Establishing Modular In-Chamber EB Welding (MIC-EBW) Capability for Thick Section Components

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Outline

- Why Consider Modular In-Chamber Electron Beam Welding (MIC-EBW)?
- DOE Project Objectives
- Phase 1 and 2
- Project Task Updates
- Summary

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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

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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

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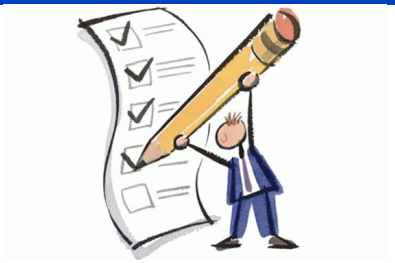
Two-Phase Approach



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 (24 months) – ORIGINAL SCOPE

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. Benchmarking & Technology Transfer (AMRC)
9. Develop/Demonstrate NDE of Final Welds (EPRI NDE)

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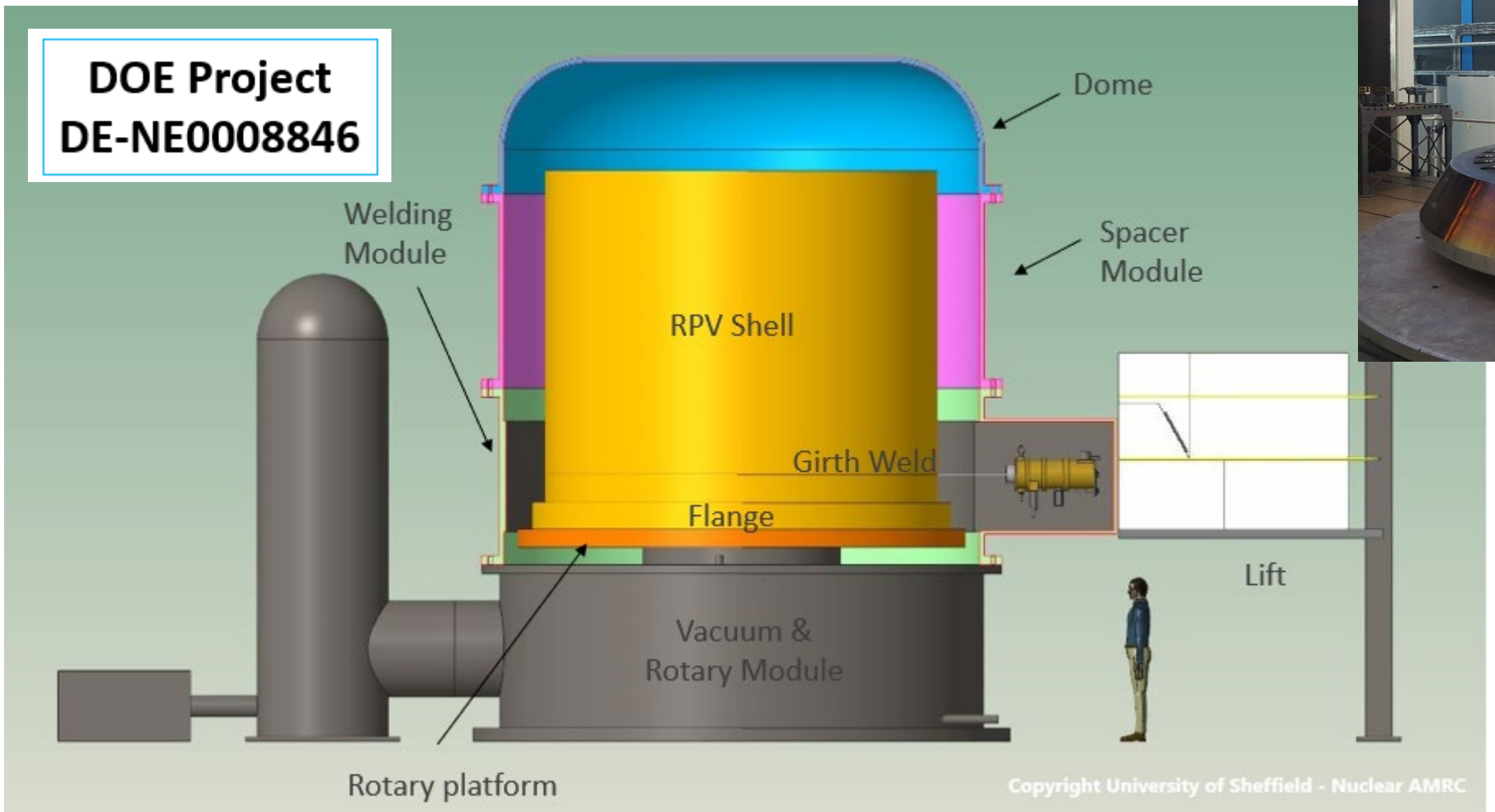
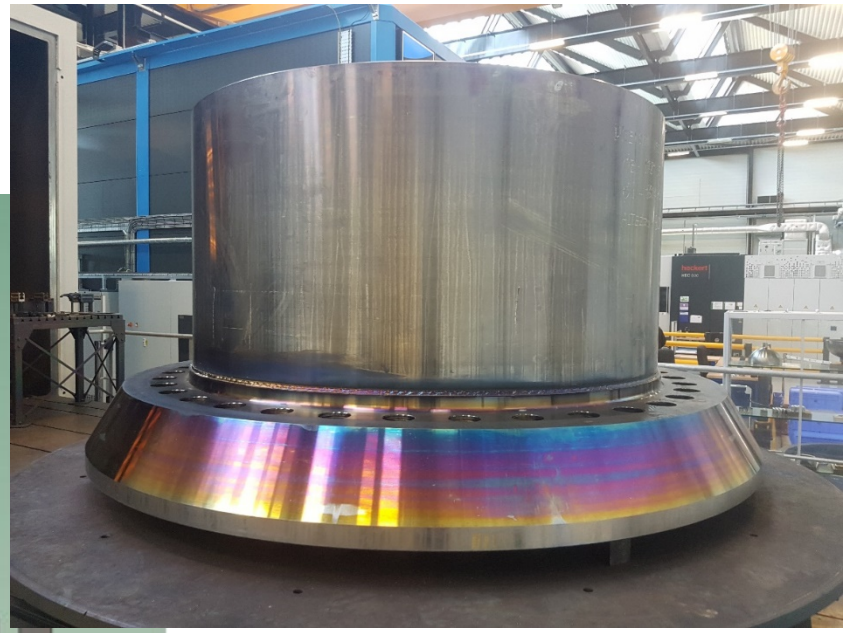
RPV Shell and Flange Shown Inside of Modular EBW Chamber (in gold)





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

Completed in 47 minutes

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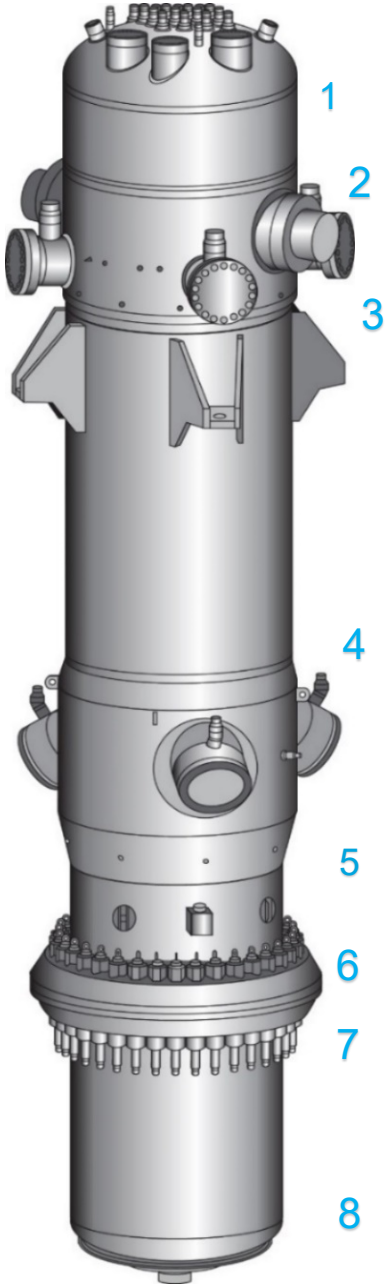
Task 1—Process Planning --Bridger Welding (lead)

- **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



EPRI Report: ANT LR 2020-01

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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**

Vacuum Equipment set up at PTR

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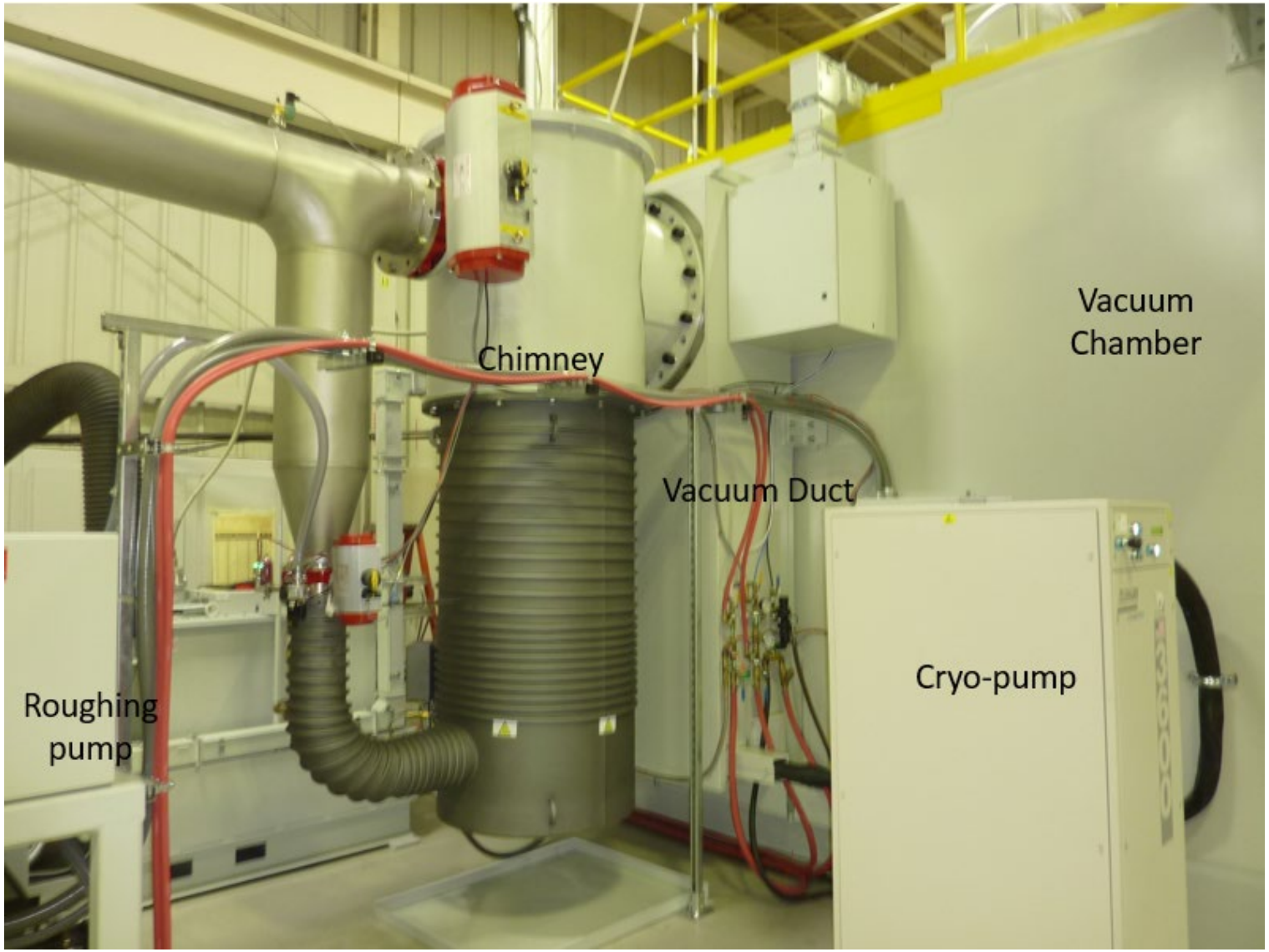
Mechanical pump package



