# SMR Pressure Vessel Manufacturing and Fabrication

D. Gandy
Sr. Technical Executive,
Davgandy@epri.com
M. Albert,
Sr. Technical Leader,
MAlbert@epri.com

**DOE AMM Technical Review Webinar**

December 18, 2019

# Outline

- Background & Objectives
- Development/Demonstration of 4 Advanced Manufacturing/ Fabrication Technologies
- 2/3-Scale SMR Manufacturing/Fabrication – Phase 1
- Component Dimensioning
- Electron Beam Welding
- Applicability to Advanced Reactors -- Summary

# Vessel Manufacture and Fabrication

- What if it only took 12 months to produce a reactor pressure vessel?
- What if you could perform an entire SMR RPV girth weld in <60 minutes?
- What if you could manufacture an entire SMR head in < 3 months with no vessel dissimilar metal welds?
- What if you could eliminate the need for in-service examinations of girth welds?
- What if you could perform vertical welds to join rolled plates without subsequent embrittlement concerns?

Representative Model of NuScale Power Reactor Vessel

# Enabling the Next Generation of Nuclear Plants -Scope

- Manufacture Major Critical Components to **Assemble a 2/3-Scale SMR Reactor Pressure Vessel**
- Jointly Funded Collaboration
  - EPRI, Nuclear AMRC, DOE, NuScale Power
- Others
  - Synertech-PM, Sheffield Forgemasters, Sperko Engineering, Carpenter, ORNL, etc.

*Photograph provided courtesy: NuScale Power*

**DOE Project: DE-NE0008629**

What Once Took Weeks,
We Can Now Do In Hours…

# Advanced Manufacturing -Objectives

- Rapidly Accelerate the Deployment of SMRs
- Develop/Demonstrate New Methods for Manufacture/ Fabrication of a Reactor Pressure Vessel (RPV) in **<12 months**
- **Eliminate 40%** from the cost of an SMR RPV, while **reducing** the Schedule by **18 Months**


200mm Electron Beam Weld

# Electron Beam (EB) Welding

## Why EBW?

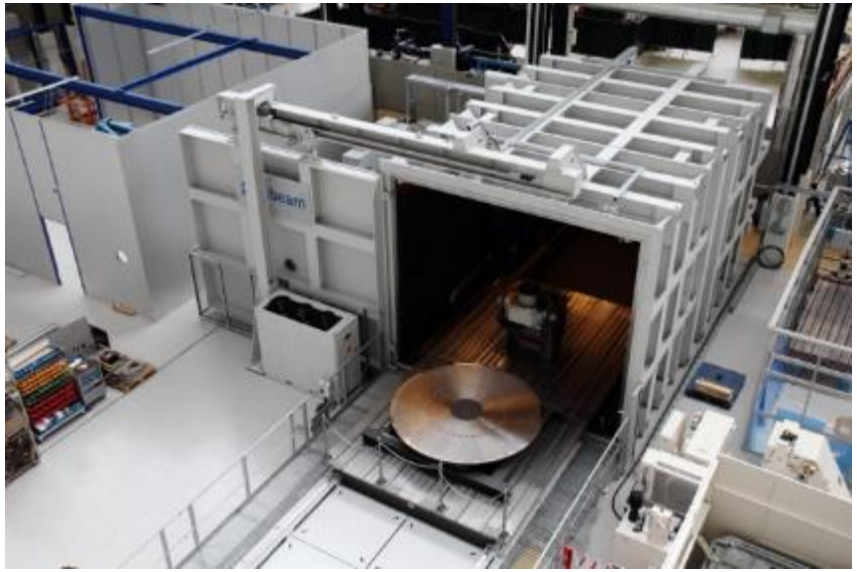
- One-pass welding!
- No filler metal required.
- EBW can produce welds w/ minimal HAZ
- Nuclear-AMRC, TWI, Rolls-Royce & EPRI have demonstrated in-chamber and/or local vacuum on thick section alloys
  - Enables field/shop welding!
- RPV girth welds (110mm thick) in <60 min

## Inspection, Costs?

- Huge savings in welding costs (again, one pass welding)
- Potential to eliminate in-service inspection!

**65mm (thick) x 3m length x 1.8m diameter**
**Welding time: <10 minutes**

*Photograph provided courtesy: TWI (UK)*



*Photograph provided courtesy: Nuclear AMRC (UK)*

# Powder Metallurgy-Hot Isostatic Pressing (PM-HIP)

## Why PM-HIP?

- Near-net shape and complex components (reduces materials cost and machining)
- Alternate supply route, shorter turn-around
- Considerable EPRI/Industry development over last 7 years.
- Ideal for multiple penetration applications (RPV or CNV head) vs expensive forgings

Large 316L SS Valve Body

Steam Separator Inlet Swirler

## Inspection, Costs?

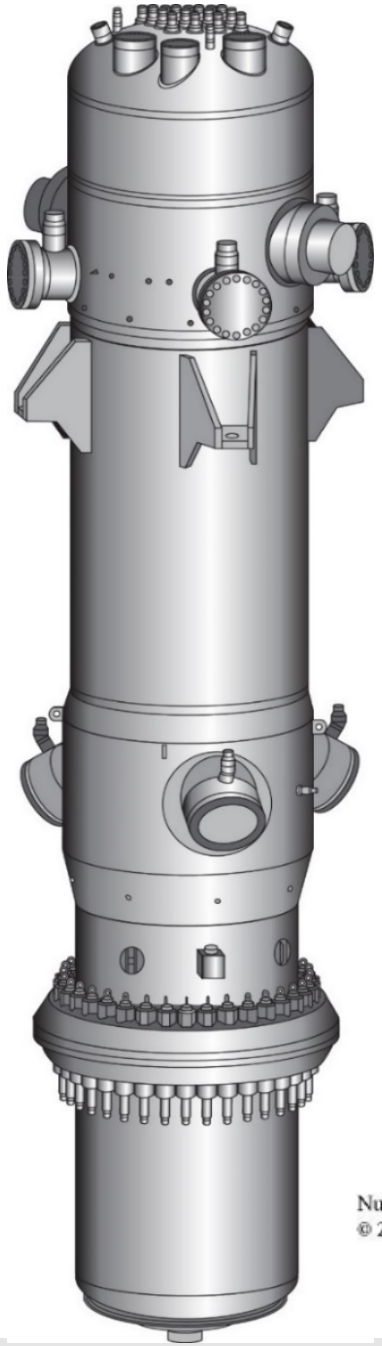
- Homogeneous-Excellent inspection characteristics
- Costs roughly equivalent to forging
- Eliminates need for welds in some applications.

