Factory Fabrication of Small Modular Reactor Vessel Assemblies

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NRC RIC: Use of Advanced Manufacturing Technology for Power Reactors

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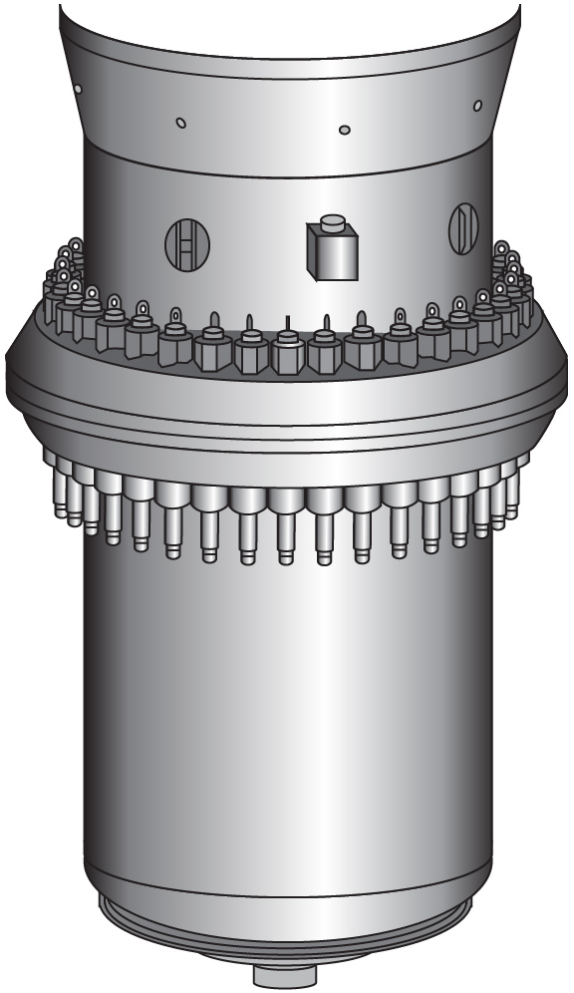
Overview

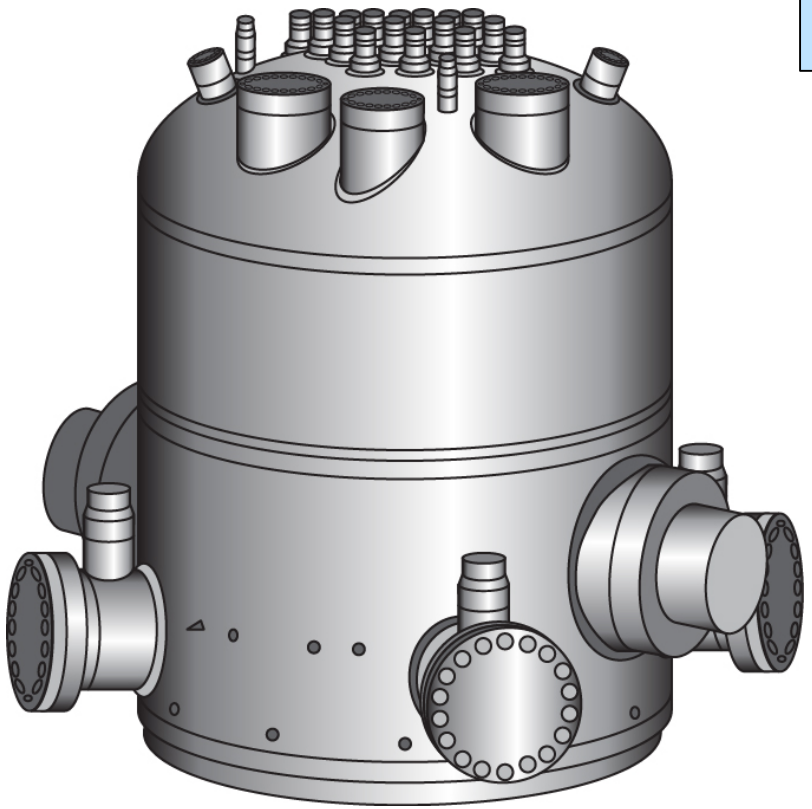
- Highlight Four Advanced Manufacturing/Fabrication Technologies
  - DOE Project: DE-NE0008629
- Introduce Two Associated Projects/Activities @ EPRI
- Fitting It Altogether--Factory Manufacturing and Fabrication

Advanced Manufacturing Technologies for SMRs

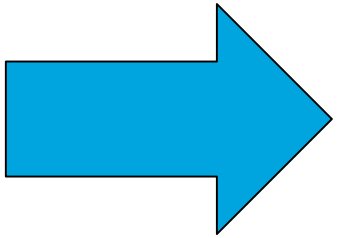
- Powder Metallurgy-Hot Isostatic Pressing
- Electron Beam Welding & Heat Treatment
- Diode Laser Cladding
- ATLAS—Advanced Large Scale HIP