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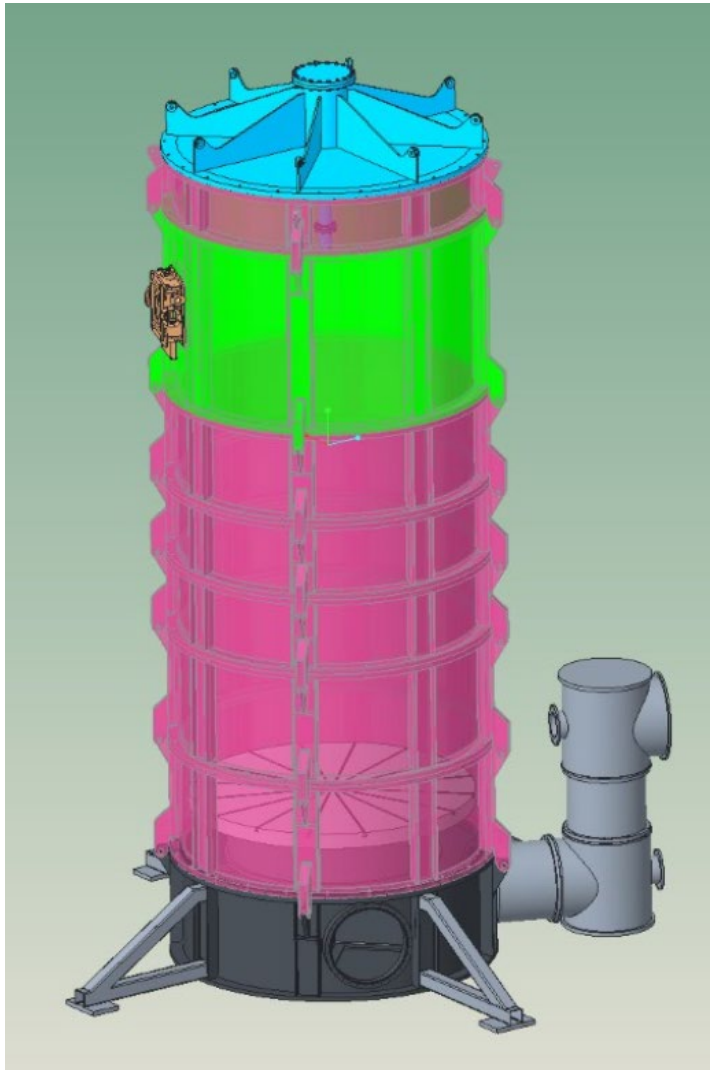
Task 3--Design/Manufacture EB Gun and Slide Module and Perform 4ft Diameter Demonstration (PTR Lead)

- 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).



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

- The MIC-EBW gun system demonstrated at PTR-Precision Components site:
  - Employs a 4ft (1.1m) diameter rotary table positioned inside a vacuum chamber.
- Considered necessary to make sure that all system components (minus the large rotary table and large vacuum chamber) work together.
- 5-inch thick 508 steel rings sufficient to demonstrate the MIC-EBW gun and slide capability.

Large diameter steel rings

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Assembly of the EB welding equipment for the MIC-EBW system

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Control Console and 4ft Diameter Demonstration Vacuum Chamber

PTR
PRECISION TECHNOLOGIES, INC.

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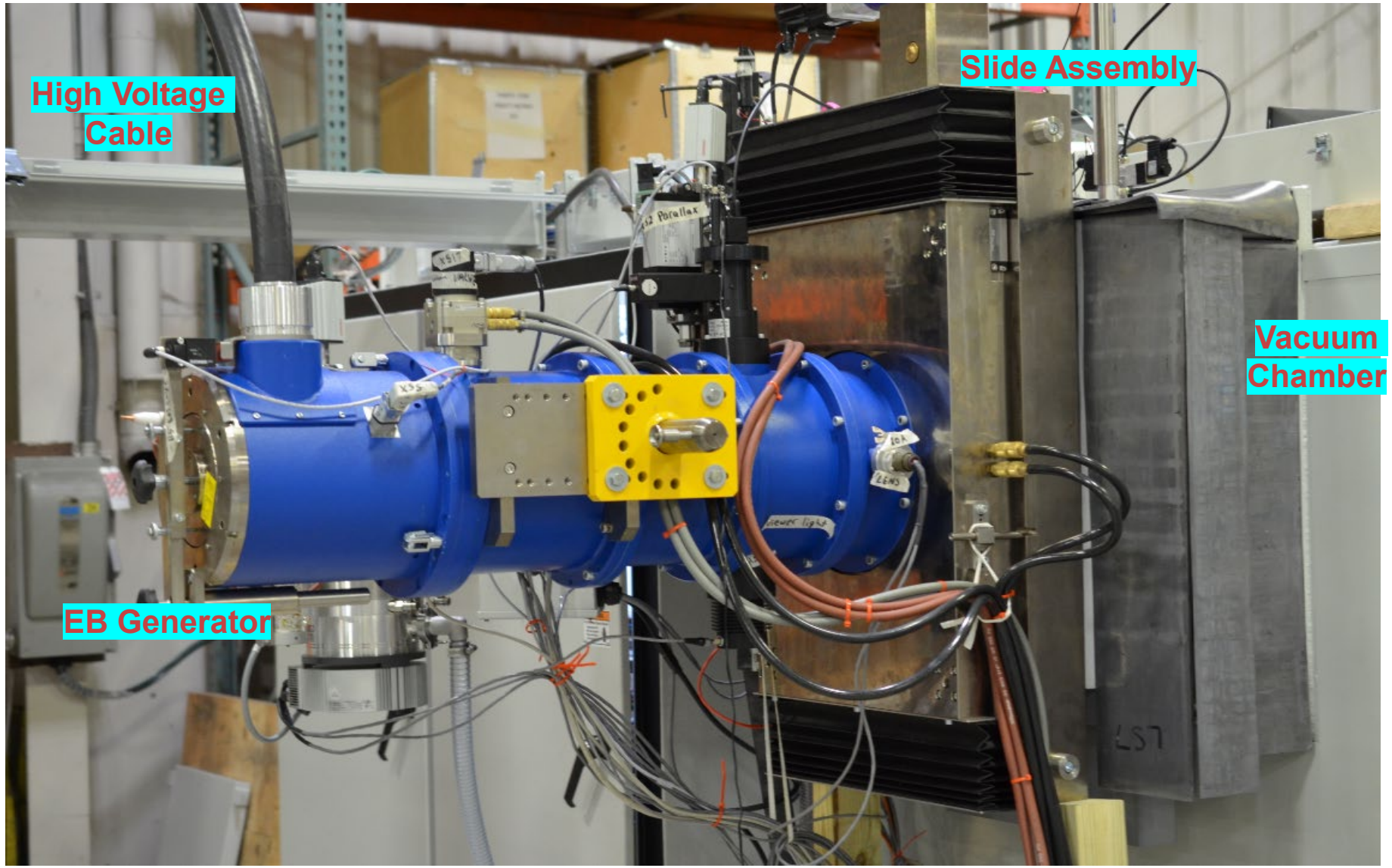
EB Generator and Slide attached to the vacuum chamber



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Secondary Viewing System & EB Jump Capability

- Electron Beam Optics
  - To scan, view, and track the weld seam.
- EB View and Electron Optical Viewing
  - Alternative to CCD camera and light optics

- EB Jump Capability & Software
  - Simultaneous welding at different locations
  - Joint detection with EB system
  - Multi-process applications
    - Simultaneous welding
    - Preheating
    - Smoothing of a weld.

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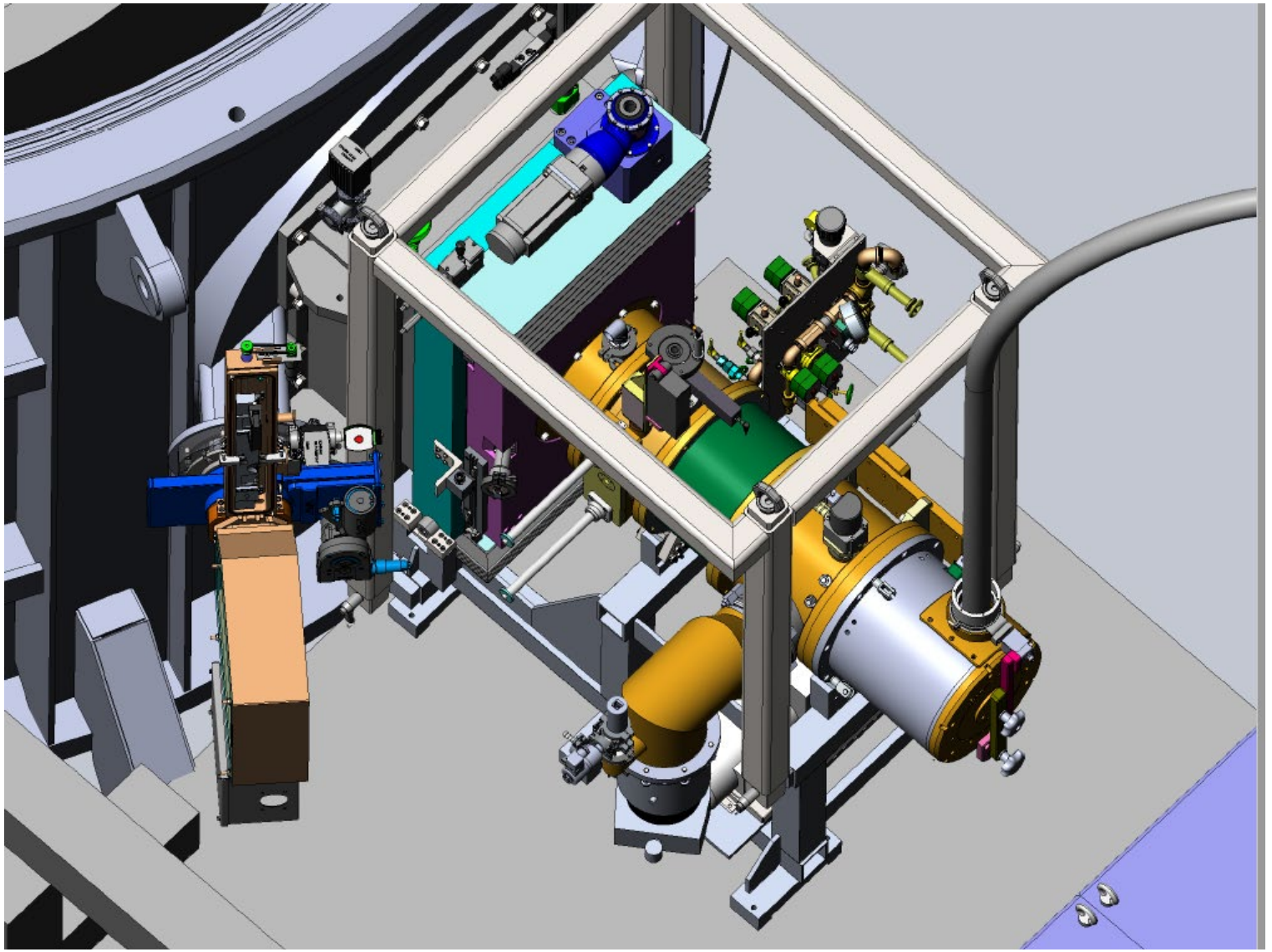
EB Generator Lifting Cradle



