Small Modular Reactor Pressure Vessel Manufacturing & Fabrication Technology Development

Project Update

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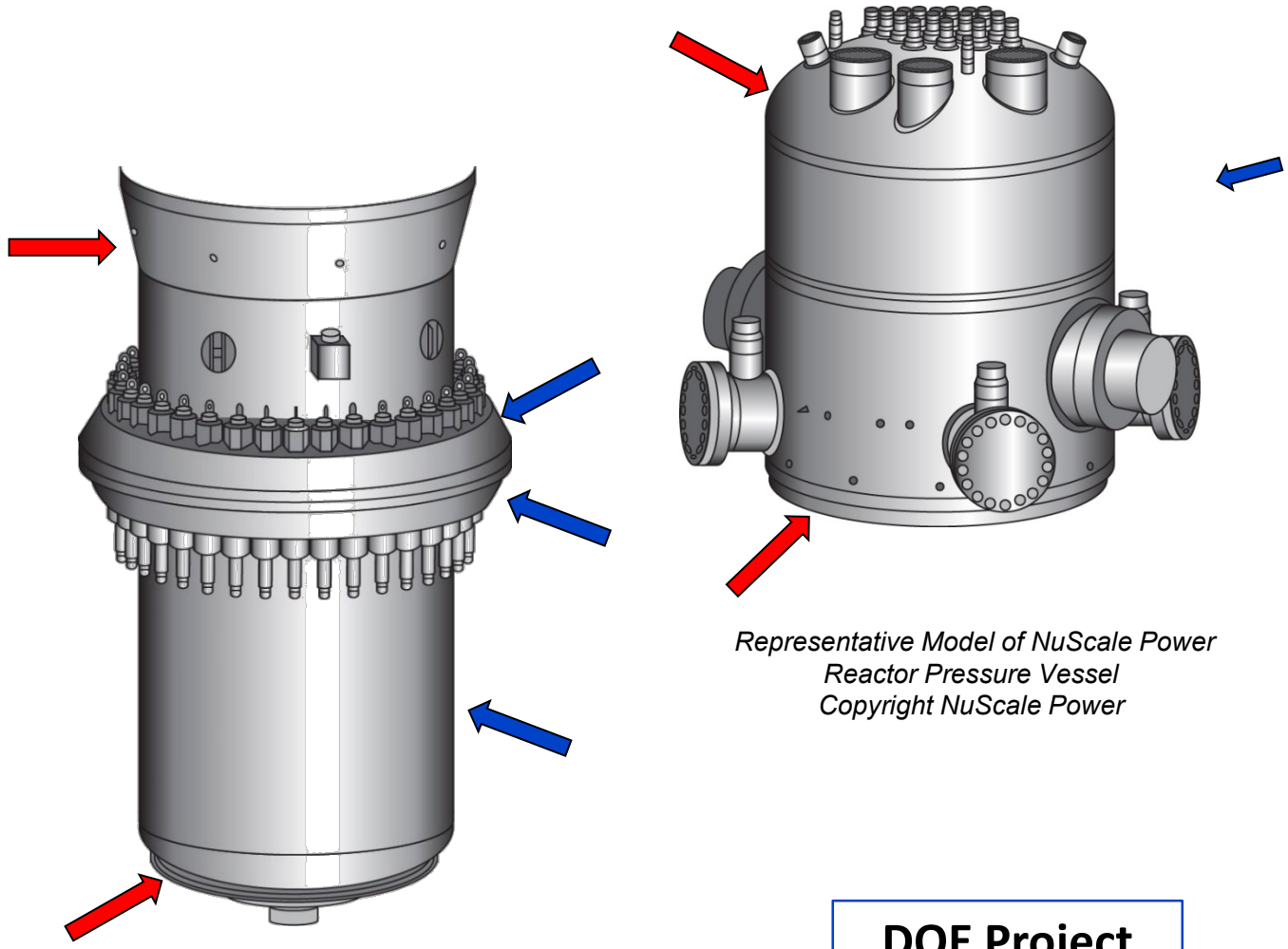
Outline

- Objectives
- Project Status Overview
  - Powder Metallurgy-HIP Progress
  - EB Welding Progress
  - Diode Laser Welding Progress
  - Heat Treatment Parameter Development
- Next Steps—Phase I
- Phase II Tasks
- Summary

Objectives – SMR Advanced Manufacturing Project

- Rapidly accelerate the deployment of SMRs
- Develop/Demonstrate new methods for manufacture / fabrication of a RPV in **< 12 months**
- Eliminate 40% from the cost of an SMR RPV, while significantly reducing the schedule
- Primary Advanced Methods:
  - PM-HIP
  - Electron Beam Welding
  - Diode Laser Cladding



Representative Model of NuScale Power Reactor Pressure Vessel
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DOE Project DE-NE0008629

Status – SMR Advanced Manufacturing Project

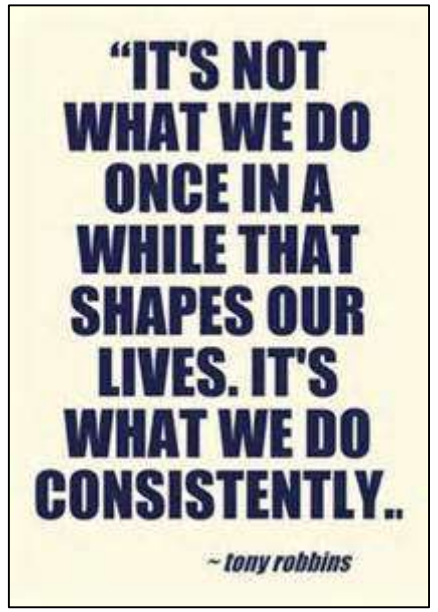
- EB Weld Development
  - Weld parameters for A508 steel --complete
  - Head halves EB weld mockup --completed
  - Lower flange-to-shell mockup --completed
- Diode Laser Cladding
  - Parameter optimization and cladding heads selected
  - Bottom Head cladding mockup --complete
- Bottom Head
  - Four one-half lower heads fabricated from PM-HIP --complete.
  - Bottom head weld prep machining, fixturing, and welding --complete
- Transition Shell
  - Four sections of transition shell manufactured; Articles 5 and 6 in Q4 2020
  - Assembly scheduled for early in 2021.
- Flanges, Lower and PZR shells have been forged and delivered

Year 2 Progress Report:
3002019335
(April 2020)

Powder Metallurgy-HIP Progress

Chemistry and Charpy Toughness – A508

- Produced ~20 heats so far (meets SA508 chemistry requirements)
  - Air melt and VIM *atomization* used
- Toughness properties—Varies widely from 62-130ft-lbs
- Tensile properties—Yield and tensile easily met
- VIM atomized heats (4) consistently above 110ft-lbs (as-received powder)
- Air melt atomization heats in 80-95 ft-lbs generally (as-received powder)
- Focus on reducing:
  - Targets: oxygen (<100ppm) and silicon (0.05-0.20 wt%)

