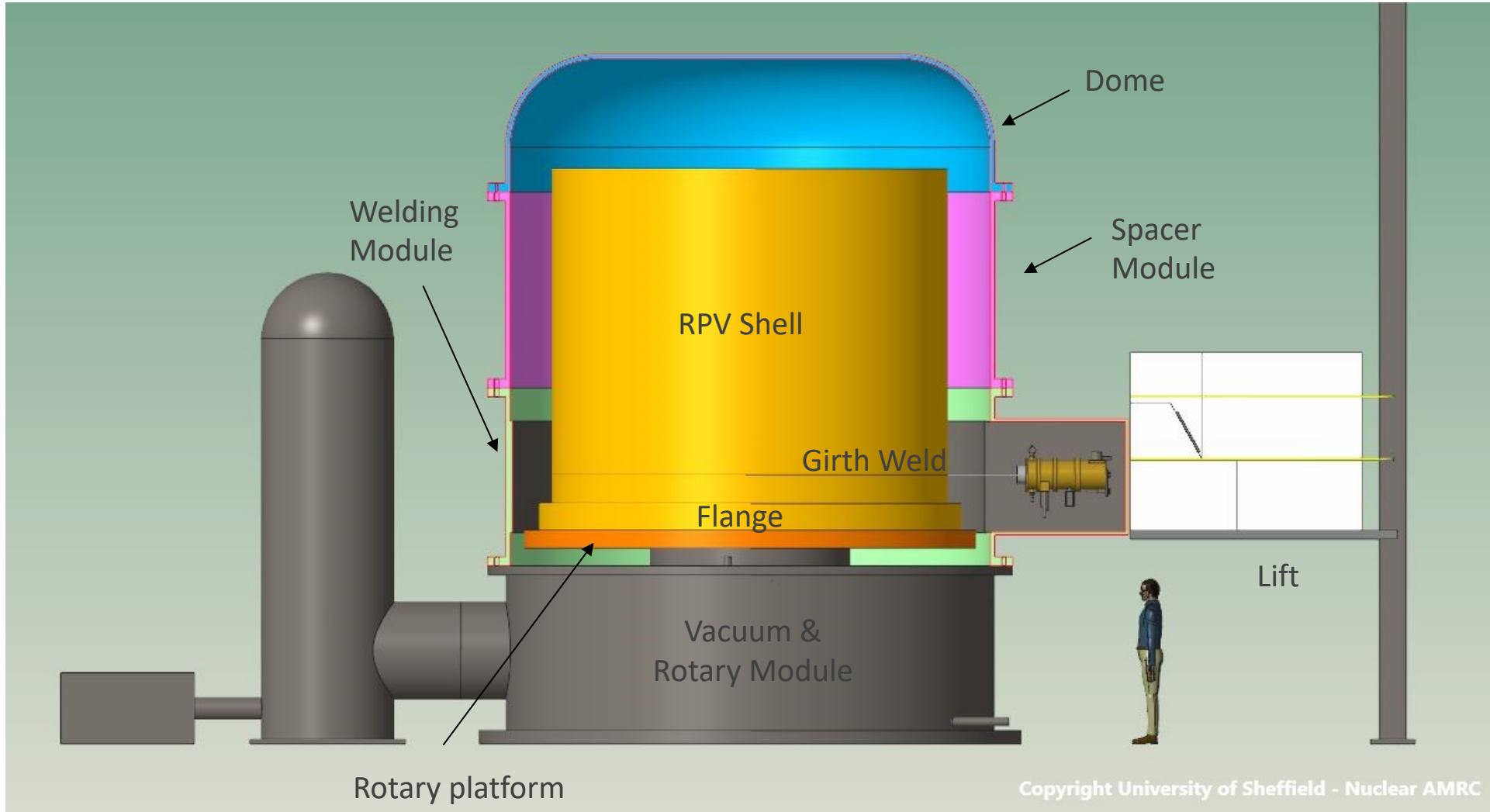
1. Process Planning—Welding, Inspection, and Manufacturing Stages (Bridger)
2. Design/Manufacture of the Pumping Stages of EB System (PTR)
3. Design/Manufacture EB Gun Stage/Slide & 4/5ft diameter Demonstration (PTR)
4. Design Vacuum Seals for Modular Ring Sections (AMRC)

Phase 2. Full-Scale Modular In-Chamber EB Welding Demonstration (**18 months, starting after initial 6 months of Phase 1**) – unfunded at present

