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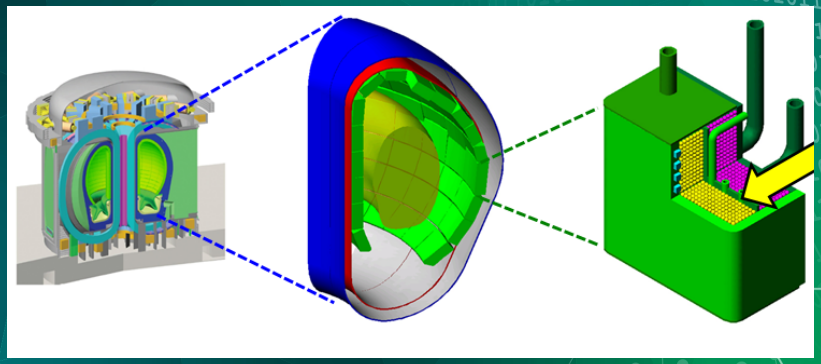
Fusion Blanket Design



C. E. Kessel

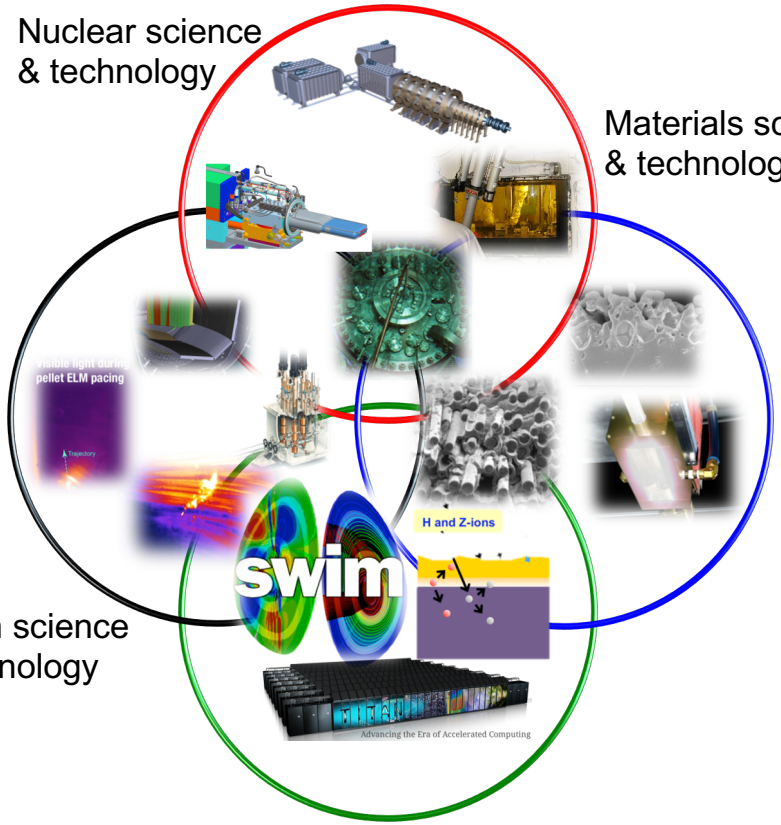
2020 Introduction to Fusion Energy and Plasma Physics

June 22, 2020

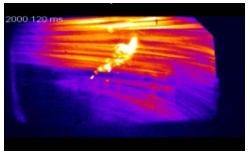
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

ORNL, Where the Science Comes Together to Make Solutions



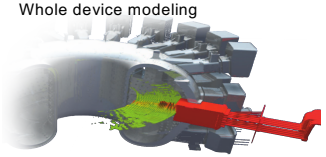
Pellet injection

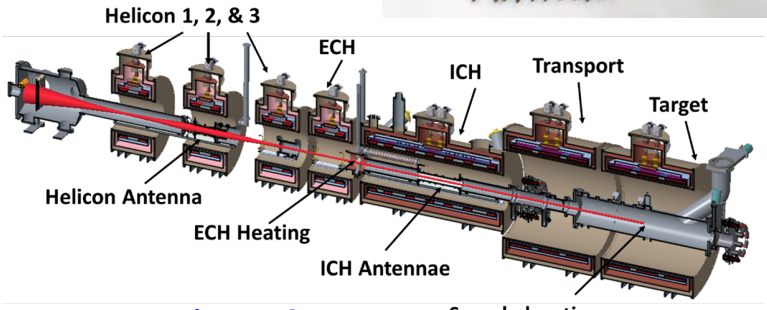

Shattered Pellet Injection

Leadership-class computing

Materials in High Flux Isotope Reactor

Whole device modeling





Material Plasma Experiment, MPEX

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Come Take a Look at Oak Ridge National Laboratory