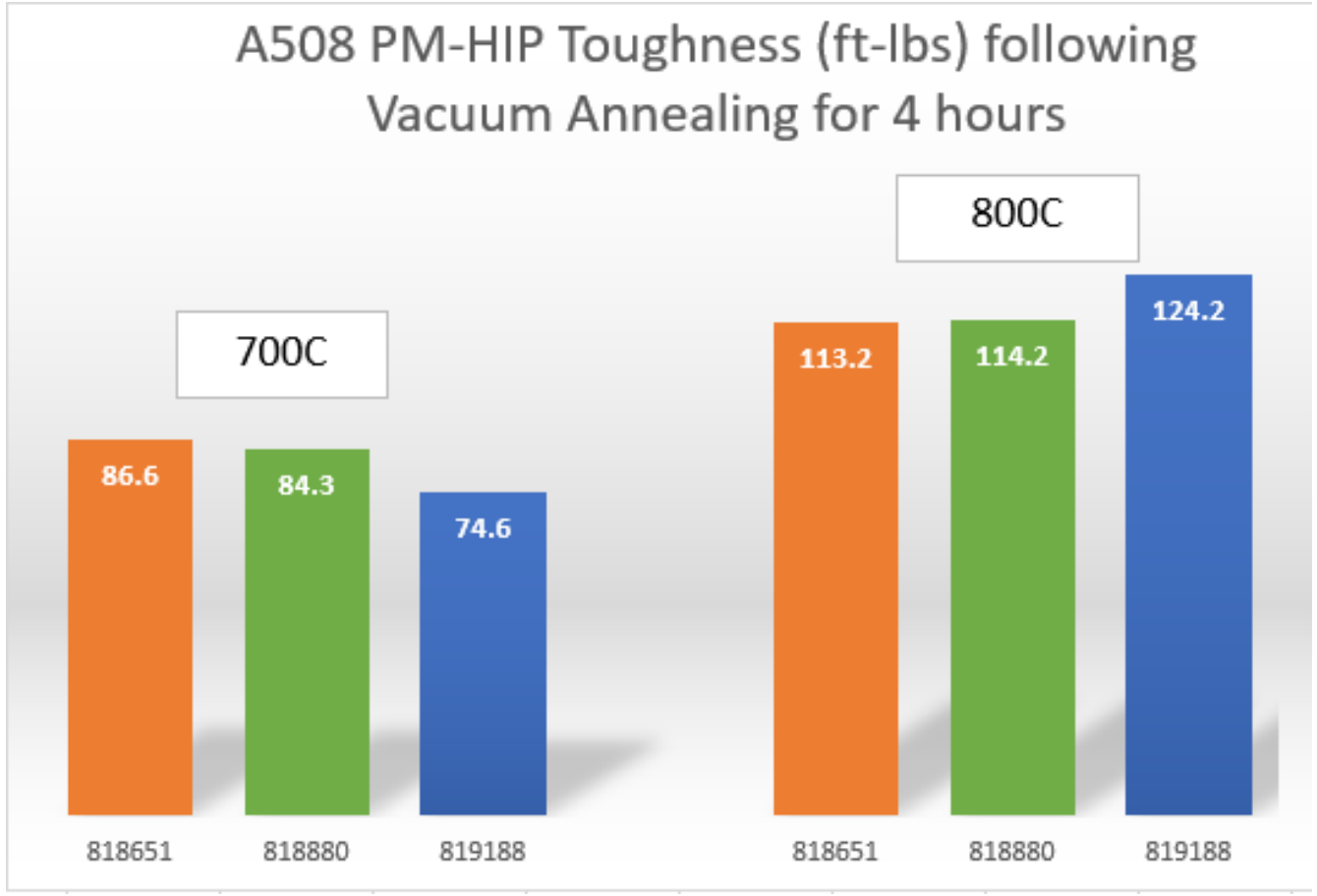


Powder Metallurgy-HIP Progress

Vacuum Annealing– A508

- Vacuum annealing of powder produces pristine powder condition
  - Removes oxygen from powder
  - 7 heats above 110ft-lbs
  - Next slide

Comparison of 700C and 800C Vacuum Annealing Across Three A508 Heats



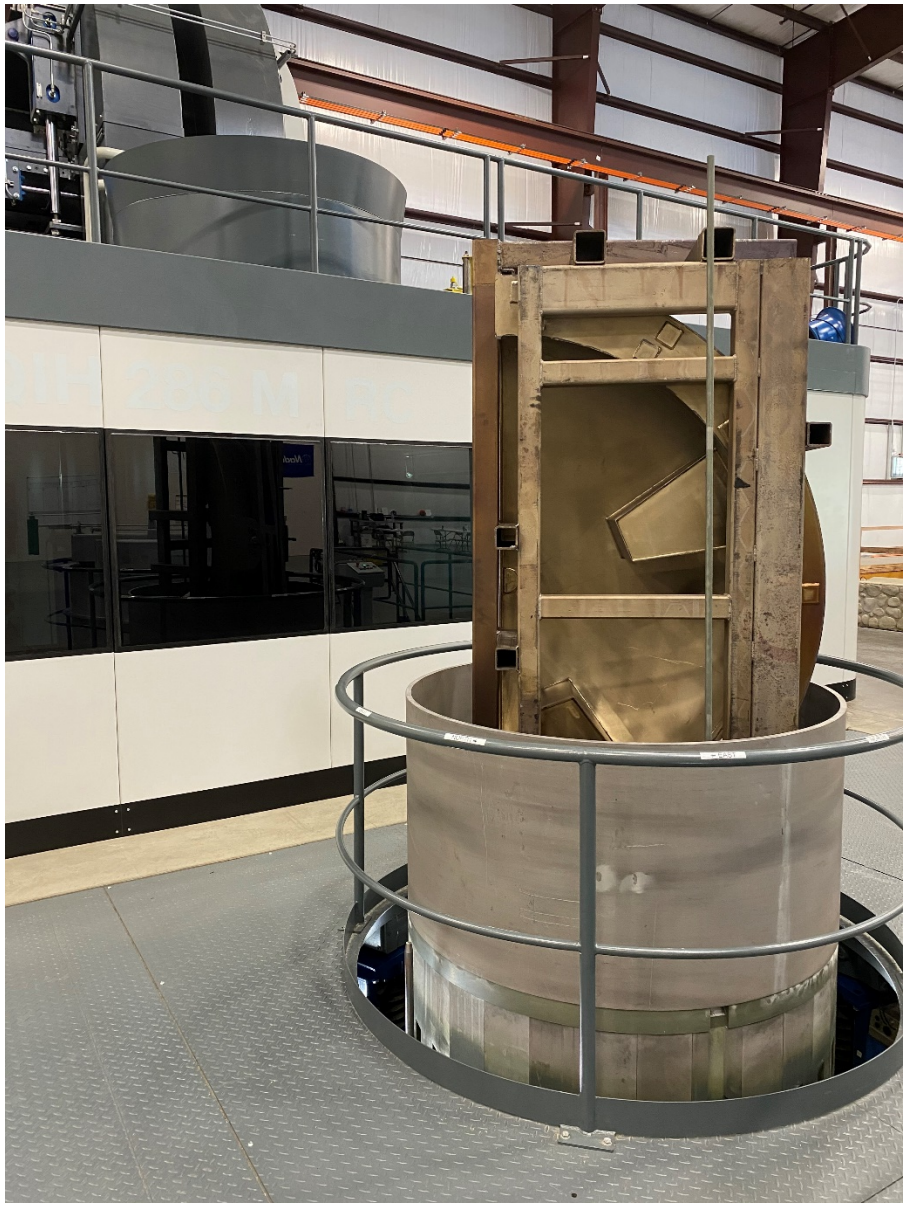
6 x 6 x 6 blocks were SQNT --Tempered for 10 hours

Four hours at 700C vacuum anneal does not appear sufficiently long enough to removal residual gases to generate good toughness properties; however, 800C does.

One-Half Lower Head Capsule in Frame for HIP'ing

70-inches in diameter, ~6300lbs each

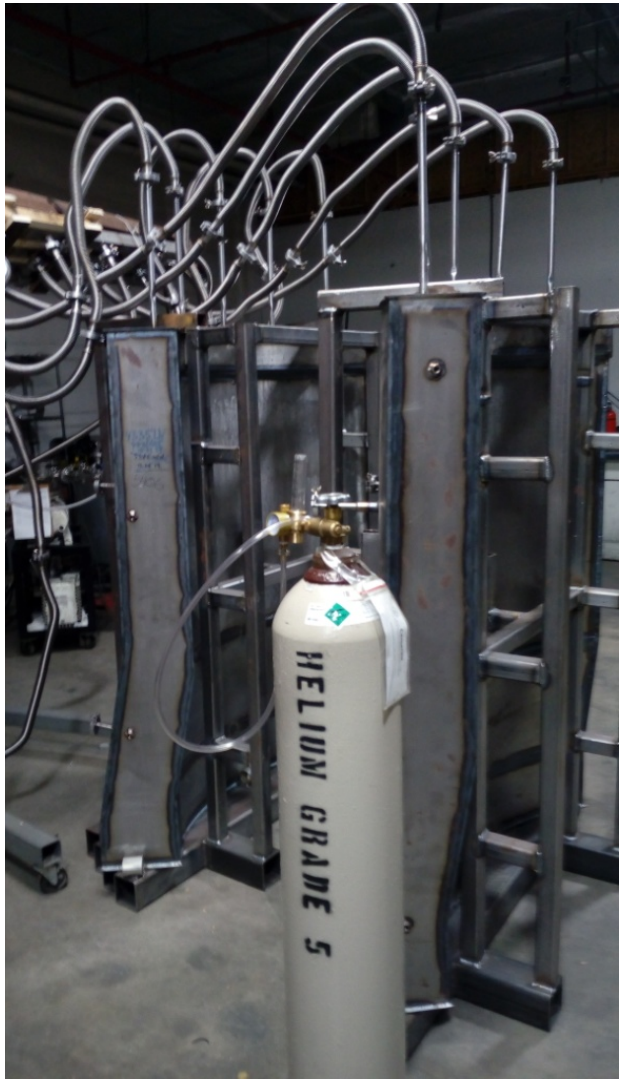
Capsule & Frame are inserted into HIP; Lower Head after HIP