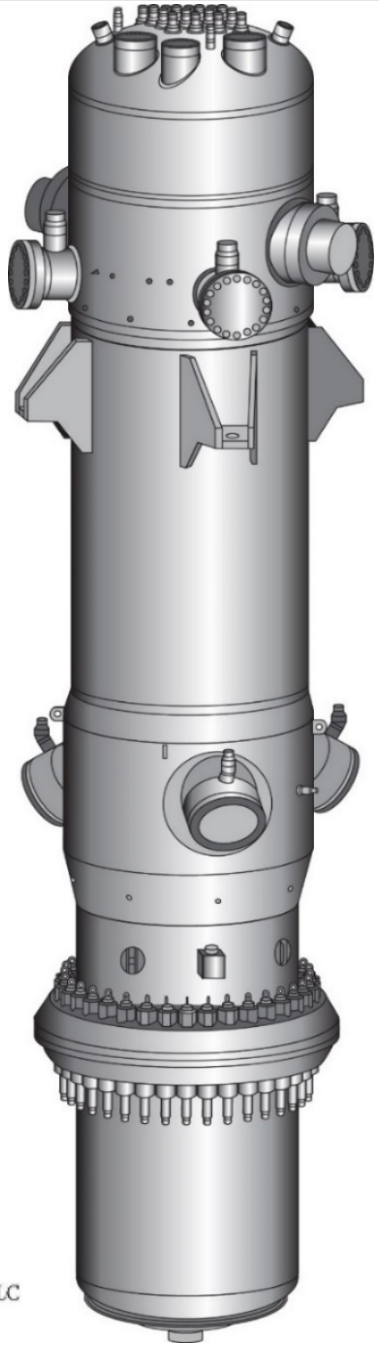
2/3rds Scale Small Modular Reactor Manufacture/Fabrication





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





DOE Project: DE-NE0008629

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 9 years.
- Ideal for multiple penetration applications (RPV or CNV head) vs expensive forgings

Large 316L SS Valve Body

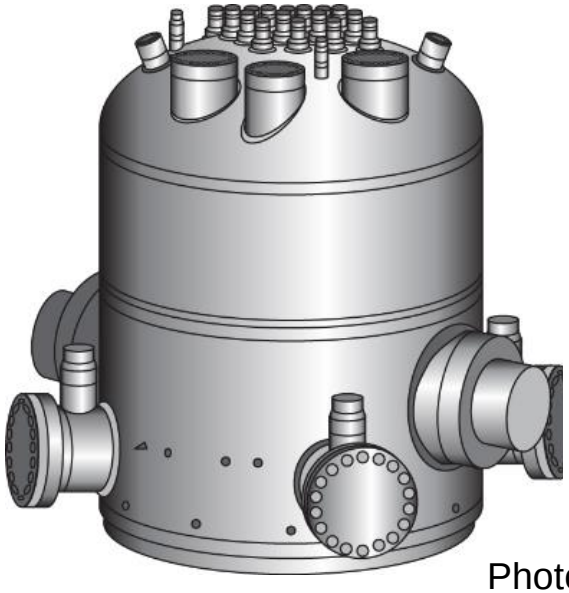
Partial RPV Ring Section

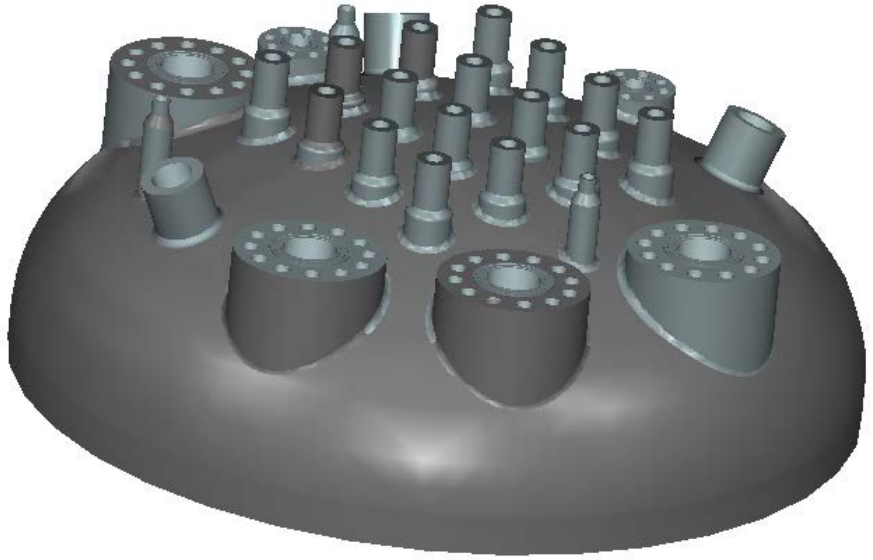
Inspection, Costs?

