LIFE

Laser Inertial Fusion Energy

Chamber-Blanket Design for LIFE

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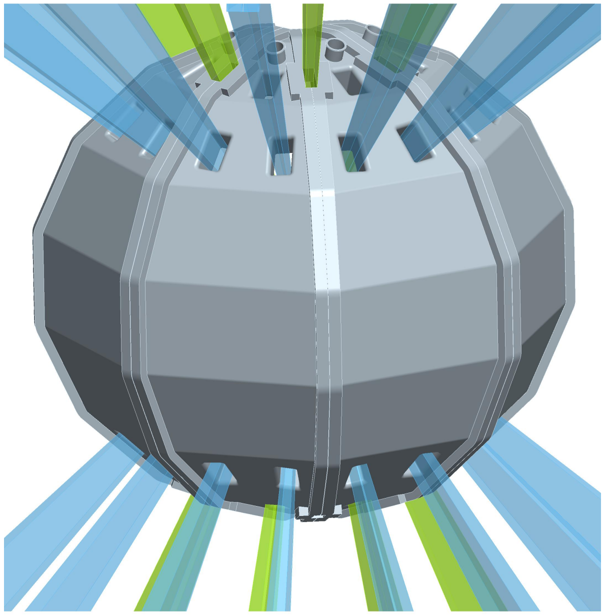
November 18, 2010
ODS 2010 Materials Workshop

Lawrence Livermore National Laboratory

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

The LIFE chamber design must satisfy a number of requirements

Fabricate from an available material
(commercially available & weldable)



Capture and transmit thermal power to balance of plant
(handle 0.5-1.5 MW/m^2)

Produce tritium to replace that burned in previous targets
(Tritium breeding ratio ≥ 1.08)

Operate at high temperature for high thermal efficiency
(T_{wall} ≥ 600°C for η_{th} ≥ 40%)

Enable successful propagation of target and laser beams
(Propagation efficiency ≥ 95%)

Remove residual material left behind by previous shot
(material-dependent requirement)

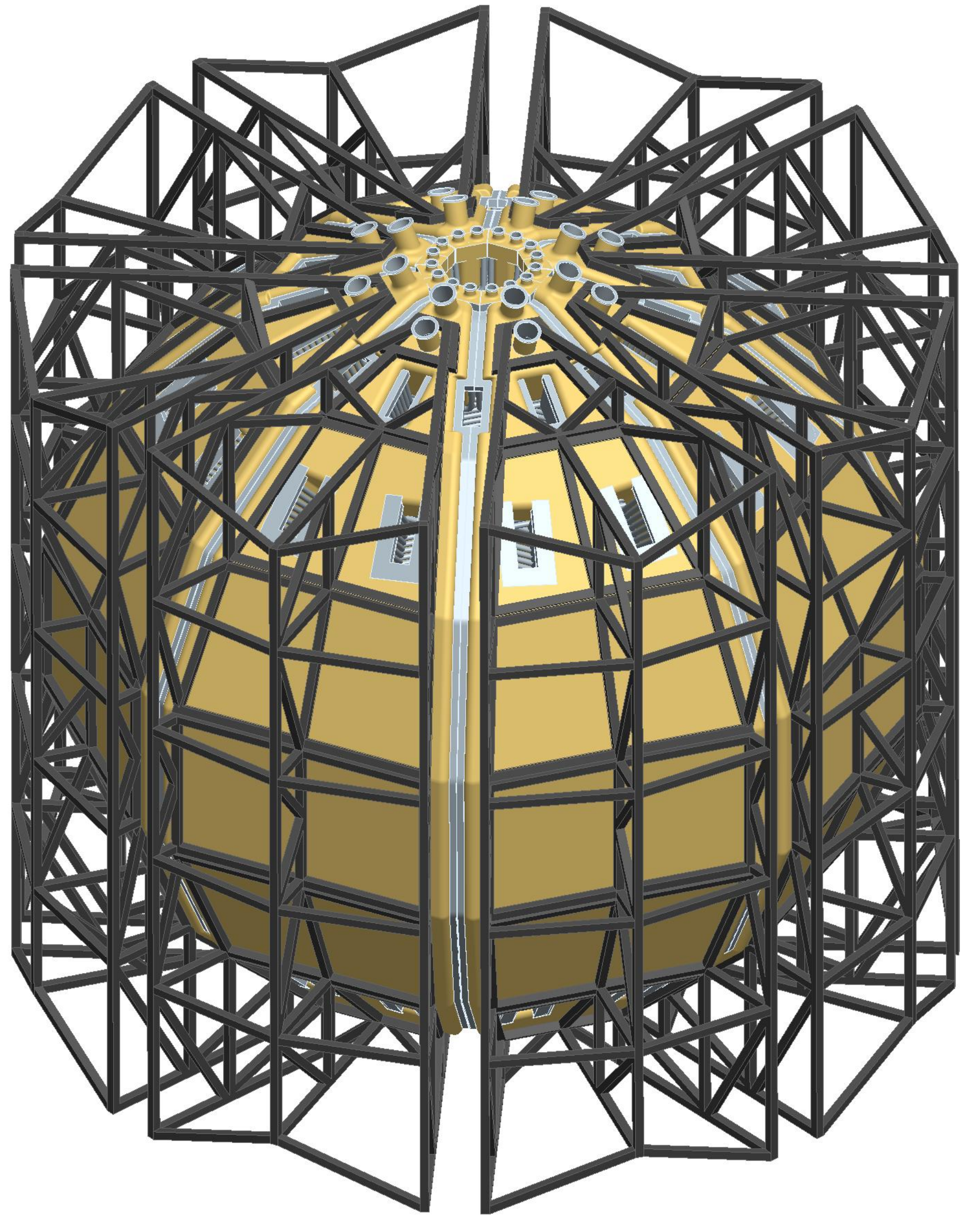
Collect and process target debris through exhaust port
(Material recovery ≥ 99%)