Lower Head After HIP

Transition Shells Ready For Vacuum Annealing, then HIP

Two Transition Shells--Vacuum Degassing

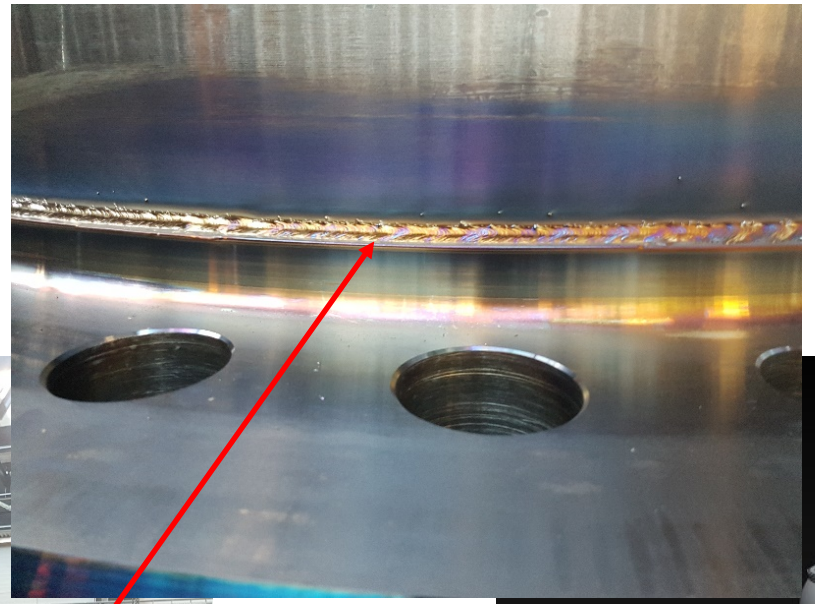


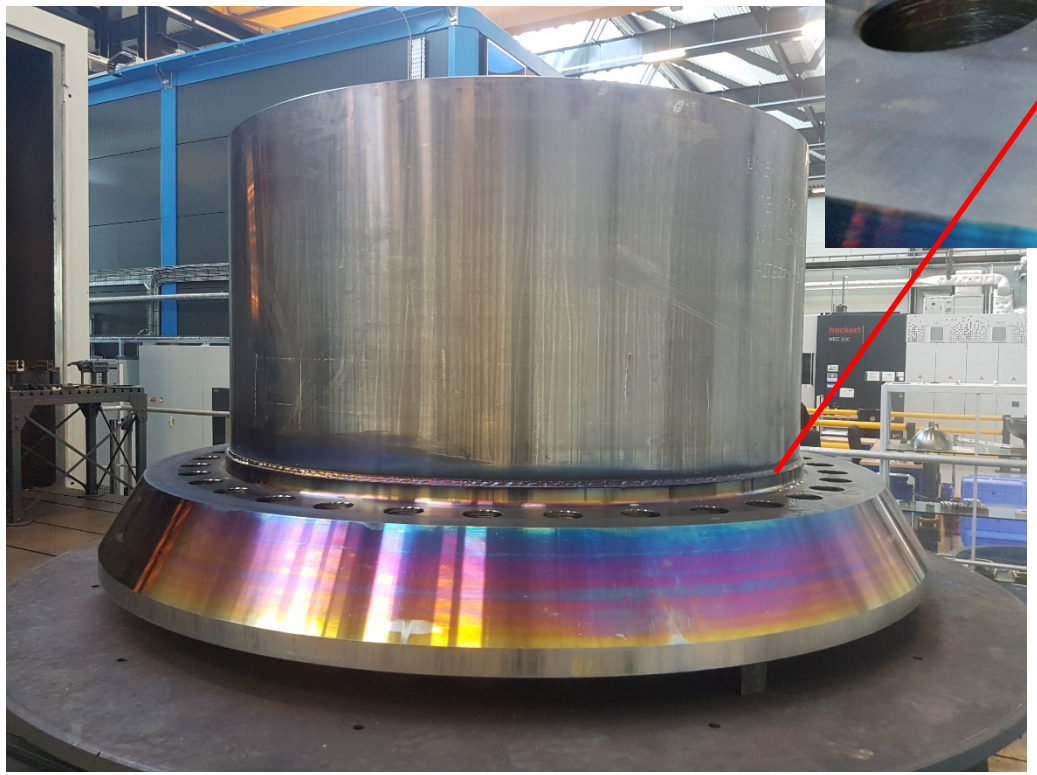
Completed Transition Shell

4620 lbs. each, ~6ft tall

Electron Beam Welding Progress

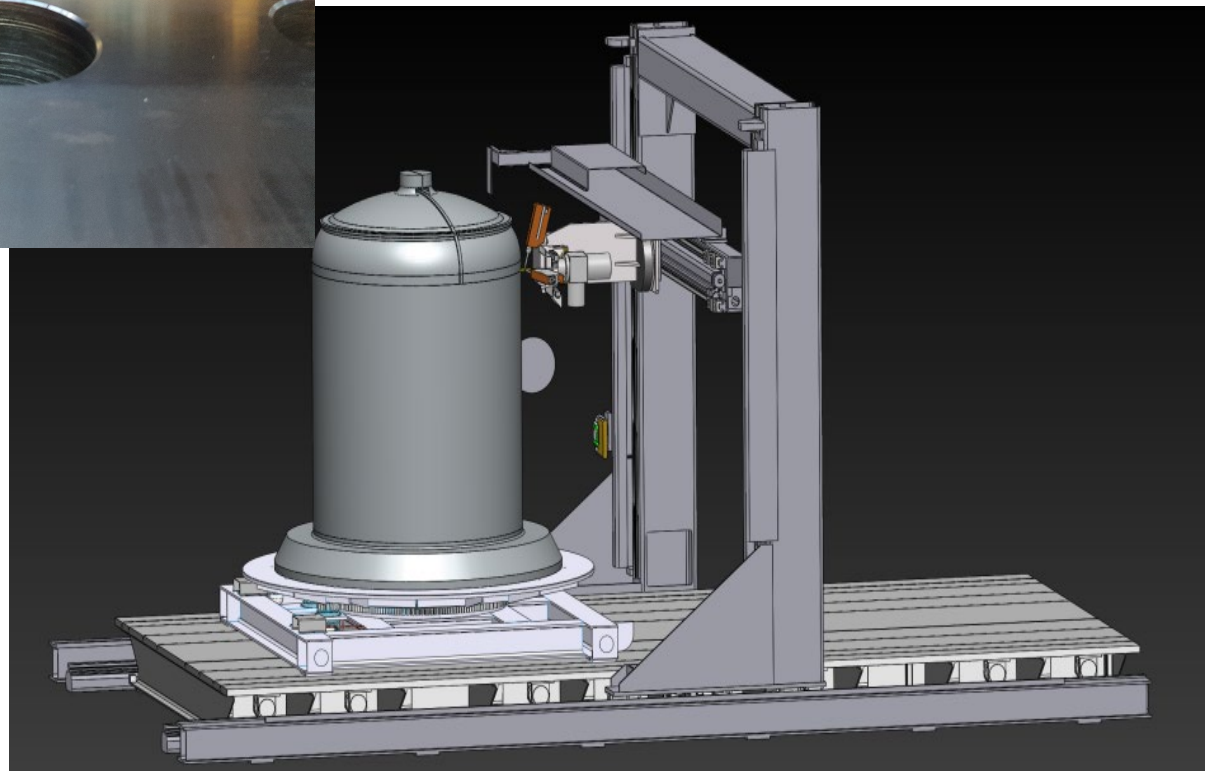
EB Welding—Shell-to-Flange





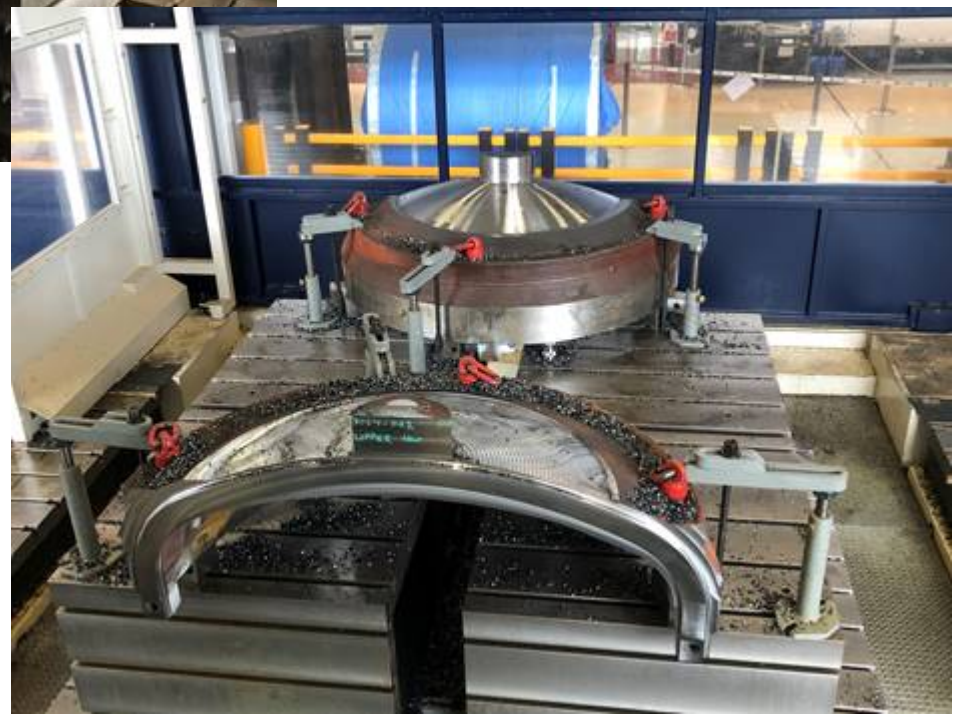
Lower Flange Shell Mockup EB Weld -- ~6 ft (1.82m) diameter (Note, mockup is upside down)