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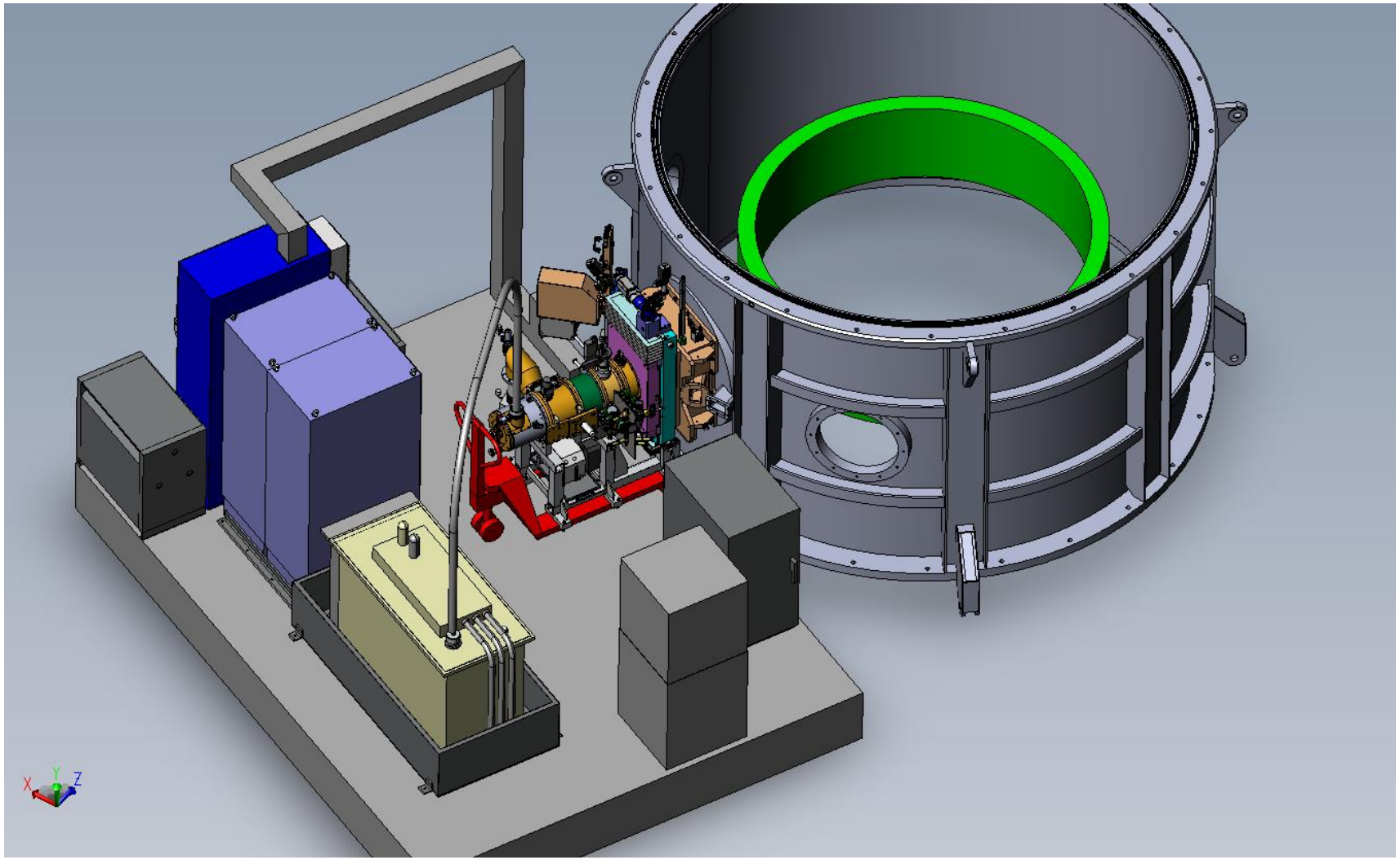
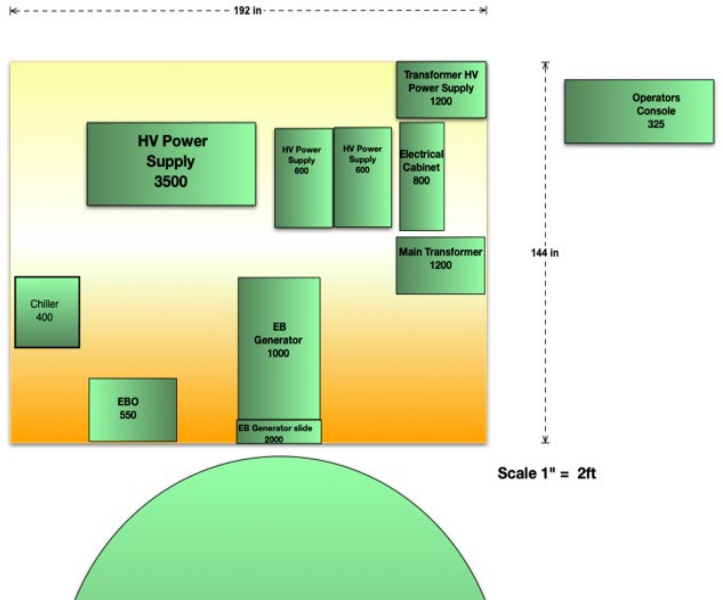
Platform & System Layout





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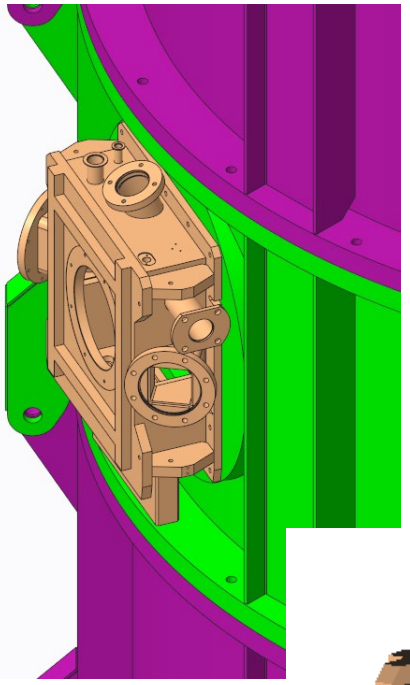
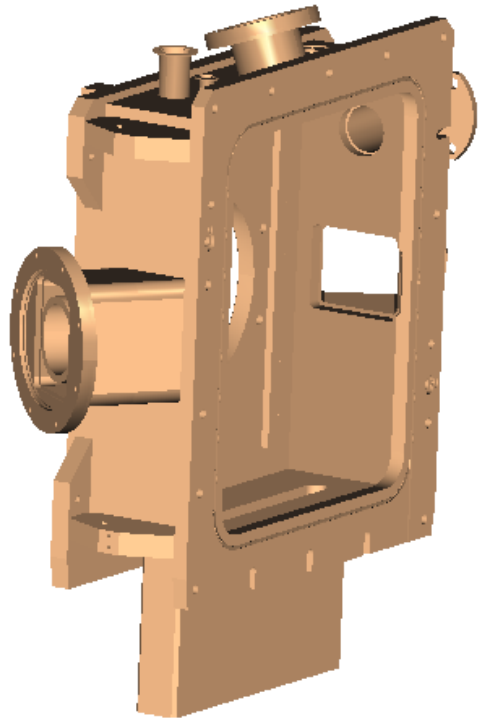
EB Gun Slide and Module Interface Plate

- The “EB gun and slide” is 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.
- 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.





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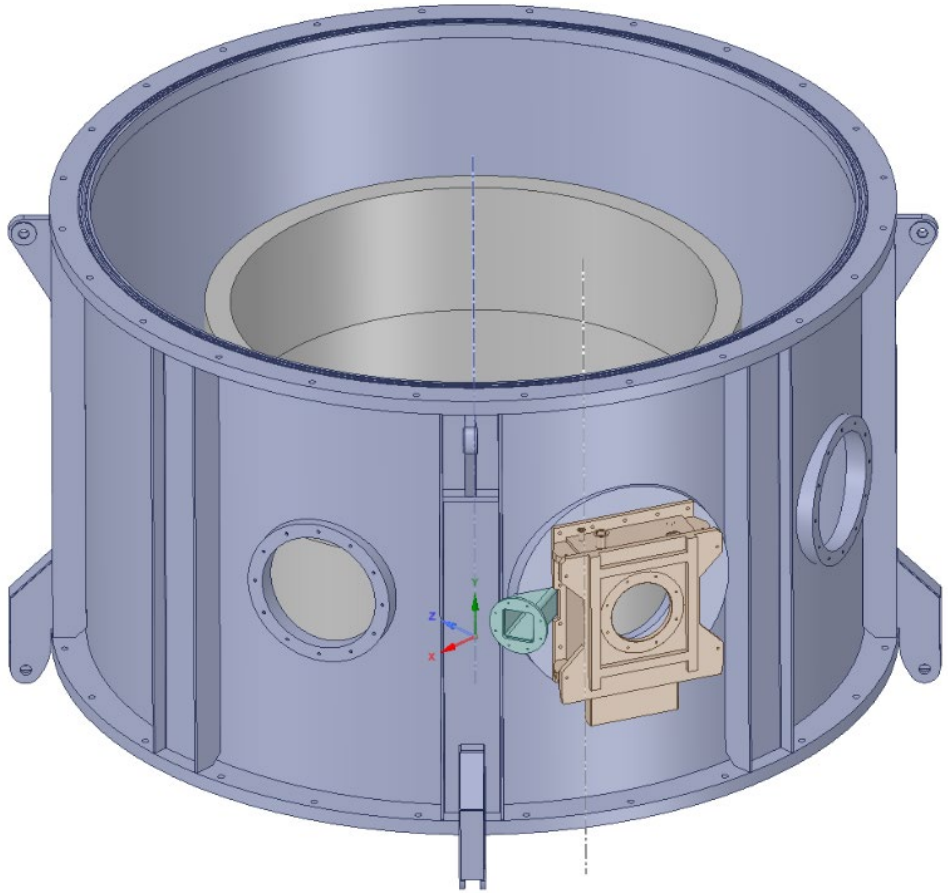
Component Parts of EB Module – Outer Shell