Maintain with high availability
(support ≥ 92%; flowdown TBD)

Reset for the next shot
(Support pulse rate of 10-15 Hz)

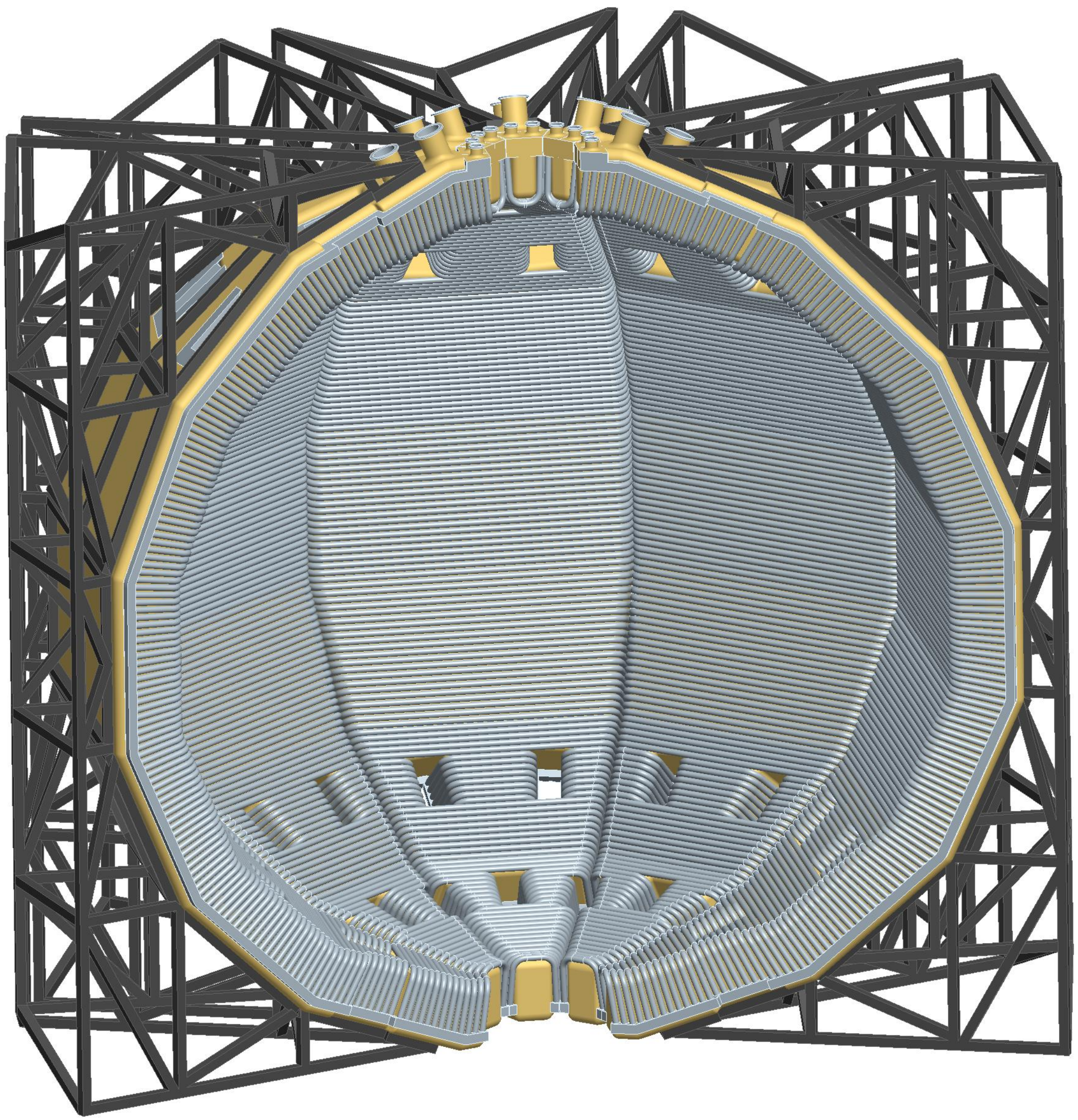
The LIFE chamber uses a steel structure and a liquid lithium coolant

- **Eight separate modules plumbed in groups of two**
- **Modified-HT9 for LIFE.1 and 12YWT for LIFE.2**
- **Liquid lithium greatly reduces tritium permeation and has good performance**

