Integrated Chamber Design for the Laser Inertial Fusion Energy (LIFE) Engine

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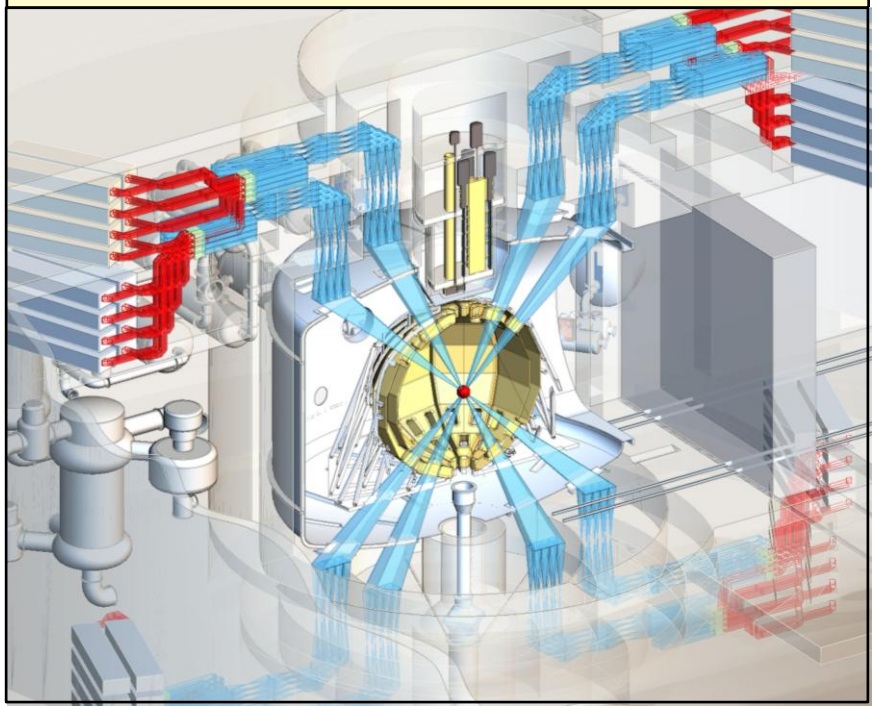
LIFE makes maximum use of available technologies, industrial capabilities and simplicity in design

Gas-protected first wall enables use of steels

Coolant selection and large chamber coverage provide ample tritium breeding margin and high blanket gain

Coolant selection greatly reduces tritium permeation and reduces site inventory

Chamber designed to be modular and easily replaceable

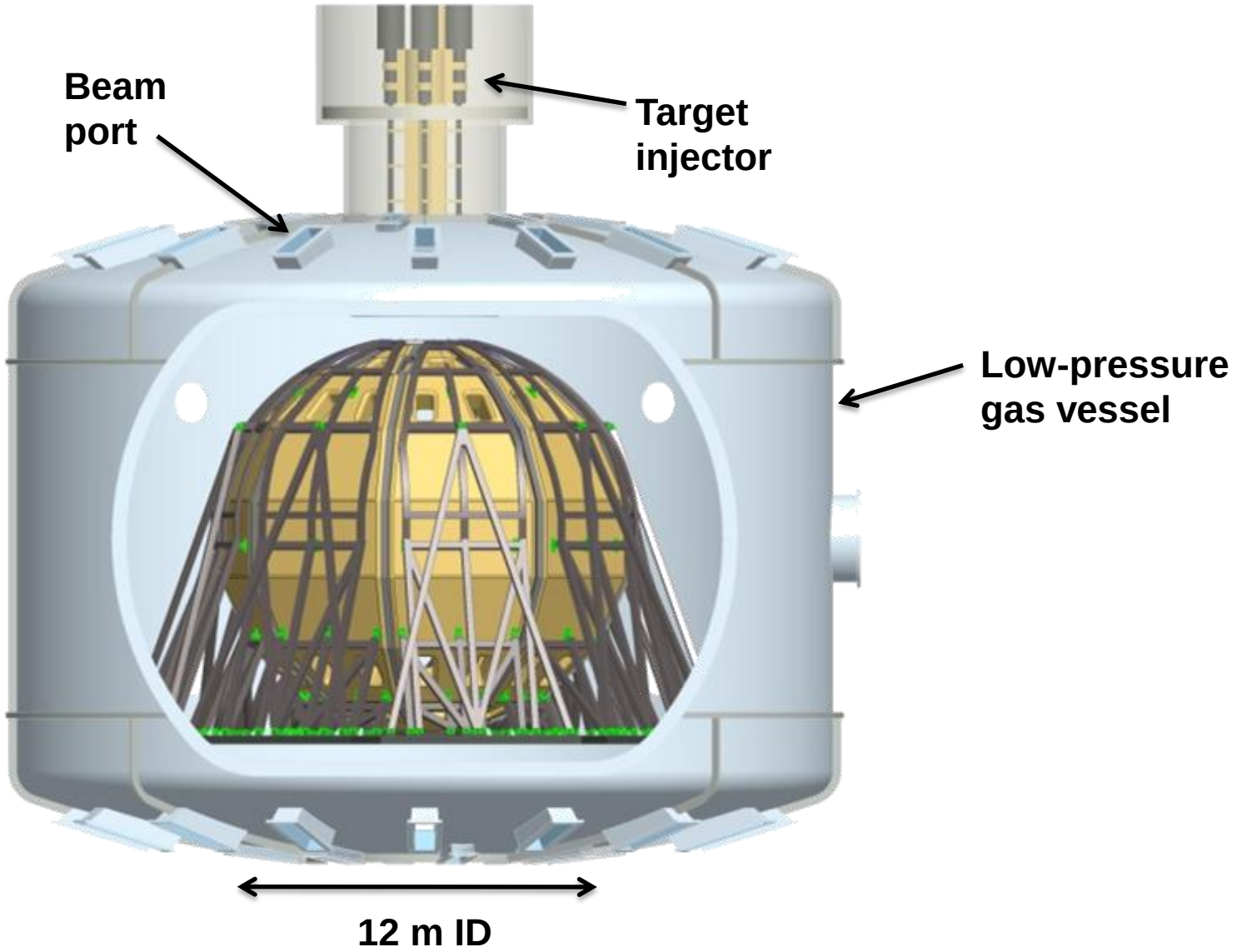


Target material selection eliminates need for chamber clearing

Commercially available power cycle provides high (and improving) efficiency

Radiation-tested final optic solution is available

The LIFE "chamber" is an unsealed, segmented array sitting within a low pressure gas environment