- 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



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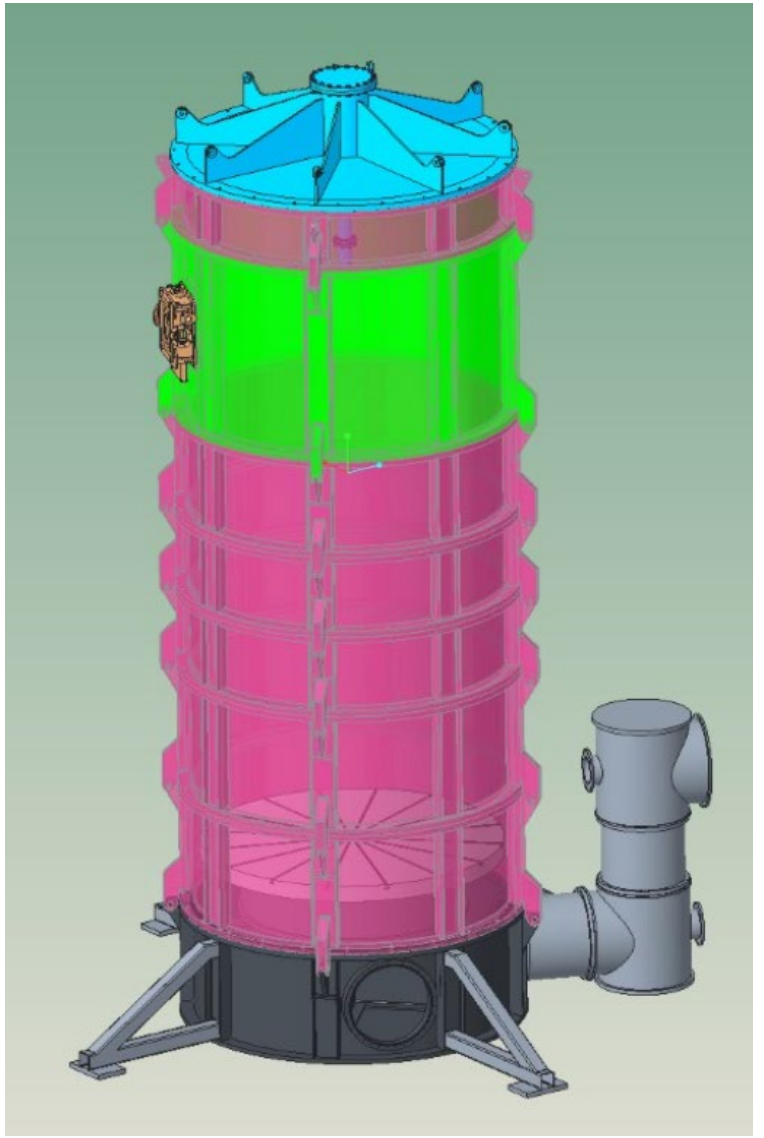
Task 4--Design Vacuum Seals for Modular Ring Sections (AMRC-UK Lead)

- Precise coupling of modular ring sections is required to eliminate air leakage and to achieve high vacuum (~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



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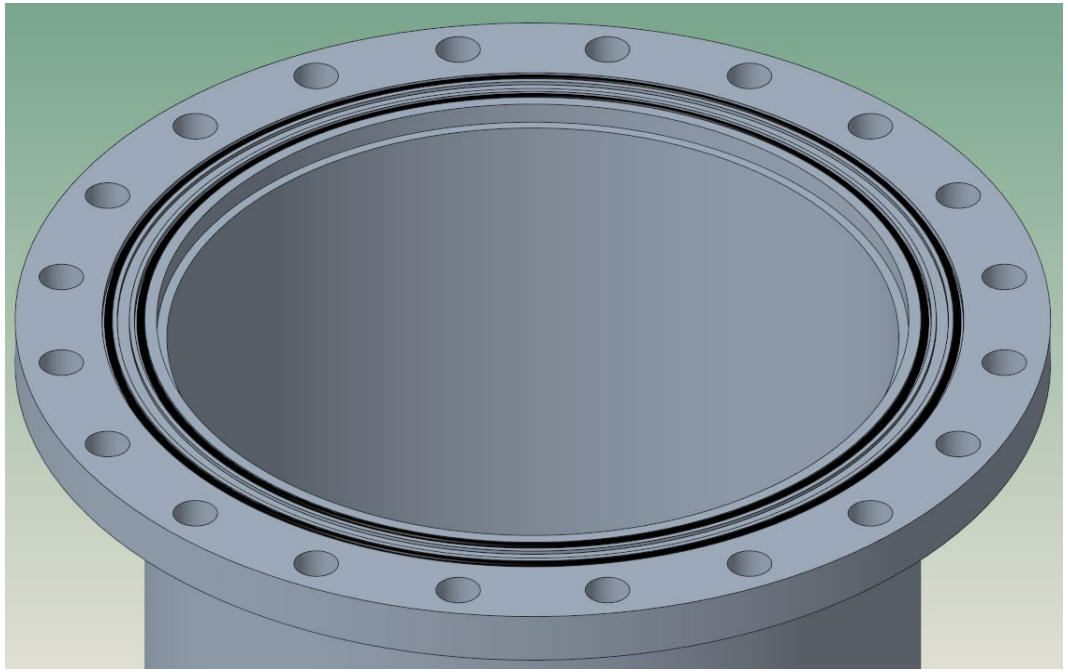
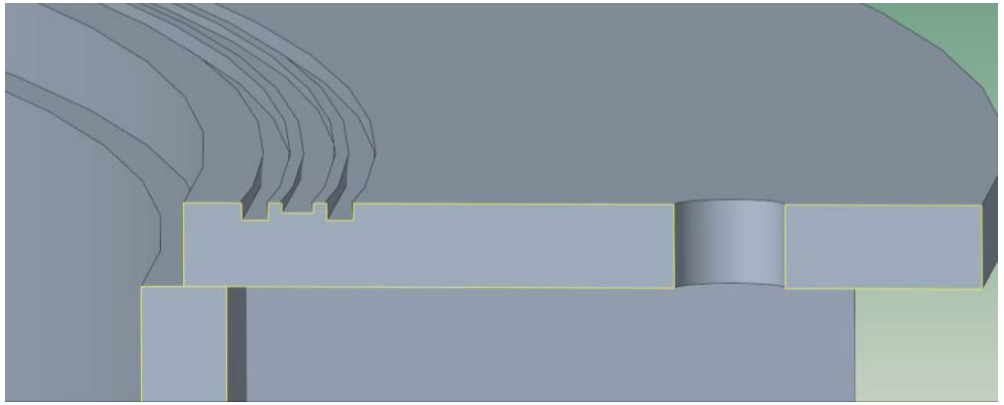
Task 4--Design Vacuum Seals for Modular Ring Sections --AMRC Lead

- 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

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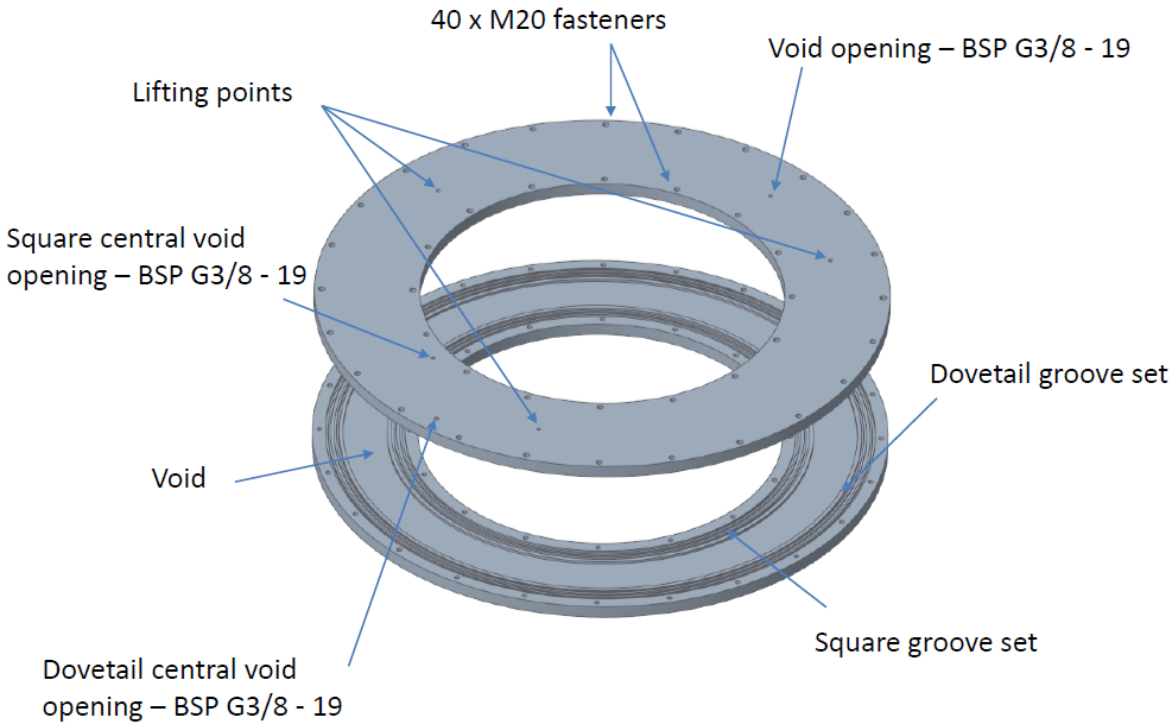
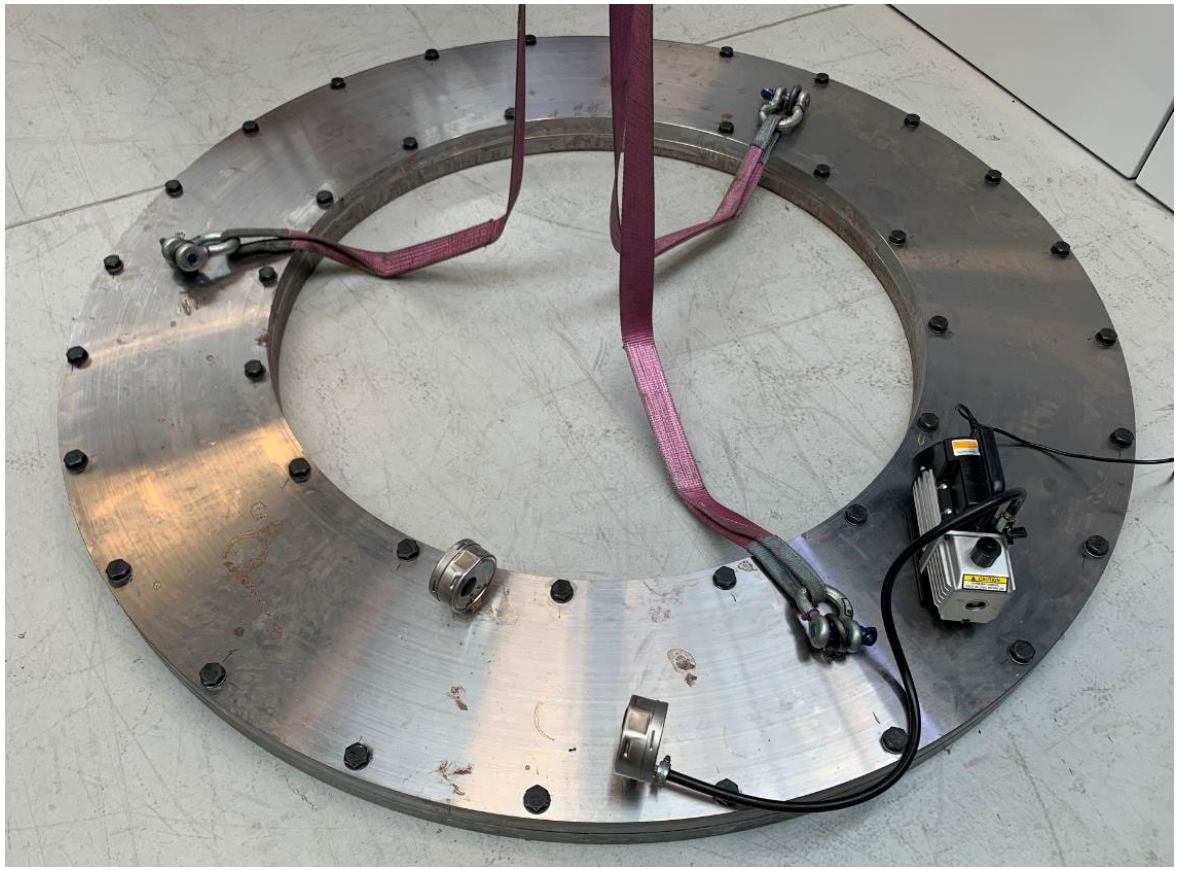
Vacuum Seal Test Mockup