Oak Ridge National Lab, America Calls

https://www.youtube.com/watch?v=xudKFiWv5OI&list=PLD37DC0FD306E52C6

ORNL, Big Impact

https://www.youtube.com/watch?v=u3W-sY9QcY0&list=PLD37DC0FD306E52C6&index=7&t=0s

High Flux Isotope Reactor

https://www.youtube.com/watch?v=RTRC1Fd_F5I

People at ORNL

https://www.youtube.com/watch?v=8yu1qrXdsh0&list=PLD37DC0FD306E52C6&index=4

Advanced Manufacturing

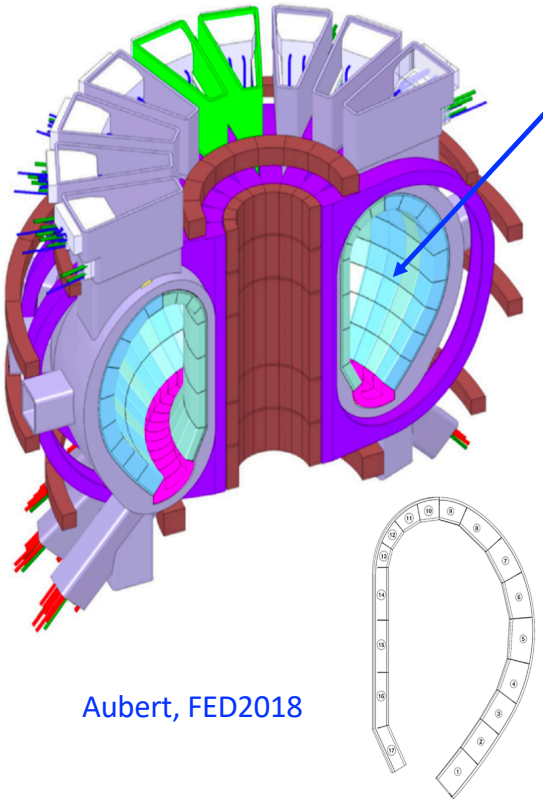
https://www.youtube.com/watch?v=RCkQBIFJRN4

The Fusion Blanket

Blankets (blue)

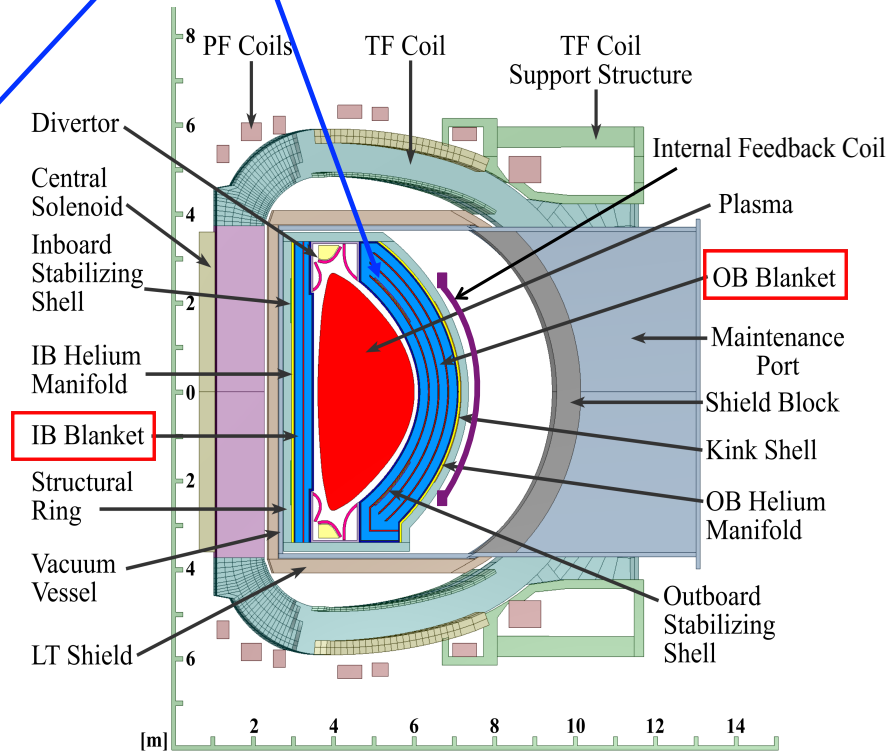
The fusion blanket surrounds the burning plasma

EU DEMO Pre-Conceptual

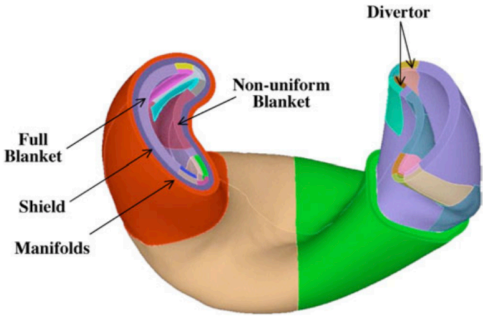


Aubert, FED2018

US FNSF Pre-Conceptual



ARIES-CS Blanket (stellarator)



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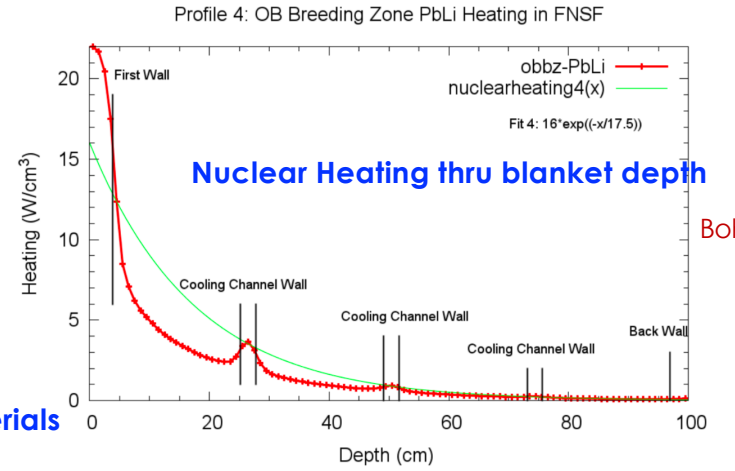
What is a Fusion Blanket?