Making the chamber a line replaceable unit (LRU) enables operational phasing

Phase 1: Pilot Plant

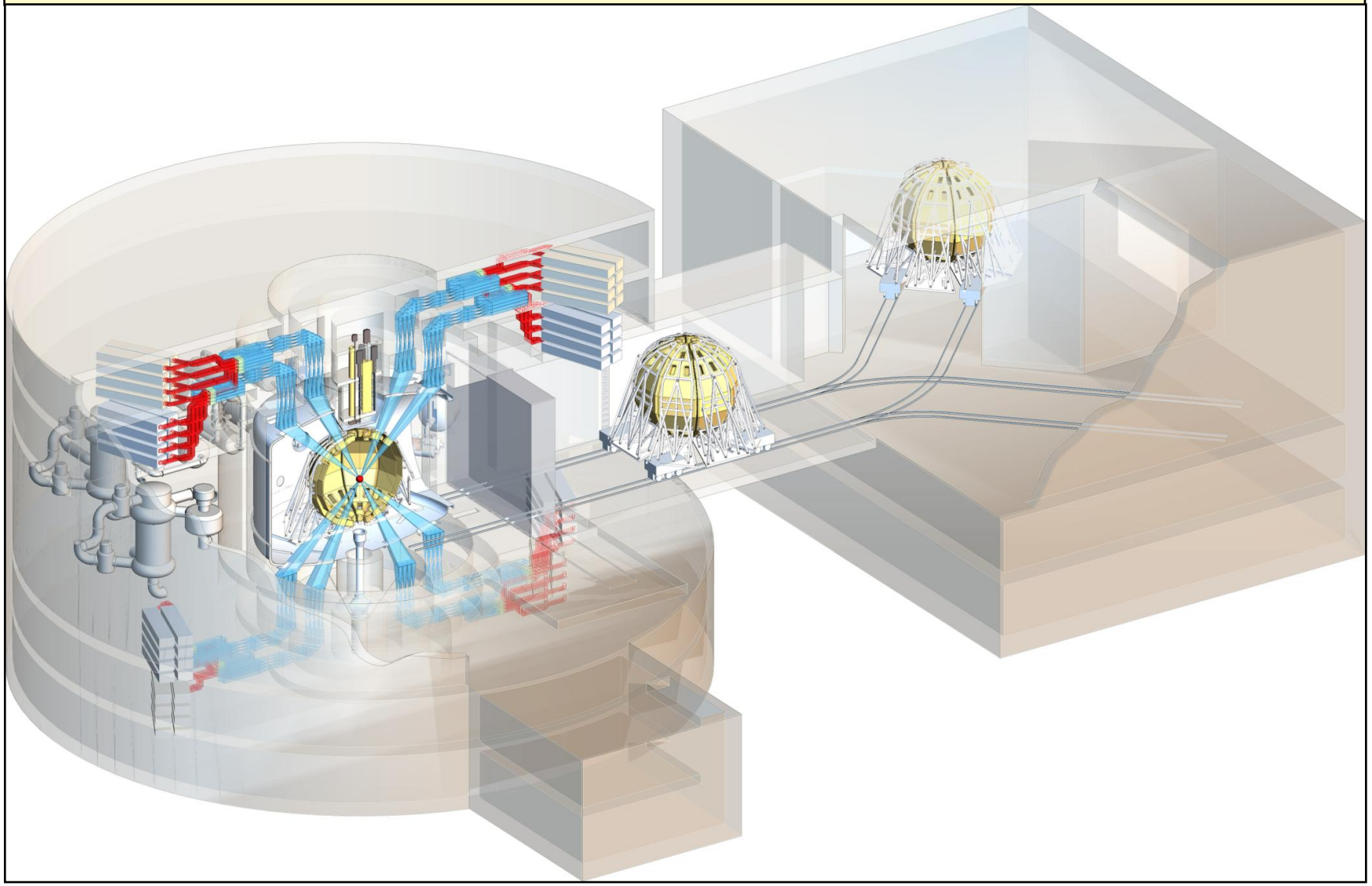
- 250 – 400 MWe net output
- ~ 0.5 MW/m^2 heat load
- ~ 10 dpa / 100 appm He lifetime
- Eurofer, F82H or modified HT-9 structural material
- Pure lithium blankets
- Accelerated materials testing