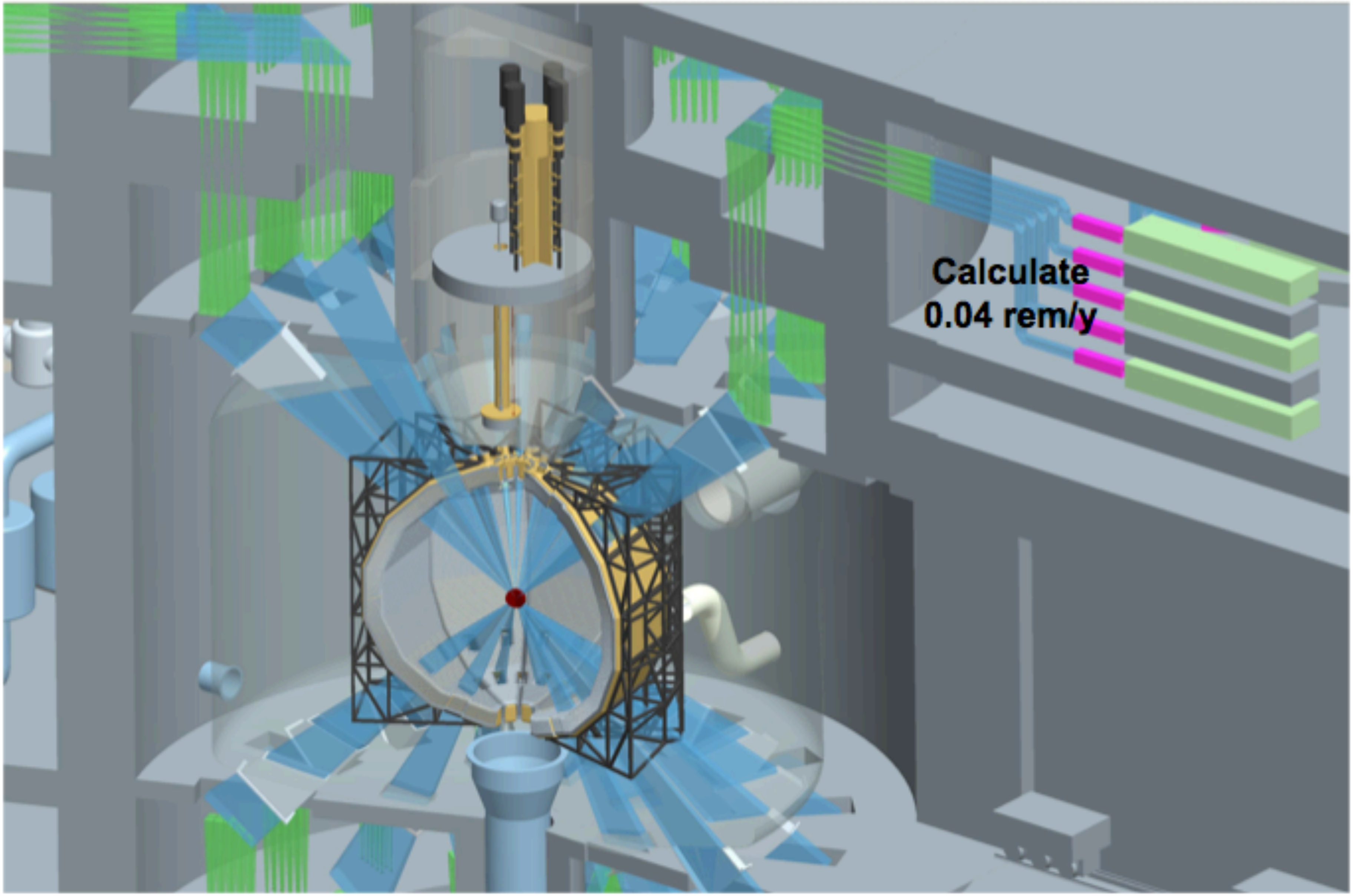


Current point design for LIFE utilizes a tube-based first wall for high strength to weight ratio

- **10 cm diameter tubes with 1 mm thick walls**
- **6 m radius to first wall:**
  - **— 1.1 MW/m^2 heat load**
  - **— 3.8 MW/m^2 neutron load**
- **~ 1 m thick blanket**
- **Note that chamber is *NOT* the vacuum barrier**
- **Tubes provide excellent strength, good fabrication pathway, and superior cooling**