A Fusion Blanket Must: Functions

- Breed tritium
- Absorb Neutron heating
- Shield outer components

- Provide a Plasma Facing Component
- Pressure vessel (vacuum outside)
- Resist thermal and electromagnetic transients
- Contain tritium bred
- Resist failures in accident scenarios

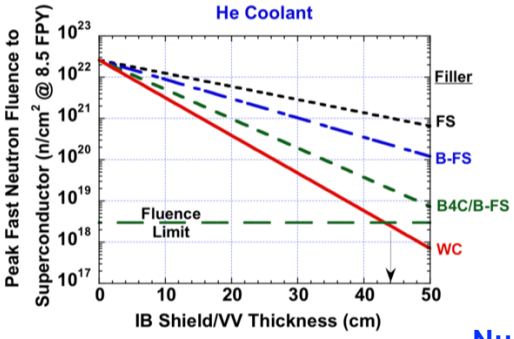
$n + {}^{7}Li \rightarrow {}^{4}He + \mathbf{T} + n'$ (requires > 2.47 MeV)
$n + {}^{6}Li \rightarrow {}^{4}He + \mathbf{T}$ (gives 4.78 MeV)



Nuclear Heating thru blanket depth

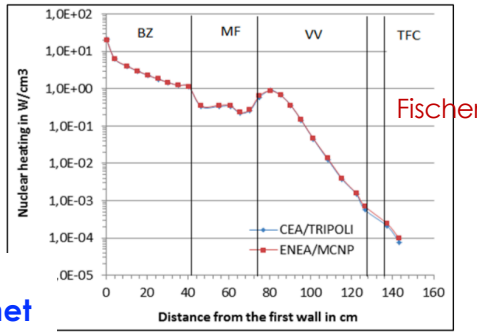
Bohm

Shielding by different materials



El-Guebaly

Nuclear heating profile



Fischer

Nuclear Heating Blanket to magnet

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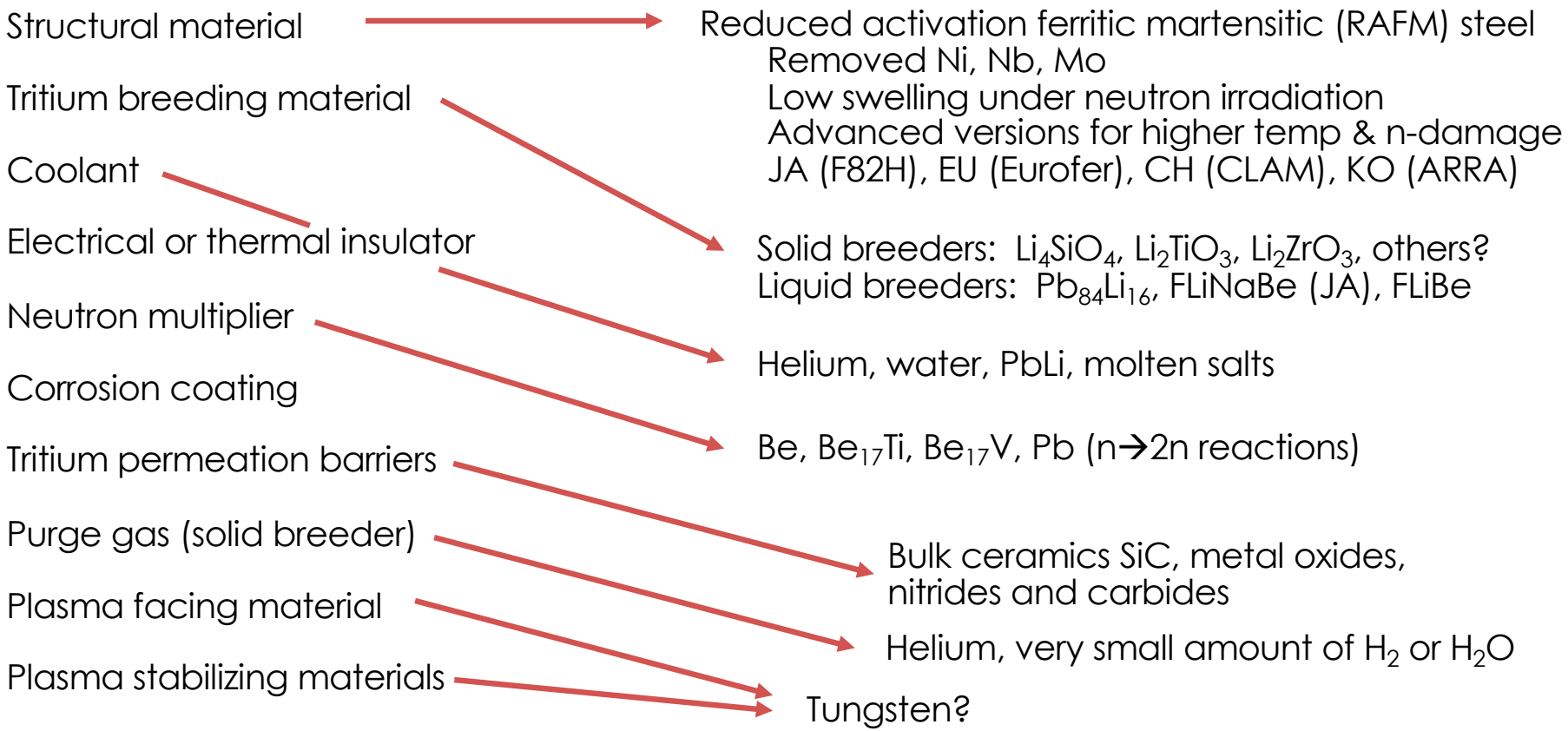
What is a Fusion Blanket?