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

Subsea Manifold.
Courtesy: Sandvik

Small Modular Reactor Upper Head--Example



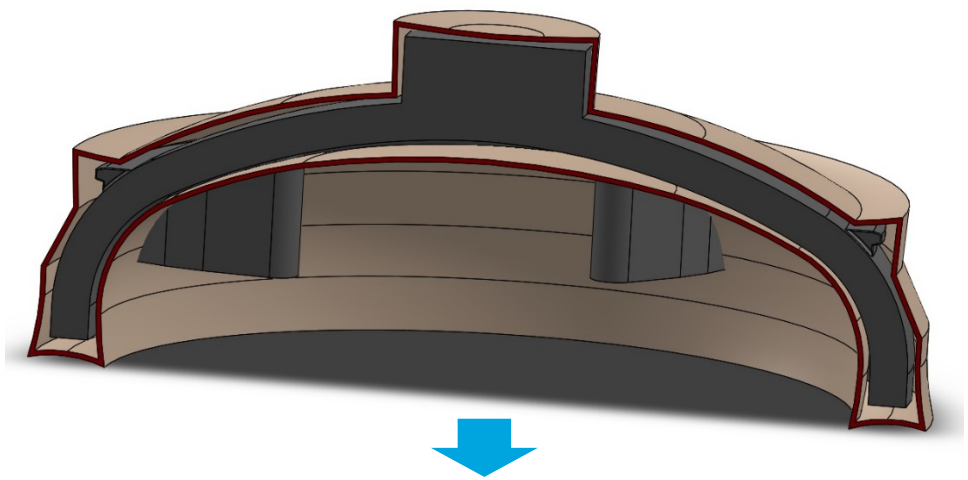


Photographs courtesy of EPRI and NuScale Power

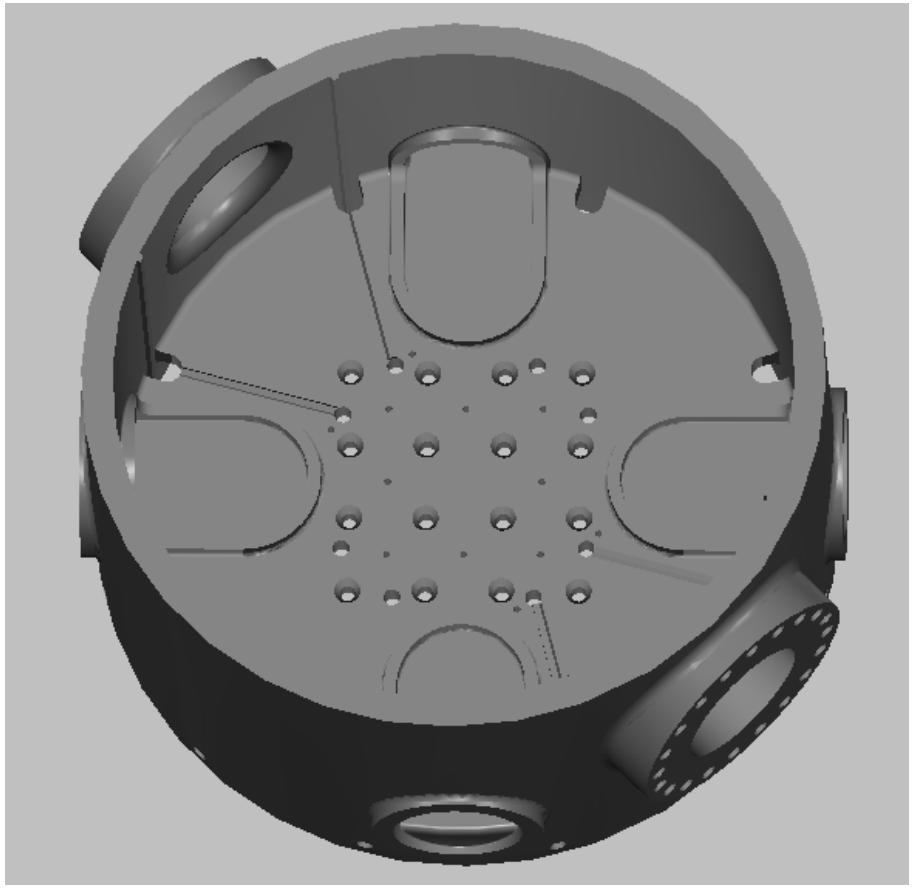
- ~44% scale
- Single monolithic structure
- A508 Class 1, Grade 3
- 27 penetrations
- 1650kg (3650lbs); 1270mm (50 inches) diameter
- Next, 2/3-scale head
- Need larger HIP Vessel -- ATLAS

DOE Project: DE-NE0008629

Small Modular Reactor—Other PM-HIP Components



Access Head—8400lbs
(full size)