Beamtubes stop at the vacuum vessel wall for ease of chamber replacement

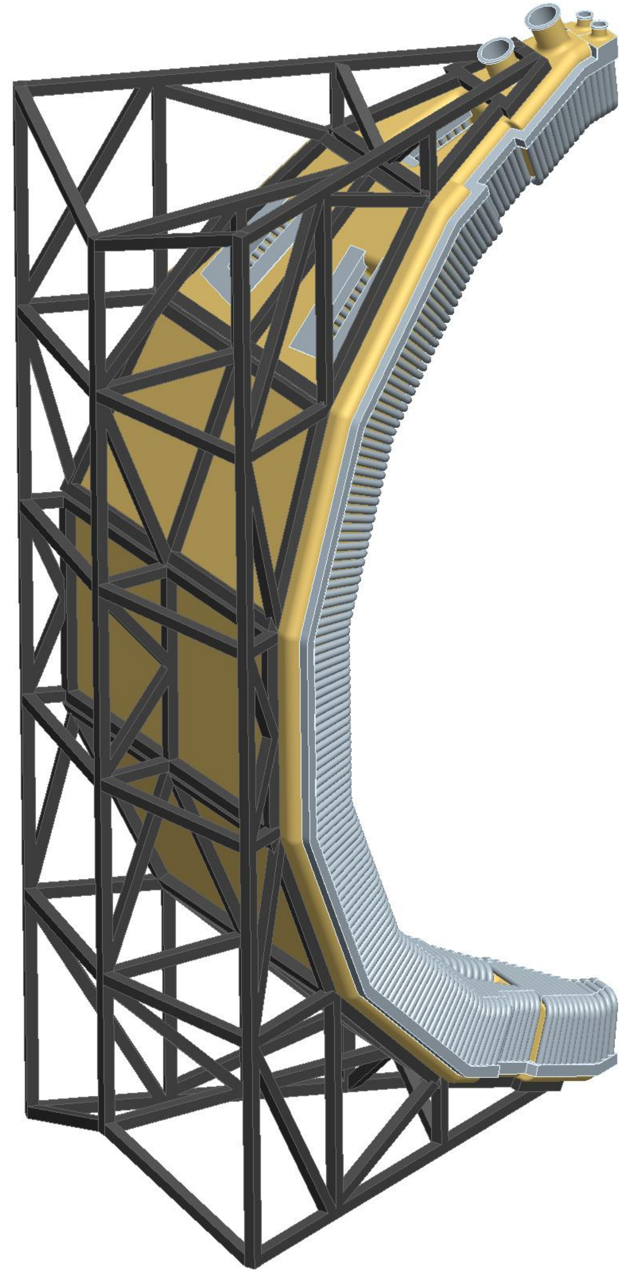


LIFE maintenance philosophy is based upon NIF's use of line replaceable units (LRUs)

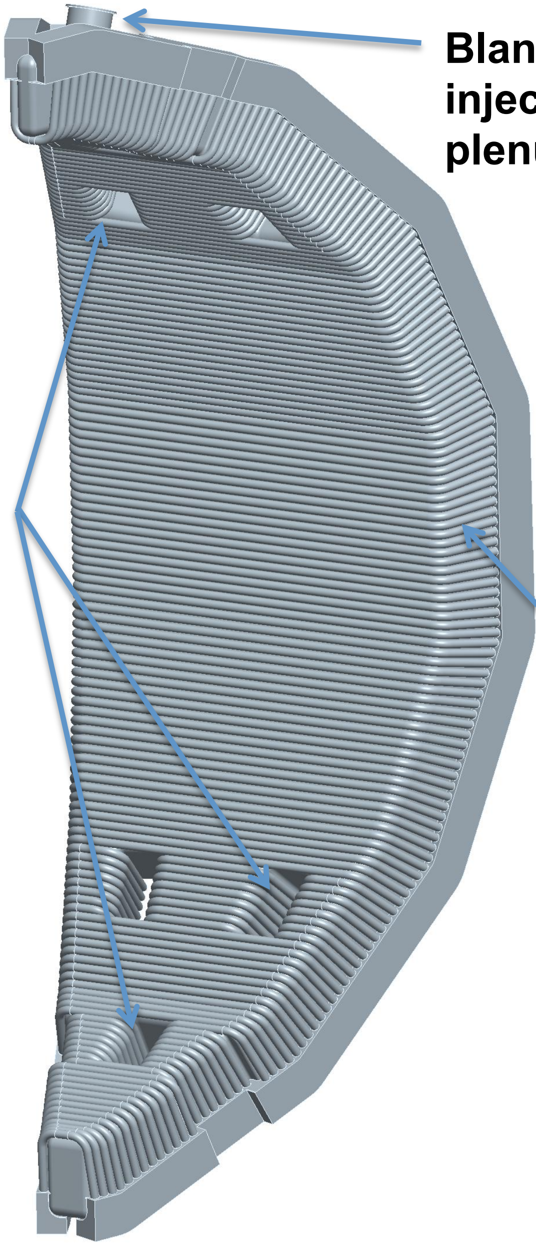
- LIFE plant would receive 8 factory-built chamber modules:
  - Two modules connected in the maintenance bay to form a ¼-section of the chamber
  - ¼-section shares two sets of common coolant injection and extraction plena (first wall and blanket)
  - The ¼-section of the chamber would be transported to the engine bay
  - ¼-sections are not attached to each other

- Quick connects made in the engine bay using hydraulically operated couplers (technology used for oil supertankers)

- Subset of the first wall flow is looped into the blanket for additional heating



Current point design calls for an all lithium-cooled first wall and blanket chamber module



Modified-HT9 or SS304/316 offer a near-term structural material option for LIFE.1