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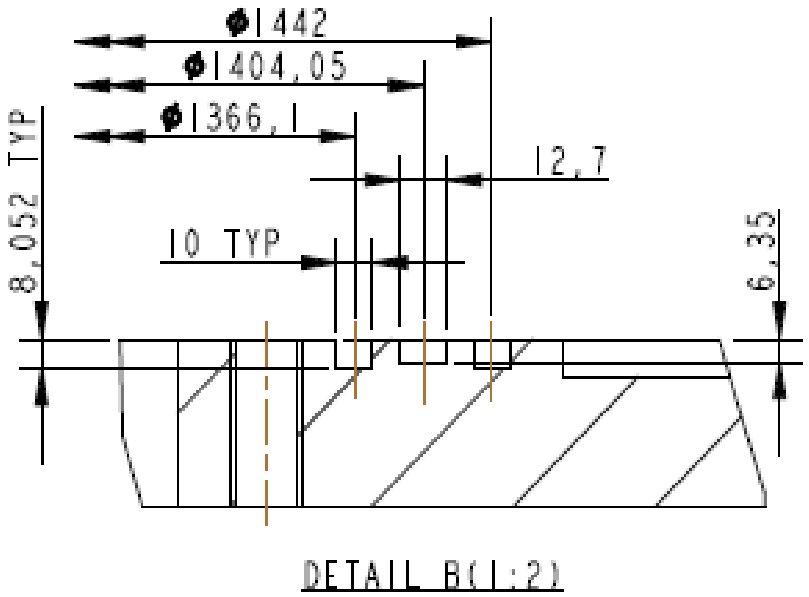
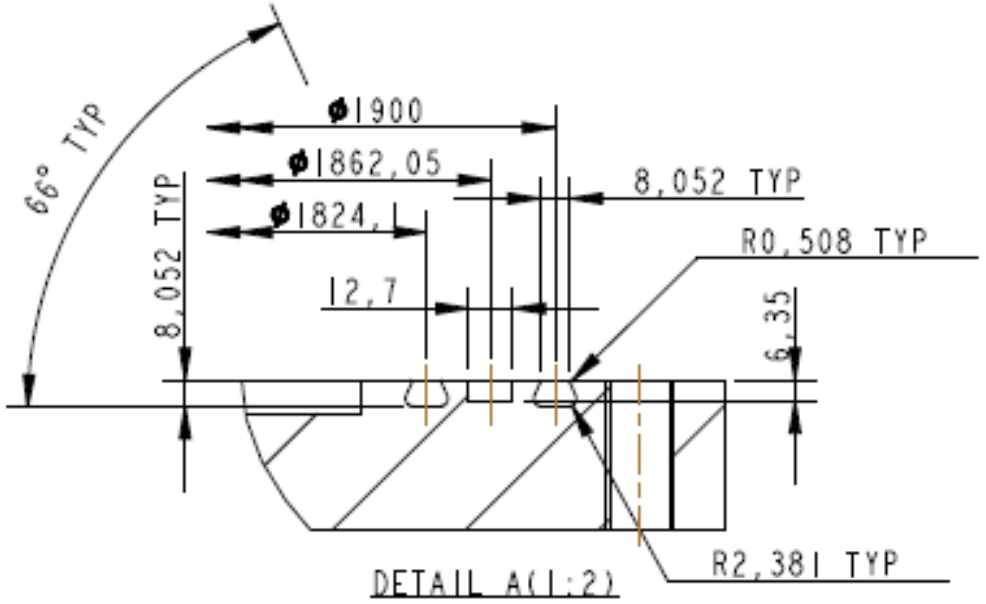
Two Geometries Tested

Silicon O-Ring material w/ medium Shore A Hardness of 60 selected



Square groove



Dovetail groove

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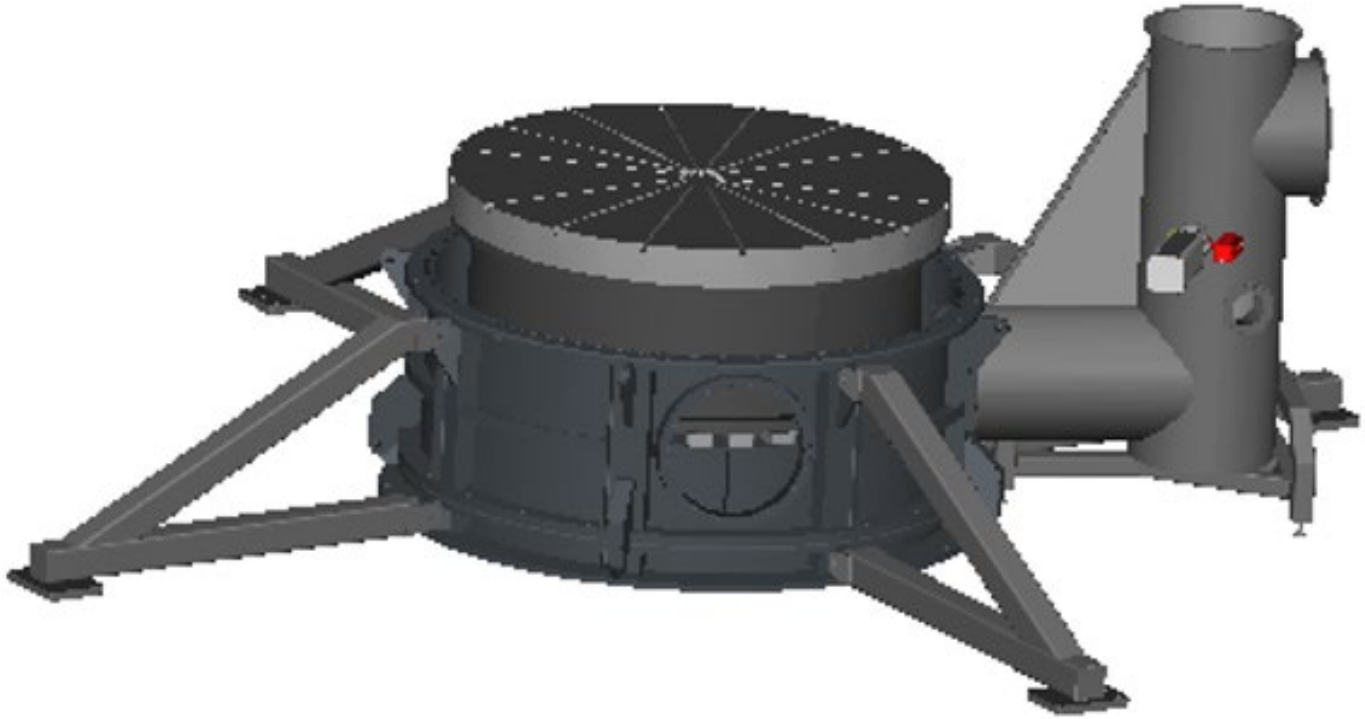
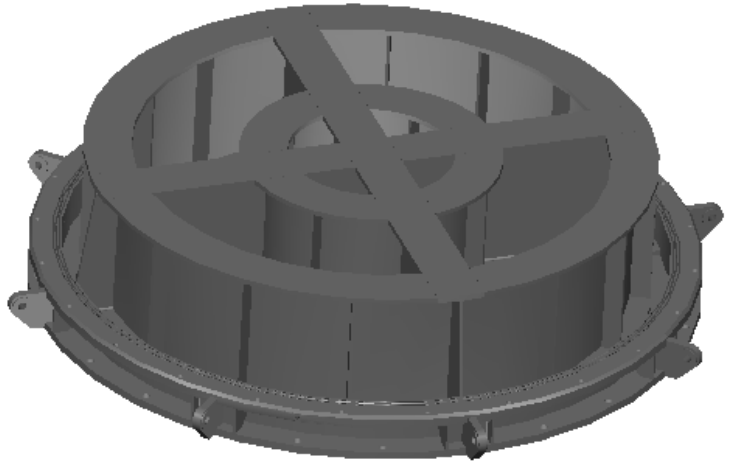
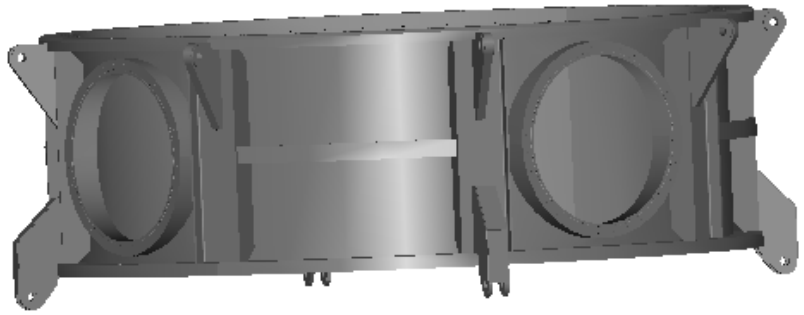
Vacuum Module Design