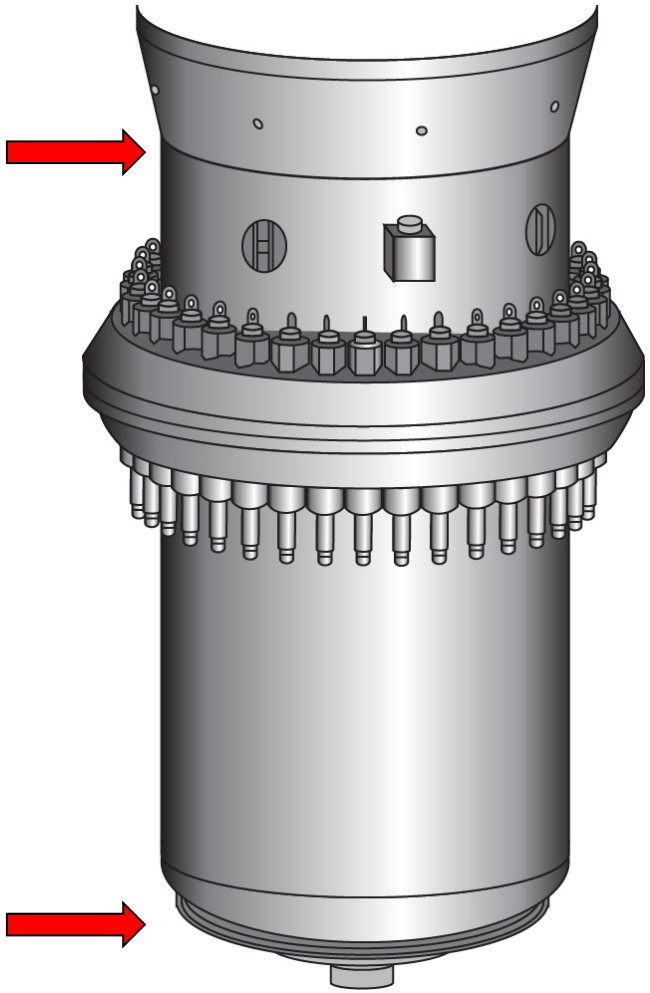
3700 lb BWR nozzle

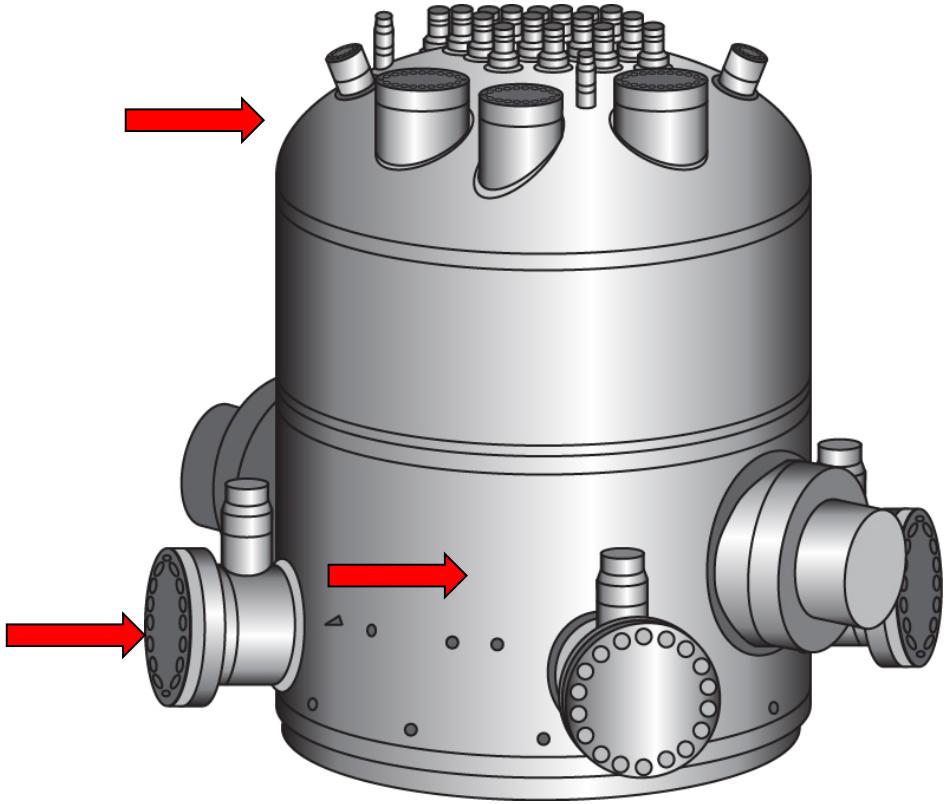
Partial RPV Ring Section

# 2/3rds Scale Small Modular Reactor Manufacture/Fabrication

- EPRI
- Nuclear-AMRC
- US DOE
- NuScale Power

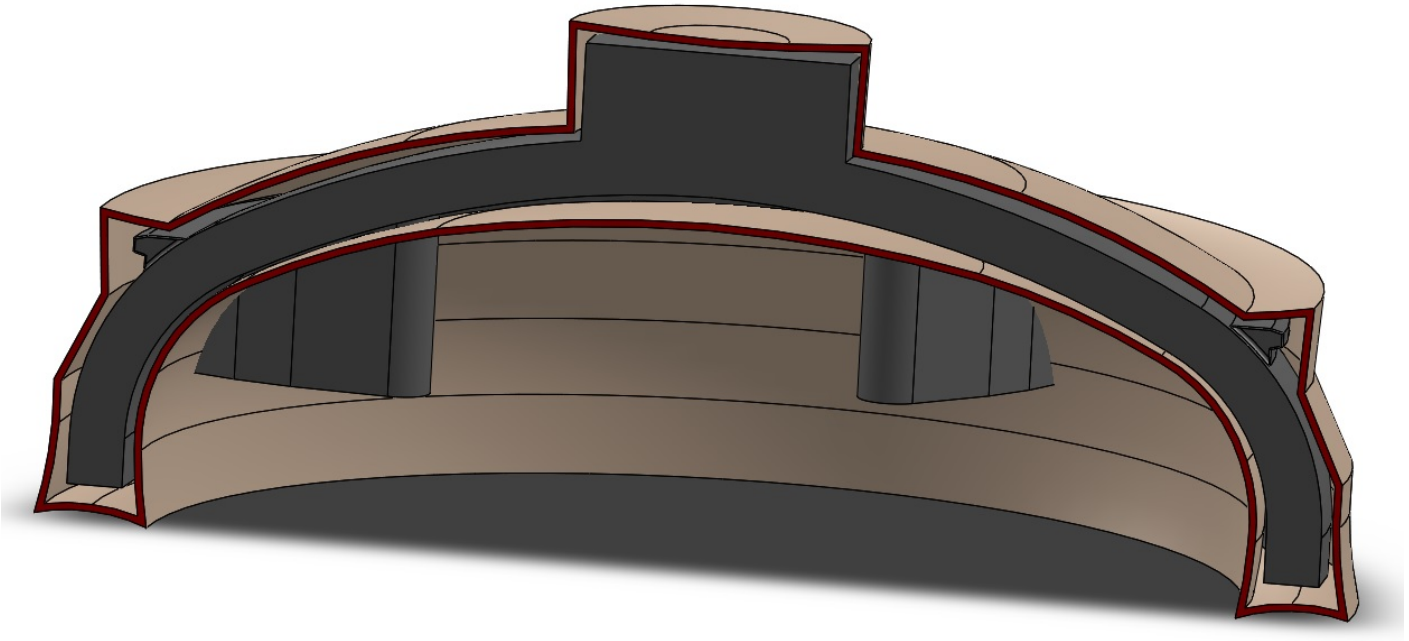






# Lower Head – One-Half Section

# Lower Head—Article 1



**HIP Modeling—Shows Lower Head inside of the Finished Capsule**

**Final part: ~6500lbs (2950 kg) @ 2/3rds scale; Full Scale is ~11,000lbs (1/2 section) (4990kg)**

# Lower Halves– Capsule Completed

# Custom Frame Built for the One-Half Lower Head Section


- **Non-symmetrical component** in one-half section.
- Custom rack required due to size of existing HIP furnaces in USA.
- 1.67m (66 inches) diameter in USA; 2m (78.5 inches) in Japan
- Must be stood upright in custom frame

# One-Half Lower Head HIP'ed & Dimensioned


6910 lbs (3134kgs)

# Lower Head Manufacture/Assembly

- Three one-half section (at 2/3rds scale) reactor heads modeled and manufactured
- 1st Article – Produced to gain understanding of movement of asymmetrical ½-head section during HIP
  - Modeling and canning modified based on learning from 1st Article
- 2nd and 3rd Articles produced following analysis of 1st article

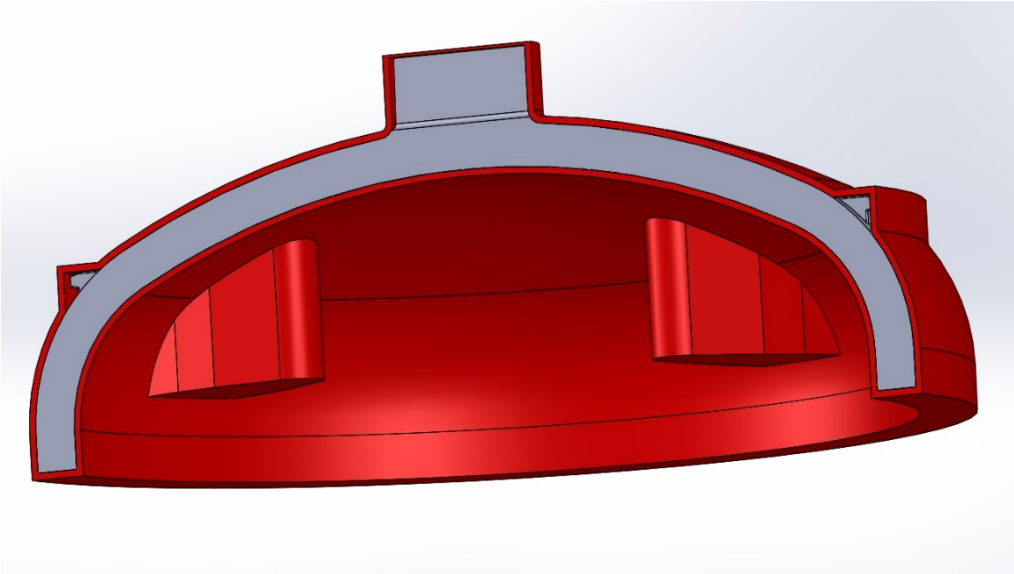
Note: Synertech-PM performed all modeling and dimensioning. HIP was performed at Bodycote Portland.

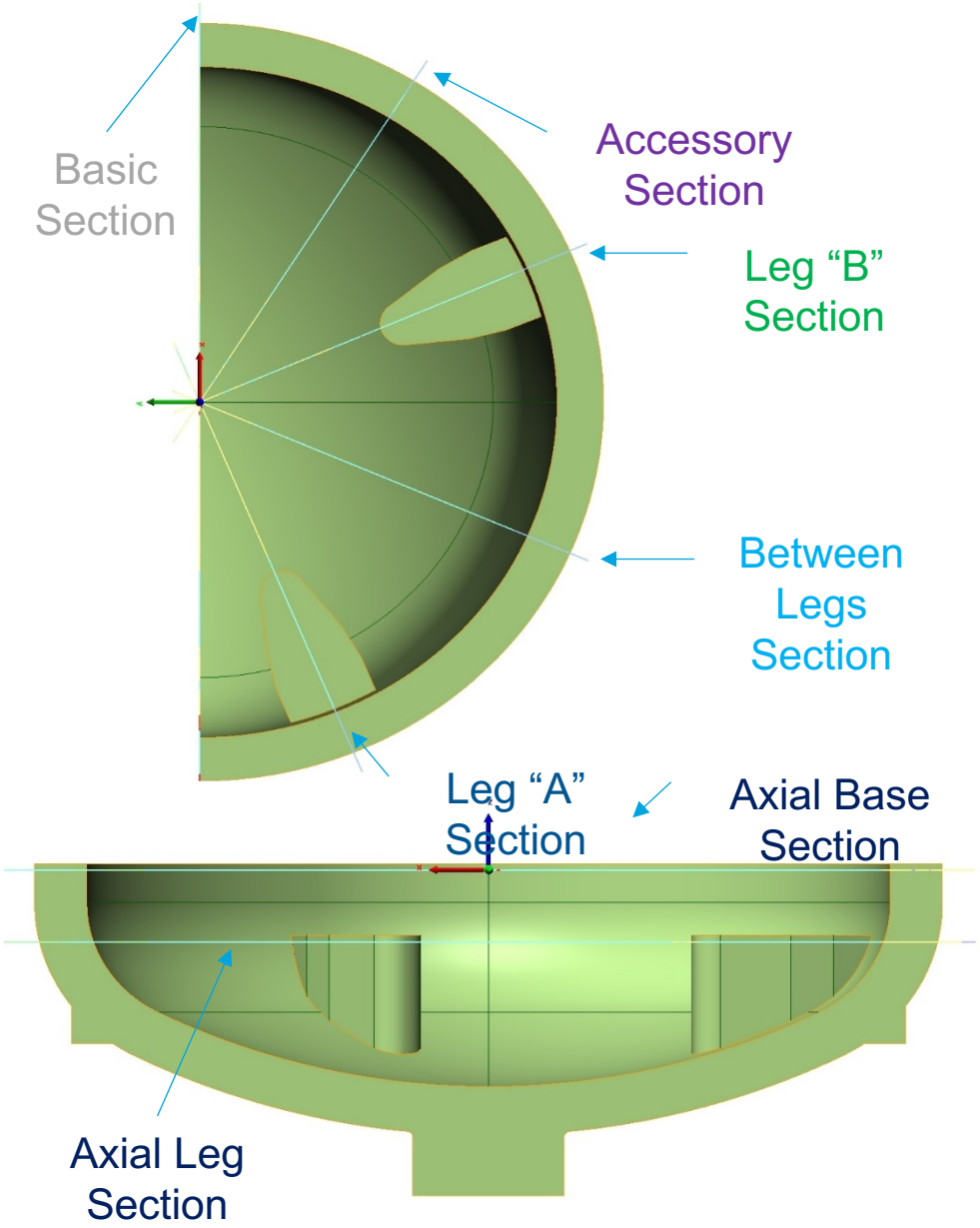
**Remember….**

1. In general, HIP is used to produce "asymmetric parts"

2. EPRI/Synertech are pushing the envelope well beyond the previous experience with HIP for very large section components