Phase 2: Full Commercial

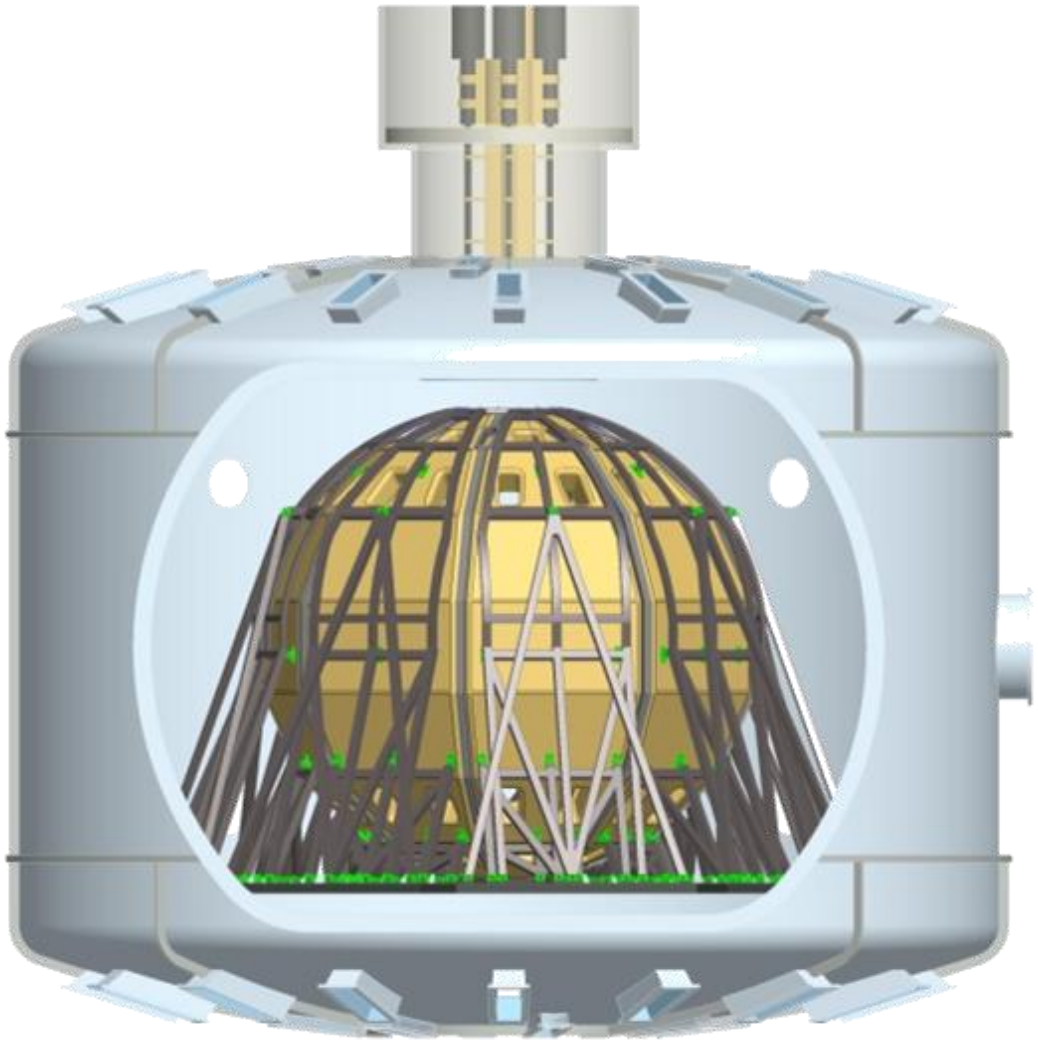
- 400 – 1500 MWe net output
- ~ 1 MW/m^2 heat load
- ~ 50 dpa lifetime
- ODS-like steel or “bootstrap” learning with Eurofer, etc.
- Possibility of tunable, high-gain blankets

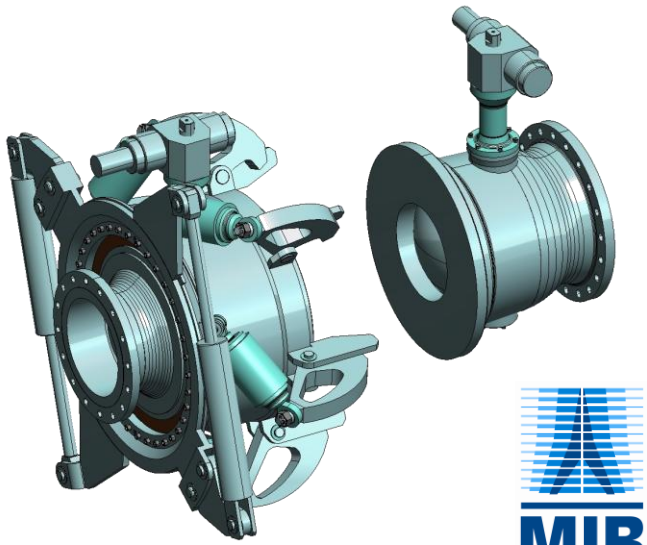
The chamber LRU can be transported for maintenance or replacement

Unsealed chamber, separate from the vacuum and optical systems



Once moved to the engine bay, cooling connections are made with hydraulic couplers from industry