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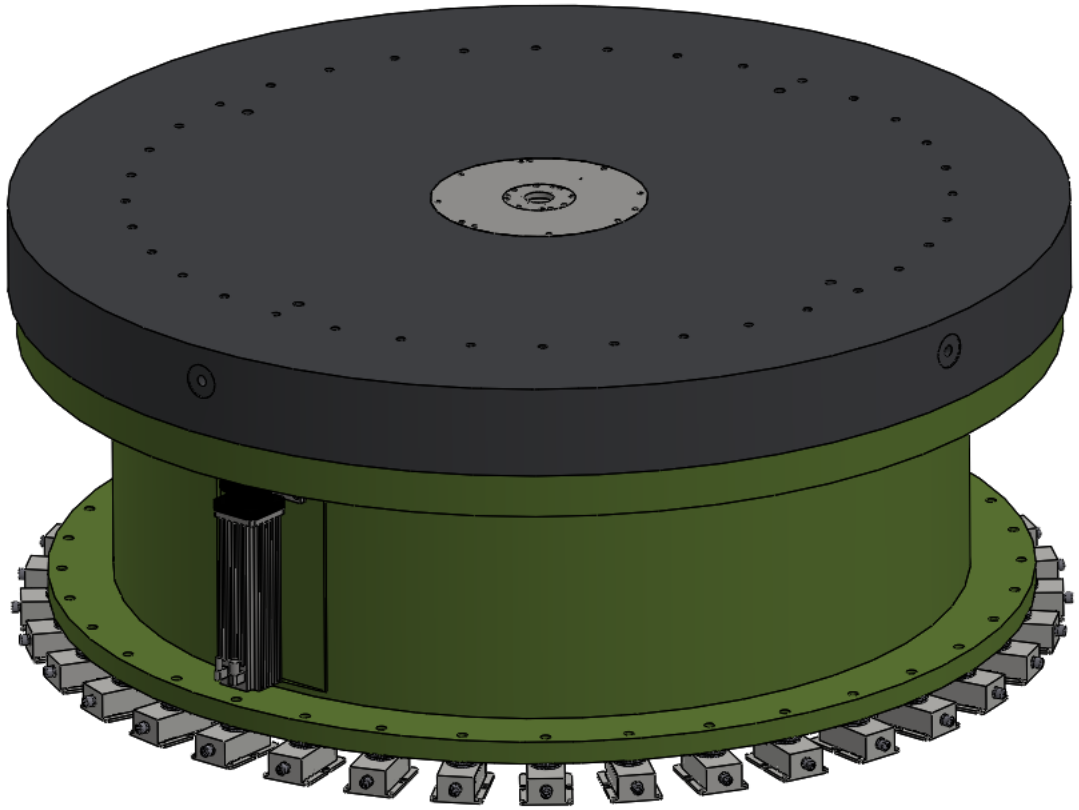
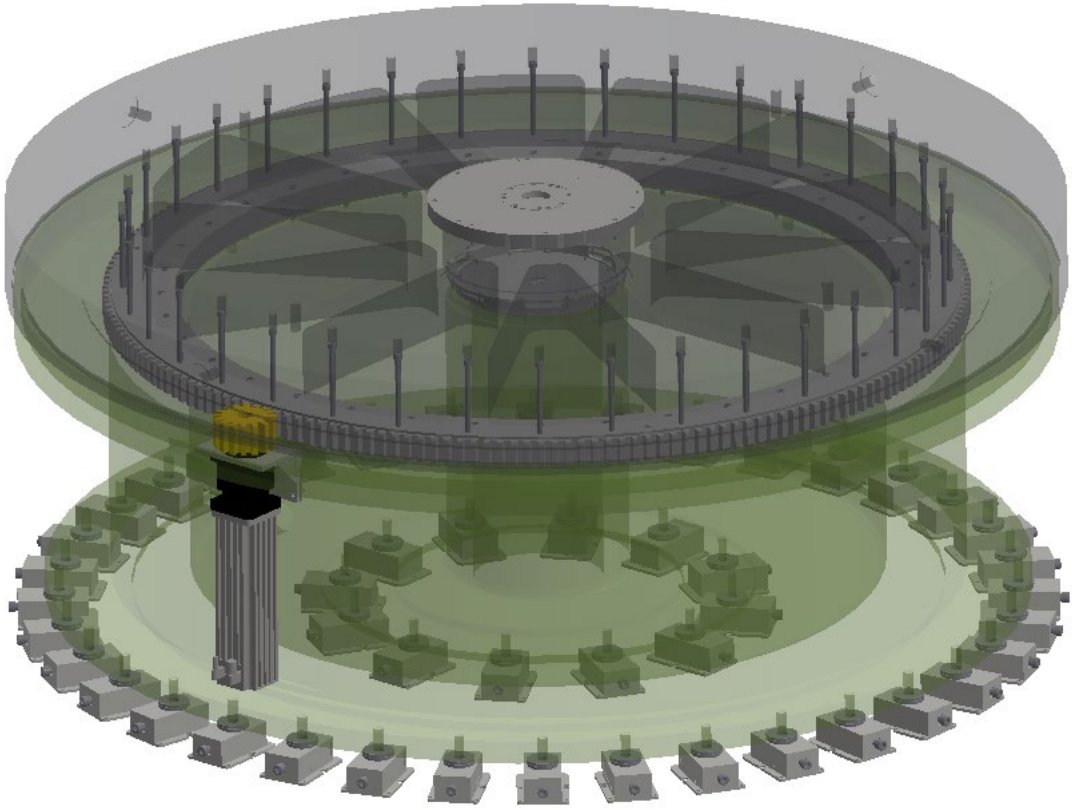
Rotary Table Design





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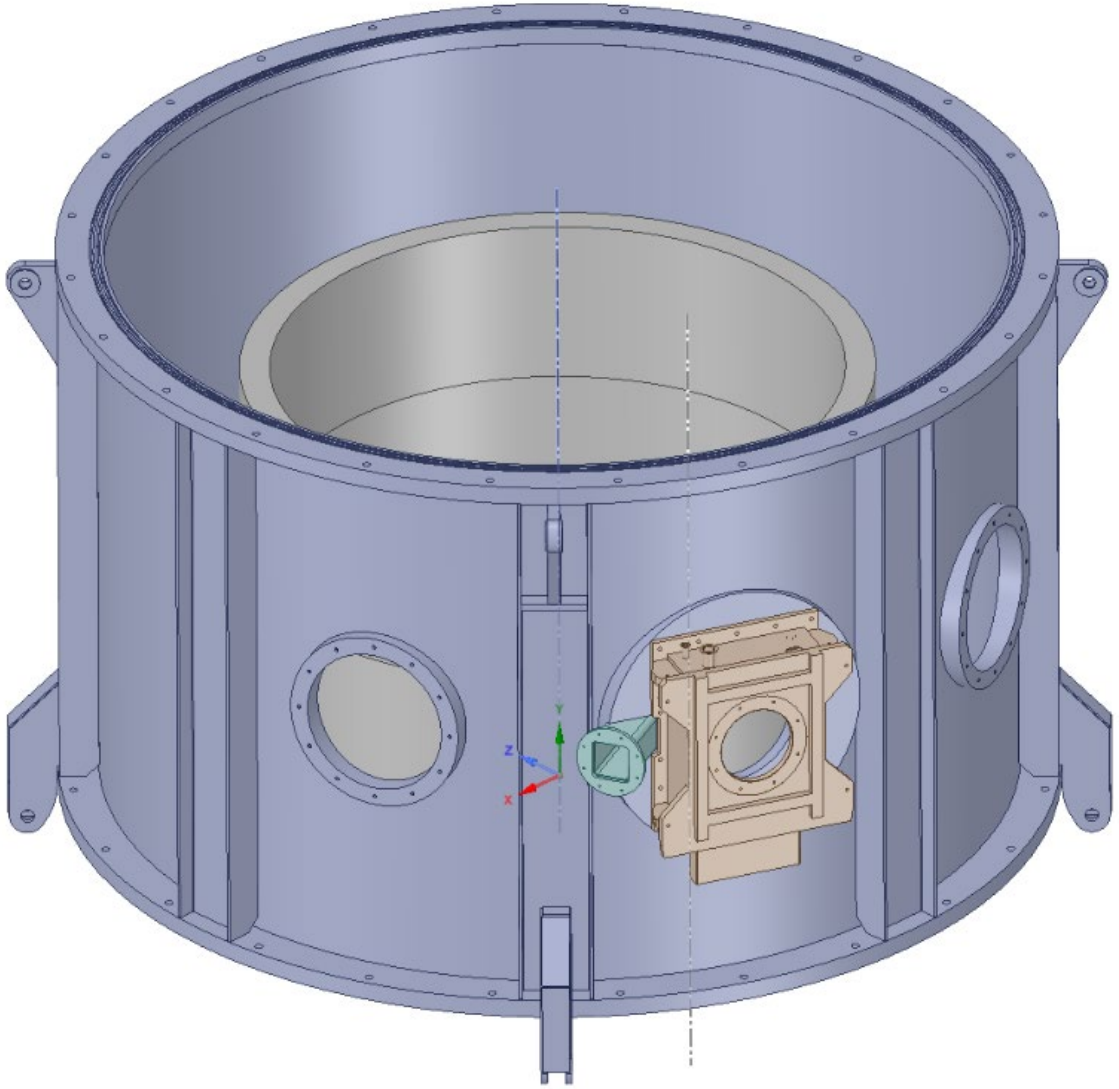
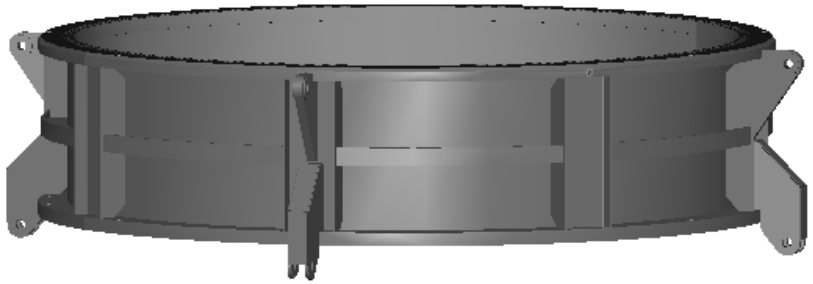
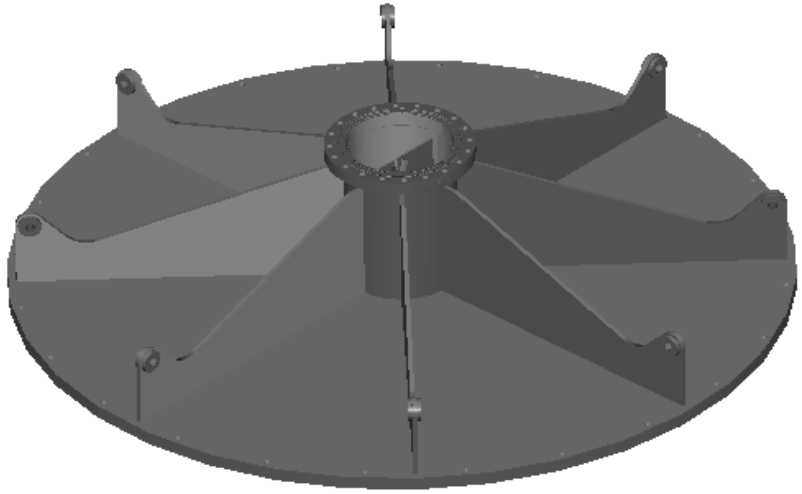
EB and Spacer Module, plus Lid



EB Module with RPV ring inside it.