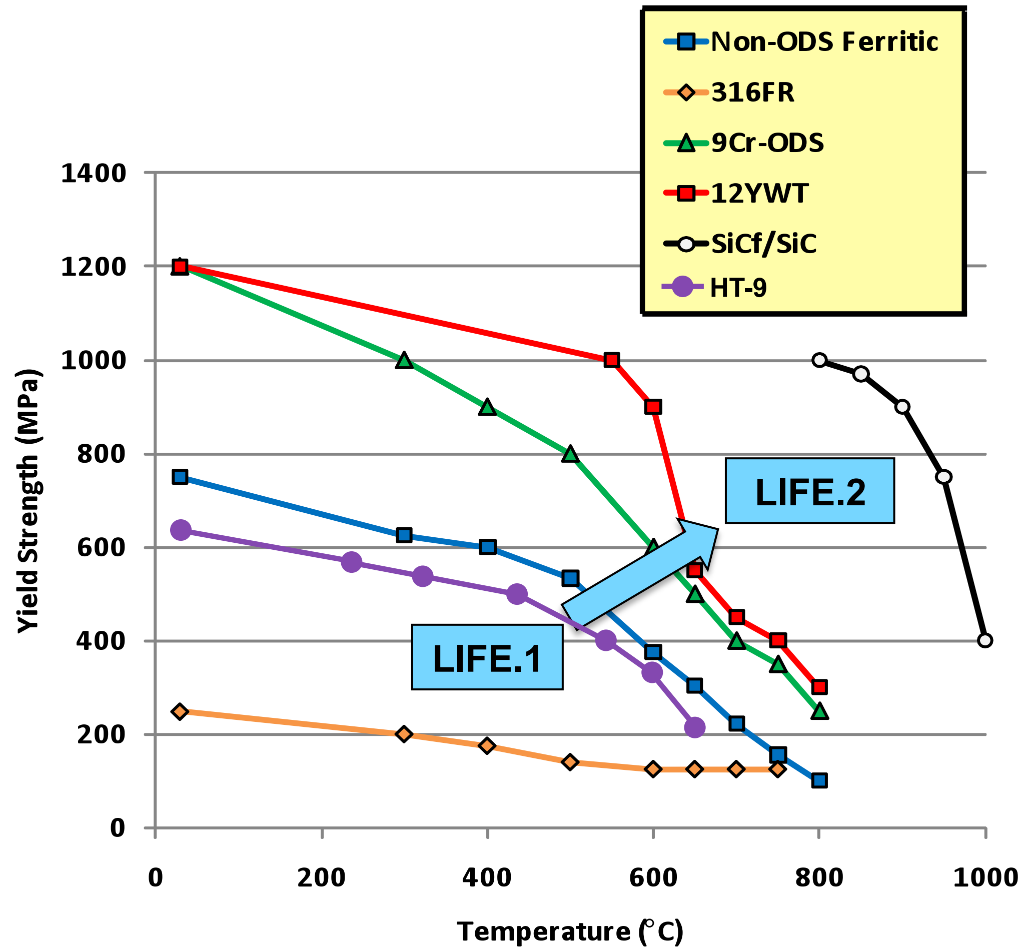
- First wall design is balance between temperature (η_{th}), size and thermal stress

- We are following ASME piping code and designing to:
  - 1/3 of tensile strength
  - 2/3 of yield strength
  - 2/3 of creep rupture strength
  - 1% creep in 10^5 hours

- LIFE.1 will use modified-HT9 steel and accept a short lifetime

- We will test materials and utilize oxide-dispersion strengthened ferritic steel on LIFE.2

- LIFE.3 could use SiC or other advanced materials



Modified steels are attractive options for the LIFE structural material

- Modified-HT9 for LIFE.1:
  - — Molybdenum is a constituent of HT9, but tungsten substitution is an option (work demonstrated this in the 1980’s)
  - — Additionally, niobium impurity must be reduced by ~ 10×
  - — We have engaged a supplier to produce small batches
  - — Ideally, unless cost prohibitive, LIFE.1 fabrication will attempt to follow ODS-like fabrication processes

- 12YWT for LIFE.2:
  - — Although not constituents, Mo and Nb impurities are problematic
  - — Reduction in impurities to similar levels as modified-HT9 is needed

Molybdenum and niobium impurities need to be reduced to the parts-per-million level to enable disposal as Class C waste

LIFE.1 will be used for accelerated damage testing of both structural materials and fission fuels

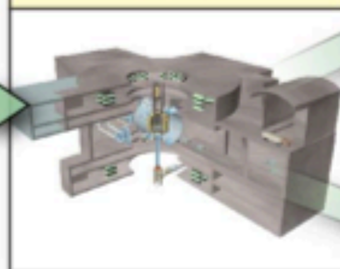
- Goal is to provide a 10× acceleration relative to expected LIFE.2 damage rates:
  - Provide damage rate of 230 dpa/fpy
  - Samples sit ~ 60 cm from chamber center
  - Superior TBR of LIFE blanket enables large testing volume
- Design requirements:
  - Accommodate rapid replacement of structures
  - Provide temperature controlled sample environment
  - High degree of neutron isochoric heating
  - Thermal load of 12 MW/m^2
- Testing would be conducted in parallel phases:
  - Coupons, welds, and sub-scale components at 1, 3 and 10× acceleration
  - Full-scale modules at 0.4×
  - FY26-30 offer ~2 FPY of LIFE.1 operation

Separability of IFE enables accelerated testing without distorting the plasma

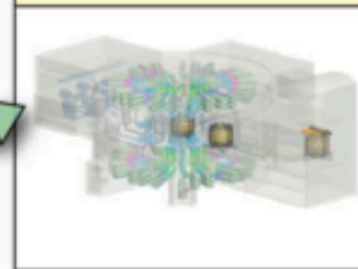
An aggressive development plant is needed for ODS fabrication and joining