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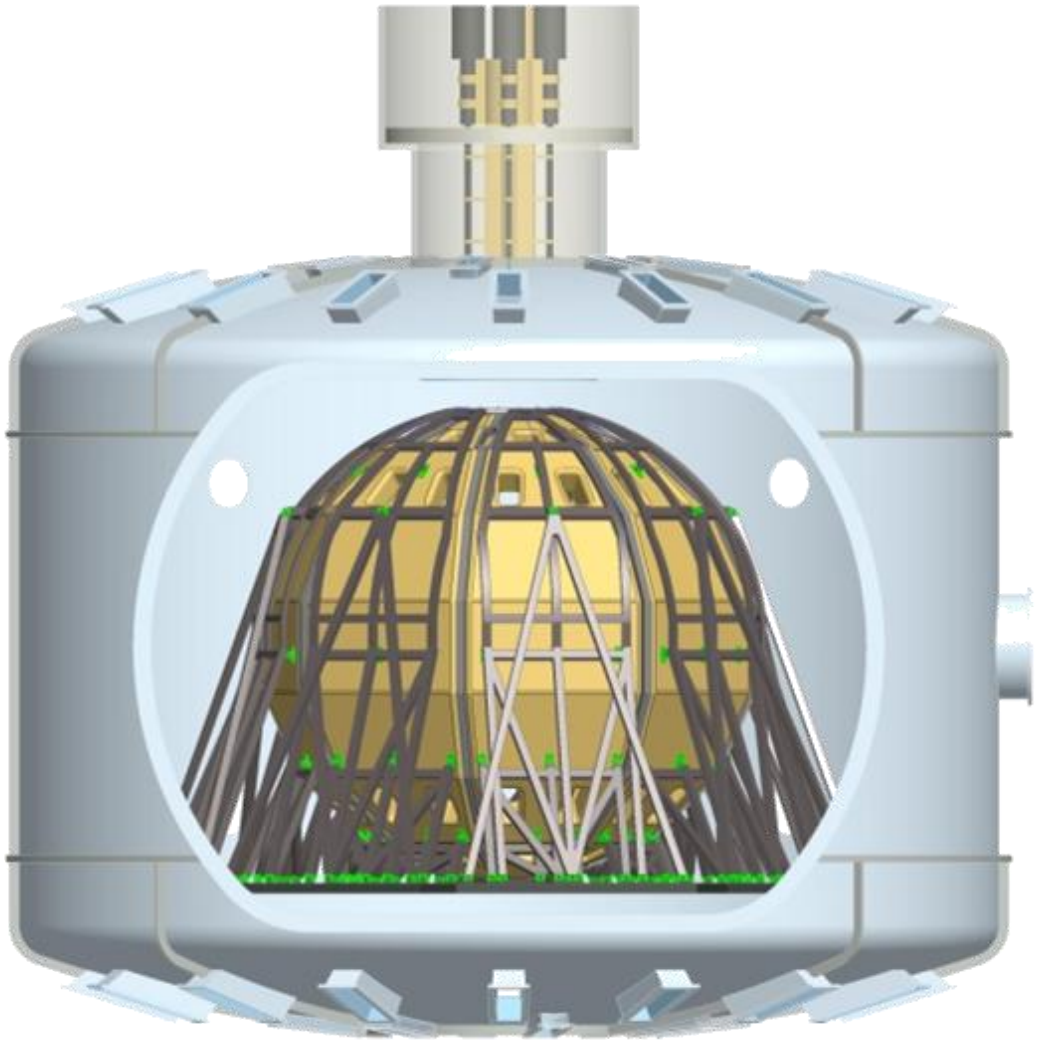
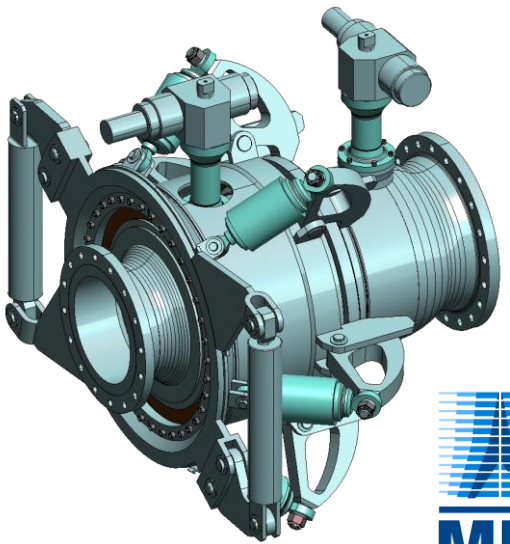
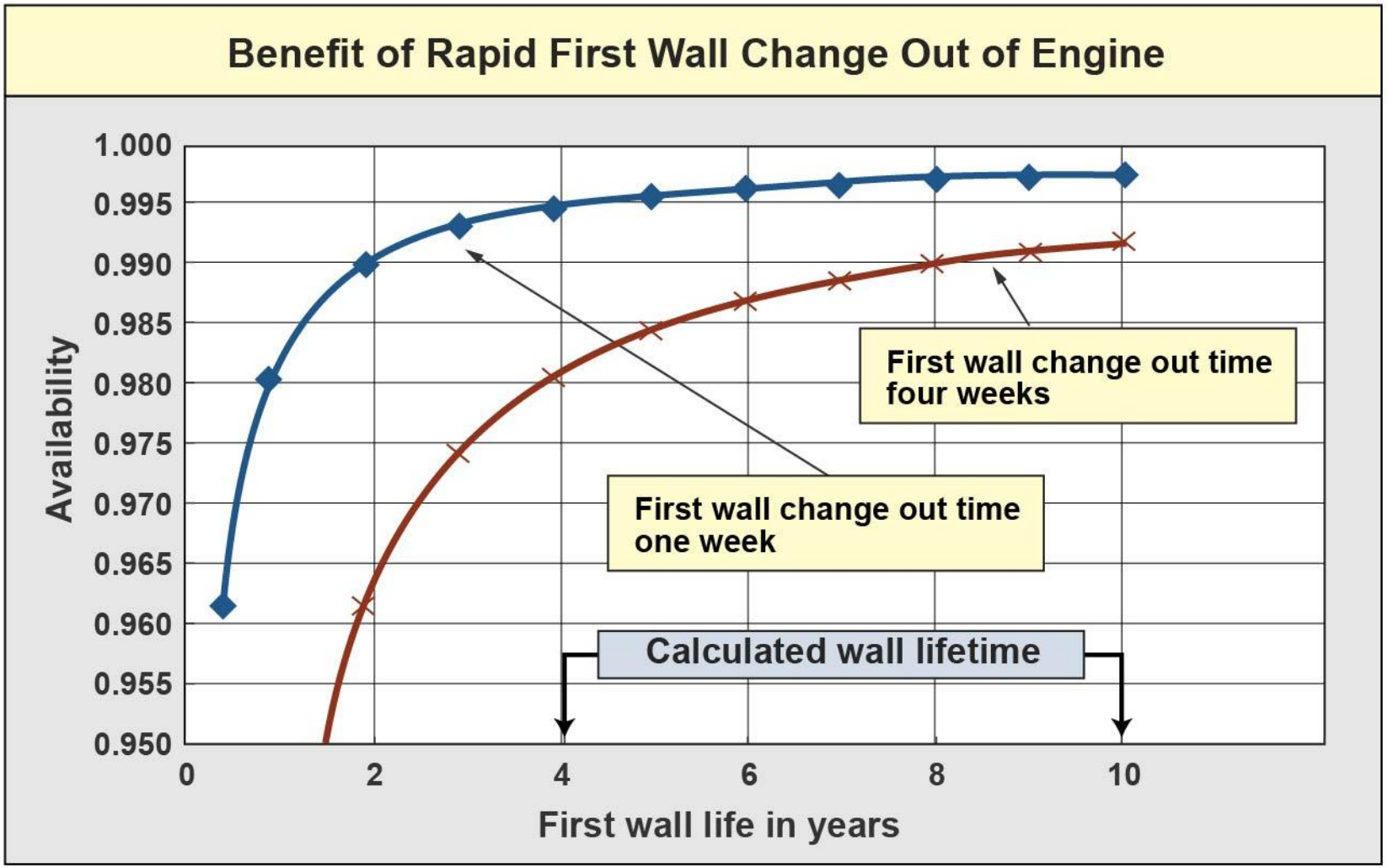