Spacer Ring



Lid

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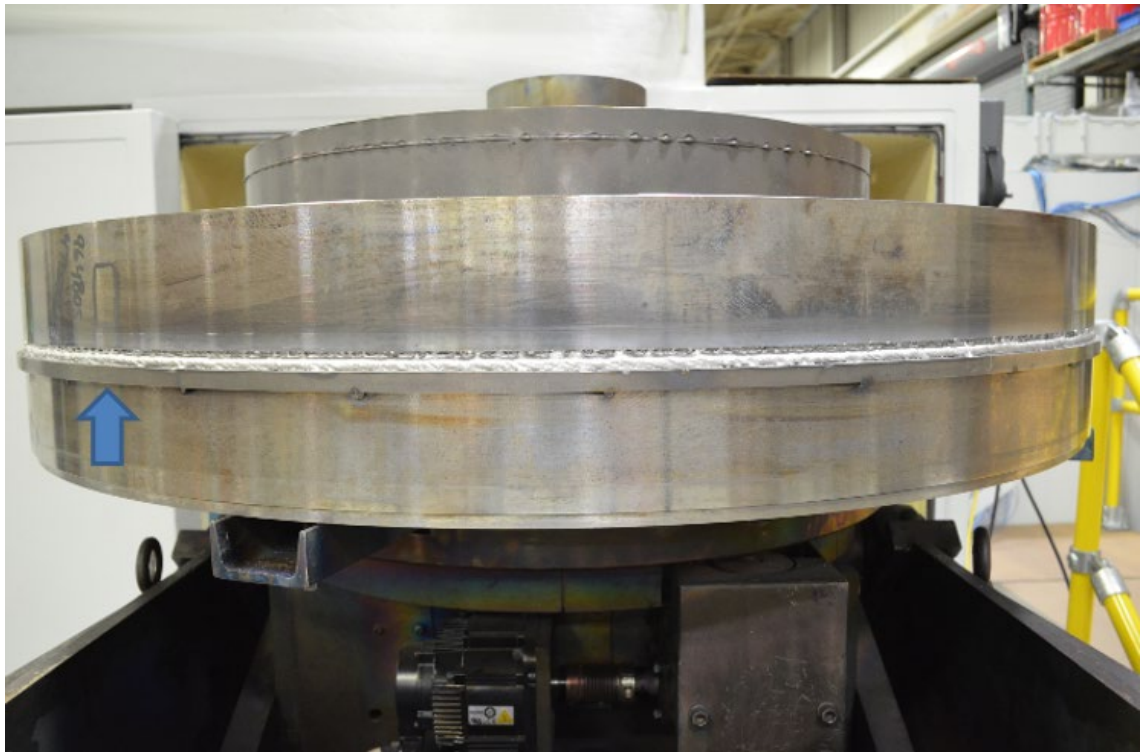
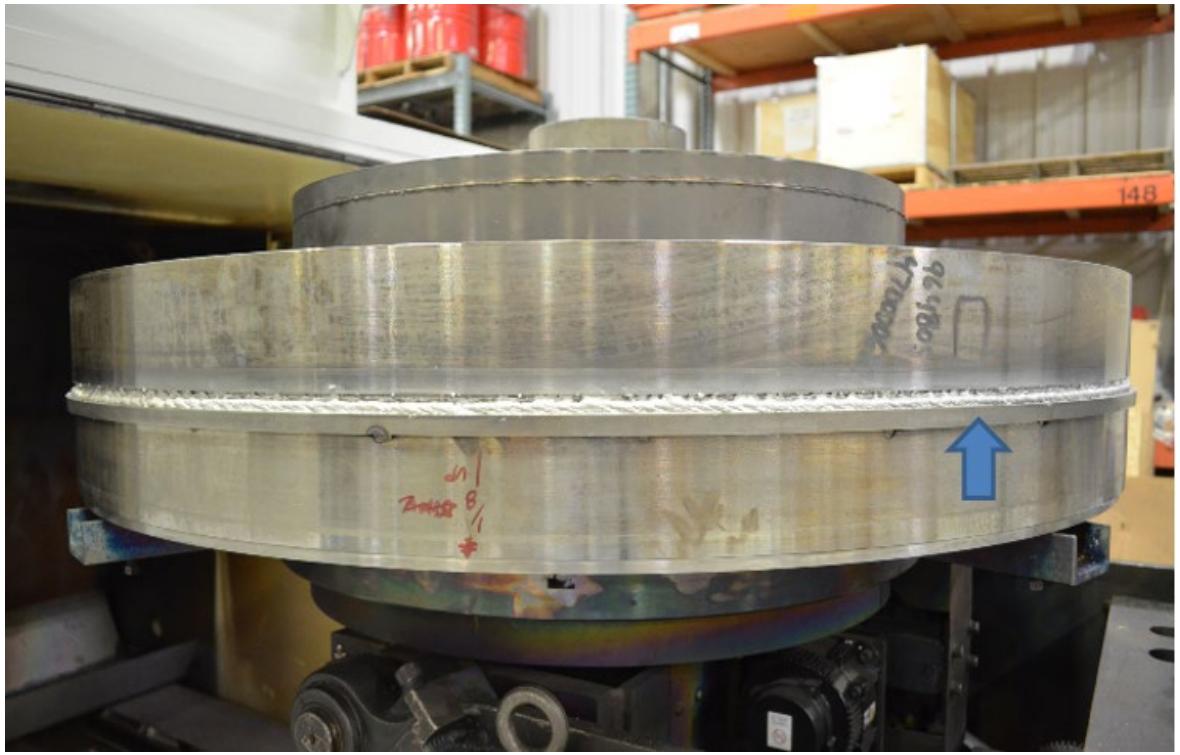
4ft Diameter x 5-inch Thick Weld Performed Using Quadrant D Parameters





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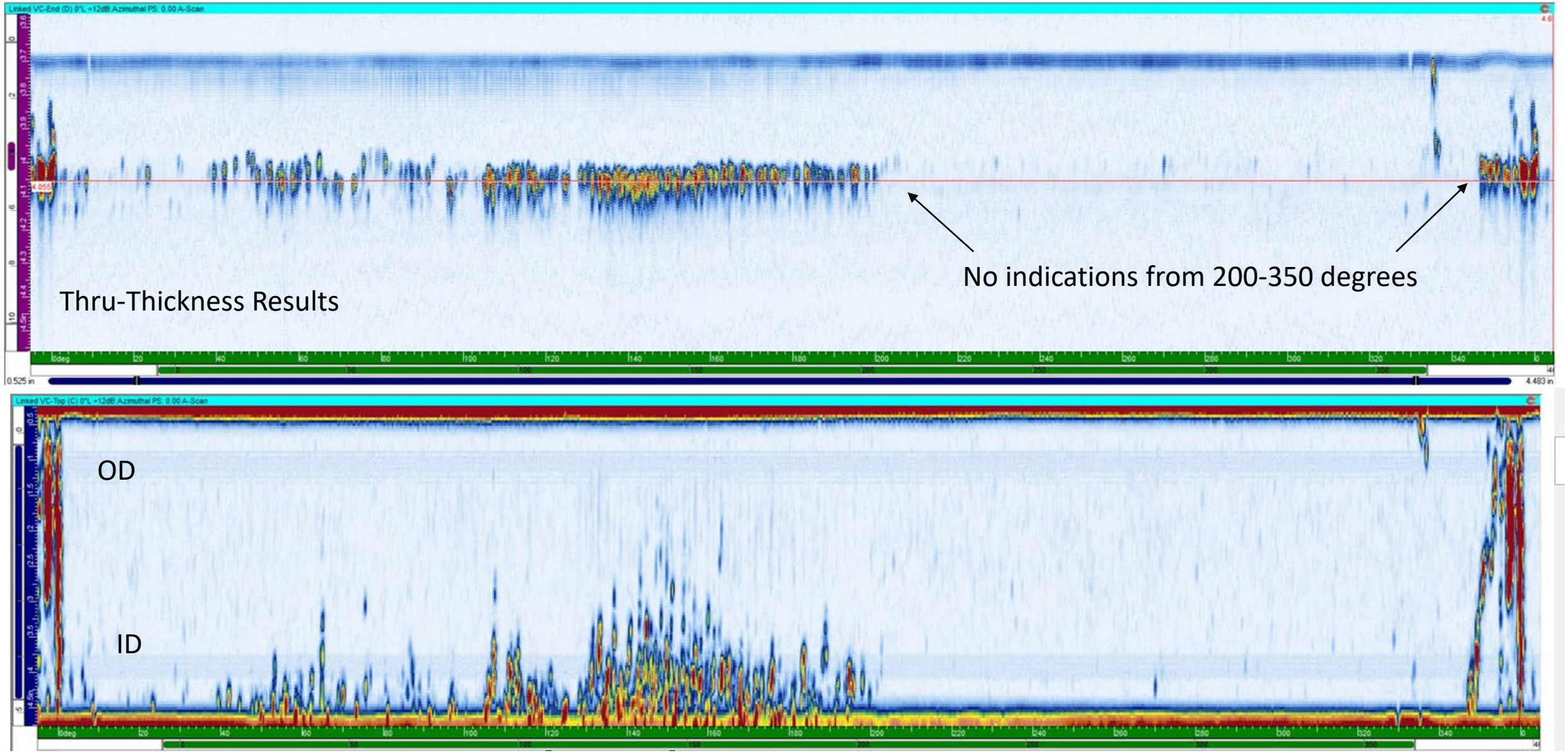
First Weld Coupon -- Ultrasonic Testing Results



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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

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Project Deliverables

Phase 1--Equipment (COMPLETED)

- 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
- Develop vacuum sealing technology for large EB modules
- Demonstrate EBW capabilities on 4ft (1.1m) diameter rings

3002018146 Final Report: *Program on Technology Innovation: Modular In-Chamber Electron Beam Welding, Phase 1—System Design and EBW Equipment Production*

Phase 2--Demonstration (awarded)