Completed in 47 minutes



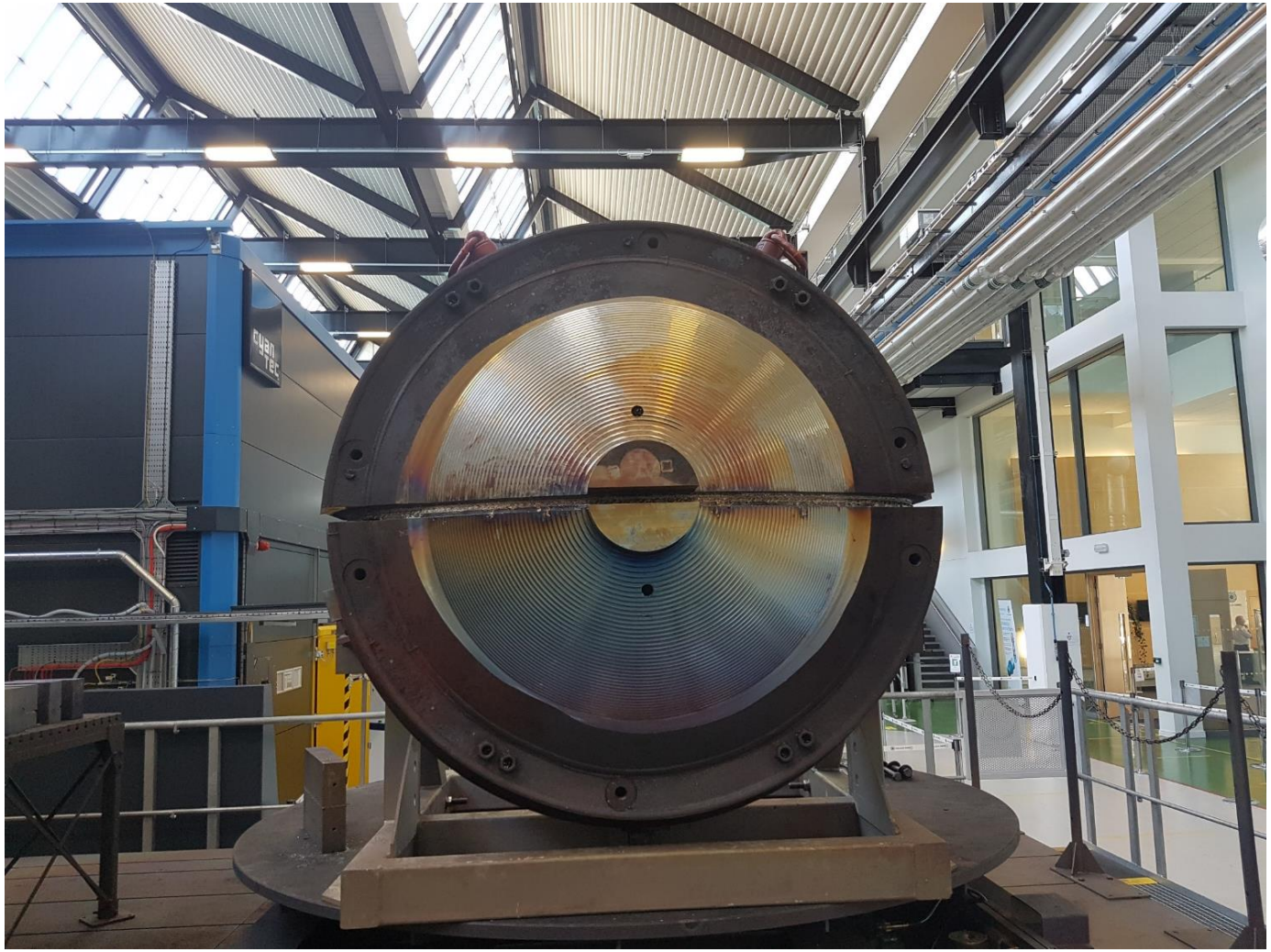
Lower head to Lower Flange Shell (again, upside down)

One-half lower head—Article 4.



Each One-half Lower Reactor Head ~6500lbs (2950 kg) x 70 inches @ 2/3rds scale

Articles 2 and 3 – EB Welding Complete



Lower Head Halves – Weld Prep for EBW

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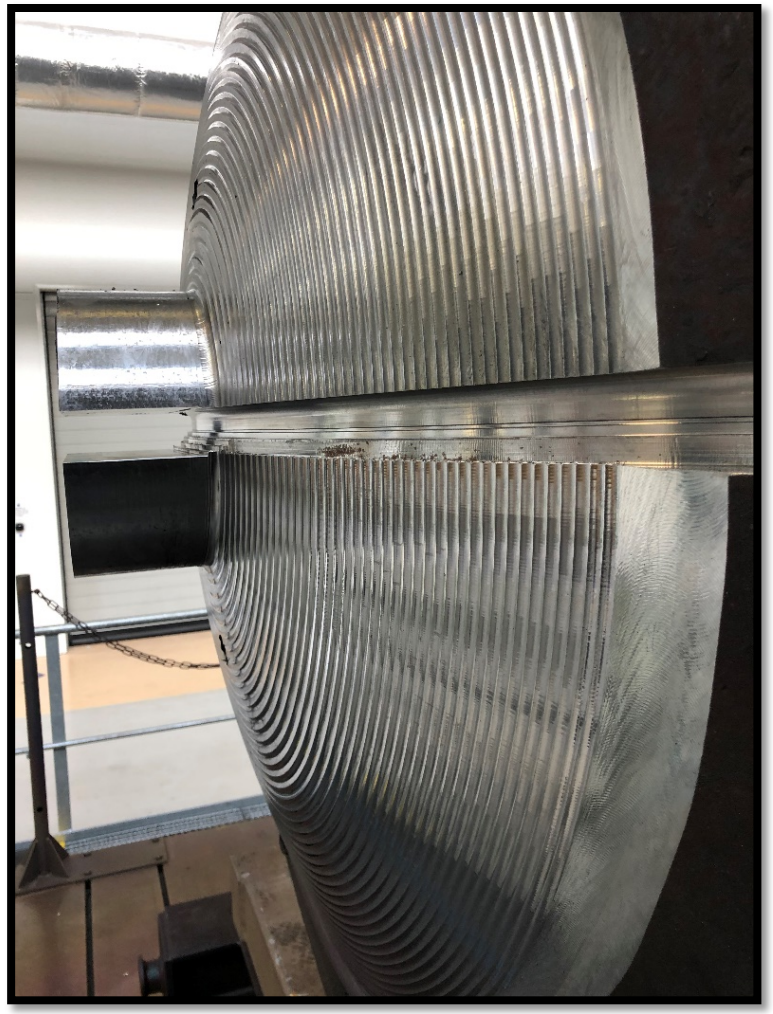