NIF

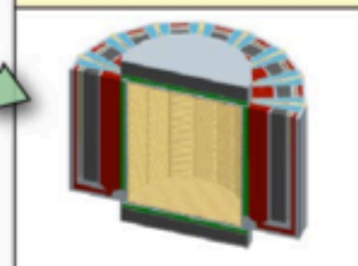
LIFE.1



LIFE.2 Pure Fusion



LIFE.2 Fusion/Fission



Full-system demonstration, "LIFE.1" in 2020s

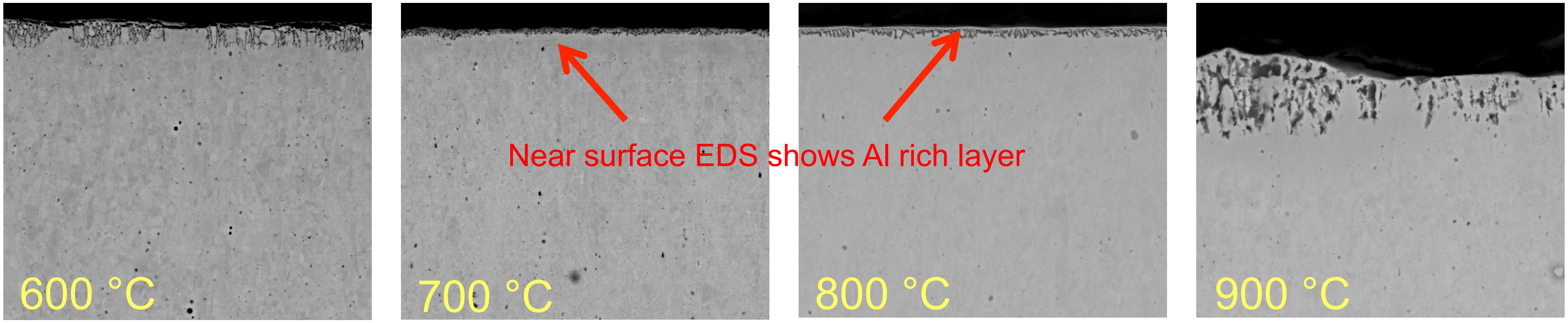
- Conservative design maximizing use of near turn solutions
- Fully integrated development and vendor readiness program
- Steady state, integrated fusion operations (~ 400 MWth)
- Define the plant availability growth program
- Materials / structure qualification for commercial plant

Commercial GWe plants, "LIFE.2" from 2030s

- Deliver baseload power to grid at relevant size (~ 1GWe)
- Uses systems and materials qualified on LIFE.1
- Defines capital and operating costs for rollout

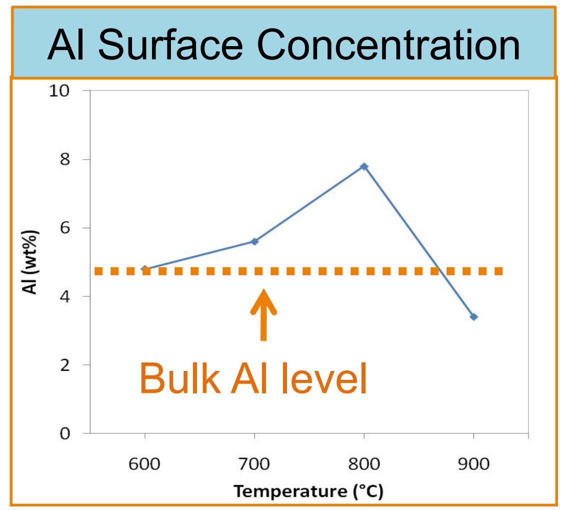
Can we do LIFE.1 straight with ODS? Either way, rapid materials testing & characterization is important to meet this timeline

Corrosion of MA956 ODS steel and Ta in FLiNaK as a Function of Temperature was Measured



10μm

	600 °C	700 °C	800 °C	900 °C
Rs (Ω)	1.353	1.327	1.347	1.296
Rp (Ω)	26.1	43.38	122.6	2.705
Yo (Ss^a)	0.1690	0.0408	0.0216	0.2251
α	0.9207	0.6827	0.7079	0.6073
W (Ω)	4.67E-01	n/a	n/a	n/a
La (H)	2.42E-06	2.31E-06	2.43E-06	2.45E-06
Ra (Ω)	4.067	3.914	4.621	4.126



- Polarization resistance R_p varies with concentration of Al at the surface
- This resistance can be used to obtain a corrosion rate since they are inversely proportional

Corrosion of MA956 ODS steel and Ta in FLiNaK as a Function of Temperature was Measured

	MA956 ODS				Tantalum	
	600 °C	700 °C	800 °C	900 °C	600 °C	900 °C
Rp (Ω)	26.1	43.38	122.6	2.705	84.06	16.05
CR (mm/yr)	11.03	6.63	2.35	106.4	3.08	16.13

	600 °C	700 °C	800 °C	900 °C
Rs (Ω)	1.353	1.327	1.347	1.296
Rp (Ω)	26.1	43.38	122.6	2.705
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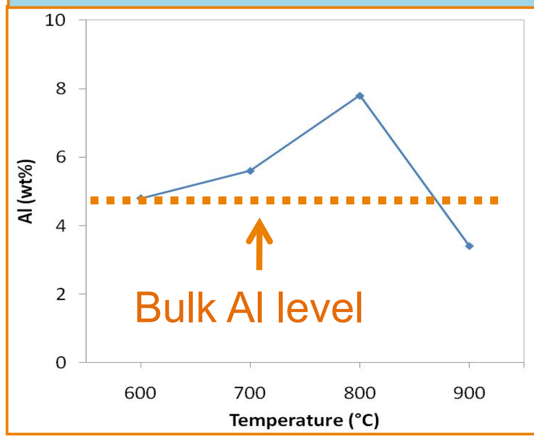
Al Surface Concentration