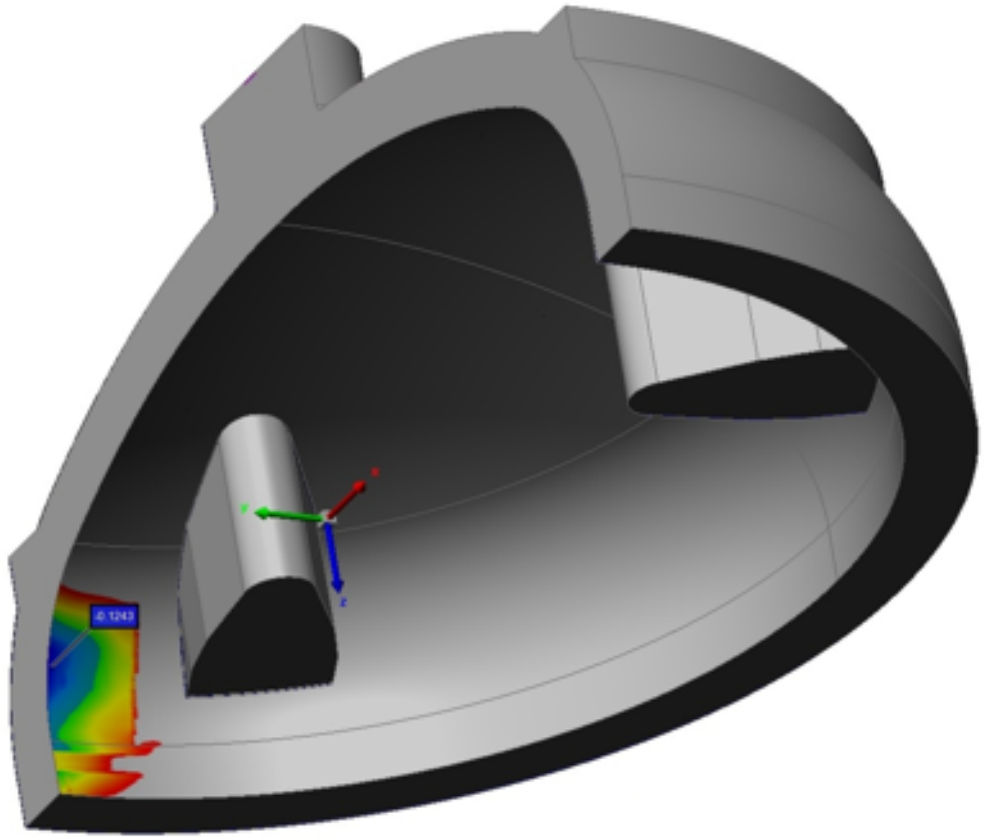
# 2nd Article—1/2 Section Head

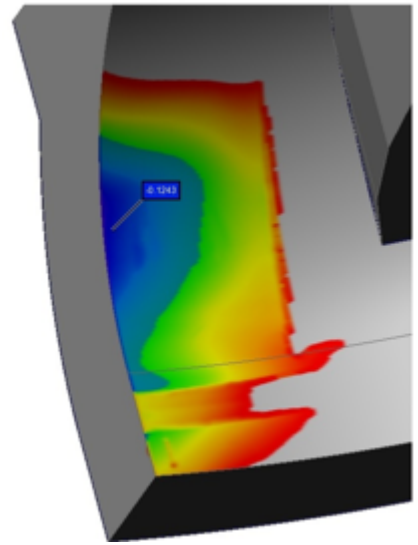




# 2nd Article—1/2 Section Head

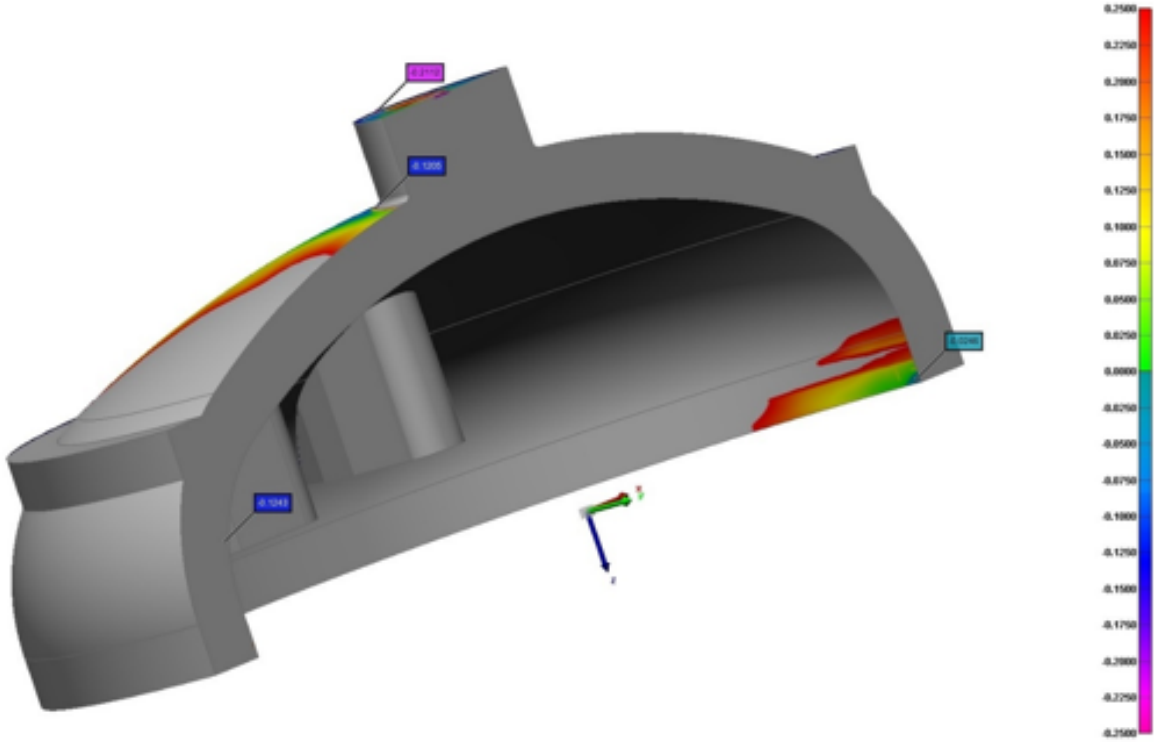
# Article 2

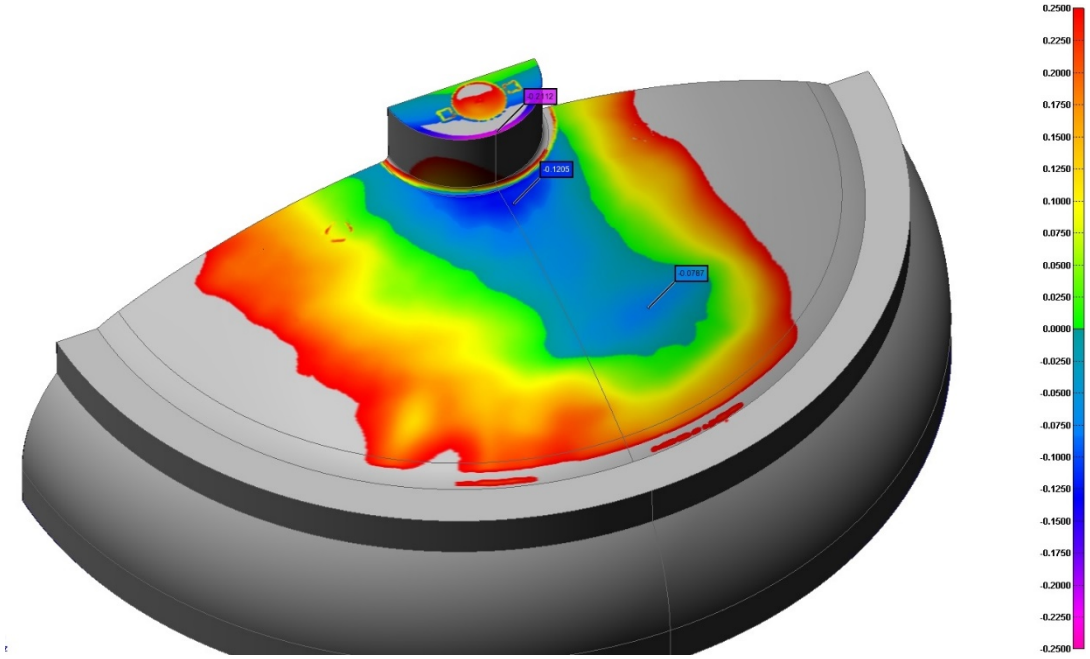


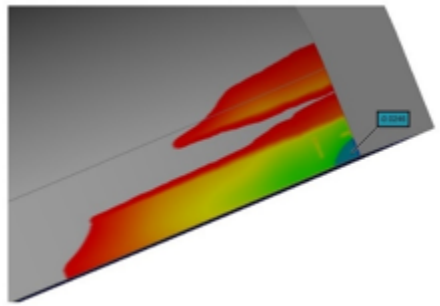
**Blue region is slightly under dimension by ~0.125-inch**