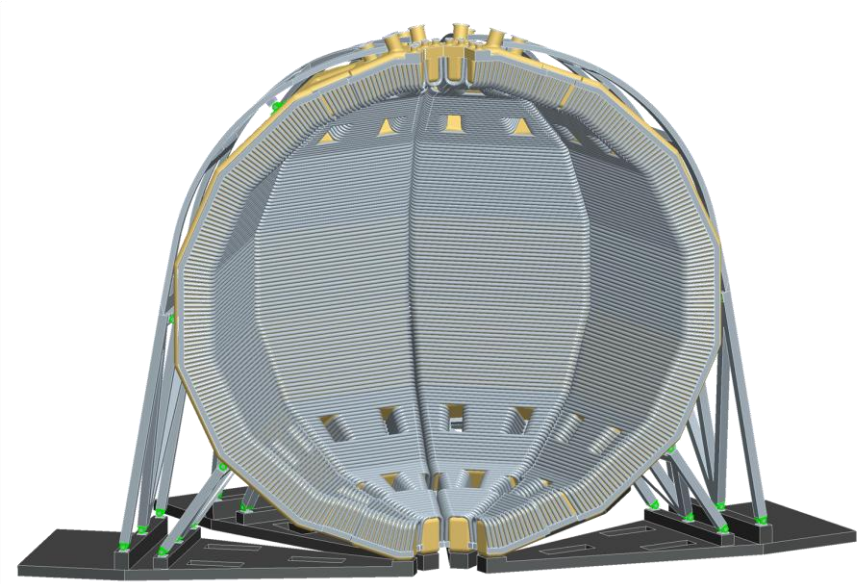


Chamber modularity results in high plant availability



First wall is comprised of U-shaped steel tubes with high strength-to-weight ratio

- 6 m radius chamber lined with 4 cm diameter, 1 mm thick tubes
- Chamber is *NOT* the vacuum barrier
- Tubes provide excellent strength and superior cooling
- Tubes can be manufactured today via extrusion and flow forming

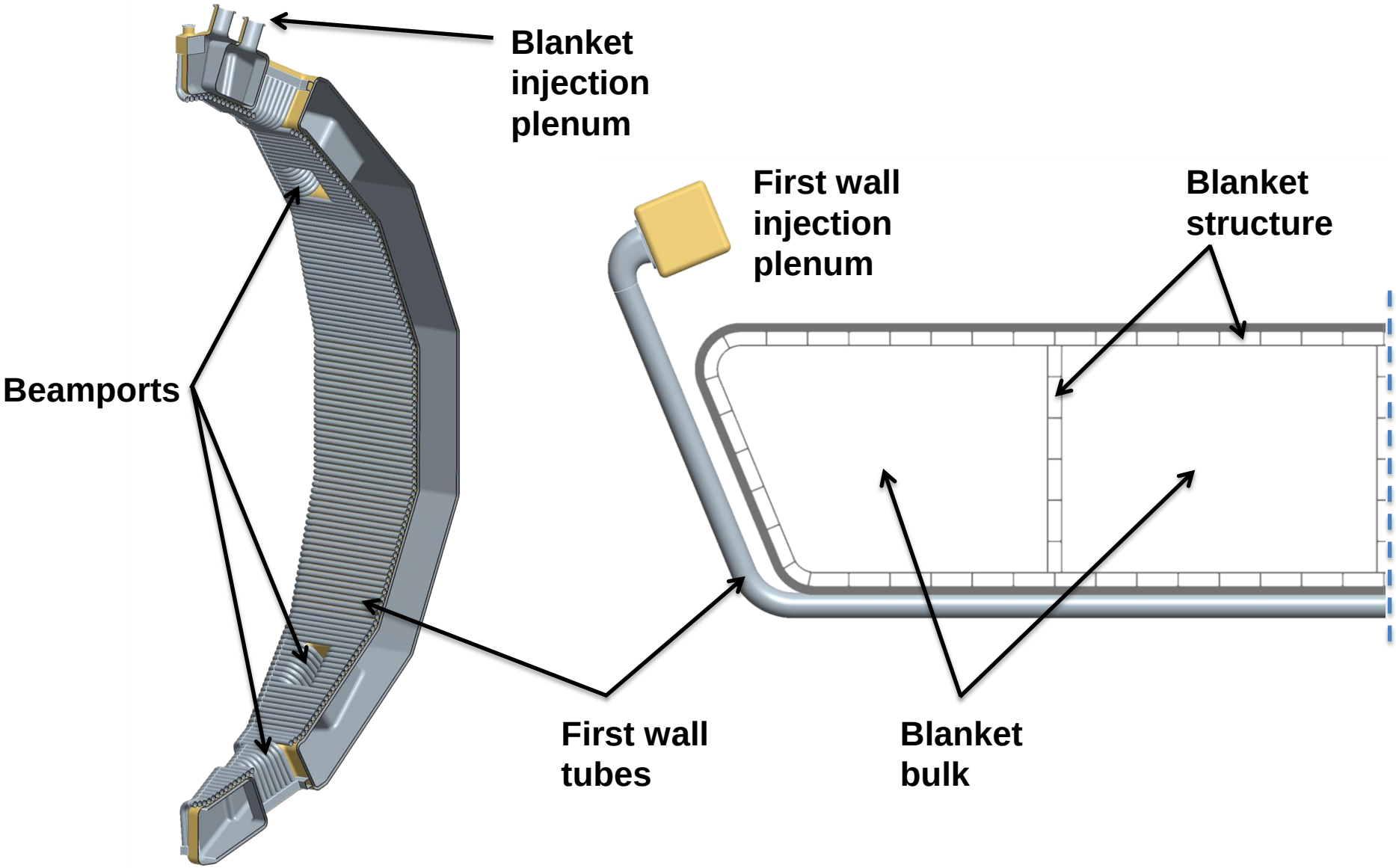


Low-impurity, modified HT-9 and ODS samples have been manufactured for LIFE

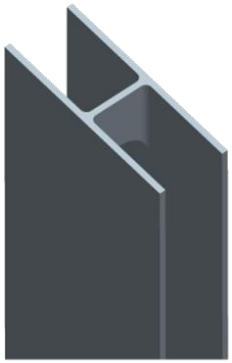
Extruded and flow formed ODS tubing (6”)