Articles 2 and 3 – EB Welding --23 minutes total welding time

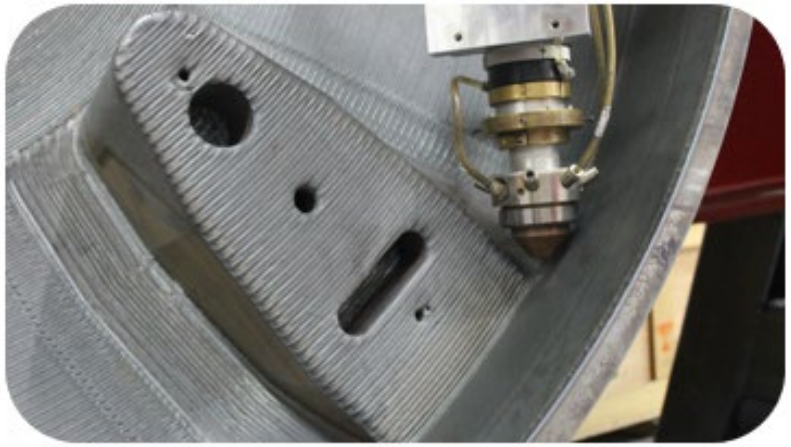
EB Welding Results To Date

- Significantly reduced weld times
  - <90 minutes for full size girth weld projected
- Elimination of weld keyhole at end of RPV diameter
  - Demonstrated technology via multiple large diameter, thick section welds
  - Should be able to share with industry by end of year.

Diode Laser Cladding Development

Diode Laser Cladding Progress

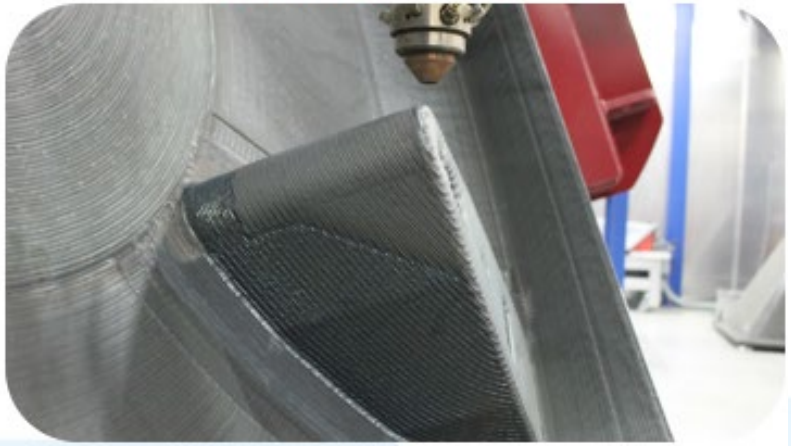
Lower_Upper_Spiral_1 start position



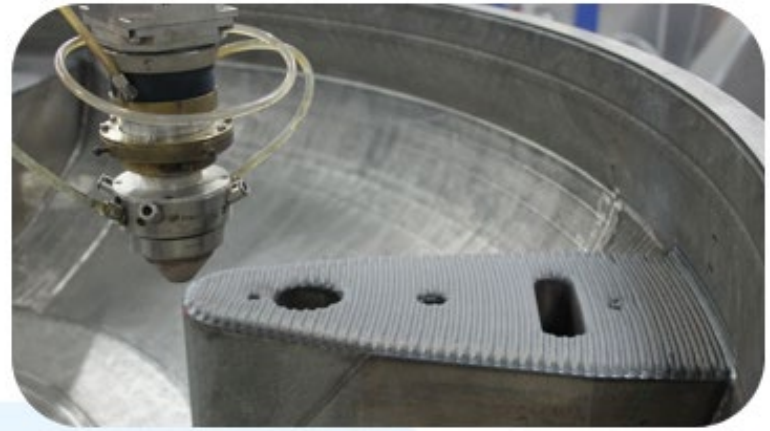
Lug_Face start position

Lug_Top start position

Lower_Upper_Spiral_1 end position



Lug_Face end position



Lug_Top end position

Programming verification for 30mm lower head assembly

30mm lower head assembly – all programs tested and surfaces re-melted.

Total process statistics for single layer:

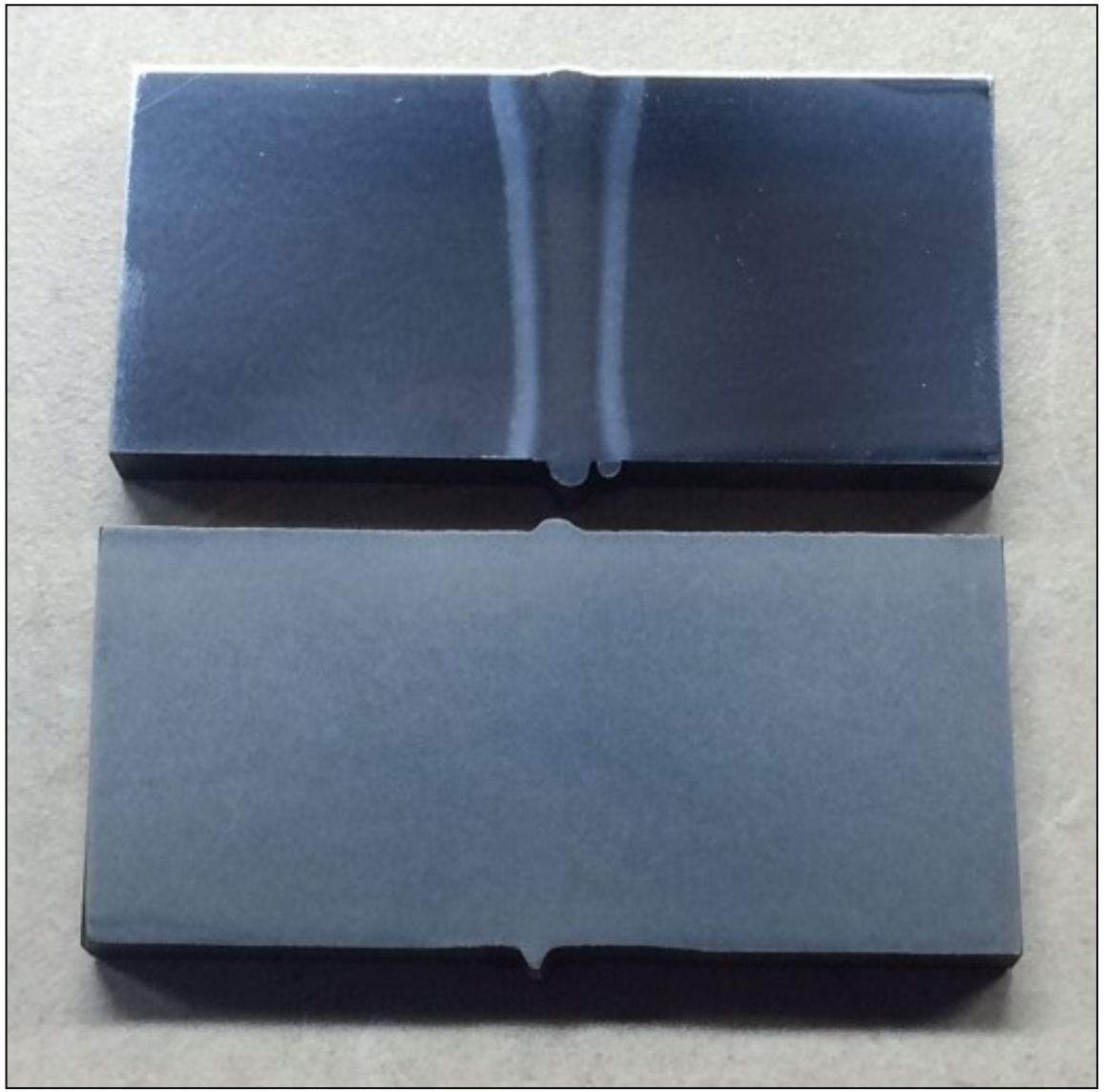
- Total laser time: 19hrs
- Total process time: 24hrs
- Total powder usage: 92kg (202lbs)

Program order:

- Lug_Face
- Lug_Top
- Dome_Center
- Dome_Fill
- Dome_Edge
- Dome_Upper_Spiral
- Dome_Lower_Spiral (1, 2 & 3)