# Article 2





**Blue region is under dimension by ~0.120-inch**



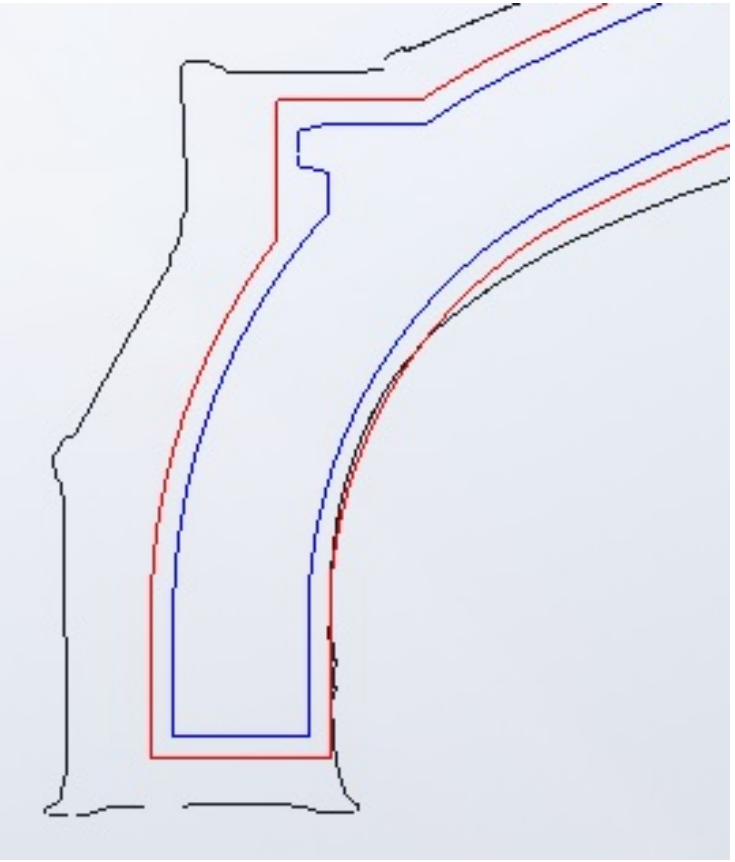
**Blue region is slightly under dimension by ~0.025-inch**

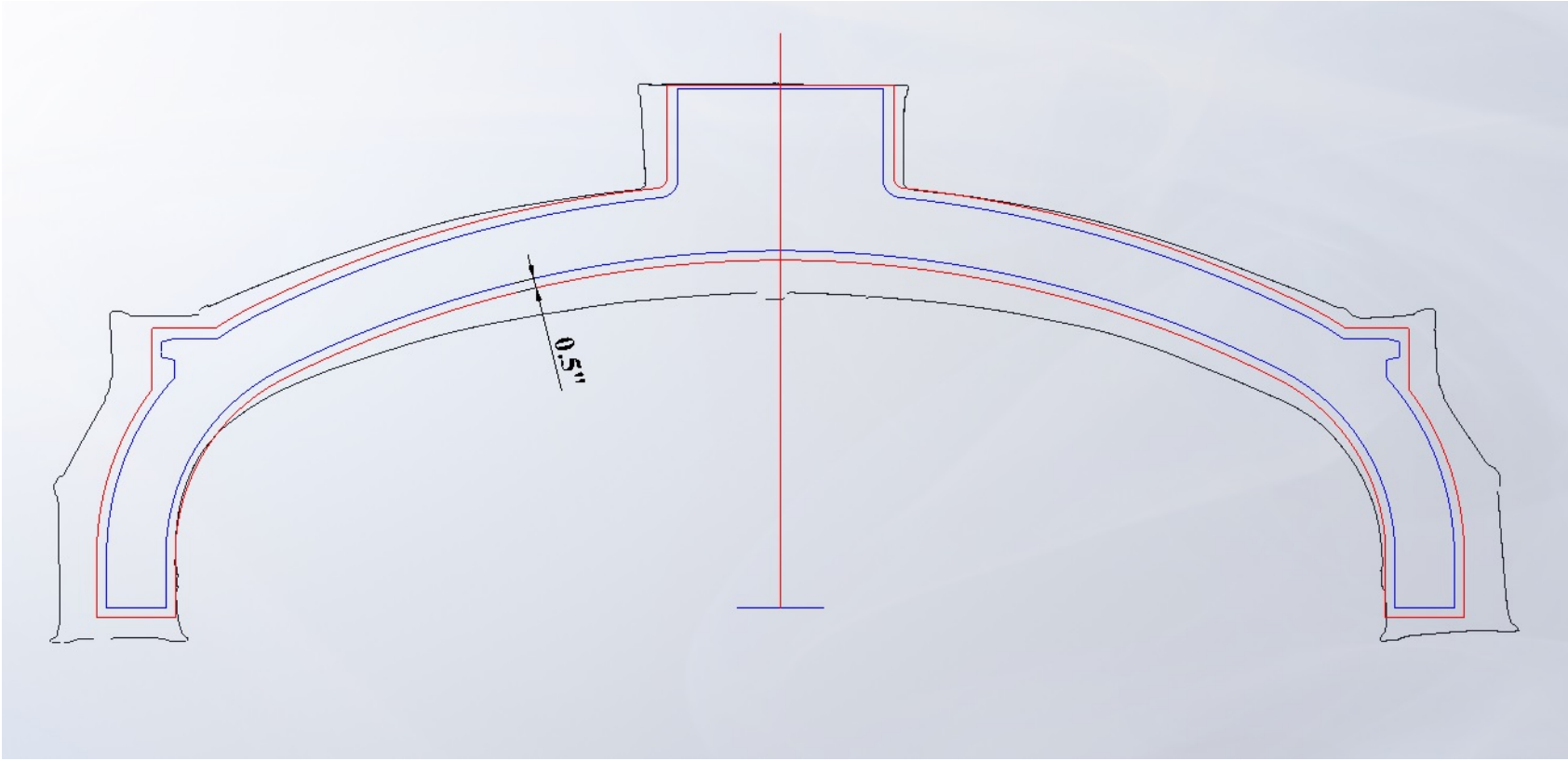
# Article 2—Another View

Blue – Design Dimension

Red – Design Component plus 1/2-inch

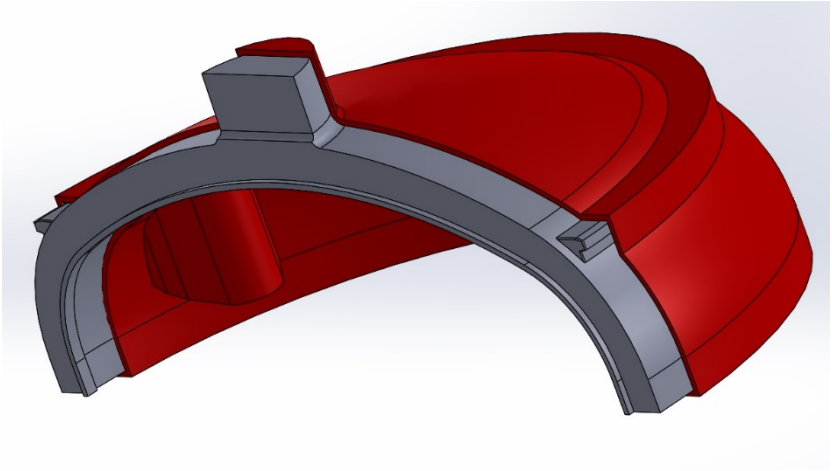
Black – Final Component with Capsule (after HIP)