- 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

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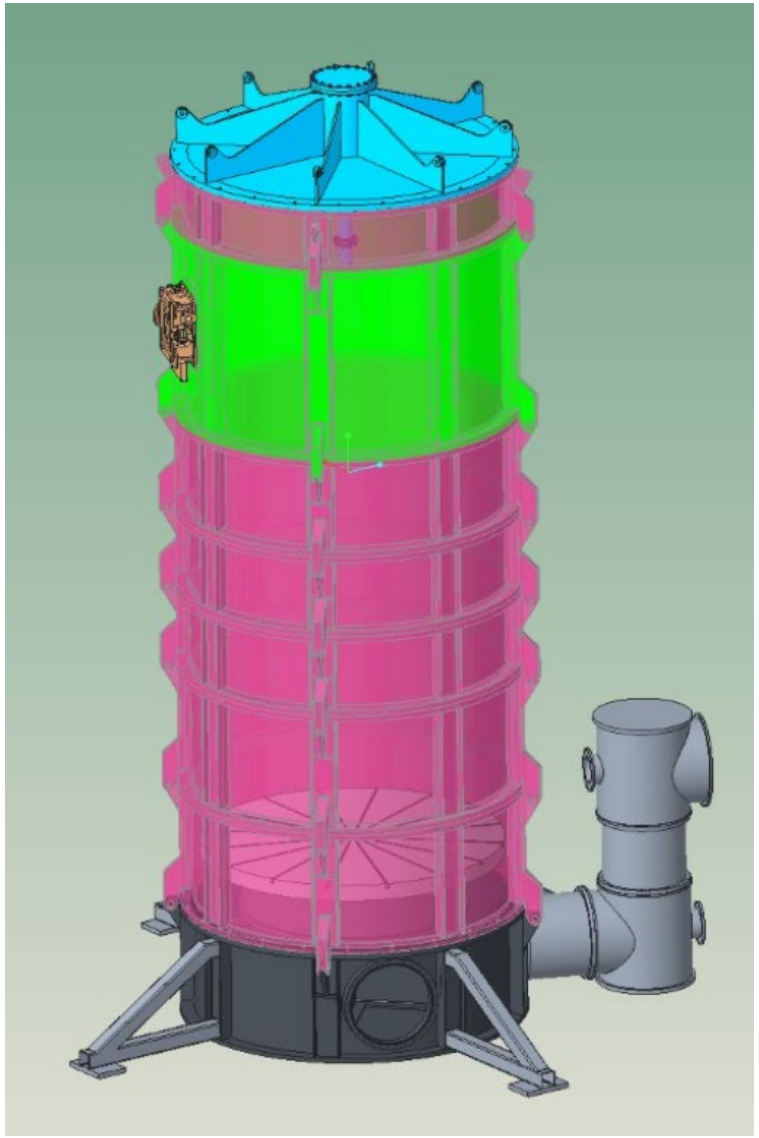
Summary

- EBW **Equipment Development** – Phase 1 (complete)
  - EPRI, PTR-Precision Technologies , AMRC, Bridger Welding
  - EBW and vacuum equipment assembled and tested
  - All design complete
  - Sealing design completed and validated
- **Demonstration** – Phase 2 (24 months)
- Will establish major capability to produce large vessel welds in USA!!!



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Phase II – MIC-EBW Project

- Task 6. Produce Modular Ring Sections/Stages and Fabricate Modular Vacuum and EBW Sections/Stages for SMR Welding/Joining
- Task 7. Demonstrate Modular EBW Capabilities at Full-Large Scale
- Task 8. EBW Benchmarking and Technology Transfer
- Task 9. Design, Fabricate, and Demonstrate NDE System
- Task 10. Facility Readiness and Support

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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 – RVI
- Host and Fabricator -- BXWT

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

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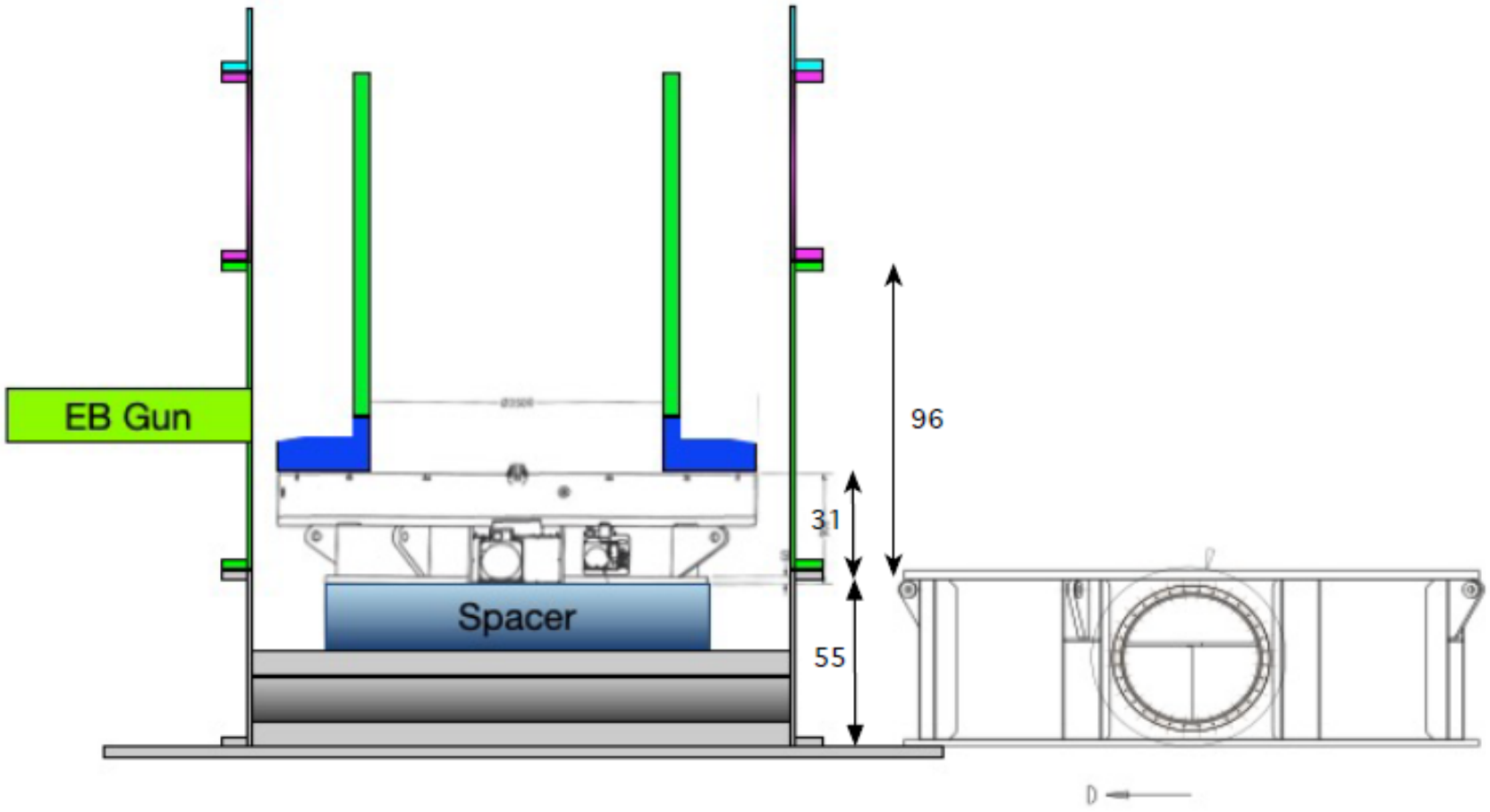
Vacuum Module and Rotary Table Assembled



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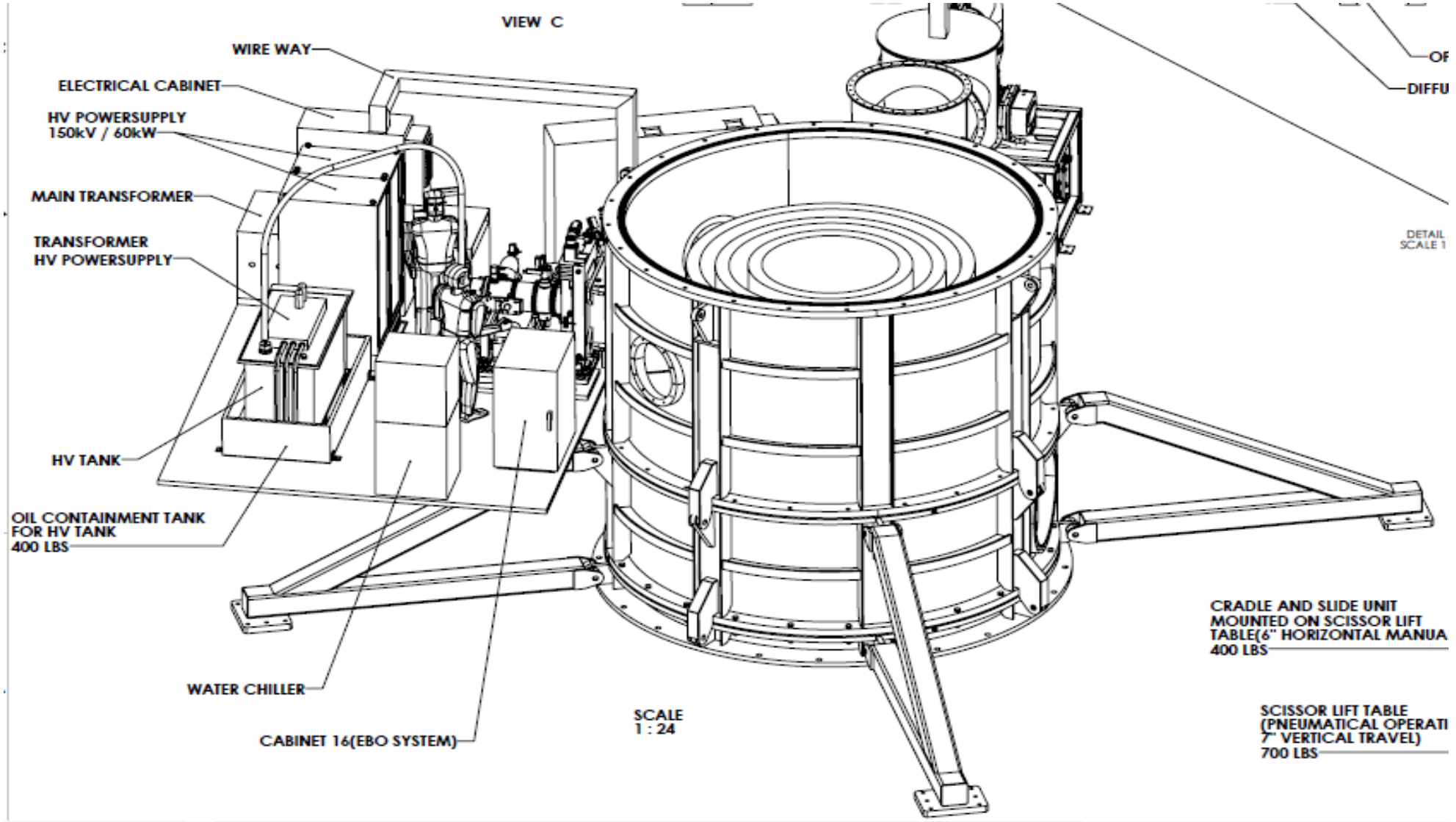
MIC-EBW System & Equipment



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