Heat Treatment Parameter Development

Heat Treatment Parameter Development



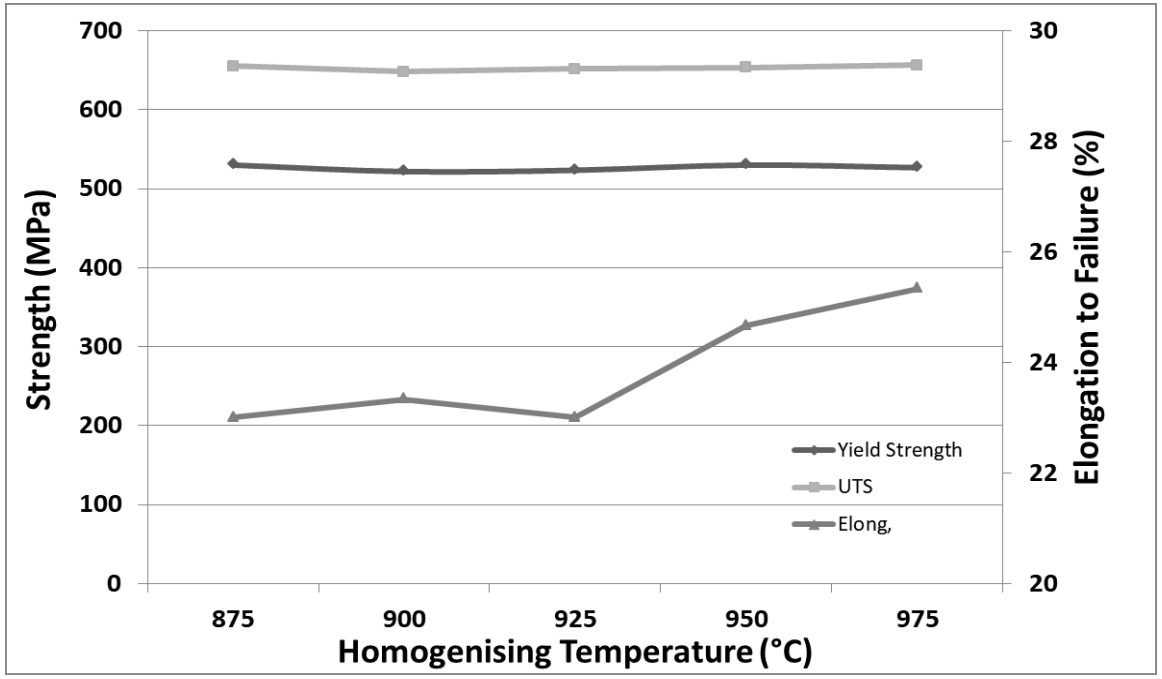
- Laboratory work suggested that evidence of weld could be removed via SQNT while providing good fracture properties.
- Can we scale this up to large components without significant distortion?
  - What is the lowest normalization temperature that removes evidence of weldment
- Working with SFEL to scale HT technology via: 1) modeling, 2) laboratory work, and 3) mockups

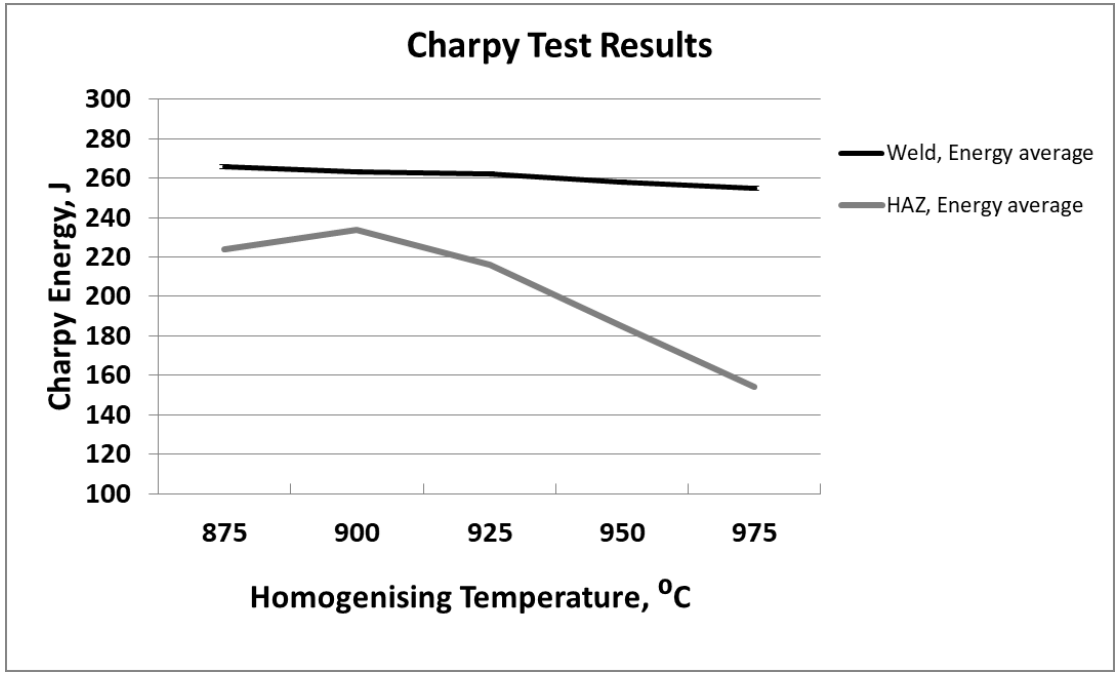
- EB Weld Coupon Size: 450 x 290 x 90 mm

Heat Treatment Development-SQNT

- Homogenize & Quench (Soln anneal) – temperatures to right
- Hardening (normalizing) – 870C±10C
- Tempering – 640C±5C

HT Temp (°C)	Energy (J), Weld	Energy (J), HAZ
875	266	224
900	263	234
925	262	216
950	258	185
975	255	154