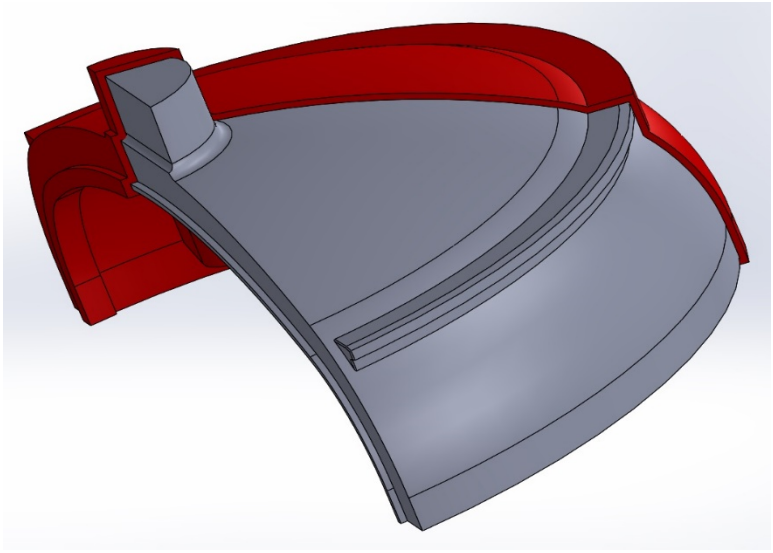




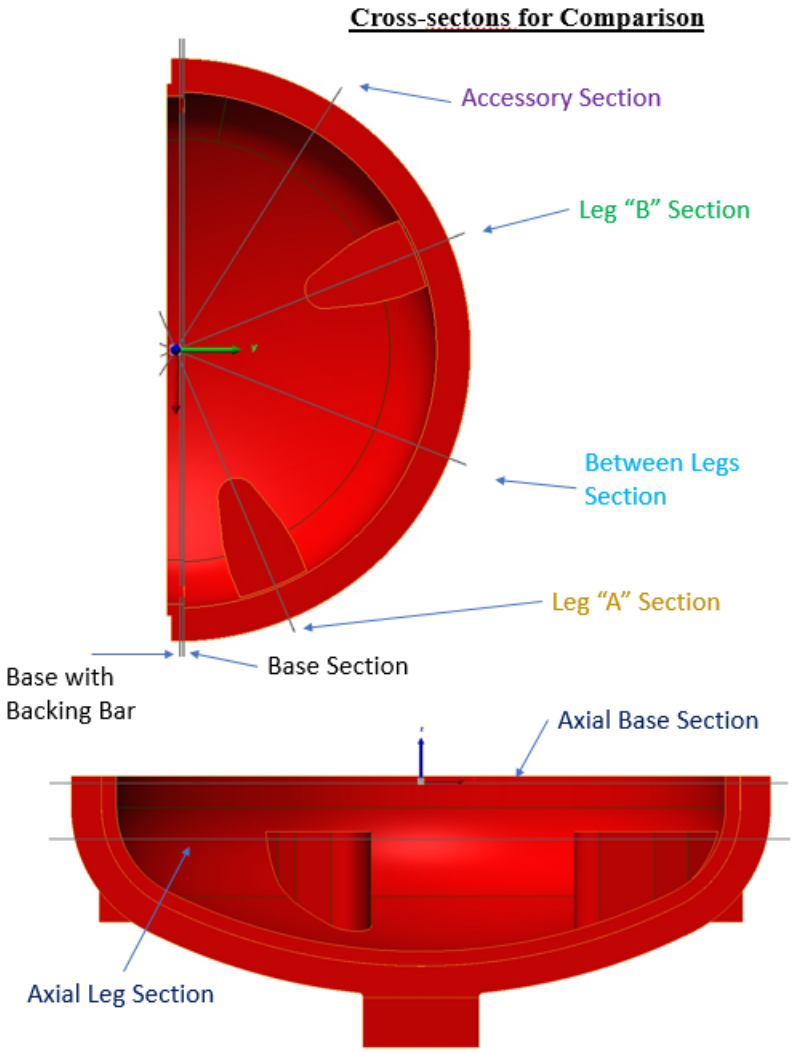
# Article 3—Lower Head

# 3rd Article—1/2 Section Head

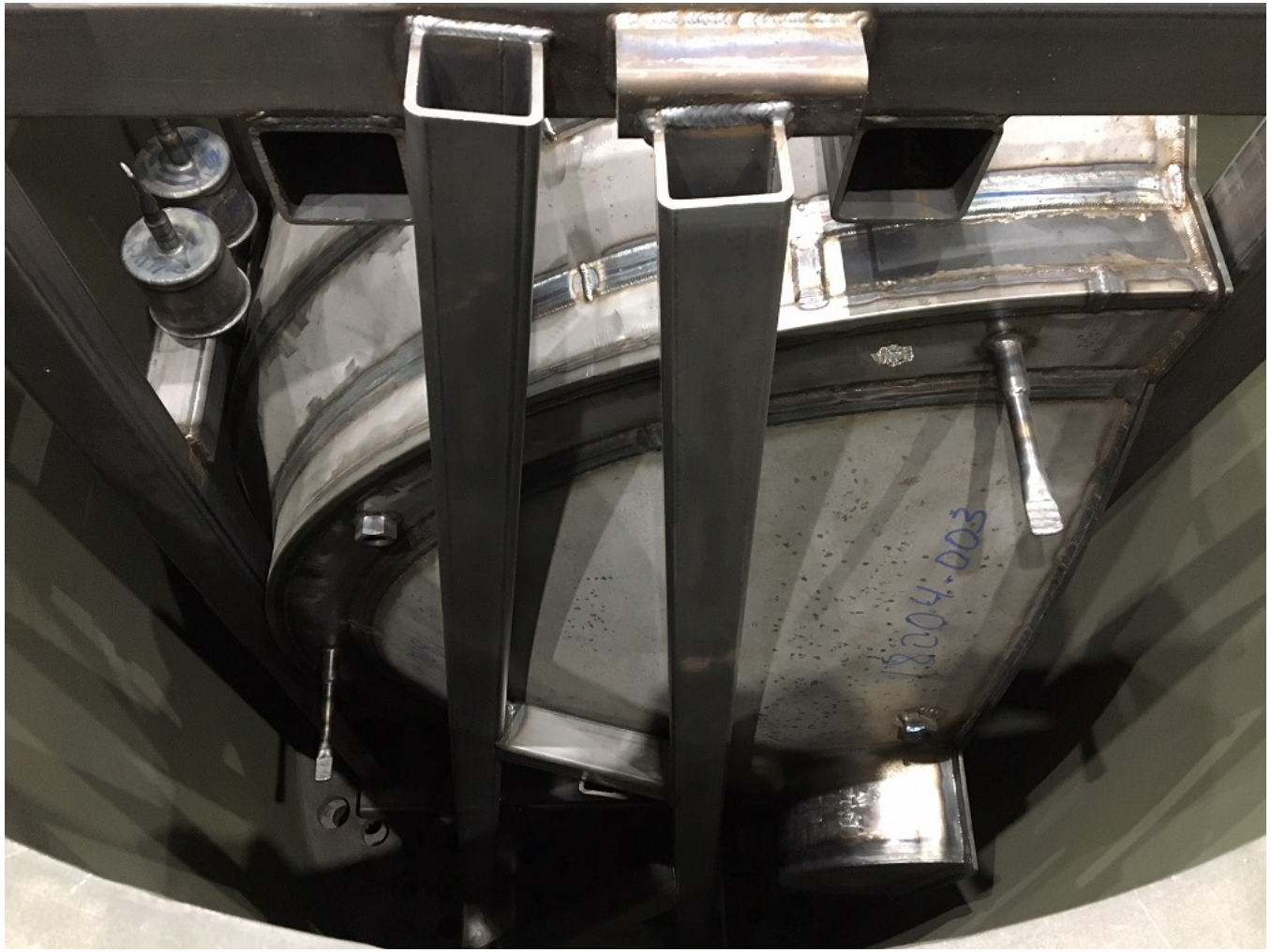




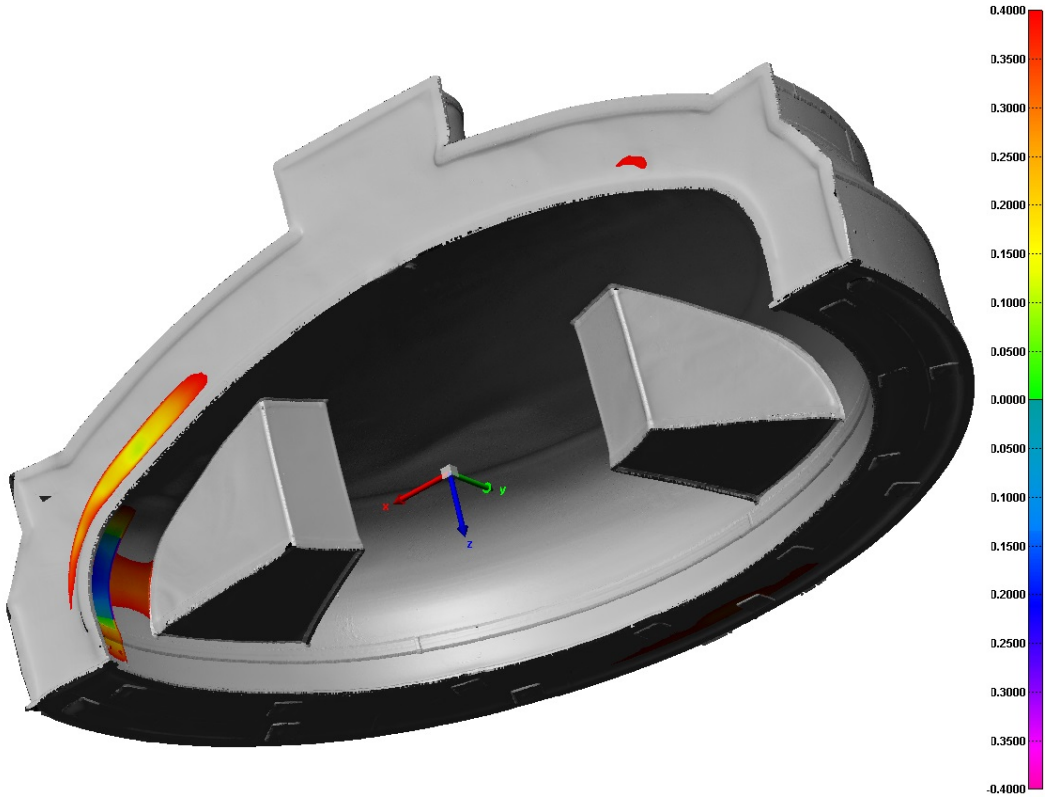
**Notice: Backing Bar is included for Article 3**

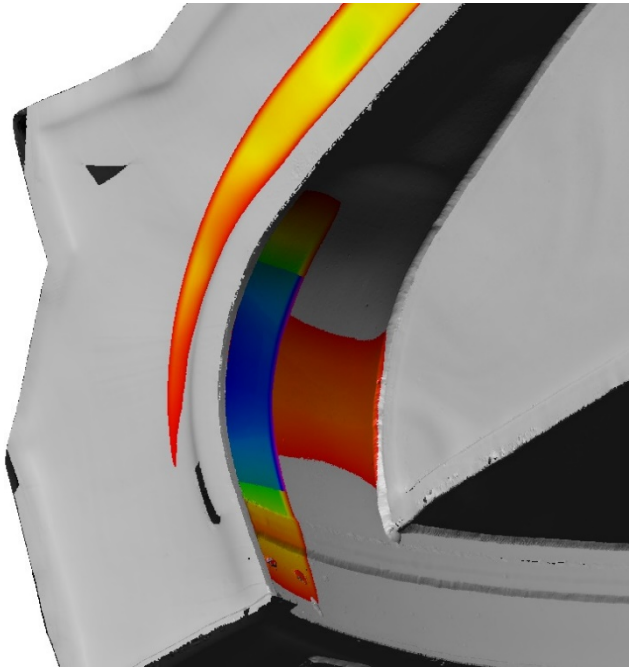


# Article 3—Lower Head



# Article 3

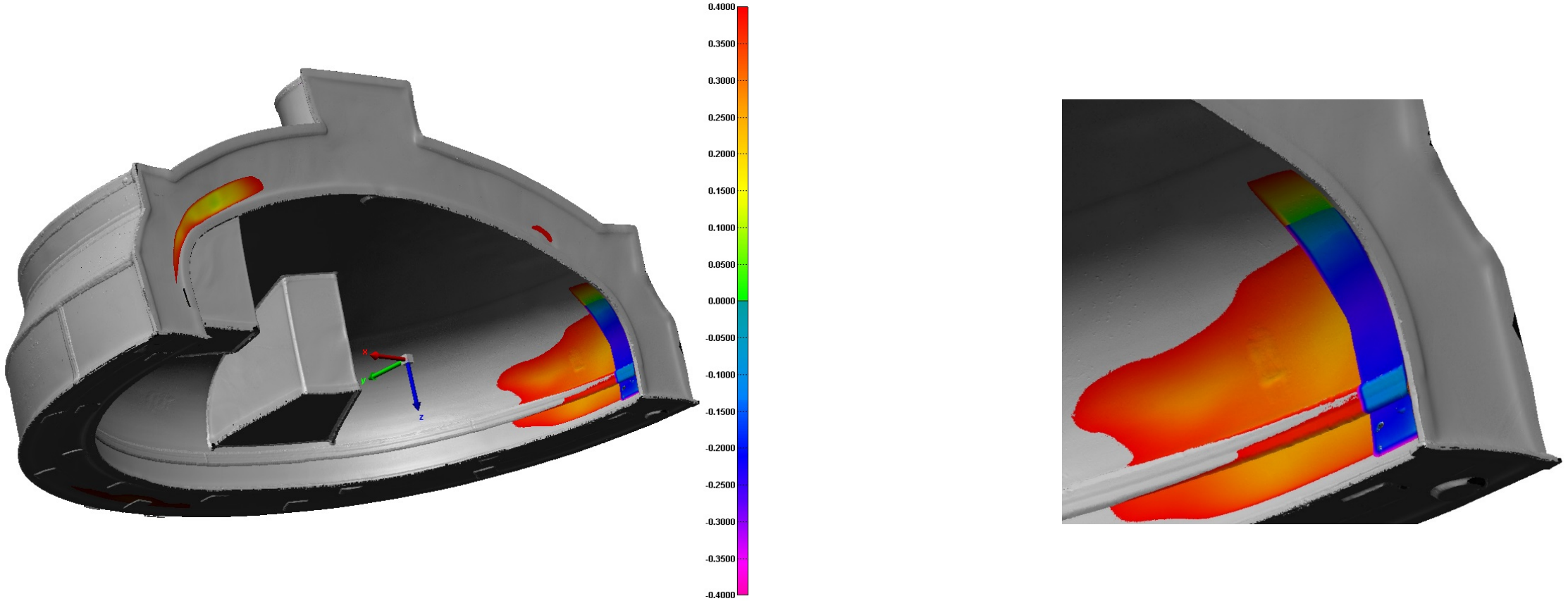


Blue region is under dimension by ~0.200-inch.