Steam Plenum Model

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

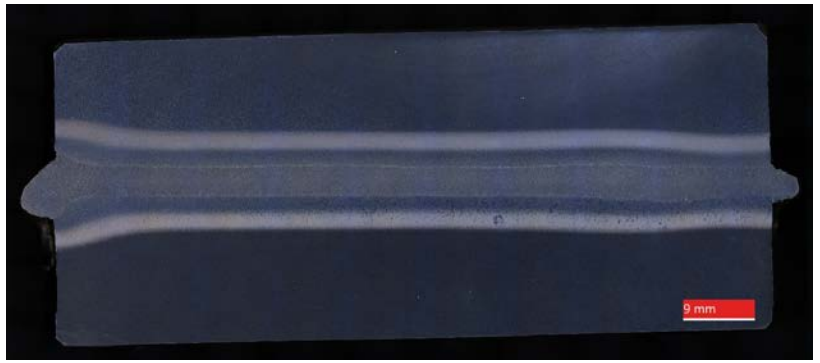
Electron Beam (EB) Welding

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

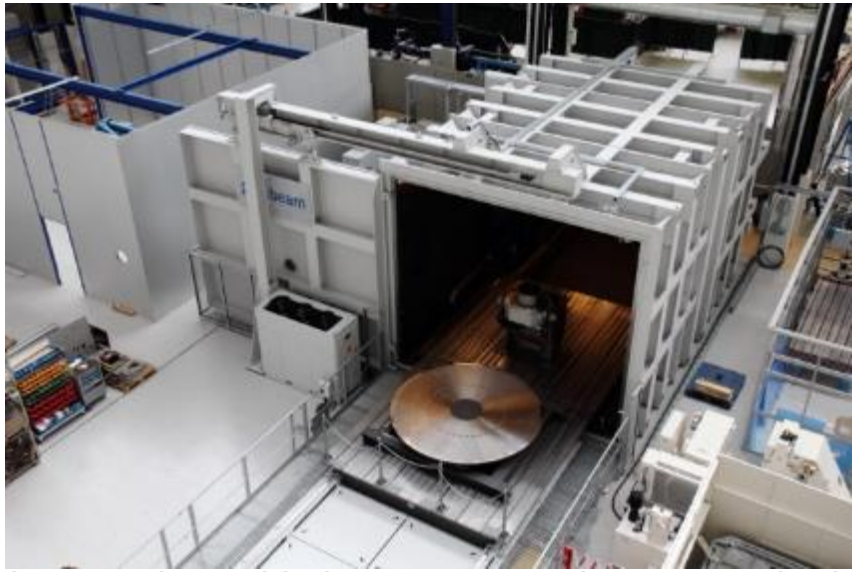
Inspection, Costs?

- Huge savings in welding costs (up to 90%)
- Potential to eliminate in-service inspection coupled with heat treatment!