*** Courtesy Lew Shoemaker, Special Metals Corporation**

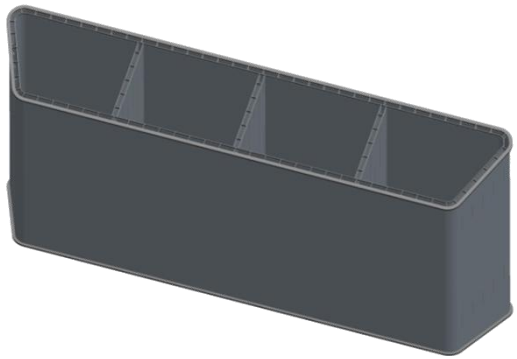
Blanket design utilizes skin cooling to provide best mechanical performance



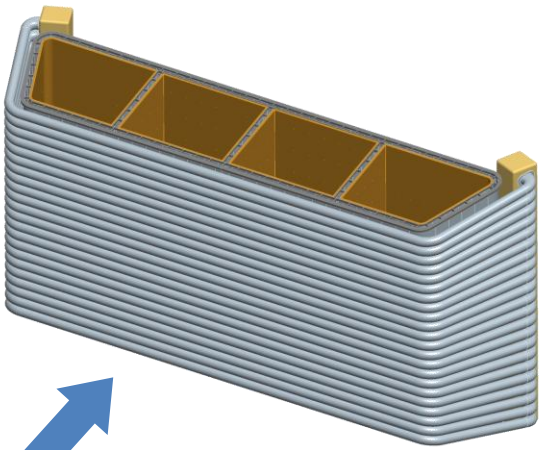
First wall and blanket can be fabricated using currently available technologies



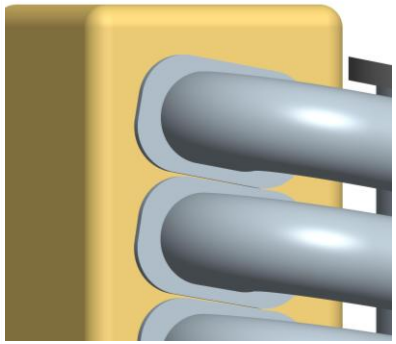
The LIFE blanket is fabricated from oxide dispersion-strengthened ferritic steel. Such extrusions can be produced today.



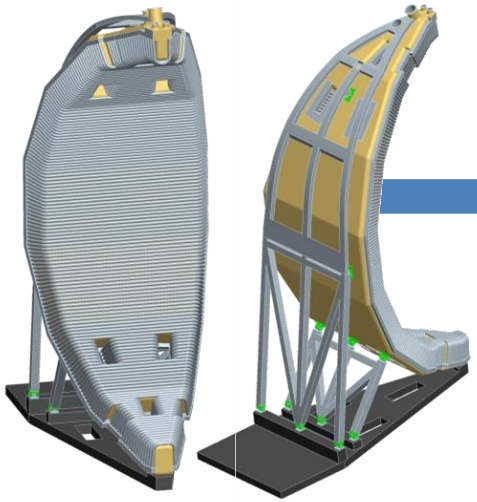
Extruded I-beams can be joined using either linear inertial or friction stir welding. This forms the blanket structure with internal cooling channels.

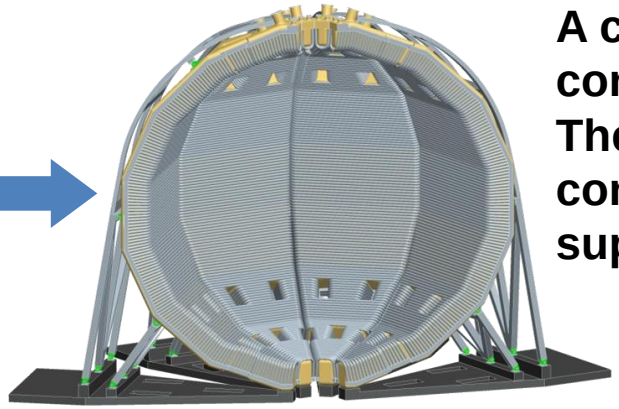


First wall tubes are connected to the manifold at the back of each blanket module.

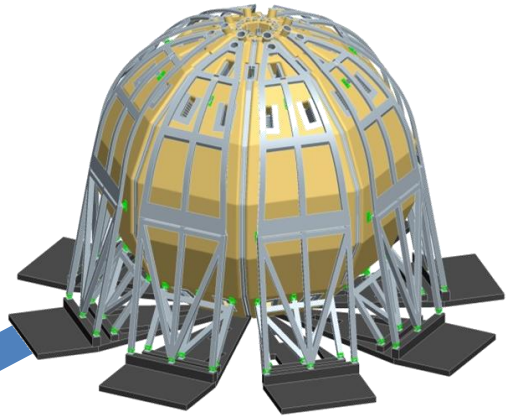


First wall and blanket can be fabricated using currently available technologies, (Cont'd.)