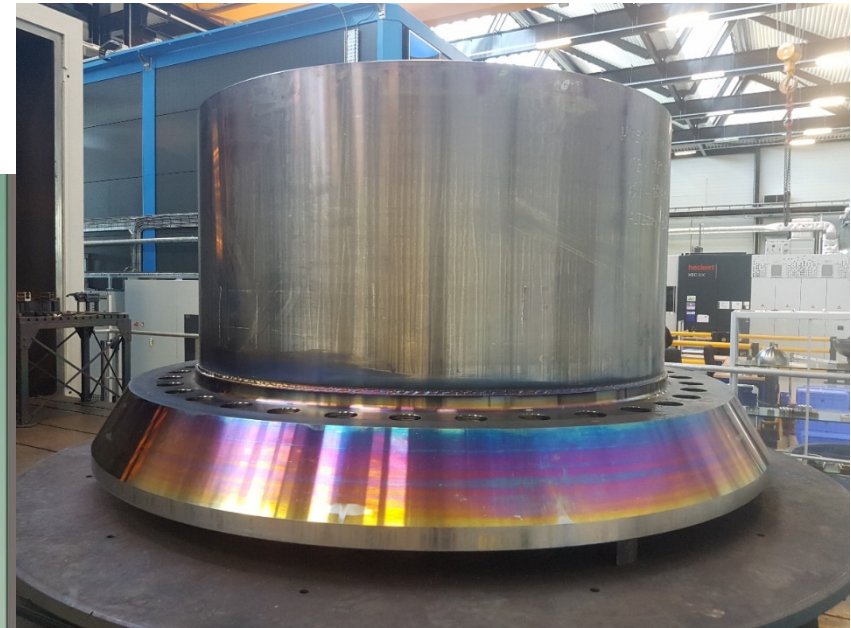
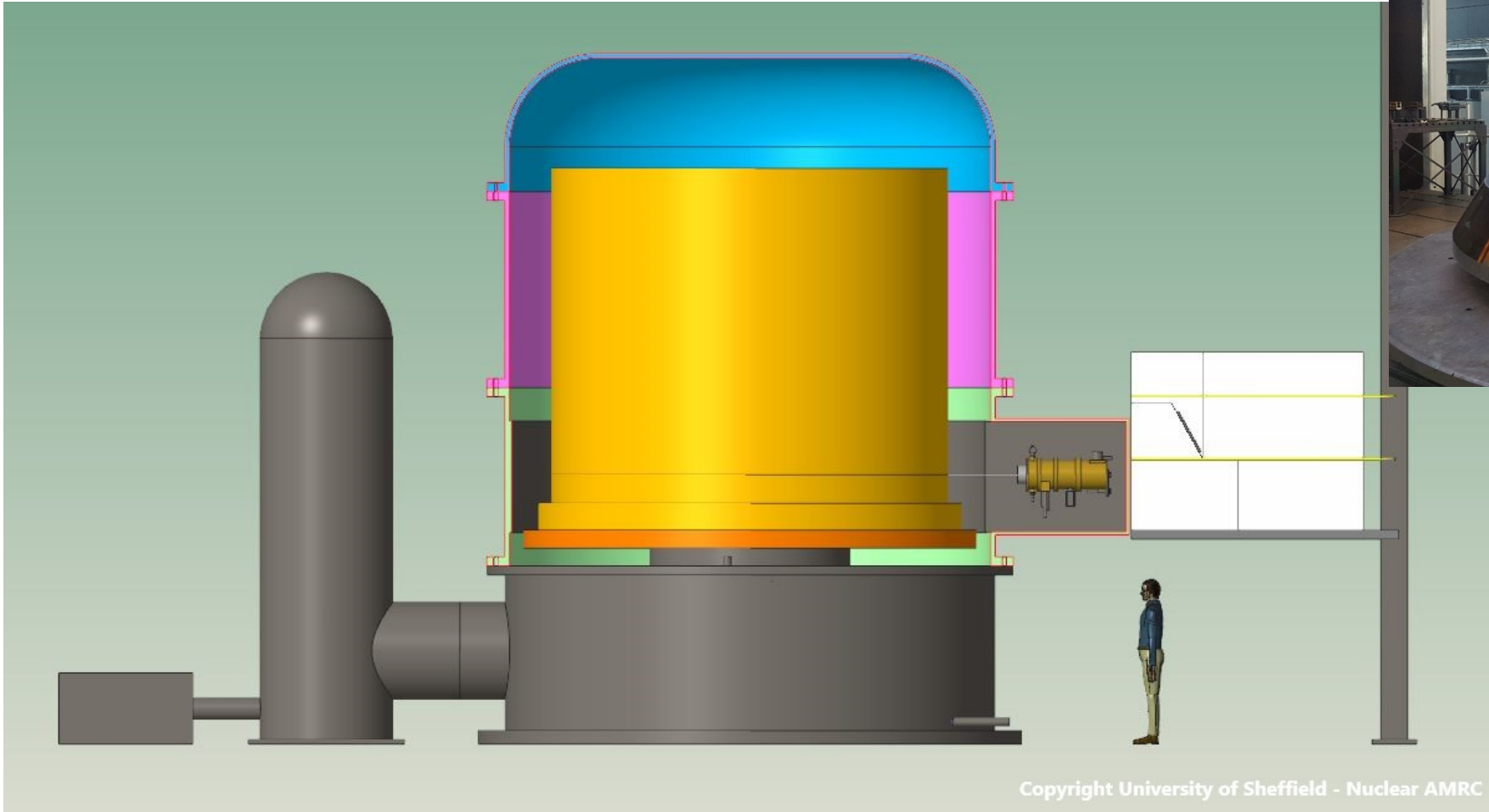
5. Design/Manufacture of the Rotary Manipulation Stage (Rusach)
6. Produce Modular Ring Sections and Fabricate Modular Vacuum Sections for SMR Welding/Joining (Fabricator)
7. Demonstrate Modular EB Welding Capabilities for Large Scale—10 feet (3.05m) Diameter Shells (Manufacture/PTR)
8. Design Lift Stage to Move the EB Power Supply and Control Panel (AMRC)
9. Develop/Demonstrate NDE of Final Welds (EPRI NDE)