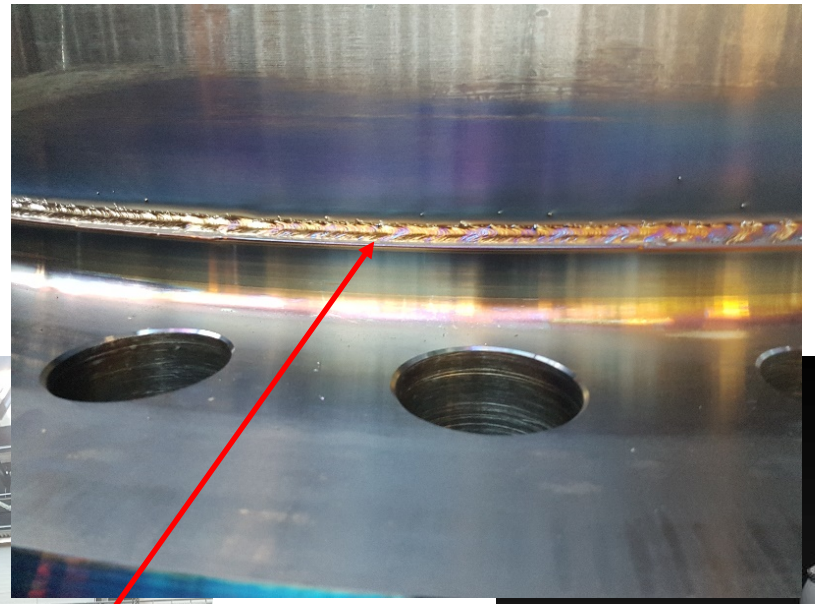
110mm (thick) EB Weld

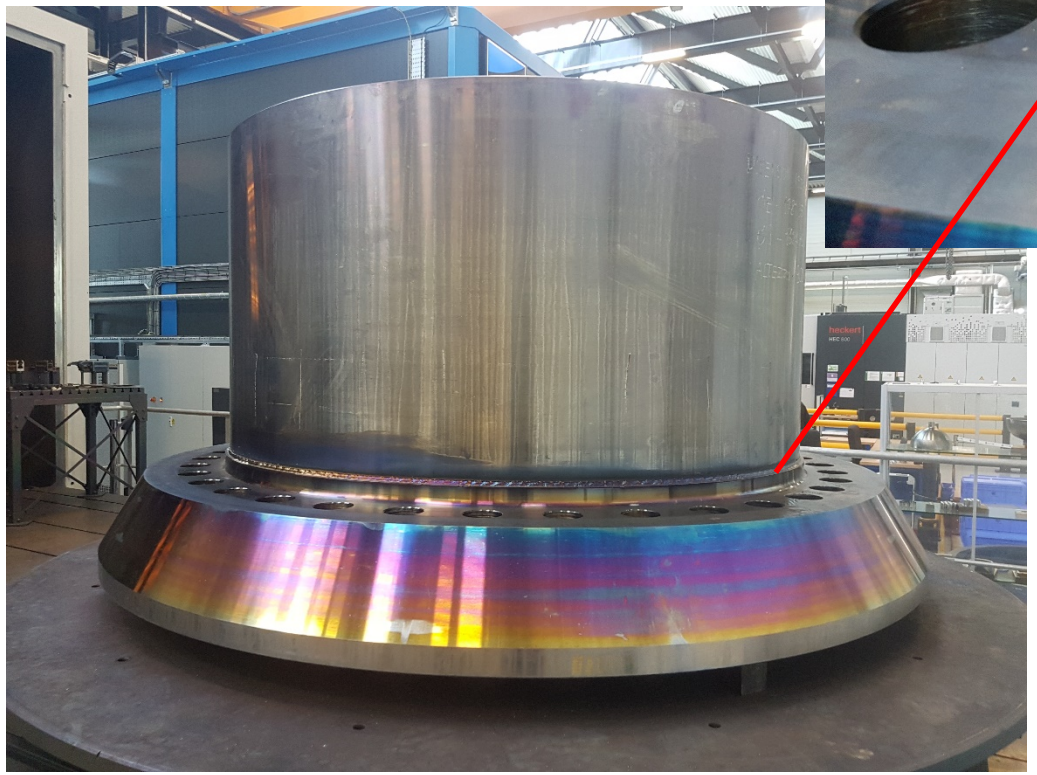
Photograph provided courtesy: Nuclear AMRC (UK)



Photograph provided courtesy: Nuclear AMRC (UK)