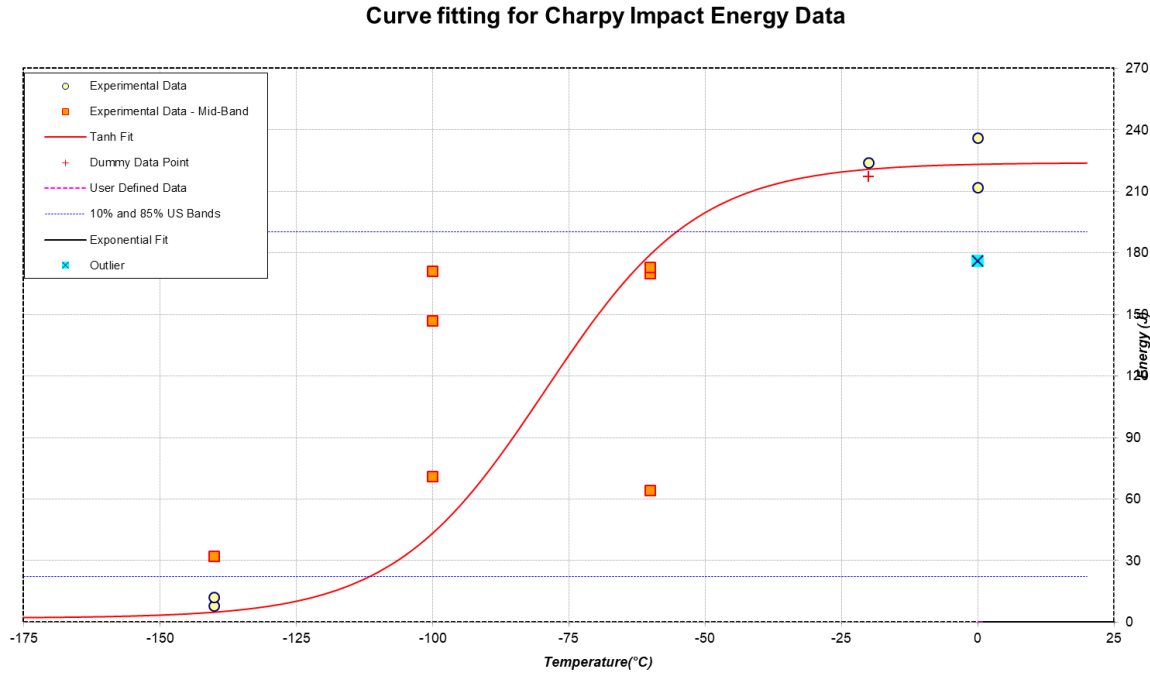


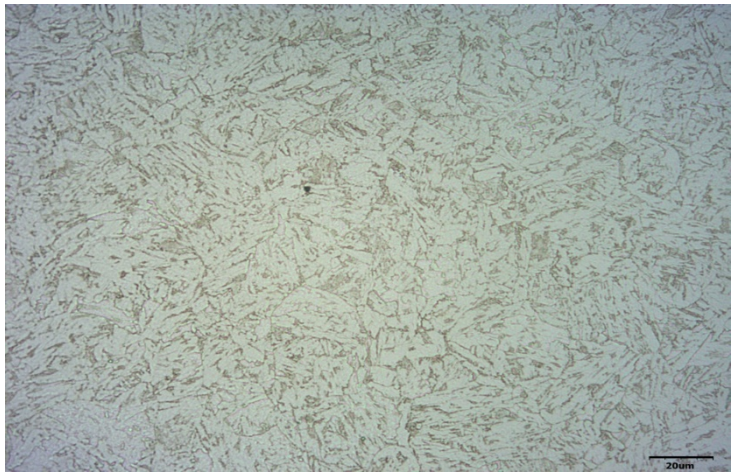


Heat Treatment Development-SQNT

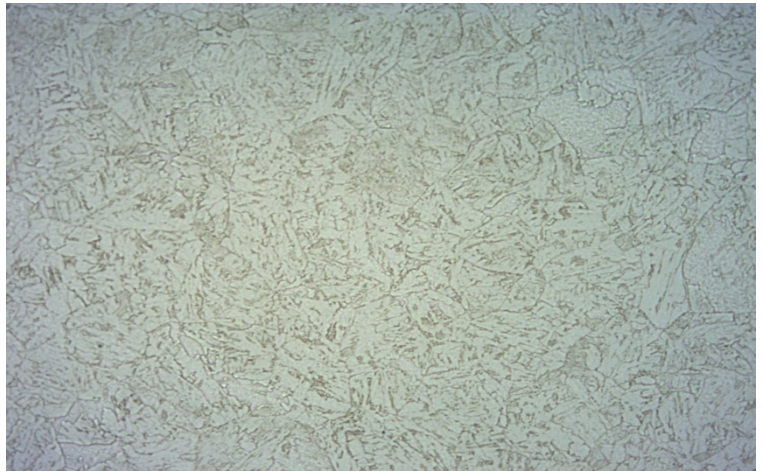
Laboratory results are encouraging – 875C