Modular In-Chamber EBW --RPV Shell and Flange Welding

DOE Project
DE-NE0008846



RPV Shell and Flange Shown Inside of Modular EBW Chamber (in gold)



Lower Flange Shell Mockup EB Weld -- ~6 ft (1.82m) diameter
(Note, mockup is upside down)

Completed in 47 minutes

Key Project Team Members

- **EPRI** – Project Management & NDE Development
- **NuScale Power** – Engineering and Project Consulting
- **PTR-Precision Technologies** – EB Equipment Designer, Manufacturer, and Medium/Large Size Mockup Demonstrator
- **AMRC** – Module Design
- **Bridger Welding Engineering** – Process Planning, General Consulting.
- Rusach International – Rotary Table Manufacture
- Fabricator – Fabricate Individual Ring Sections and Vacuum Modules
- Manufacturer– Host & Demonstration



120" x 36" x 50" Vacuum Chamber (courtesy of PTR)

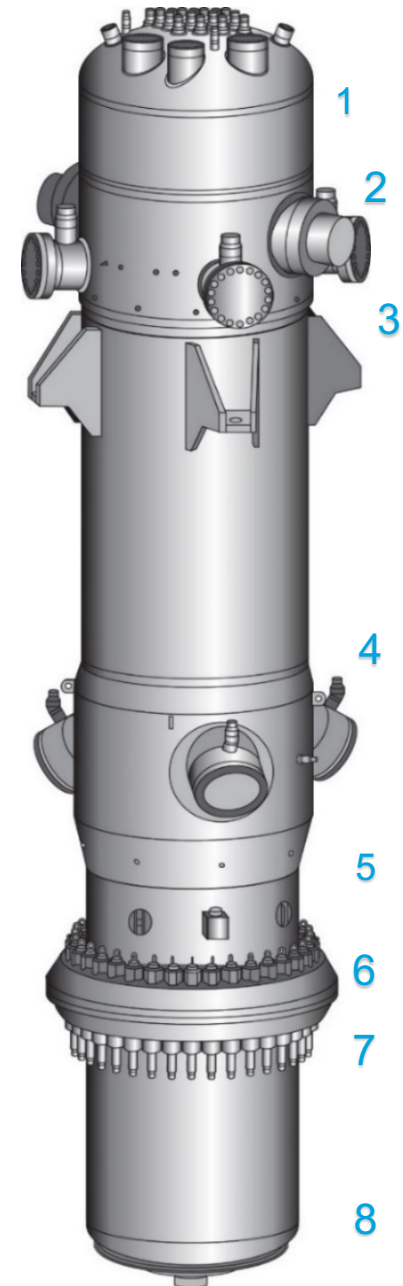
Task 1—Process Planning

--Bridger Welding (lead)

PLANNING



- **Weld Development Plan:** including components to be welded, post-weld heat treatment, post-weld inspection, and post-weld characterization
- **Manufacturing Process Plan:** including pre-weld manufacturing requirements, pre-weld setup, post-weld machining requirements, post-weld heat treatment requirements/processes, and inspection requirements
- **Inspection Plan:** including nondestructive evaluation (NDE) methods and beam location
- **Cladding Plan:** including cladding sequencing for each component



Task 2--Design/Manufacture Vacuum Pumping Stages of EBW System (PTR lead)

Vacuum Pumping System

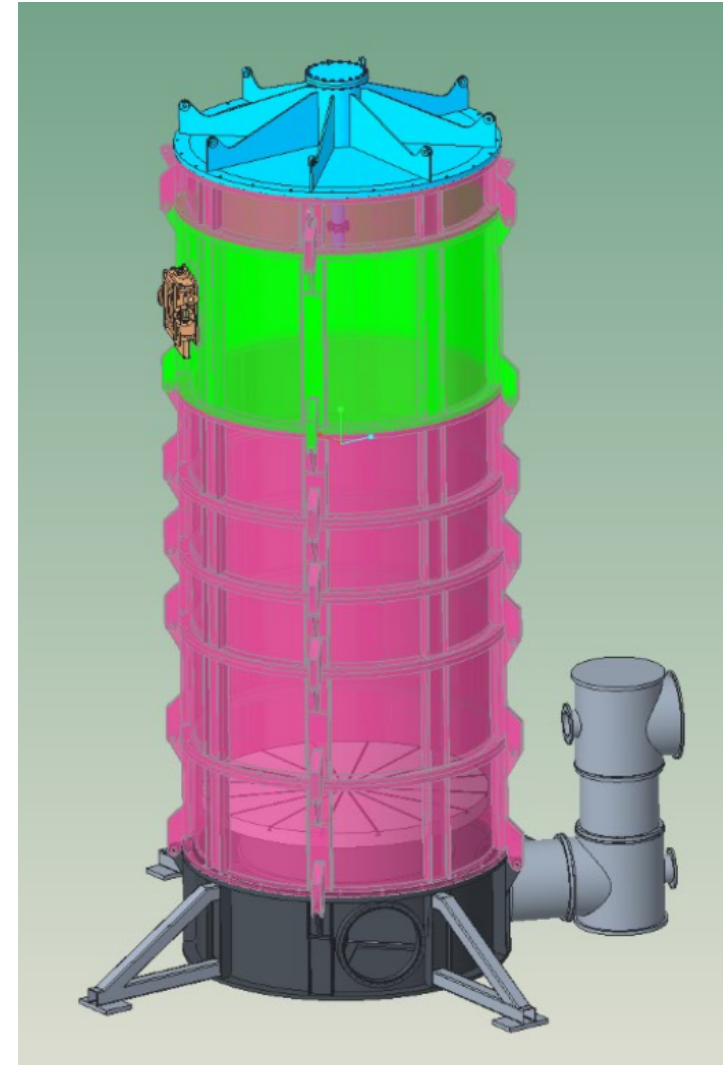
- Pumps and Blowers
- Cryo-pumping System
- Vacuum ductwork
- Chimney
- Diffusion pumps
- Note: Expected pump-down for full height system is **2-3 hours**