A Fusion Blanket is Made of:



What is a Fusion Blanket?

A Fusion Blanket is Connected to Systems:

Helium Cooling system → Thermal conversion system, Tritium recovery system, Fluid cleanup

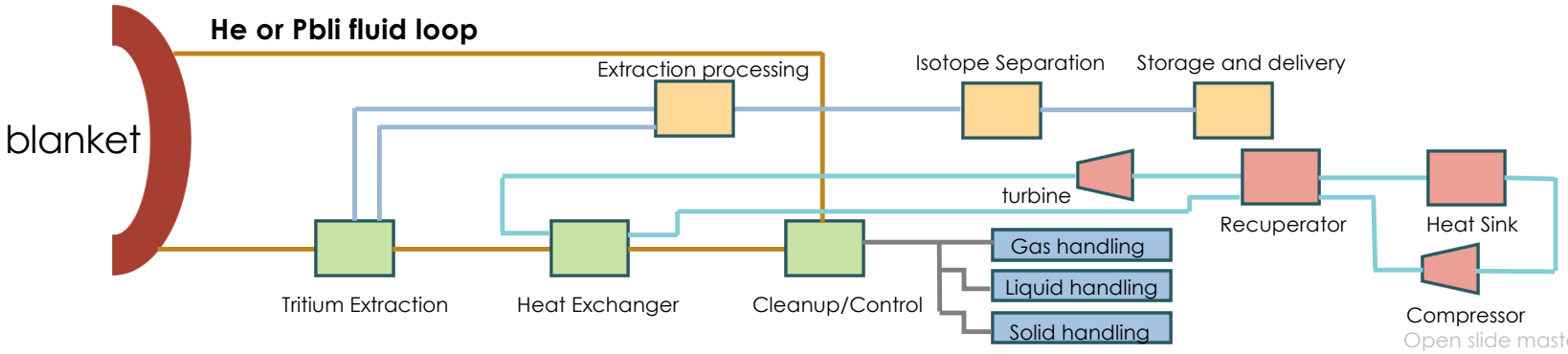
Liquid Breeder system → Thermal conversion system, Tritium recovery system, Fluid cleanup

Helium Purge Gas system (solid breeder) → Tritium recovery system, Fluid cleanup

Fusion Core Structural system → Blanket, structural ring, vacuum vessel, low temp shield

Fusion Core Neutron Shielding system → Blanket, strong-back, vacuum vessel, shield

Maintenance, Inspection, Access, Hot Cell system → Sensors, in-vessel actions, cask, cask-support systems, transfer to hot cell, hot cell breakdown



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What is a Fusion Blanket?

A Fusion Blanket has many Interfaces:

Attachment to strong back

PF armor - first wall structure

Liquid metal – structure

Liquid metal – flow channel insert

Solid breeder – structure

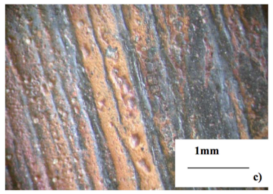
Solid breeder – purge gas

Plasma – PF armor

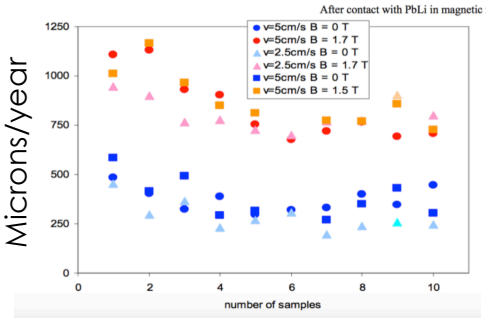
Coolant – structure

Coolant – coating

Coolant, purge, liquid metal - manifolding



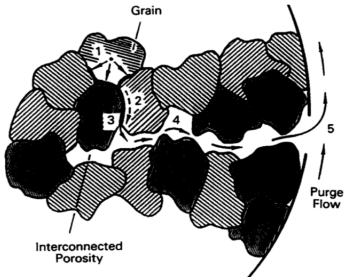
Plantacis

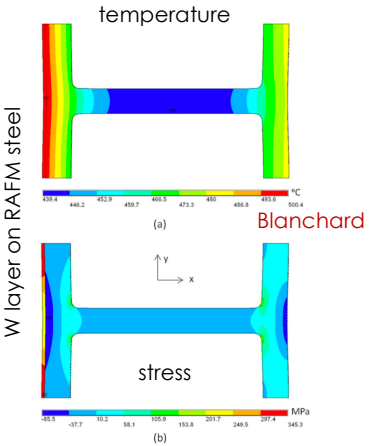


Corrosion of RAFM by PbLi in a B-field

Solid breeder tritium release

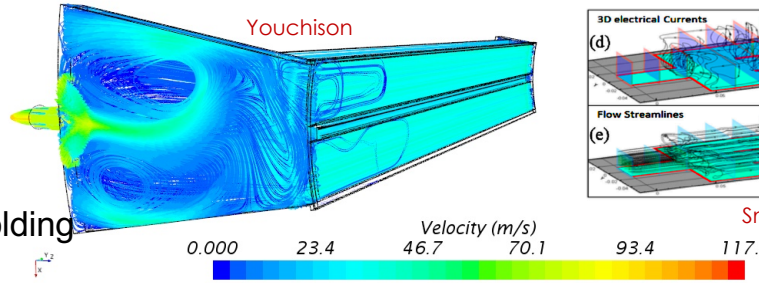
1. Inter-granular diffusion
2. Grain boundary diffusion
3. Surface adsorption/desorption
4. Pore diffusion
5. Purge flow convection





ELM response at W-RAFM FW

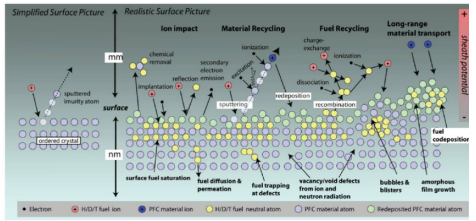
Manifolding helium into the blanket



LM manifold flow

Smolentsev

Plasma material interactions at FW



Zinkle

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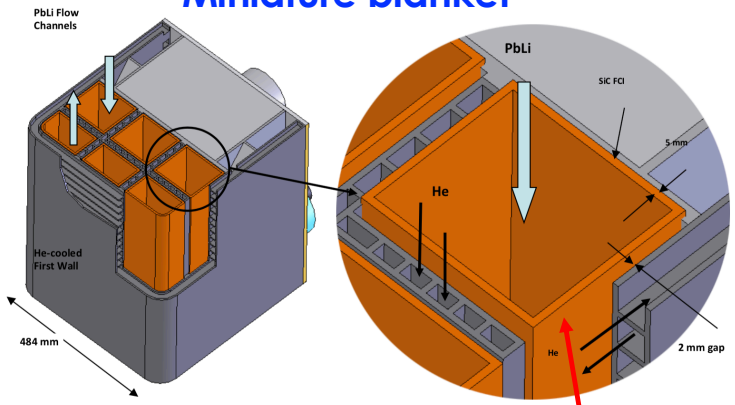
US Liquid Breeder Blanket Concept

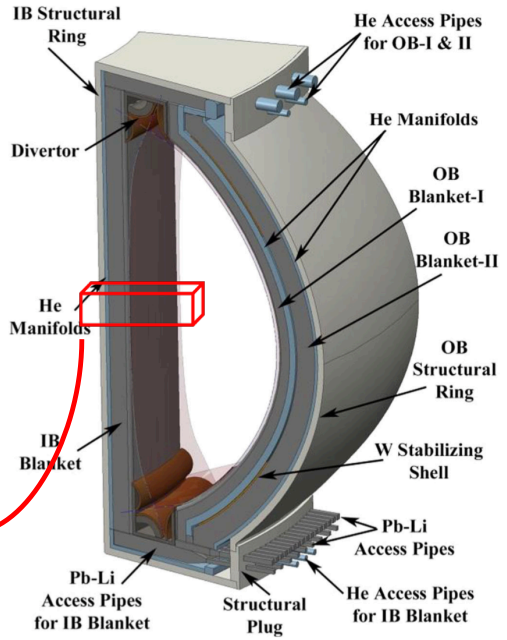
Miniature blanket



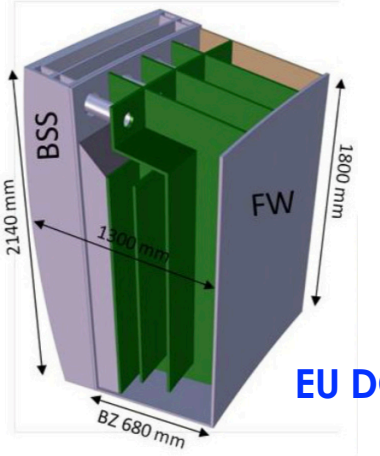
Helium Cooled Blanket concept

Helium flows through the small channels

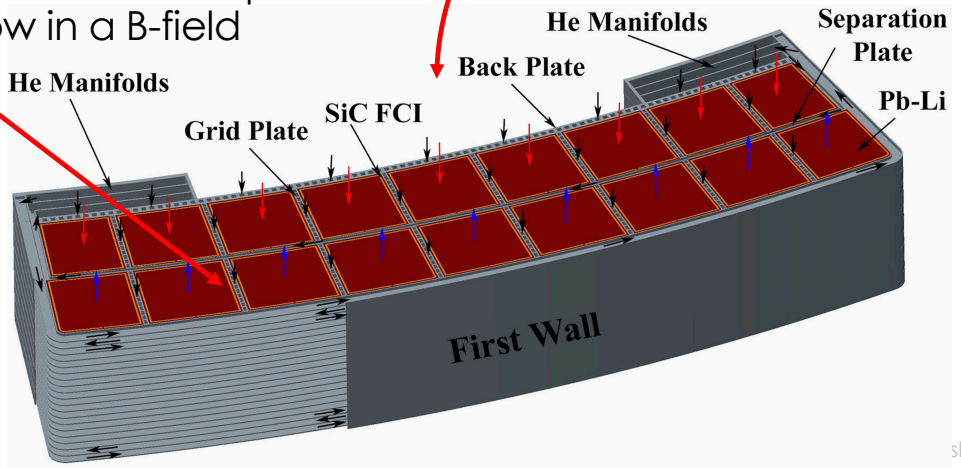
$Pb_{84}Li_{16}$ flows through the large channels