Polarization resistance R_p is related to the corrosion rate *CR* by:

$$CR = C \cdot \frac{EW}{R_p \cdot A \cdot \rho}$$

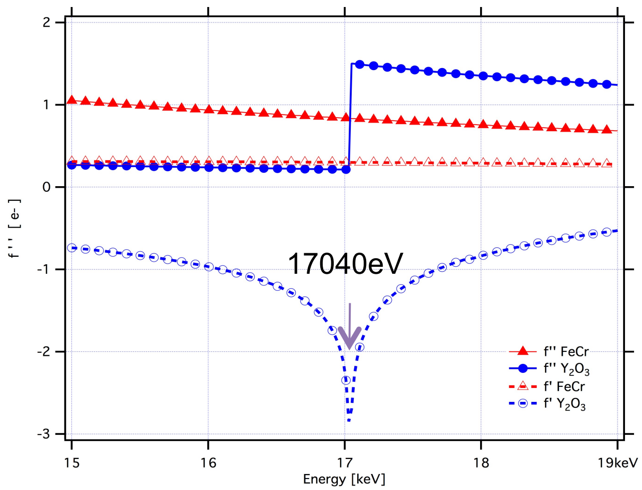
We have utilized ASAXS to distinguish nanofeature sizes in ODS steels

Motivating Factor:

- In order to do hydrogen/tritium effect studies, we need an understanding of how introduction of gas into ODS steels can affect the microstructure.
- Understanding how the introduction of gas bubbles into a complex solid solution alloy system changes the SAXS signature will allow for more sophisticated *in-situ* experiments.

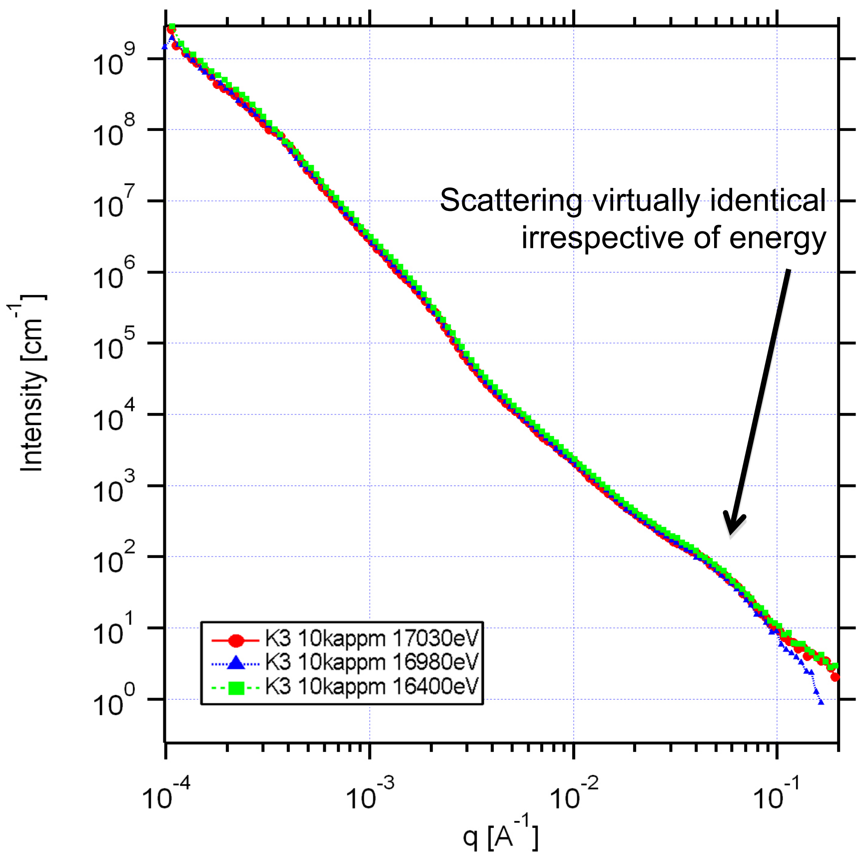
Experiment:

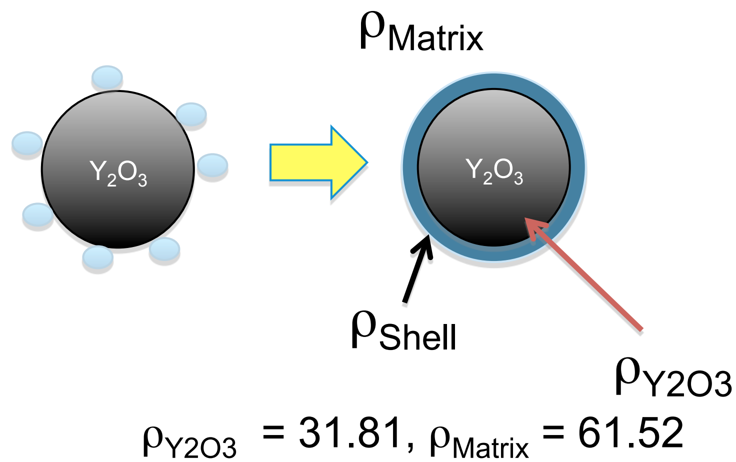
- Advanced Photon Source beamlines 32ID and 5ID: SAXS technique.
- X-ray transparent 40-50μm thick MA956 and K3 ODS specimens.
- He implanted to 1,000 and 10,000 appm. Annealed at 400 and 700C.
- SAXS performed at energies near Yttrium K-edge to utilize any anomalous scattering effect.