Example equipment ordered for vacuum pumping system

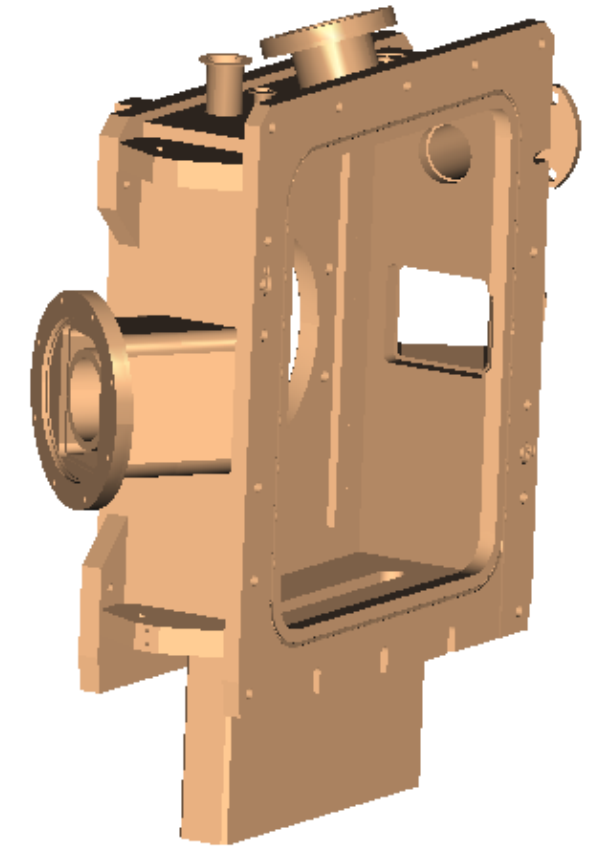
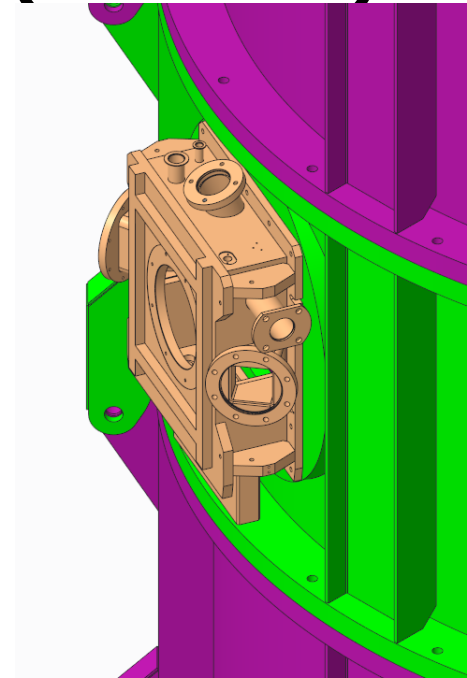
Task 3--Design/Manufacture EB Gun and Slide Module and Perform 4ft Diameter Demonstration (PTR Lead)

- The EBW gun is operated in a fixed horizontal welding position,
 - and the component is rotated on a heavy platform.
- Welding gun will be based on a **150 kV triode gun design**
 - Already produced by PTR-Precision Technologies for other applications.
- The EB gun will be attached to a dedicated EBW stage (green)
 - Will be capable of sliding in and out over some defined range (and up and down—Z-direction)
 - Allows the EB gun to accommodate various diameters (again, within a certain range).