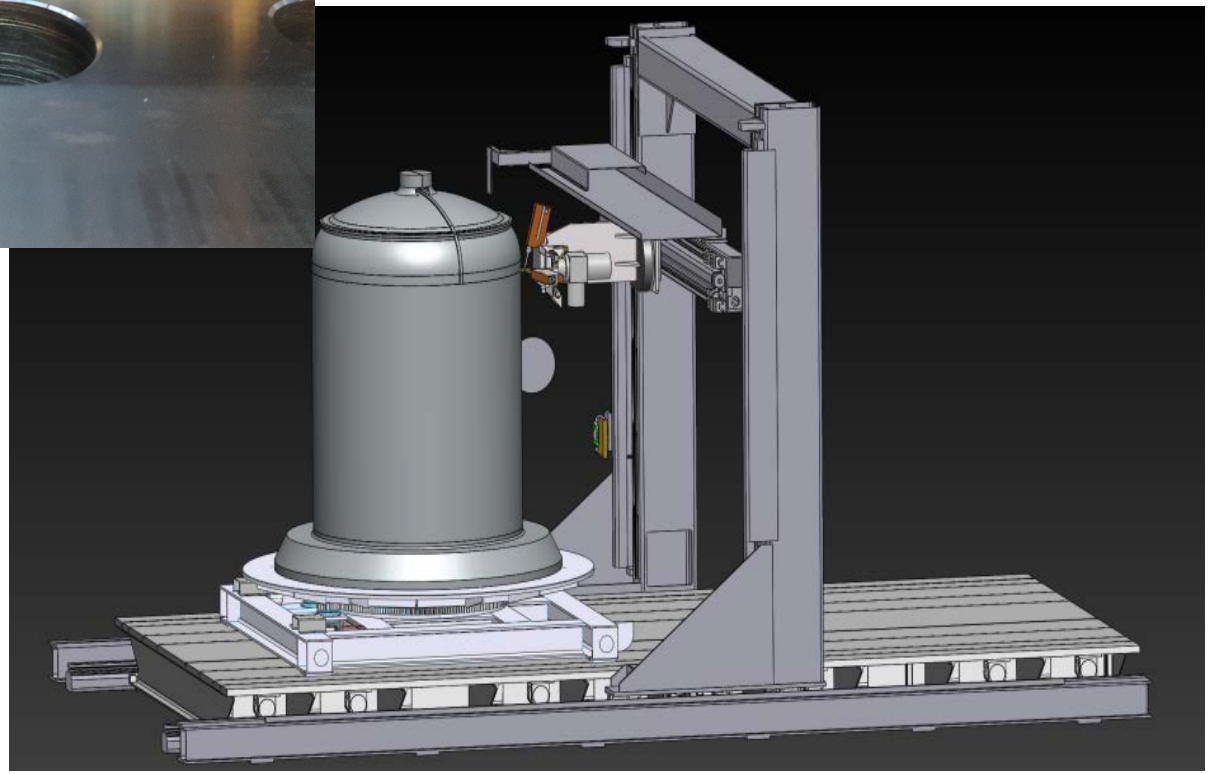
Electron Beam Welding





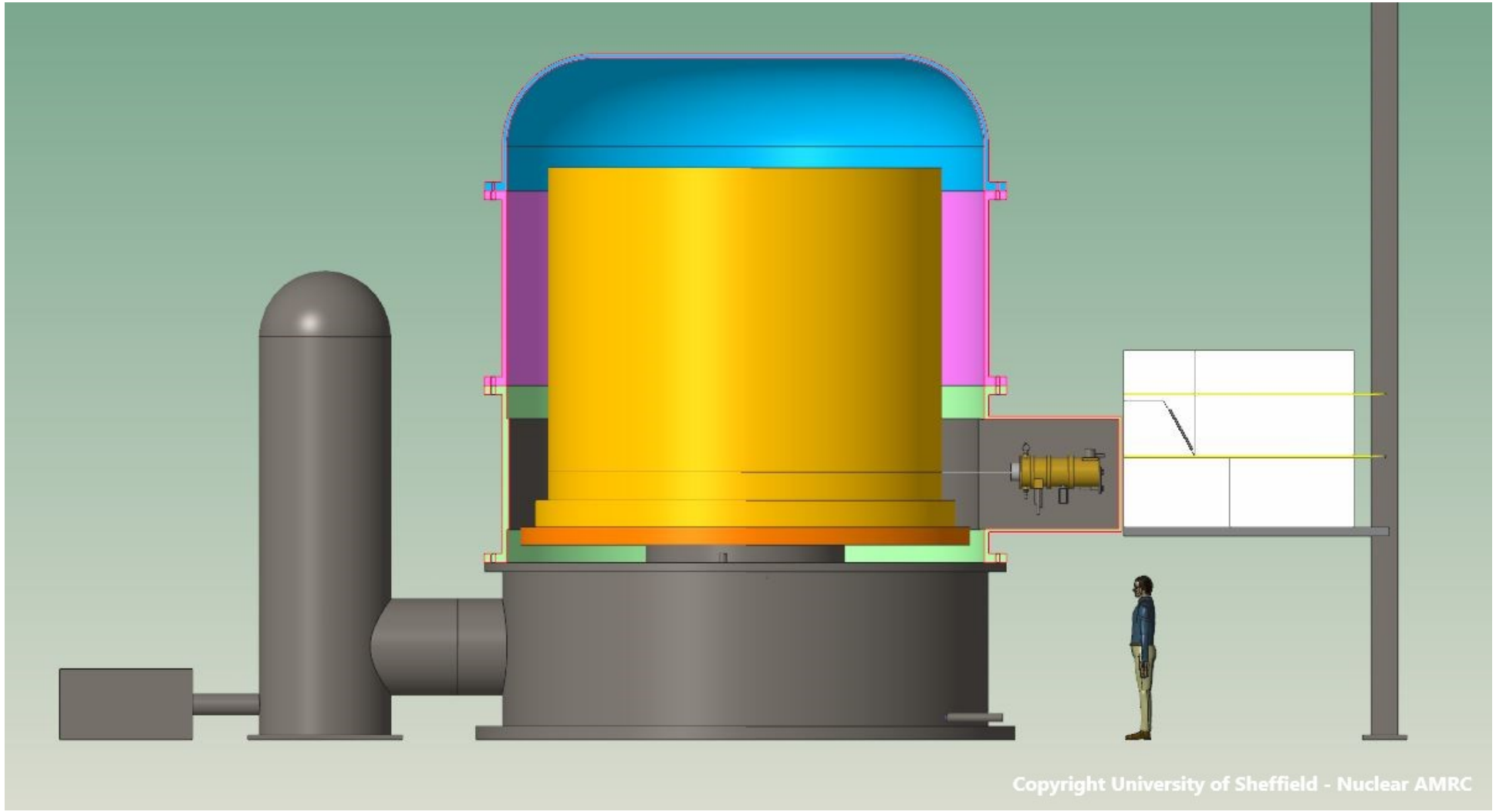
Lower Flange Shell Mockup EB Weld -- ~6 ft (1.82m) diameter (Note, mockup is upside down)