Results show nothing new….

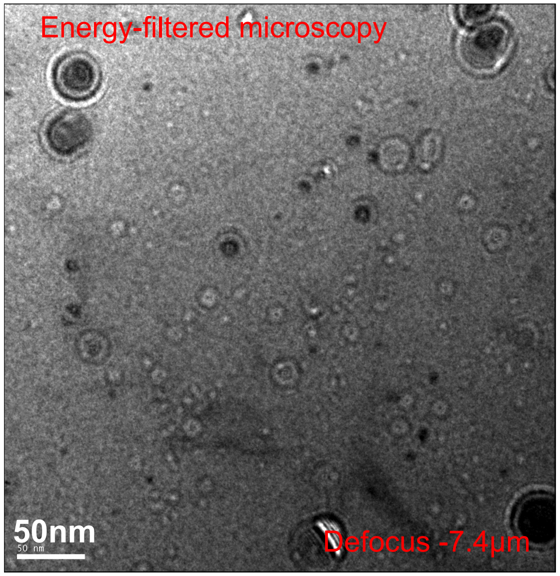
Results of Anomalous SAXS indicated that a core of yttria is surrounded by a "film" of He:





ρ_{Y2O3} = 31.81, ρ_{Matrix} = 61.52

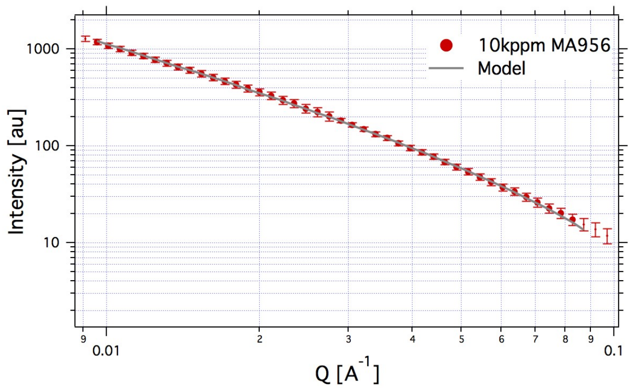
This is in line with the TEM observation that He forms a shell around the yttria

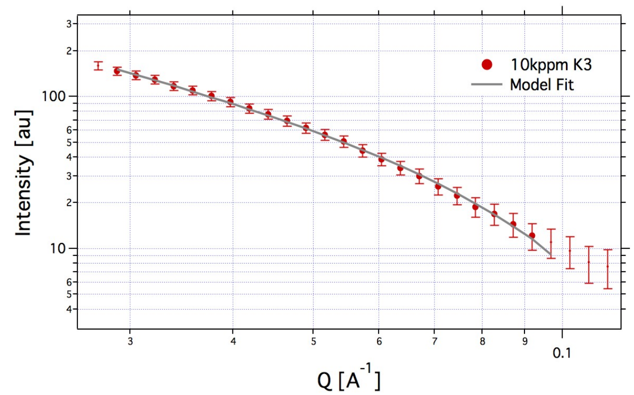


Hsuing, Fluss et al.

…Or do they?

Fitting the scattering to a core/shell model yields insight into oxide/bubble morphologies:





- MA956 Distribution:
  - Core Y_2O_3 ∅: 18.1nm
  - **Shell thickness: 1.8nm**
  - Shell density (FeCr): 0.135 g/cm^3
  - Shell density (Y-O): 0.128 g/cm^3
  - Total vol/ frac: 8.5x10^{-3}
- K3 Distribution:
  - Core Y_2O_3 ∅: 7.9nm
  - **Shell thickness: 2.2nm**
  - Shell density(FeCr): 0.11 g/cm^3
  - Shell density (Y-O): 0.105 g/cm^3
  - Total vol/ frac: 7.1x10^{-3}

Ability to characterize complex nanofeatures is critical for planned hydrogen charging experiments

Valuable core/shell information previously unknown can now be obtained and used in the modeling of He/H-oxide interactions (*e.g. mechanical models, ion beam experiments etc)*

Conclusions

- **The LIFE point design relies on modular, factory-built first wall/blanket modules to be constructed from near-term materials and rapidly replaced as needed:**
  - **LIFE.1:Tungsten substituted for molybdenum in HT-9**
  - **LIFE.2: Reduced impurities needed for 12YWT to ensure qualification as Class C**
  - **This allows us to reach remote handling dose rates with ~ 6 hours after shutdown**

- **We have invested effort into developing rapid assessment techniques to allow for testing of materials in various states efficiently:**
  - **High temperature *in-situ* corrosion facility to measure corrosion rate (to be adapted at INL's high temperature Tritium loop)**
  - **Synchrotron characterization to study the effect of fabrication/processing on nanofeatures**

- **We are actively pursuing FSW to better understand both its limitations and effect on microstructure (and how we can deal with it)**

Rapid development of both materials databases and fabrication techniques critical to meet the timeline set for commercialization