Note: This area is confined solely to the backing bar region.

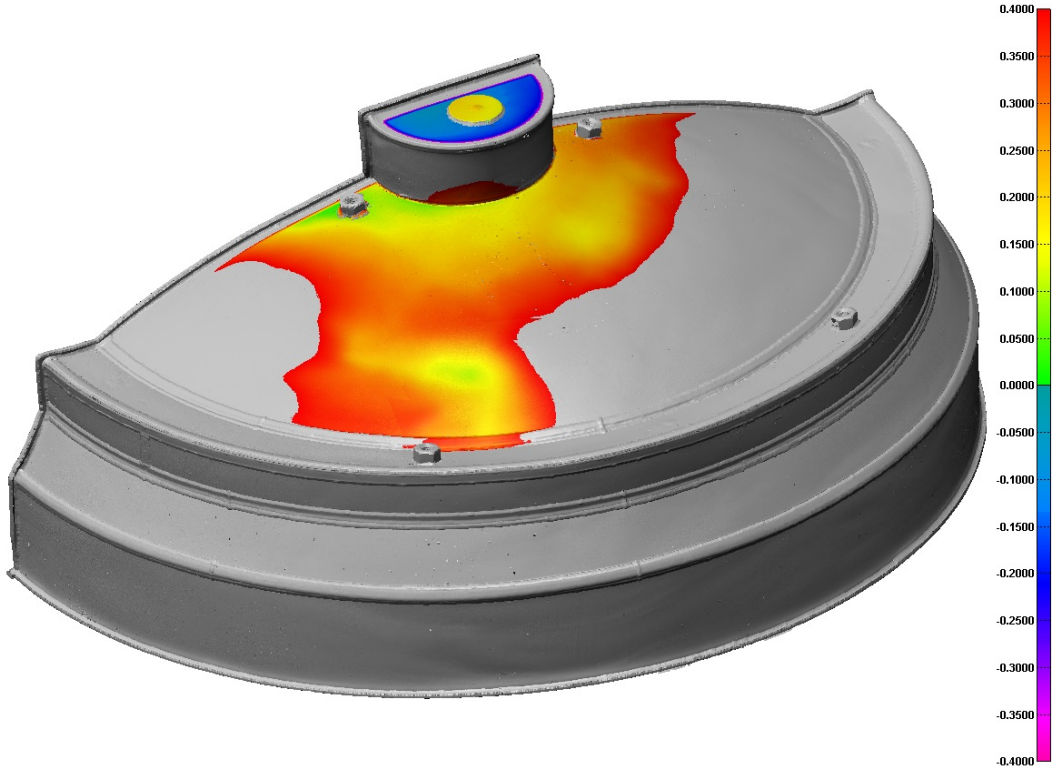
# Article 3




Blue region is under dimension by ~0.200-inch.

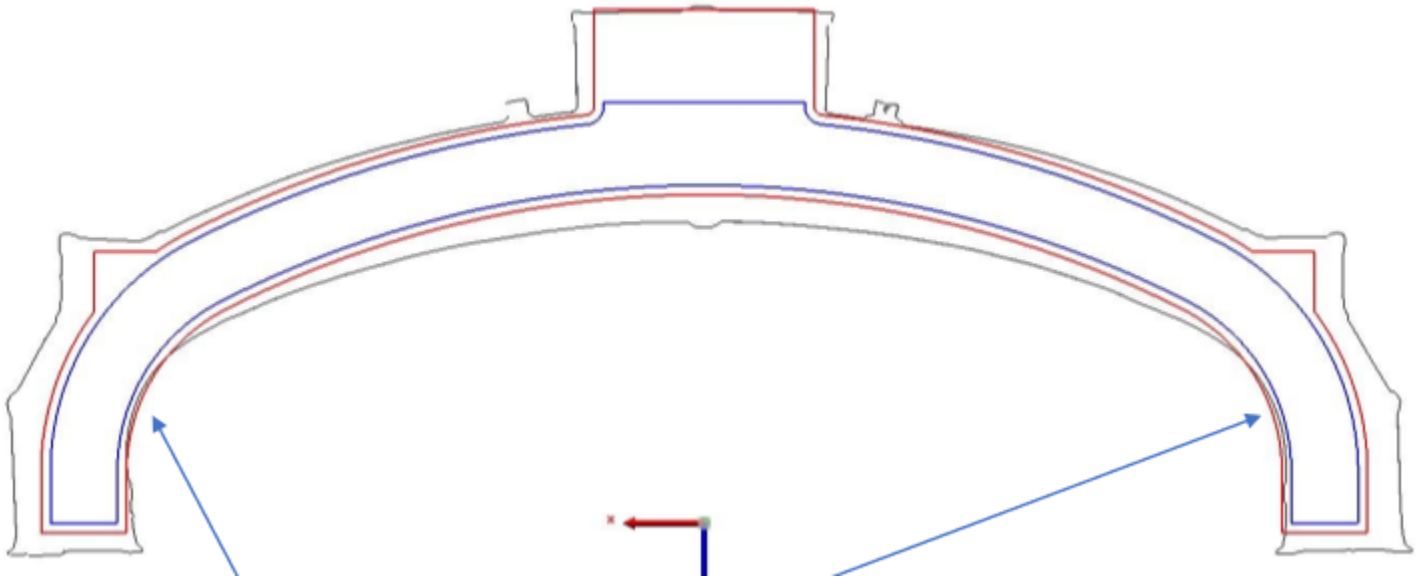
Note: This area is confined solely to the backing bar region.