Electric insulator for liquid metal flow in a B-field

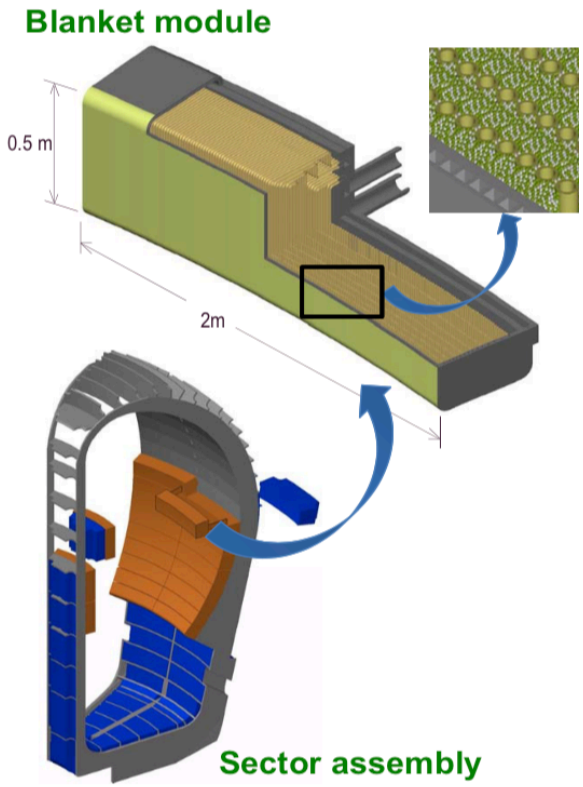


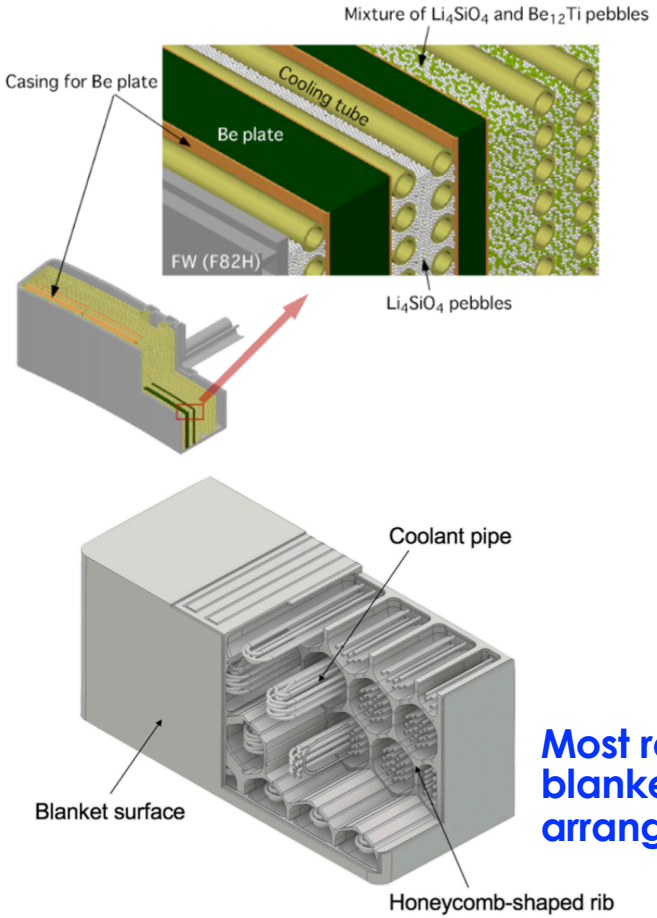
EU DCLL



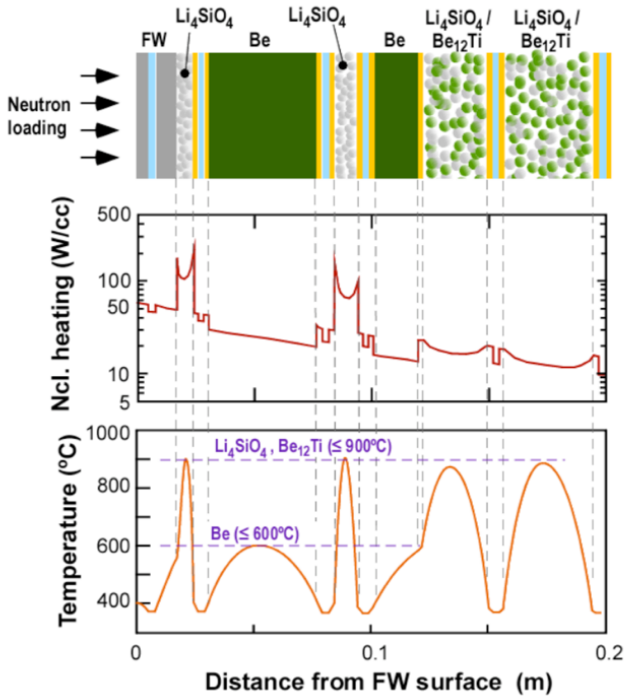
Japanese Solid Breeder Blanket Design

Water cooled blanket concept





Most recent blanket arrangment