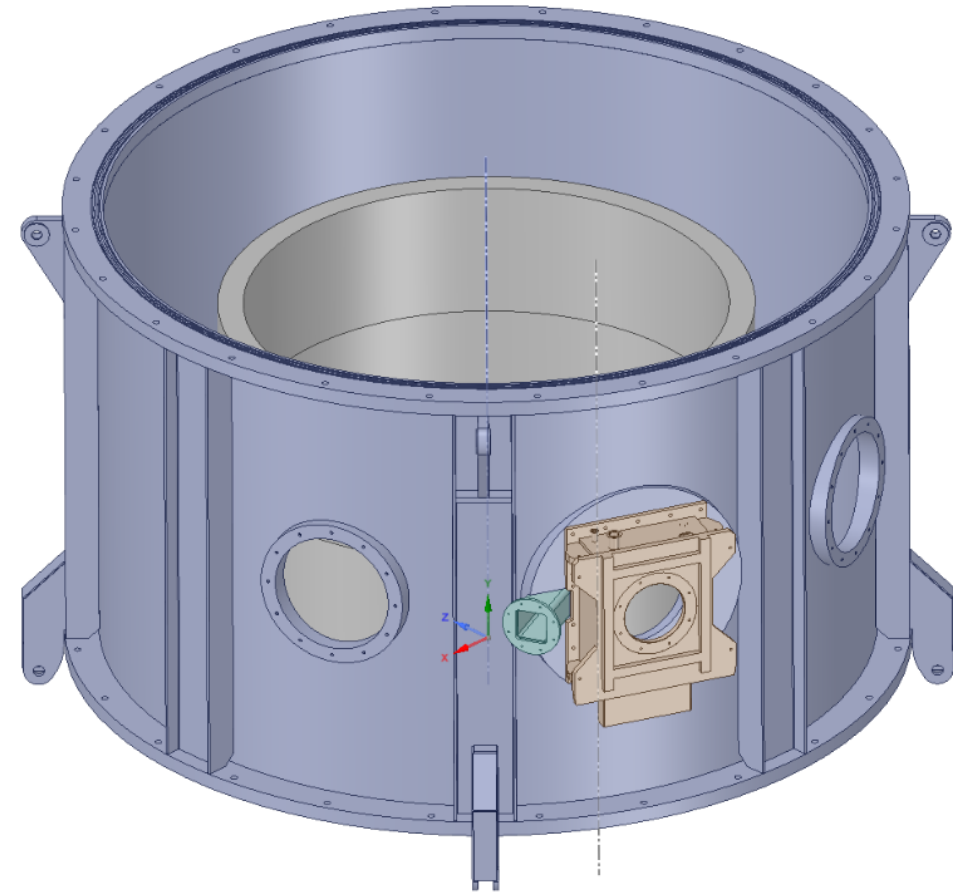
Task 3--Design/Manufacture EB Gun and Slide Module and Perform 4ft Diameter Demonstration (PTR Lead)

- The “EB gun and slide” will be semi-permanently attached to the side of the EB gun and slide module.
- The entire “EB gun and slide stage” must be capable of being disconnected from the module/stage below it and moved to accommodate another module.
- Control and power center (transformer, power supply, chiller, and so on) will move up and down with the EB gun and slide stage to minimize the high-voltage cable length and diameter.