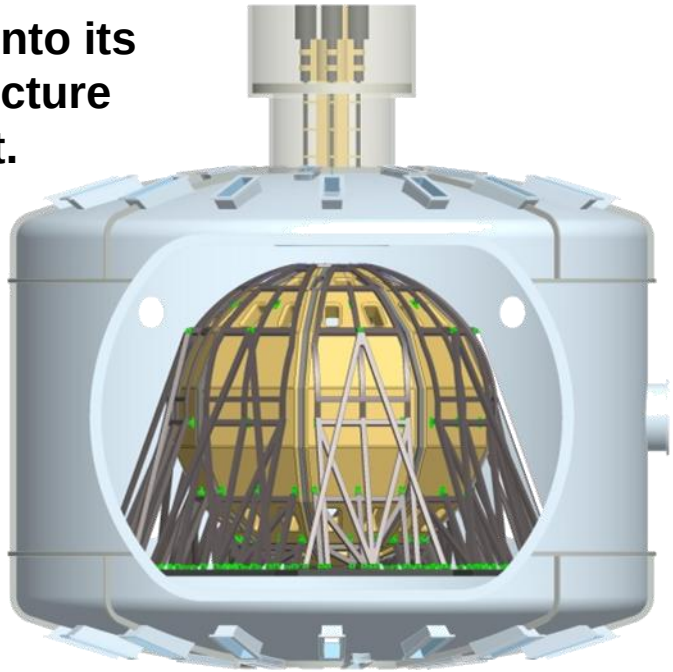




A completed LIFE chamber consists of eight modules. The modules are not physically connected other than via the support structures.



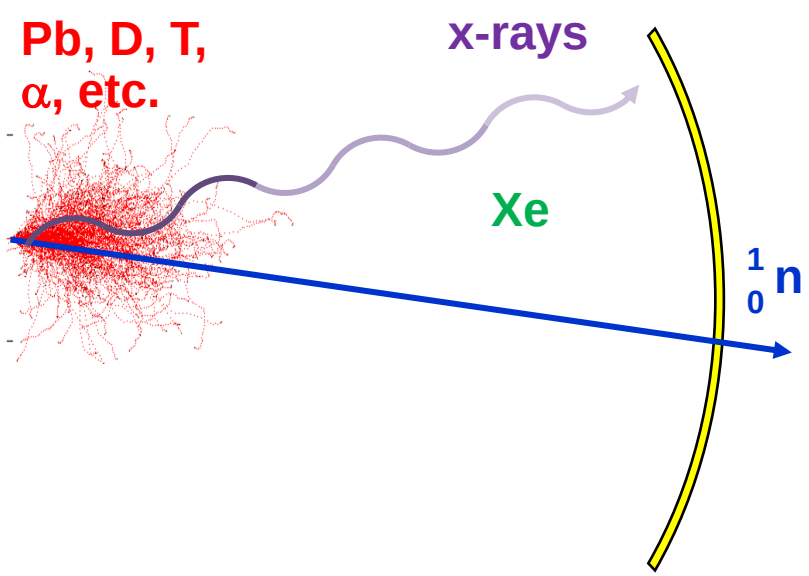
A chamber module is mounted into its support structure for transport.



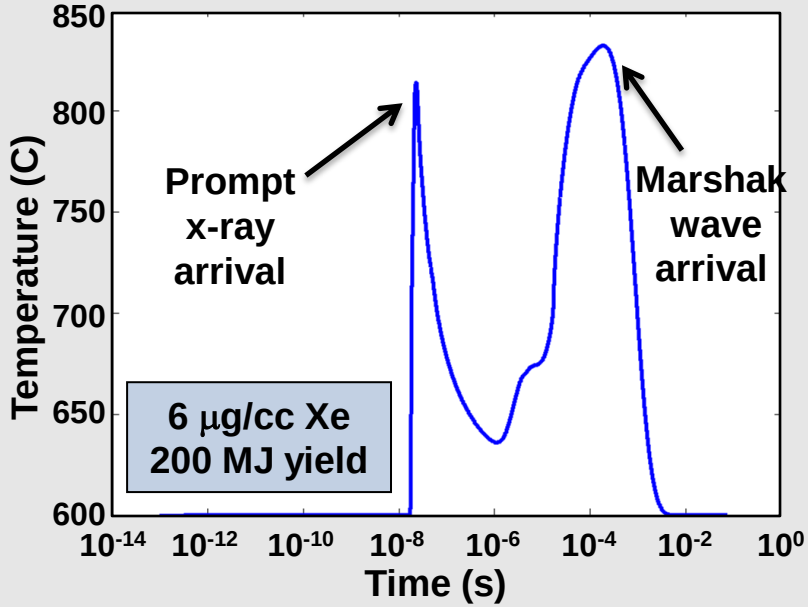
Once transported to the vacuum vessel, cooling lines are connected to the LIFE chamber. No beamline connections are necessary.

Chamber gas mitigates the threat to the first wall – allowing a NIF-sized, steel chamber to be used

Ions are stopped in ~ 10s of cm of xenon gas and x-rays are mostly absorbed



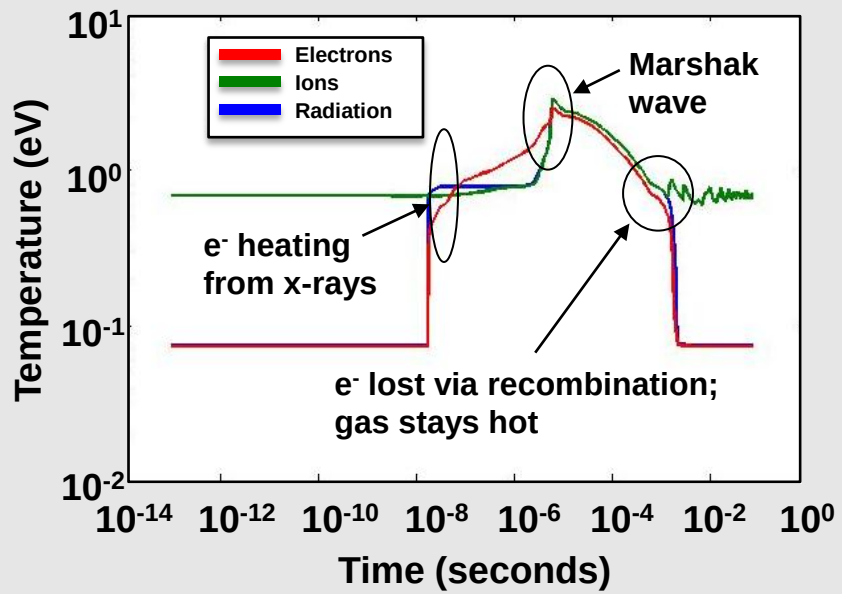
First wall heating is low enough to eliminate the need for tungsten coating