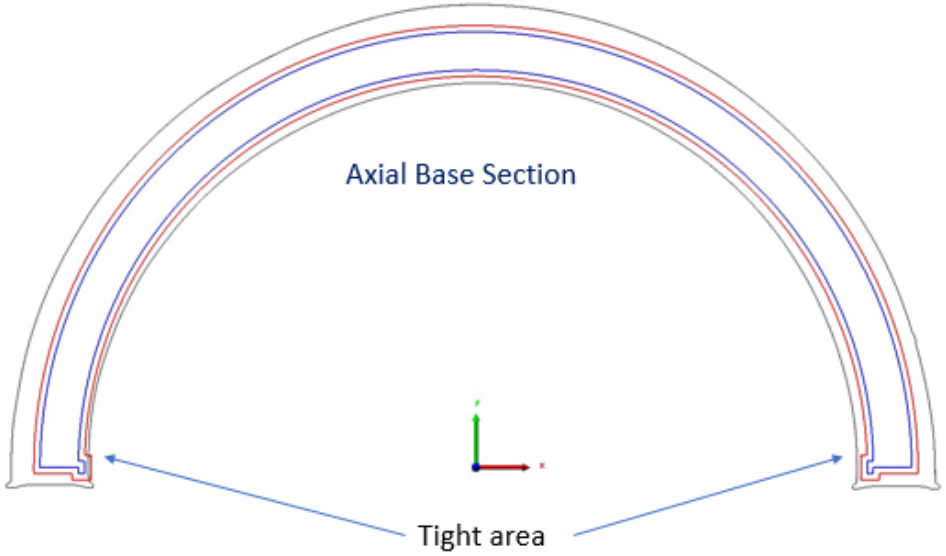
# Article 3

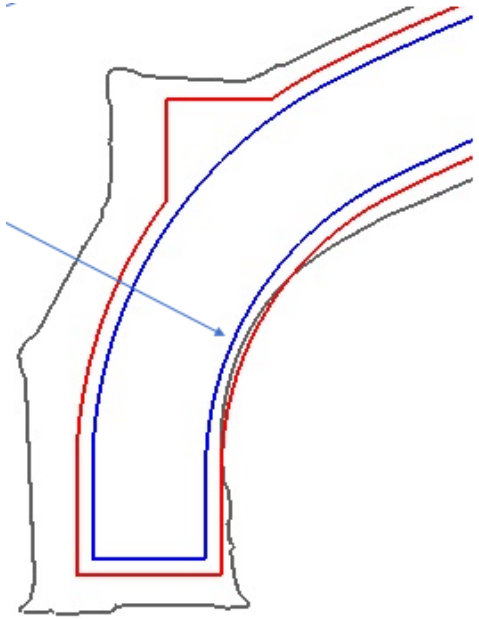


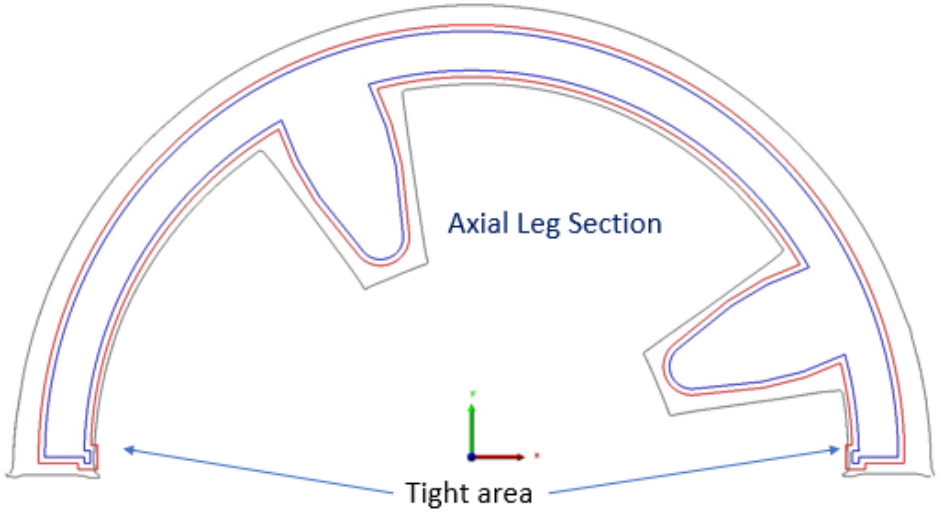

Blue region is slightly out of dimension

# Article 3 – More Views





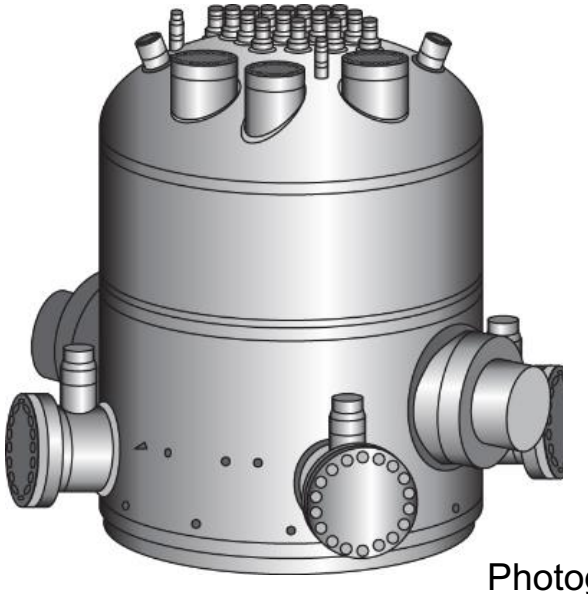


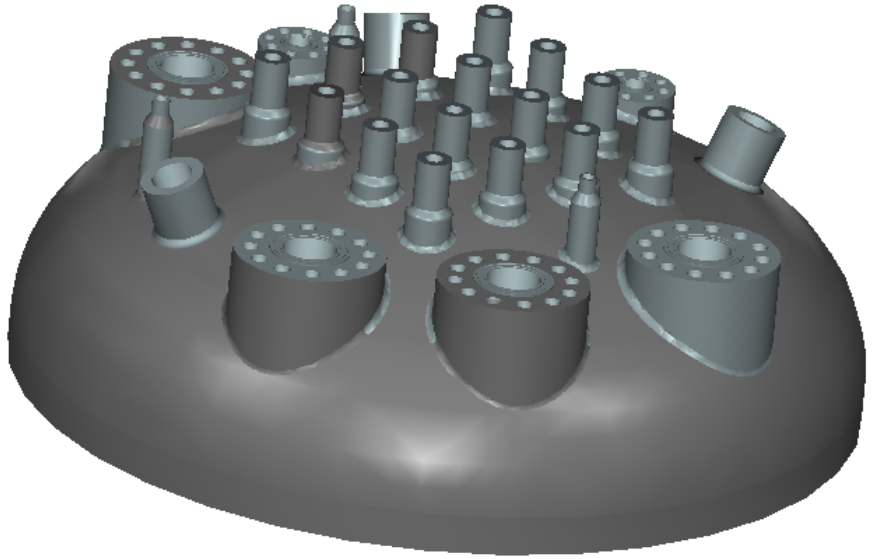

Blue – Design Dimension

Red – Design Component plus 1/2-inch

Black – Final Component with Capsule (after HIP)

# Small Modular Reactor Upper Head





Photographs courtesy of EPRI and NuScale Power

- ~44% scale
- A508 Class 1, Grade 3
- 27 penetrations
- 1650kg (3650lbs); 1270mm (50 inches) diameter
- Next, 2/3-scale head
- Need larger HIP Vessel -- ATLAS

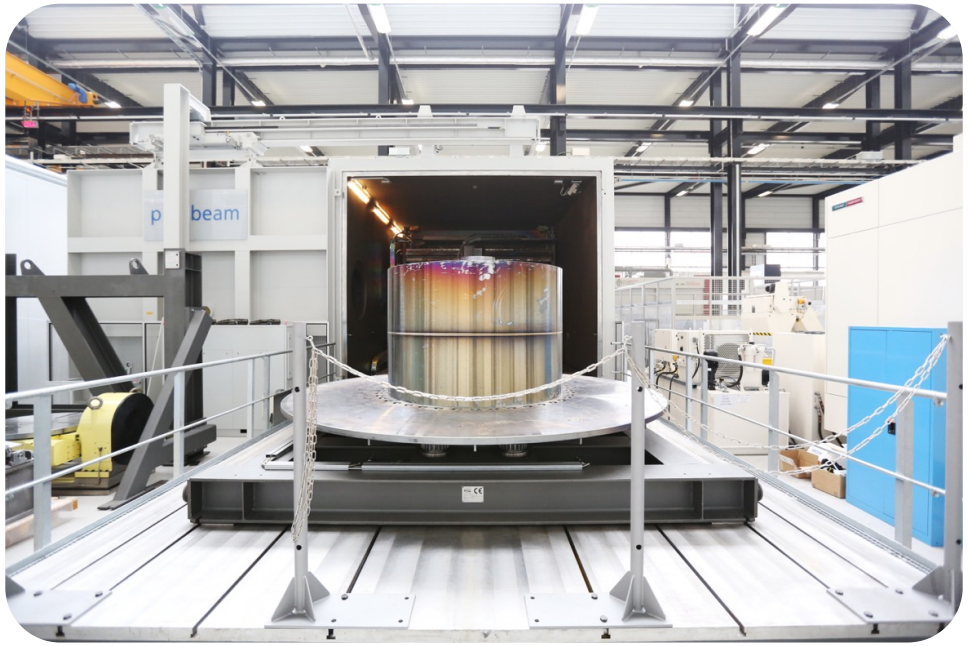
**DOE Project: DE-NE0008629**

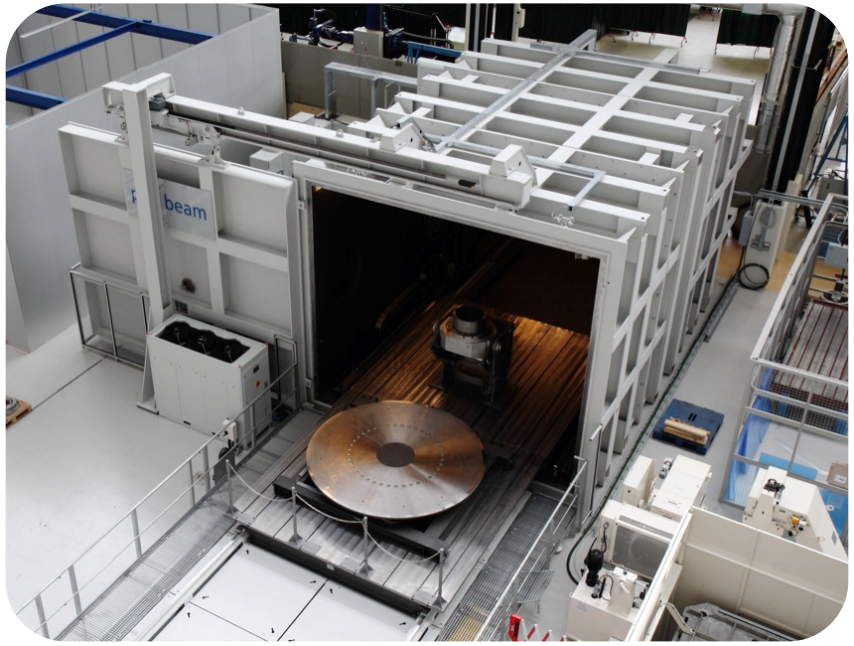
# EB Welding Development

# Nuclear AMRC capabilities

## Pro-beam K2000

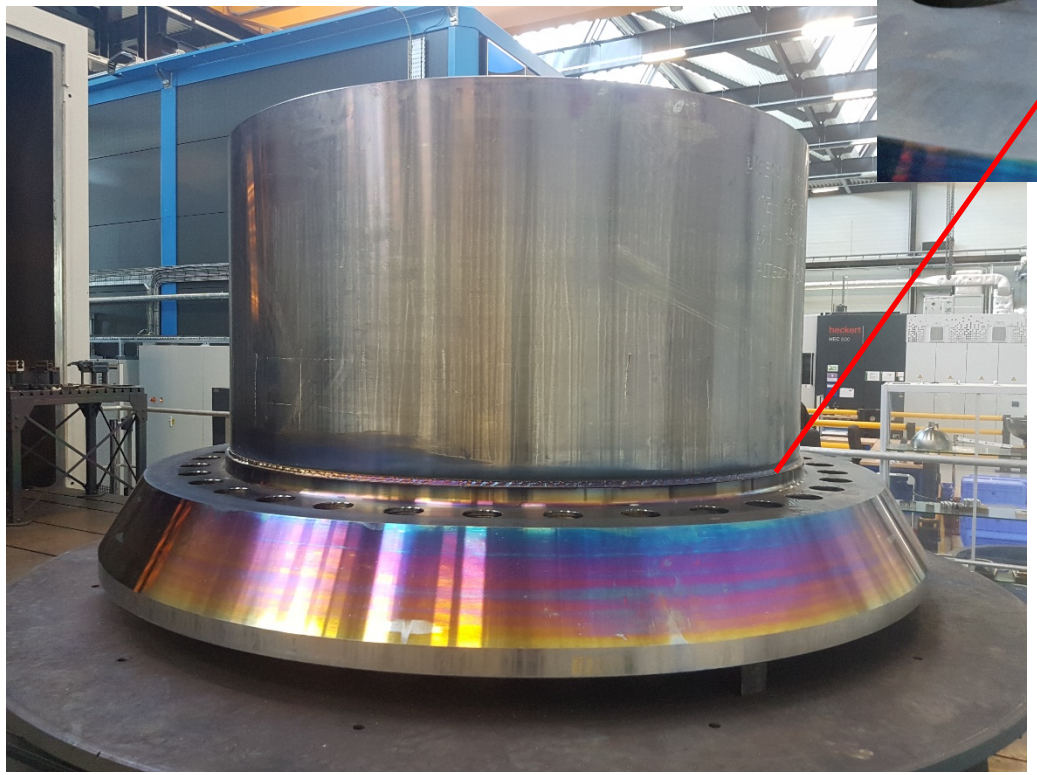
| | Pro-beam K2000 |
|---|---|
| Chamber size | **8.7 x 5.2 x 4.6 m³** |
| Chamber volume | 208 m³ |
| Max Work piece size | 6.4 x 4.0 x 3.2 m³ at 100 tonne |
| Acceleration voltage | 60 or 80 kV |
| Max beam power | 30 or 40 kW |
| Wire feeder | 2 off |
| Pump down time | 45 min |