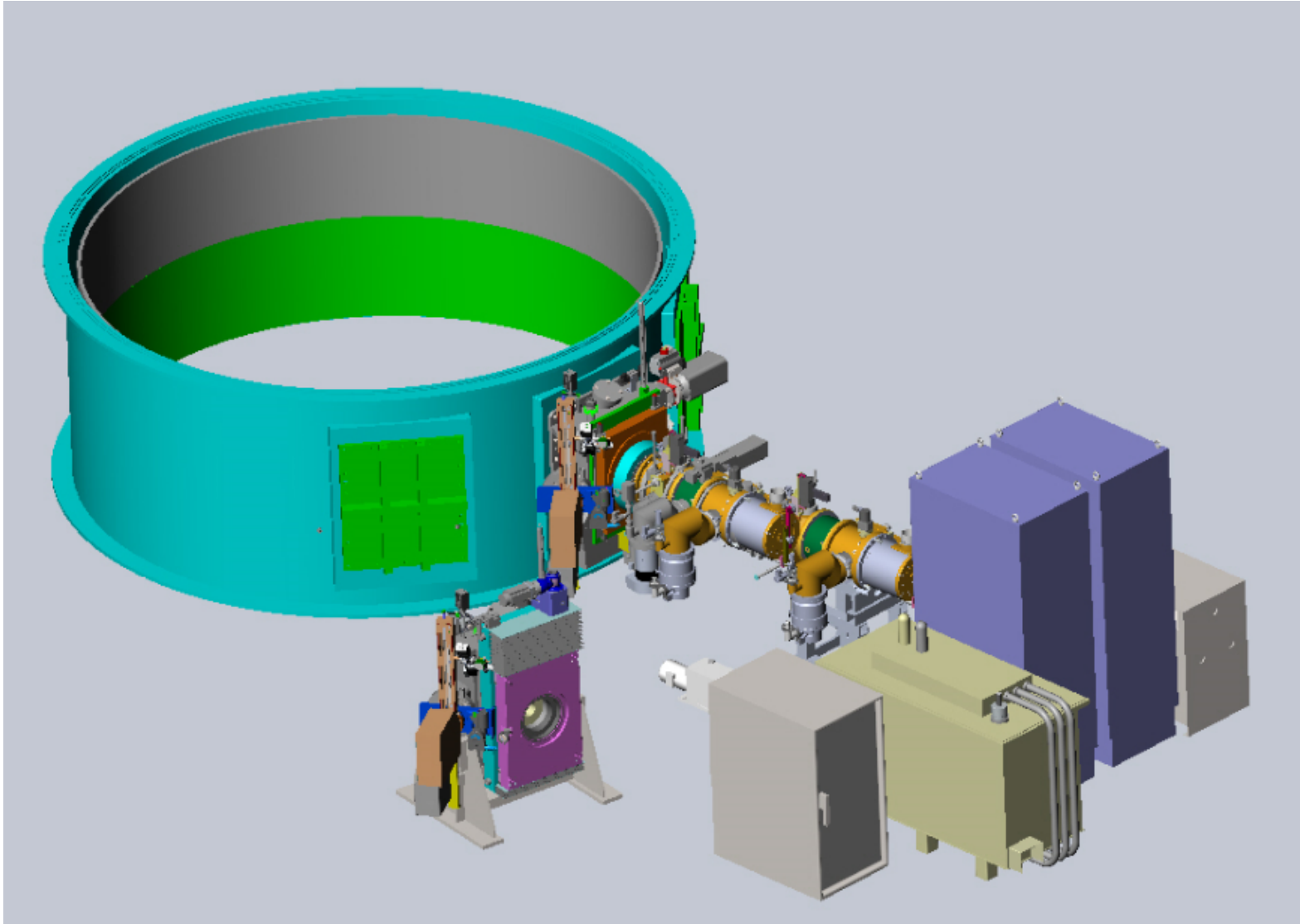


Component Parts of EB Module – Outer Shell

- Outer shell 1.5 “ thick C-Mn Steel
- Sealing the same as other modules
- Lead shielding on OD if needed
- Only module designed for radiation
- Additional ports added for future options
- Current design is 8ft tall



All EB System Components



Task 3--Design/Manufacture EB Gun Stage and Slide Module and Perform 4ft Diameter Demonstration (PTR Lead)

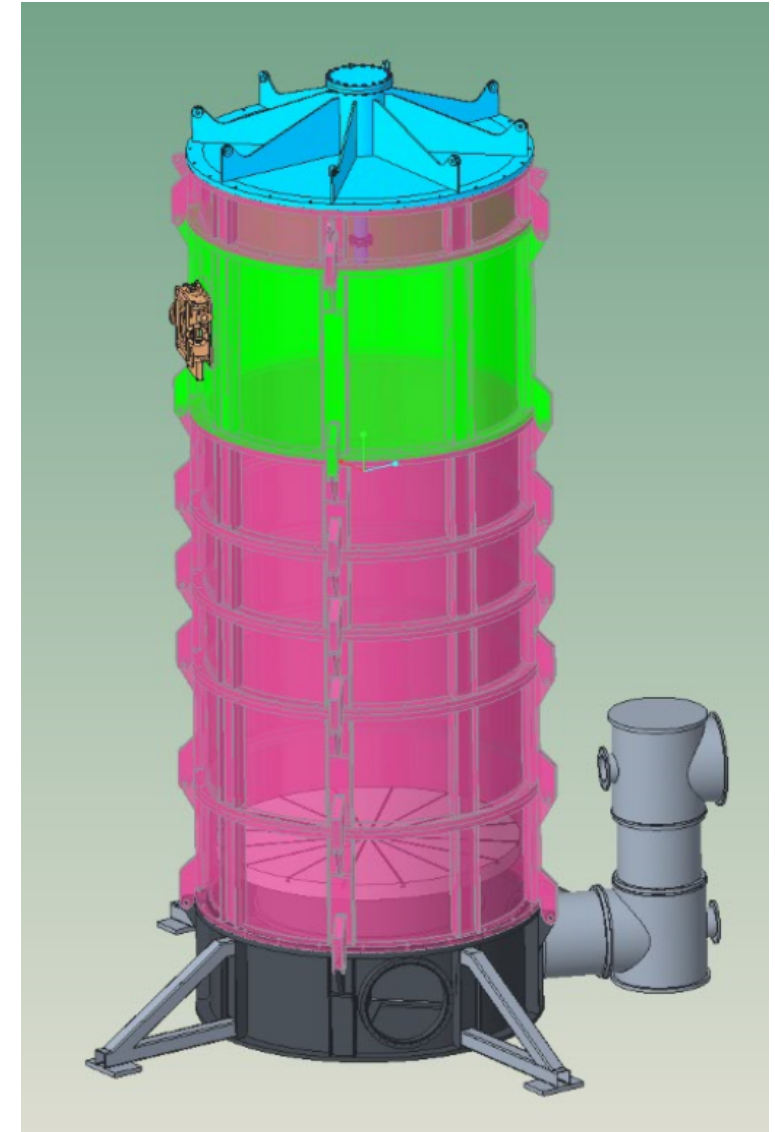
- The MIC-EBW gun system will be demonstrated at PTR-Precision Components site:
 - Employs a 4ft (1.1m) diameter rotary table positioned inside a vacuum chamber.
- Demonstration is considered necessary to make sure that all system components (minus the large rotary table and large vacuum chamber) work together
- The demonstration will include welding on thick carbon/alloy steel rings sufficient to demonstrate the MIC-EBW gun and slide capability.