Completed in 47 minutes



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

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



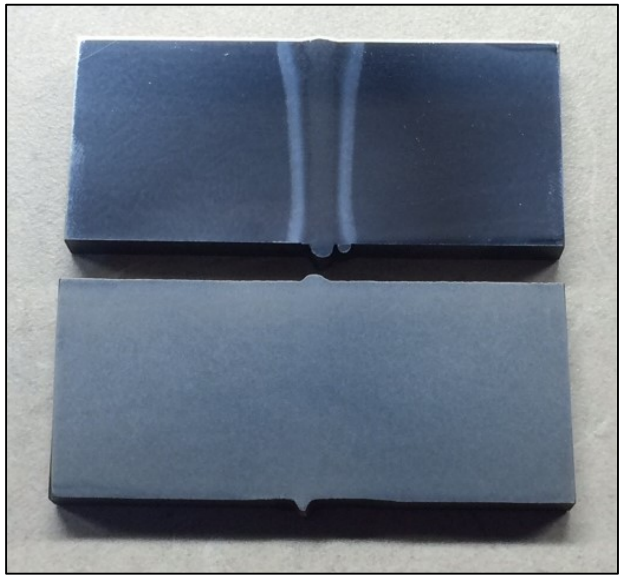
Elimination of Welds via Heat Treatment --Resetting the Clock

Eliminate the Weld through re-austenitzation at high temperature. **How?**

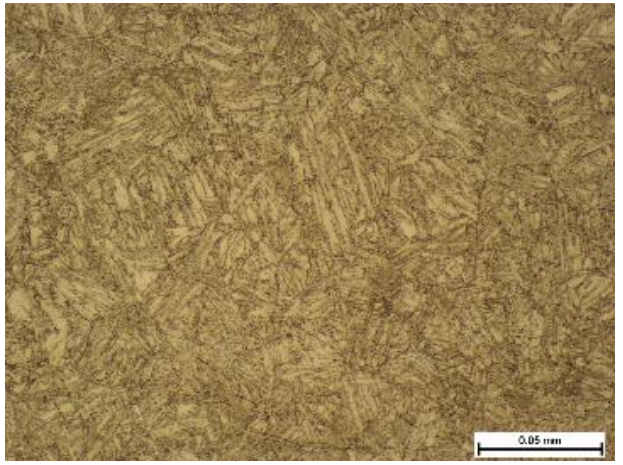
- Perform chamber EB weld of sub-assemblies
- Solution HT, quench; normalize; temper
- Resulting microstructure is same as base metal
- Fracture toughness comparable to base material

Inspection, Costs?

- Perform fabrication inspection prior to and following initial solution HT, plus N&T (SQNT)
- Following HT, no weld is visible
- Potentially no weld inspection required at 10 year intervals



$EBW+HT=0\ Weld$



EB Weld after Heat Treatment
WCL microstructure @ 500X

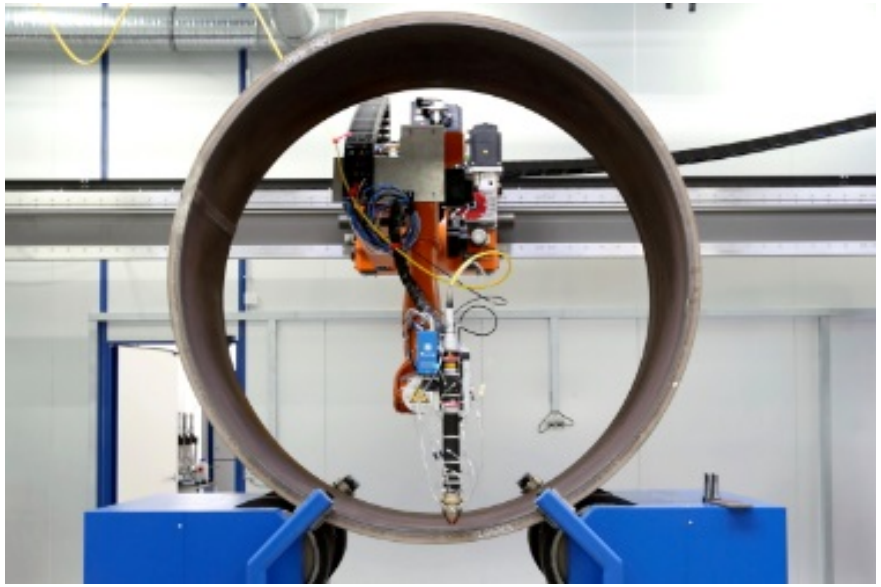
Diode Laser Cladding

Why DLC?