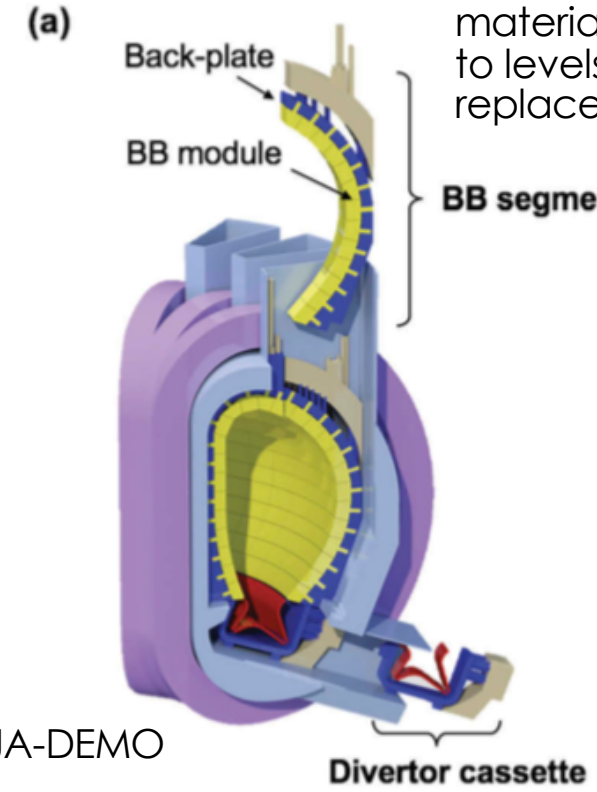


Nuclear and Thermal analysis

Tobita

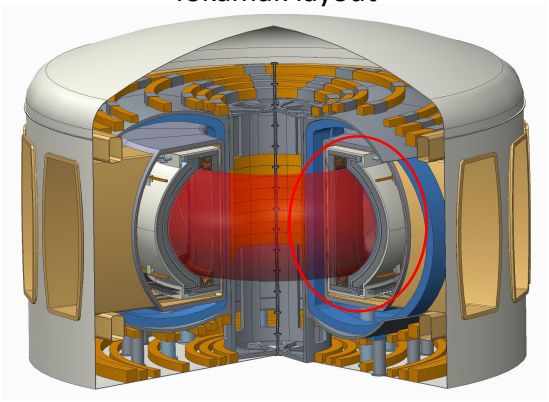
Fusion Blankets Must be Replaceable

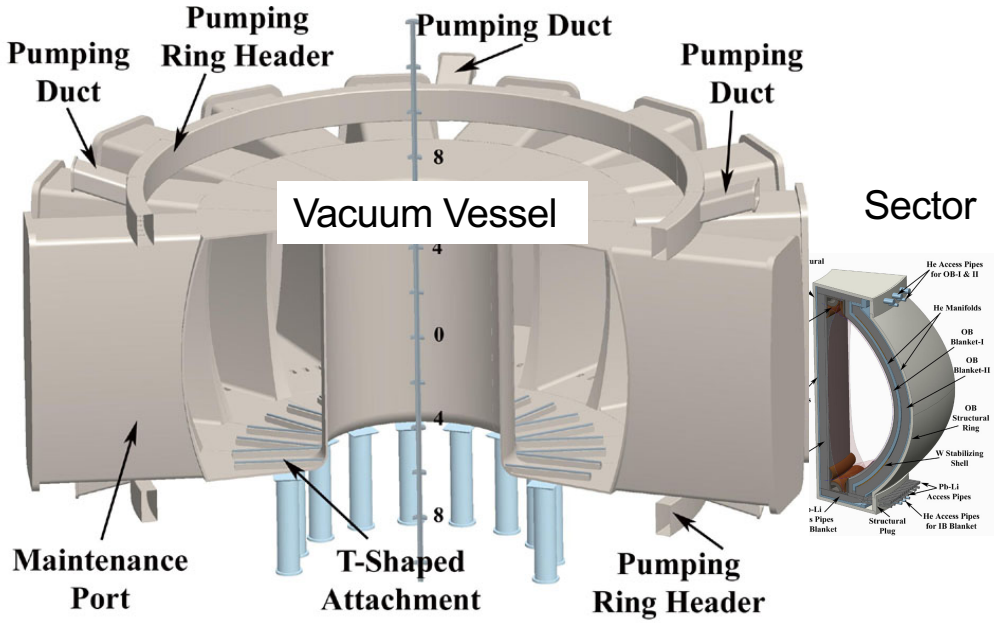
Structural and functional materials will be damaged to levels requiring they be replaced