Large diameter steel rings

Task 4--Design Vacuum Seals for Modular Ring Sections (AMRC-UK Lead)

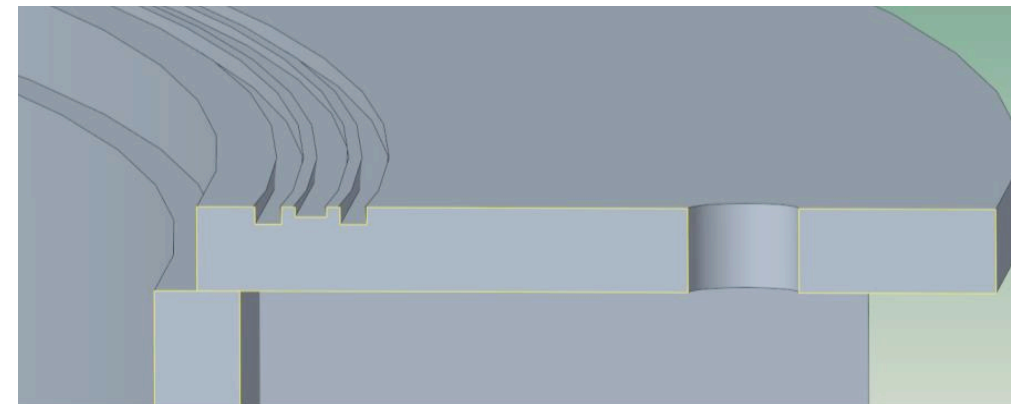
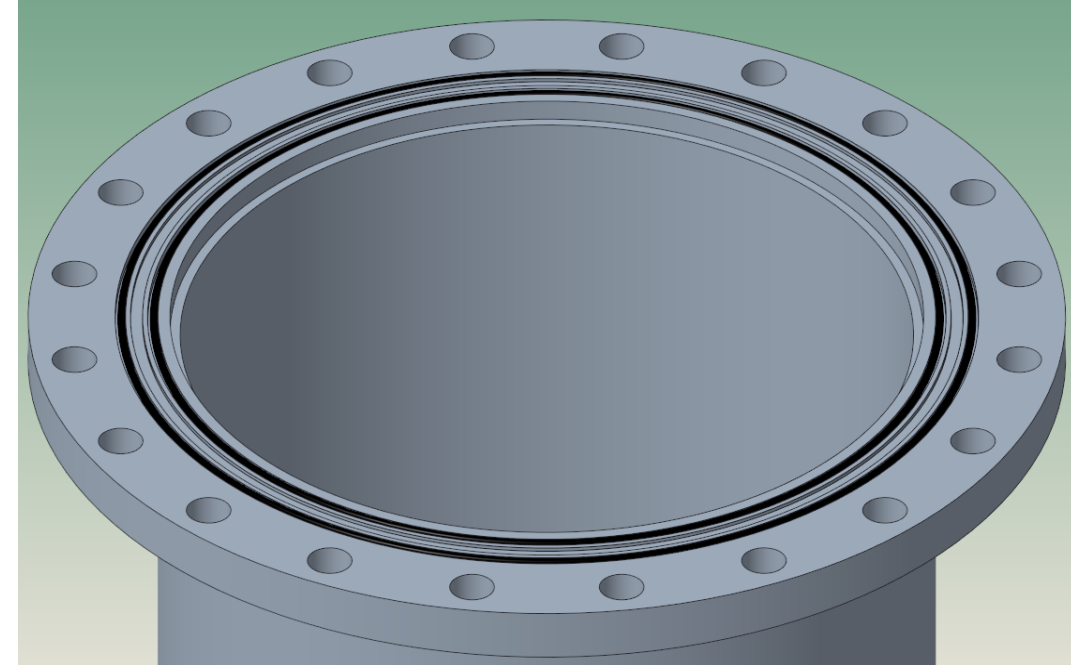
- Precise coupling of modular ring sections is required to eliminate air leakage and **to achieve high vacuum ($\sim 10^{-4}$ torr)** between individual sections.
- MIC-EBW allows various “modular ring sections” of the vacuum chamber to be moved or added to accommodate RPV girth welding at different heights.
- The vacuum seals will be designed for use in each modular ring section under this task



Task 4--Design Vacuum Seals for Modular Ring Sections

--AMRC Lead

- Individual “ring sections” will be produced (Task 6) from >1.5 in. (>38.1 mm) thick carbon steel.
- A flange will be attached to both the upper and lower extremities of the ring section via welding to achieve a good junction between two modules.
- A tight fit is achieved at the junction between the two modules through two engineered vacuum seals.
- A sensor will be positioned between the two vacuum seals to allow vacuum tightness to be checked
 - before pump-down
 - and monitoring during pumping to detect any leaks—extremely important in EBW activities.



Vacuum seals rings--example

What Does the MIC-EBW System Include?