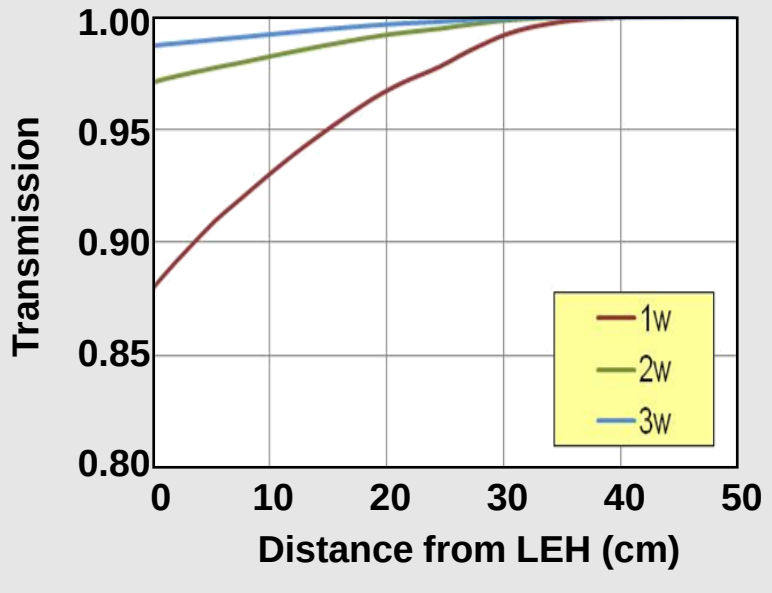
Wall is protected from ion and x-ray target output

Since the beam can propagate through lead vapor, "chamber clearing" is not actually required

Electrons lost ~ 0.5 eV; xenon stays hot from one shot to the next



Laser beam propagation through hot gas is acceptable



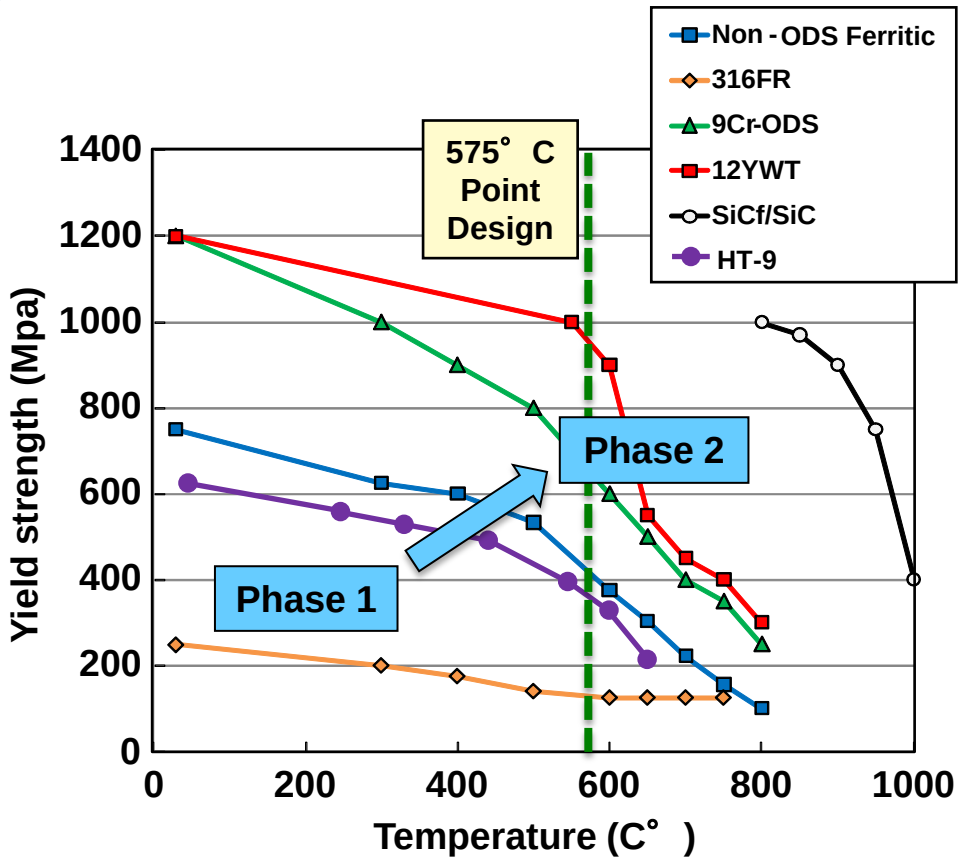
- Electronic Stimulated Raman Scattering (ESRS) has been observed in Pb
- Analysis shows metastable states saturate with investment of 20 kJ for 10^{15}/cc Pb

Chamber clearing of 1% is sufficient for a 3 g Pb target

An HT-9 chamber could be utilized at full scale with reduced fusion power

- First wall design is balance between temperature (η_{th}), size and thermal stress
- We are using ASME piping code factors of safety:
  - 3 on ultimate tensile strength
  - 1.5 on yield strength
  - 1.5 on creep rupture strength
  - < 1% creep in 10^5 hours
- Initially, LIFE would use HT-9 and accept short chamber lifetime
- Facility will enable materials testing and a move to oxide-dispersion strengthened ferritic steel

We increase these factors of safety by 2× to mitigate against material degradation under irradiation



LIFE design takes advantage of available materials, component modularity and simple solutions

- Chamber fill gas protects the first wall and enables a compact system while allowing both laser propagation and target injection
- "Chamber clearing," as traditionally thought of, is not required
- Modular, factory-built chamber modules can be constructed from near-term materials and rapidly replaced as needed
- Lithium coolant/breeder provides superior tritium breeding enabling materials testing and a highly tunable blanket design
- High T solubility greatly reduces permeation and limits site inventory to < 500g
- Ultra supercritical steam Rankine cycle provides ~ 45% efficiency today
- A fused silica diffractive optic offers radiation-tested performance

Rapid development, construction and maintenance are all enabled by separability and modular (LRU-like) design


LIFE