- Good toughness
- Homogenized microstructure

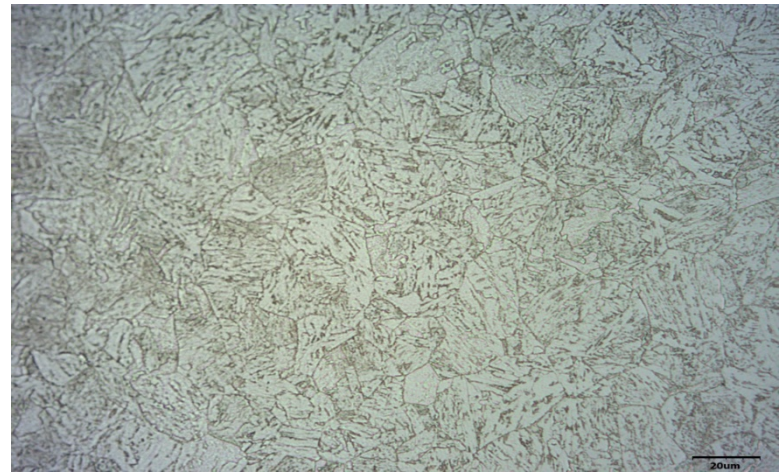




Weld



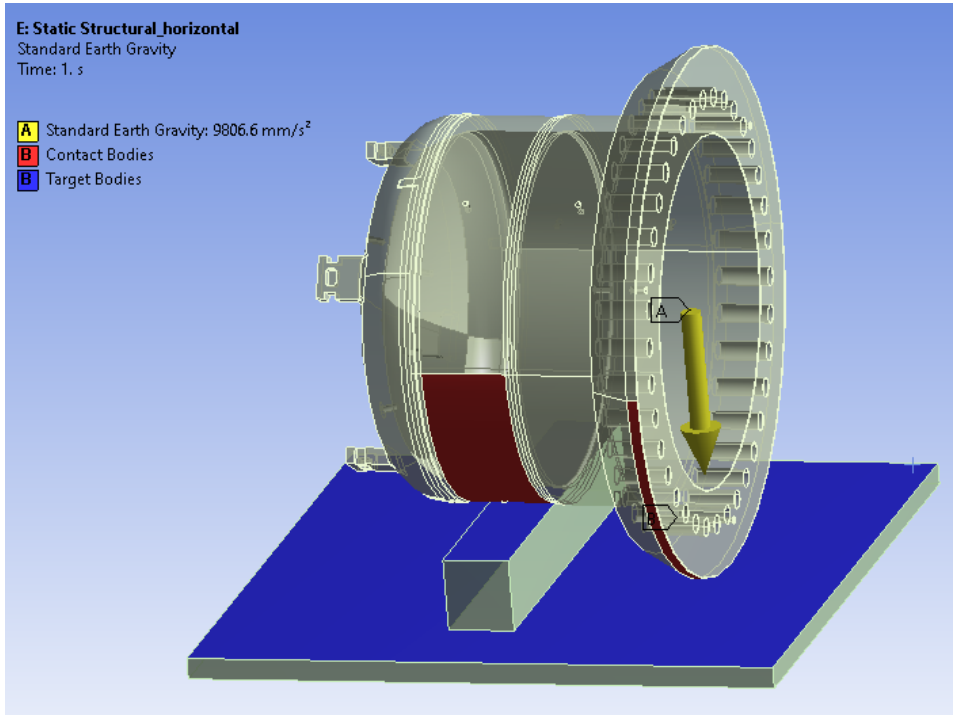
HAZ

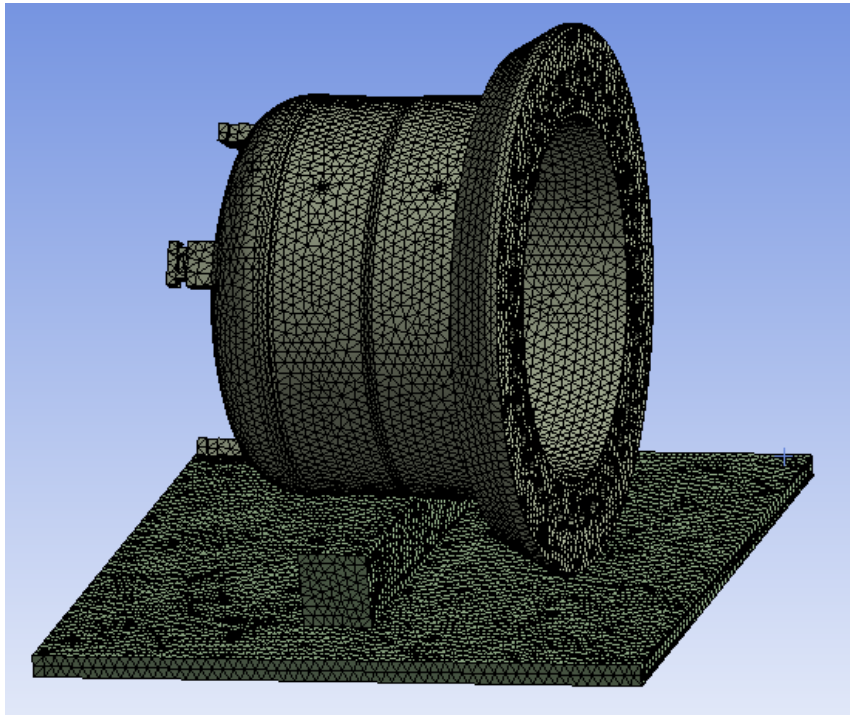


Parent

Linear analysis

Self-Buckling



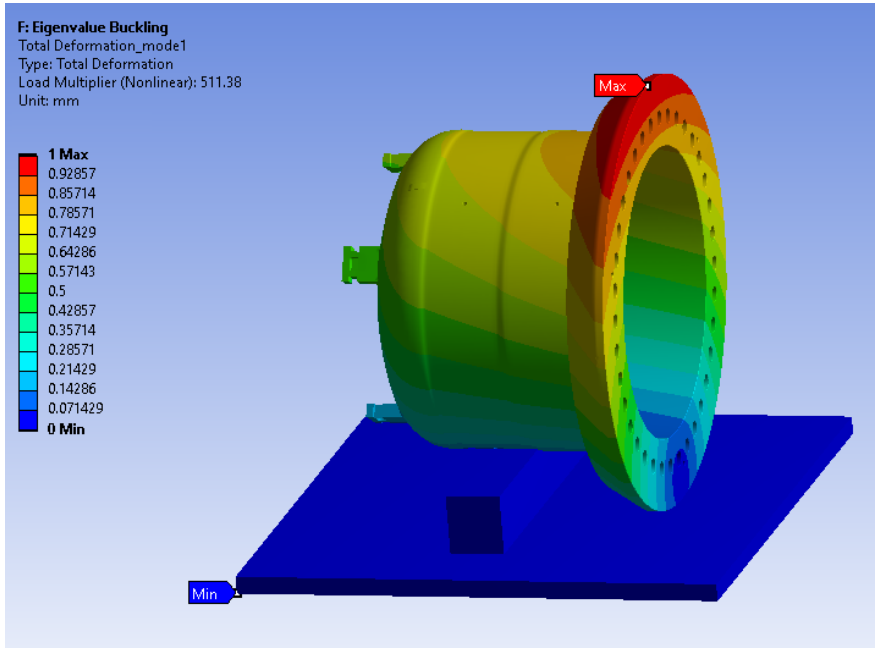


- Material of shell is SA-508-3 at 875°C
- The shell is horizontally supported
- The floor and support are considered to be very stiff
- Frictional contact is considered for the touching surfaces

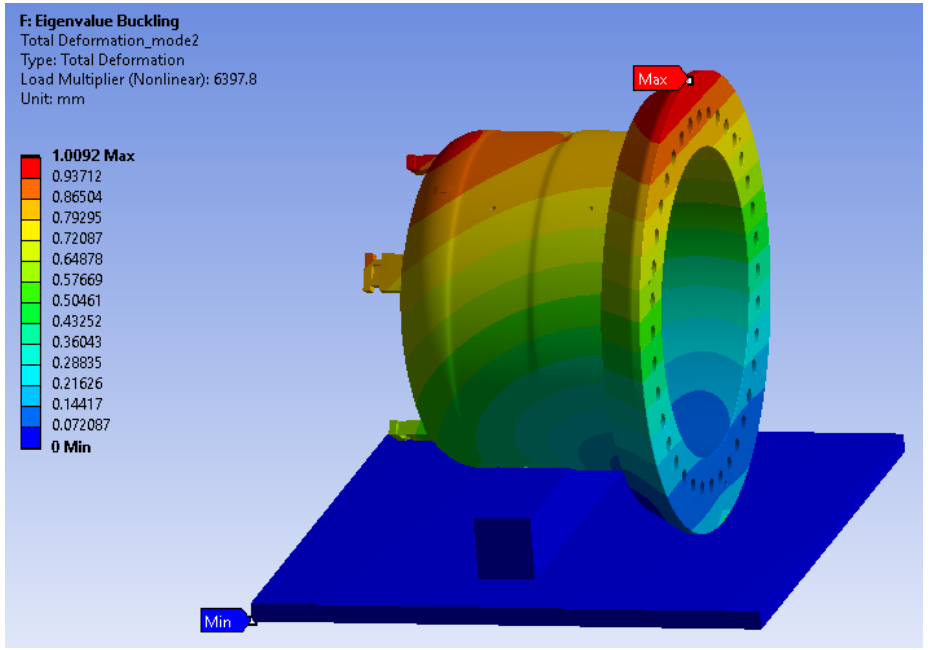
Linear analysis, mode shapes

No buckling concern due to high load multipliers!

Mode 1
Load multiplier: 511



Mode 2
Load multiplier: 6400



Heat Treatment Parameter Development --Progress

- SQNT success in laboratory on thick EB Welds
- Also, modeling looks good (no buckling and low stresses)
- Next, scale up to 2/3-scale mockup
  - Lower head, lower RPV, lower flange
- Develop EB Welds for ORNL characterization to support Code Case
  - Forged and PM-HIP

Next Steps – SMR Advanced Manufacturing Project

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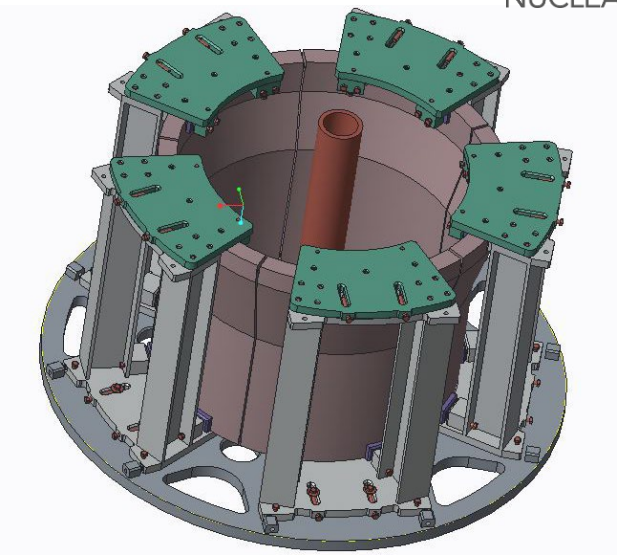
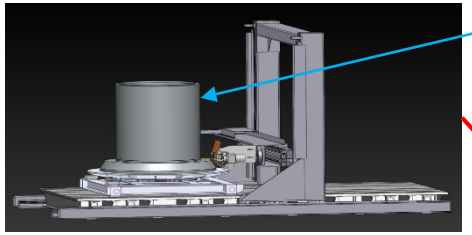
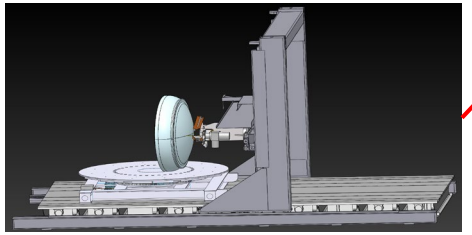
- Bottom Head-to-RPV shell forging via EB weld
- Quality HT of assembly
- Completes lower half (below parting line) of Lower Assembly
- Next, transition shell welding

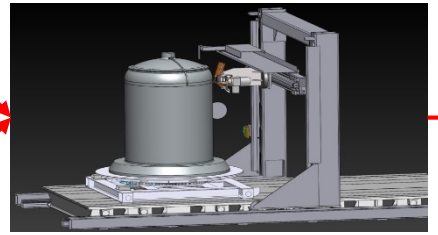


RPV Shell-Flange

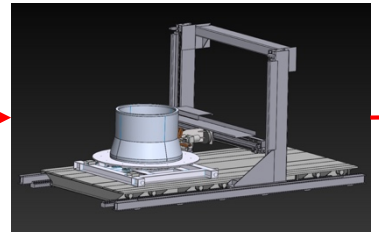




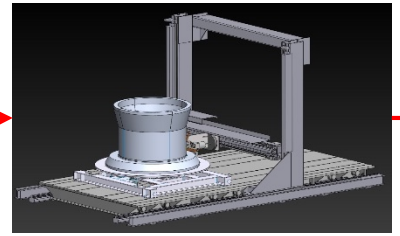
RPV Lower head halves



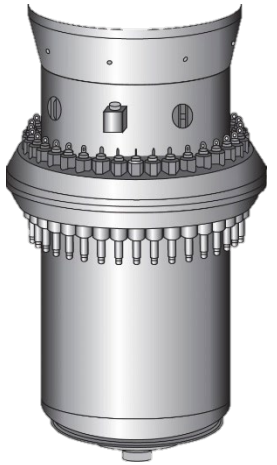
RPV Lower head-shell-flange



RPV Transition Shell



RPV Transition shell-flange



Representative Model of NuScale Power Reactor Vessel
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Summary (1)

- PM-HIP
  - VIM atomization required.
  - Vacuum annealing provides good properties too.
  - Still need to demonstrate properties on large components.

- EB Welding
  - Parameters developed
  - Lower head assembled; mockup of shell-to-flange completed
  - Next assembly & HT of lower half of lower assembly
  - Elimination of keyhole and repair contingency

Summary (2)

- Diode Laser Cladding
  - Equipment and parameter development complete.
  - Lower head demonstration completed (touching all surfaces).

- Heat Treatment Parameter Development
  - 875C will homogenize microstructure and provide good toughness
  - Need to scale up on mockup

- Phase II – Upper Assembly
  - Initiate soon.

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