EB Welding System

- EB Generator & Power Supply
- CNC Controls and Operator Console
- Secondary Viewing System
- EBO Package (for viewing, tracking, and manipulating E-beam)

Vacuum Pumping System

- Pumps and Blowers
- Cryo-pumping System
- Note: Expected pump-down for full height system is 2-3 hours



Courtesy of PTR

Project Deliverables

Phase 1--Equipment (funded)

- A process planning report that details all welding, inspection, and manufacturing steps and sequence
- Manufacture of a triode EBW gun and slide
- Manufacture of a vacuum pumping system
- Development of vacuum sealing technology for large EB modules
- Demonstrate EBW capabilities on 4ft (1.1m) diameter rings

Phase 2--Demonstration (unfunded)

- Manufacture of a rotary manipulation stage (>175 ton [350,000 lb] capability)
- Demonstration of large (10 ft [3.05 m] diameter), thick-section component EBW capability
- Development of modular EBW capability in the United States
 - Can be used for multiple diameters—versatility
 - Focus of project is for NuScale Power RPV (eight to nine modules)
- Demonstration that a large-diameter (10 ft [3.05 m]) thick-section weld can be completed in less than 90 minutes
- Development of machining and phased array inspection systems

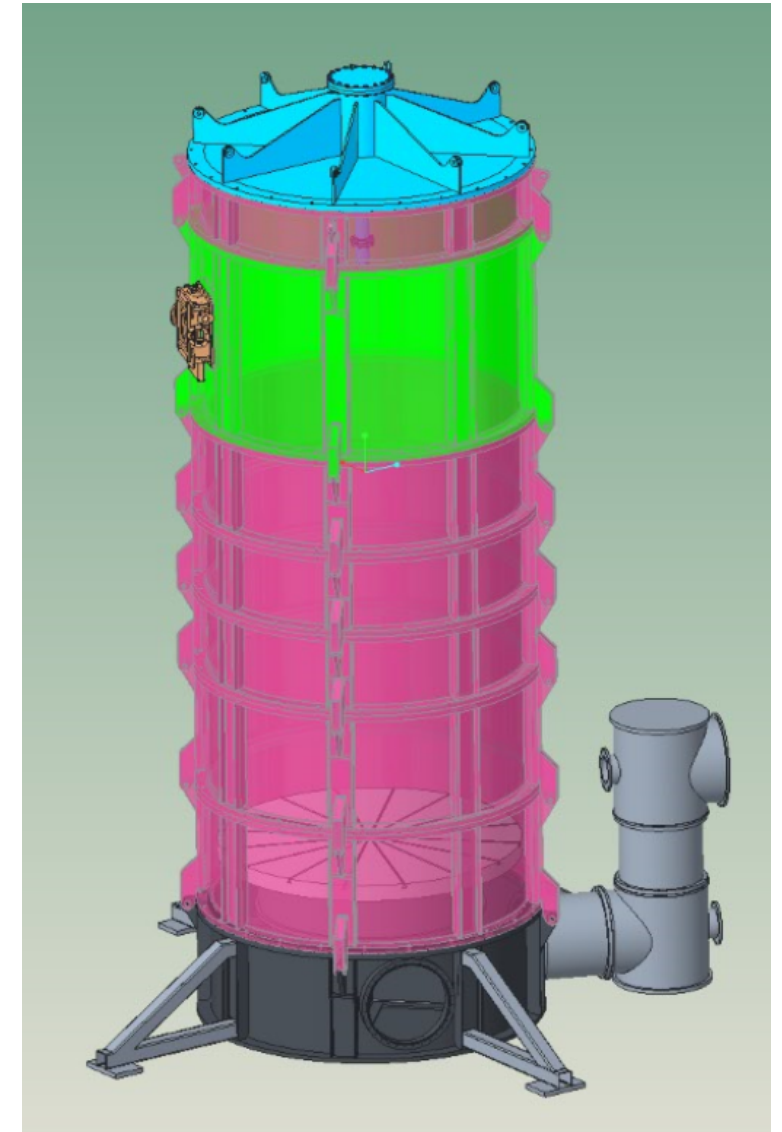
Progress



- Major equipment for EBW system and vacuum systems ordered and some assembly completed.
- MIC-EBW system design near complete; design review planned in late-January 2020. Includes: all major modules.
- Vacuum seal design finalized; mockup planned to evaluate sensors.
- Determined sequencing of NuScale girth welds and stack up of system requirements.
- Plan to finalize planning for Phase II by March 2020.

Summary

- **EBW Equipment Development – Phase 1** (12 months)
 - EPRI, PTR-Precision Technologies , AMRC, Bridger Welding
 - EBW and vacuum equipment ordered
 - Design nearing completion (January design review)
 - Sealing design complete—validation in Q1-2020
- **Demonstration – Phase 2** (18 months)
- **Will establish major capability to produce large vessel welds in USA!!!**



Acknowledgements

US Department of Energy

- Tansel Selekler, Dirk Cairns-Gallimore, Isabella van Rooyen

PTR-Precision Technologies

- David Trembly, Bill Howe, John Dowd, Ed Bonewitz, Wilfried Klein, Derek Mayes

Advanced Manufacturing Center

- Billy Redpath, James Coupe, Garth Nicholson, Merv Alford

Bridger Welding Engineering

- Keith Bridger

Together...Shaping the Future of Electricity