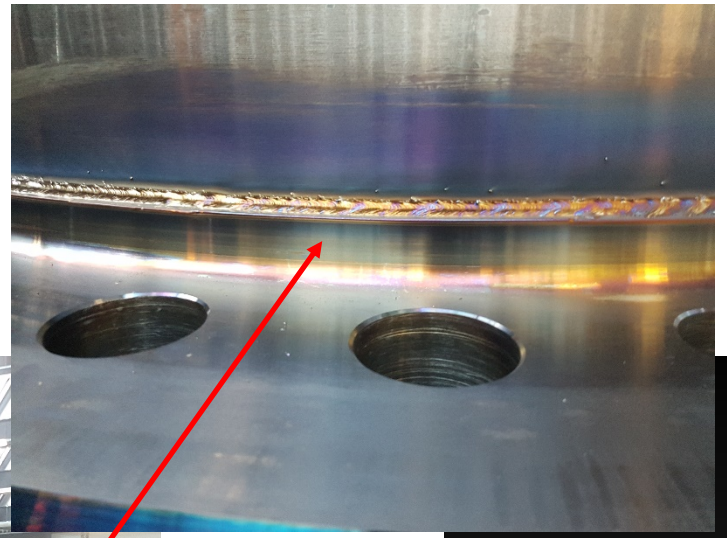



pro beam

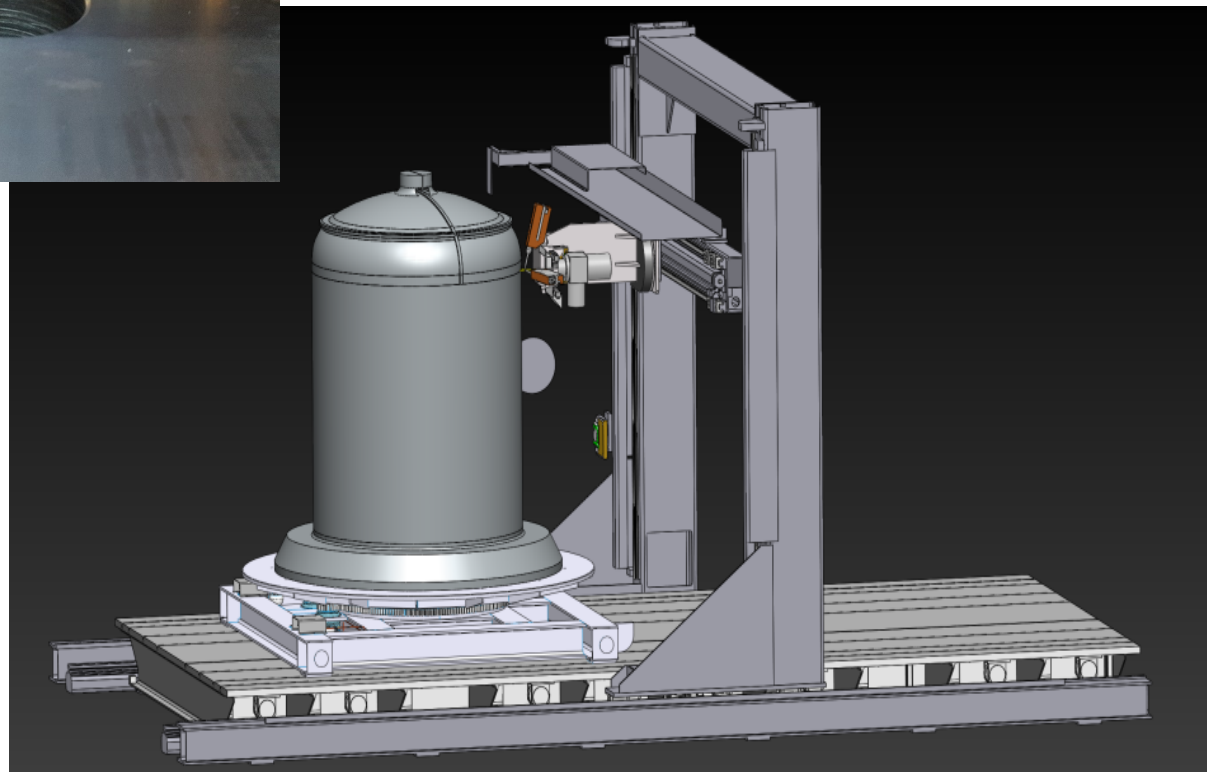
# Lower Assembly





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

**Completed in 47 minutes**

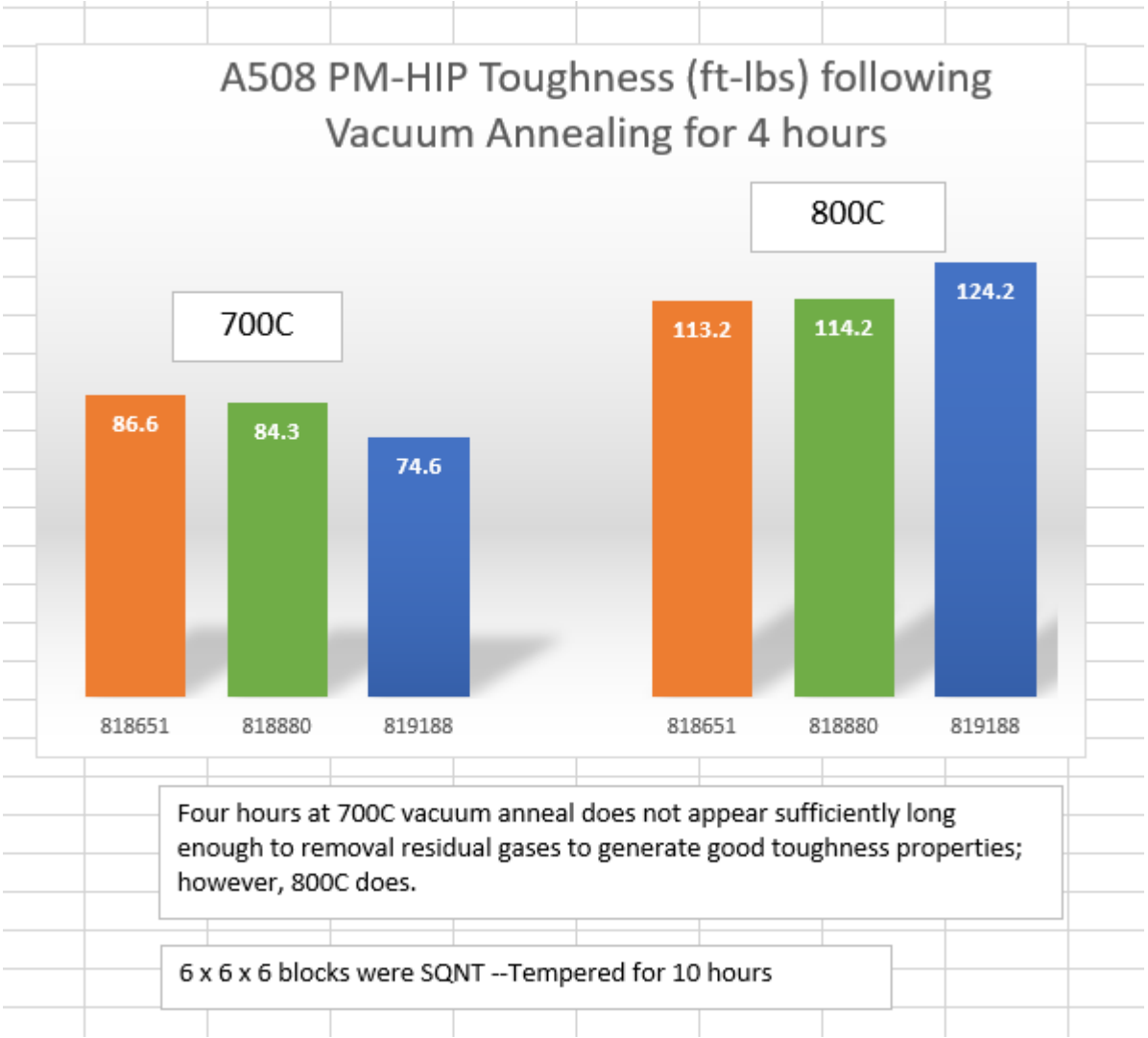


Lower head to Lower Flange Shell (again, upside down)


CLEANING STATION


# Cleaning of A508 Powders (via Vacuum Annealing) Places the Powder in a "Pristine Condition" for Consolidation

**6" x 6" x 6" Test Blocks**




**113ft-lbs = 153 joules**

84ft-lbs = 114 joules

# Project Status (thru November 2019)

- Steam plenum access port completed (EPRI ANT program)
- 44% diameter (50-inch) A508 top head completed (EPRI ANT program)
- Forgings for flanges, PZR shell, lower RPV section completed.
- Three-half section A508 lower head, completed and dimensioned.
- 1st Article for transition shell completed; two more Articles by January 2020.
- EBW & DLC development @ Nuclear AMRC – 80% completed.
- Heat treatment development – to be completed Q1-2020.
- EB Mockup assembly of lower flange-to-shell completed.
- EB Mockup joining lower head completed.
- Frame for joining transition sections assembled.
- Vacuum annealing of powders development completed.
- Annual report completed.

# SMR Vessel Manufacture & Fabrication


- Focus on properties of large section components
- Join 2/3rd scale lower RPV shell-to-flange.
- Complete another lower half head.
- Join 2/3rd scale lower halves, then weld to shell-to-flange assembly.
- Demonstrate QHT via mockup and then at 2/3rd scale
- Complete 4 transition shell sections and weld them together.
- Complete lower assembly.
- Initiate upper assembly development.

# Summary

- Promise of technology to lower costs and change the way we produce major thick section components.
- Excellent progress on PM-HIP of large components
  - Dimensionally demonstrated
  - Need to now focus on properties for large sections
  - Complete vacuum annealing of powders
- EB and DLC development – 80% complete
- Good progress on EBW Joining
  - 47 minutes for mockup of flange-to-shell weld
  - Completed mockup of lower head weld
  - Need to now complete 2/3$^{rd}$ scale welds

# Acknowledgements


**US Department of Energy**

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

**Nuclear AMRC**

- Will Kyffin, Matt Cusworth, Thomas Dutilleul, James Connell, Stephen Bloomer

**Bridger Welding Engineering**

- Keith Bridger

**Synertech-PM**

- Victor Samarov, Charlie Barre, Alex Bissikalov

# Together...Shaping the Future of Electricity