- Robotic machine & out-of-position welding
- Good deposition rates
- Significantly reduces cladding thickness required (~3-4mm)

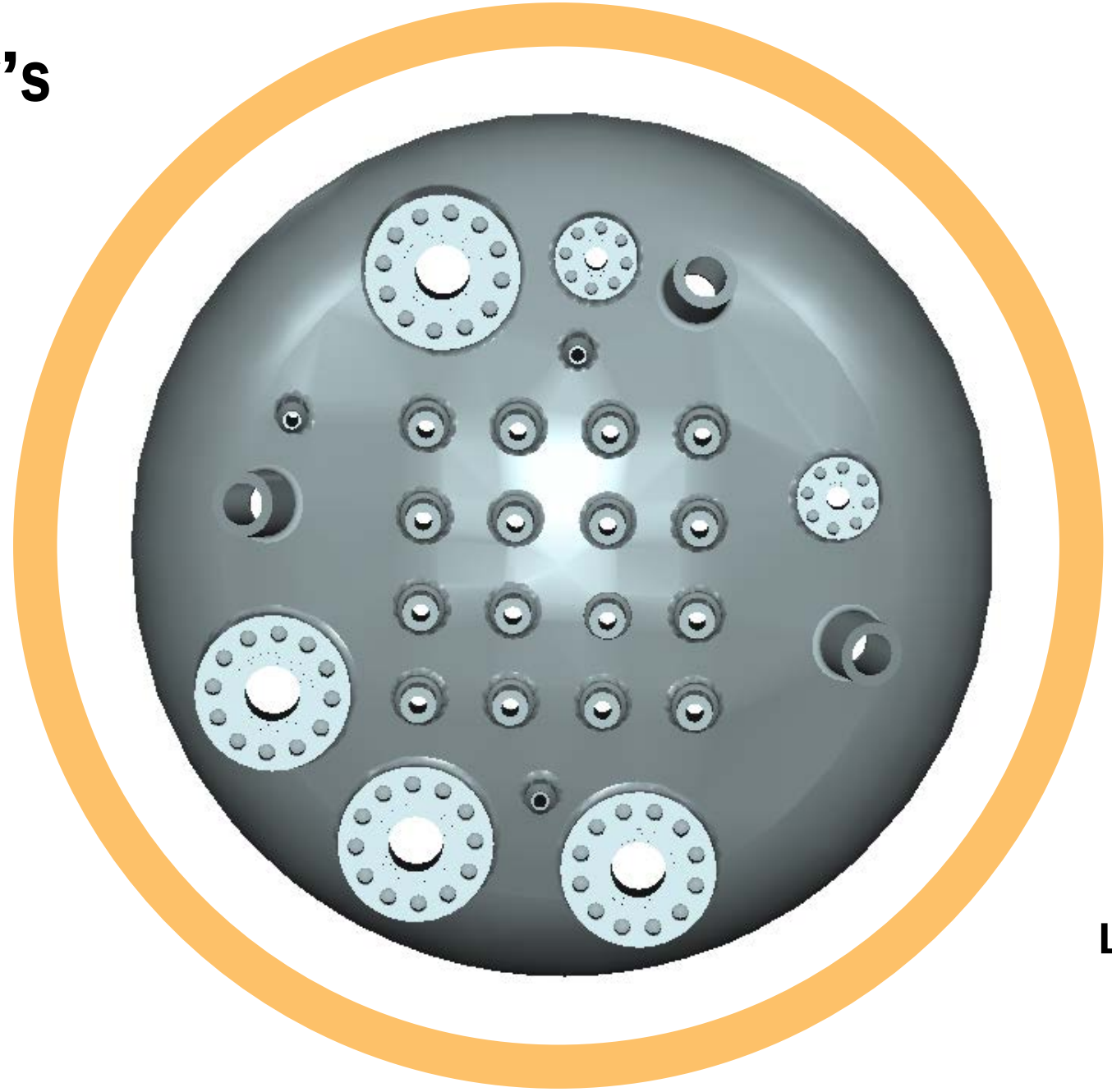
Inspection, Costs?

- Lbs. (or kg) of material required is significantly reduced since thinner layers can be applied.
- No machining after cladding required



Diode Laser Cladding equipment setup (courtesy of N-ARMC)

Tomorrow's PM-HIP



3.55m (140in) Diameter x 2m (79in) (T) HIP Vessel

ATLAS

Load capacity = 250,000 lbs (113,000kgs)

Factory Manufacturing and Fabrication

Photograph courtesy of Boeing

- Many advanced manufacturing methods available!
- Which methods can we bring forward in near-term?
  - Powder Metallurgy-Hot Isostatic Pressing
  - Electron Beam Welding & Heat Treatment
  - Diode Laser Cladding
  - ATLAS—Advanced Large Scale HIP

SMRs and Gen IV Factory Manufacture/Fabrication

- Modular Construction
  - Have to get it right this time…
- Smaller unit size is ideal for factory production
- Economy of scale—must compete with LNG!
- Must bring to bear new manufacturing and fabrication technologies to be cost effective.

Reference: Bailey, J., "What's Nu and What's Next," April 2017.

Together...Shaping the Future of Electricity