JA-DEMO

Tokamak layout





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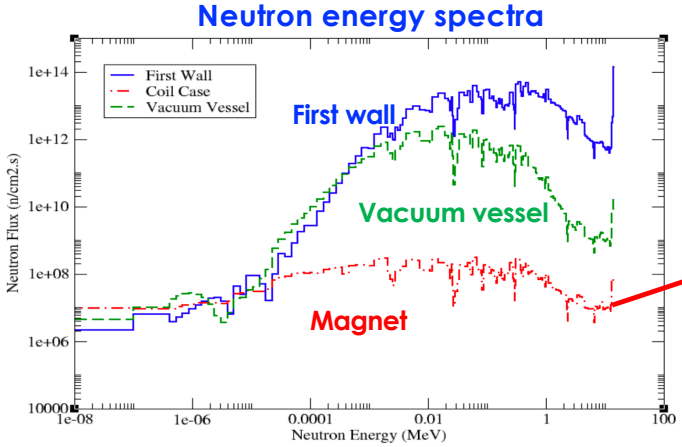
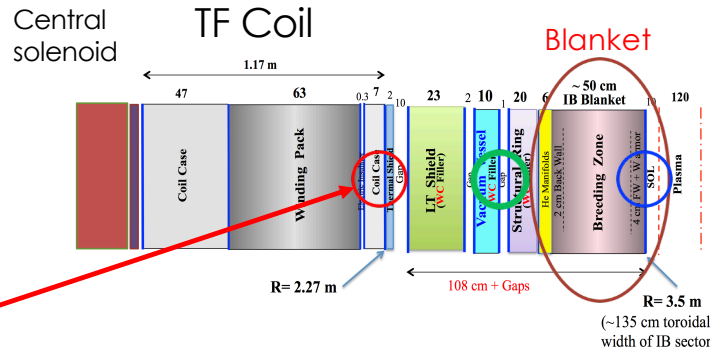
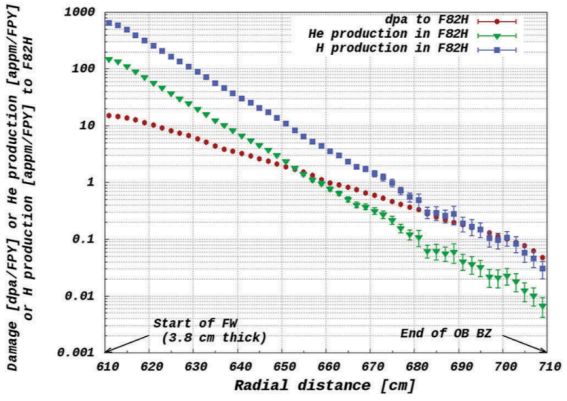
What is the Nuclear Environment Like for a Blanket?

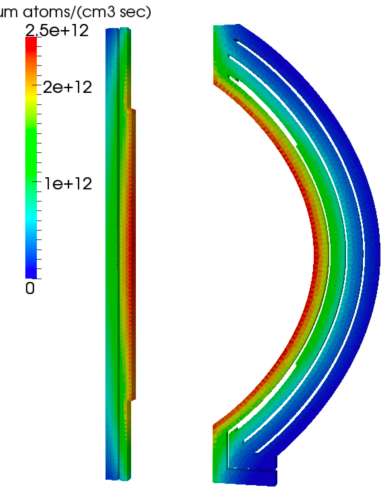




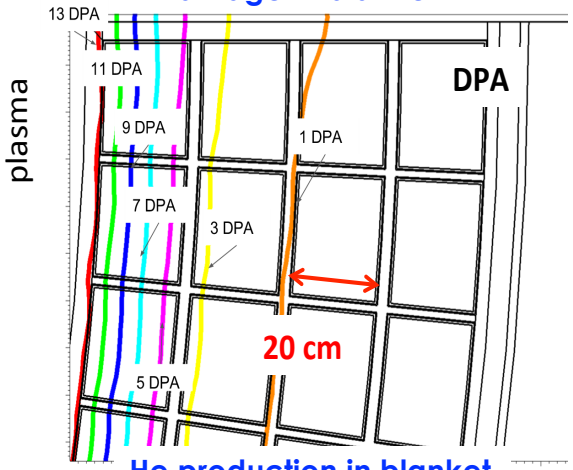
Damage
He prod
H prod



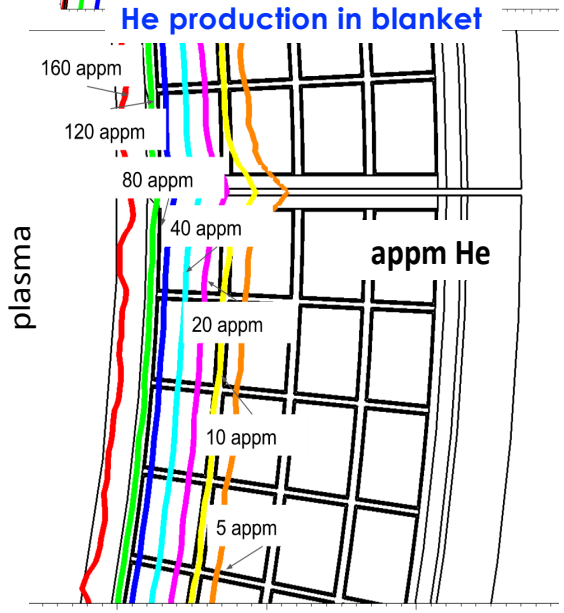
Tritium production in breeder



Damage in blanket



He production in blanket



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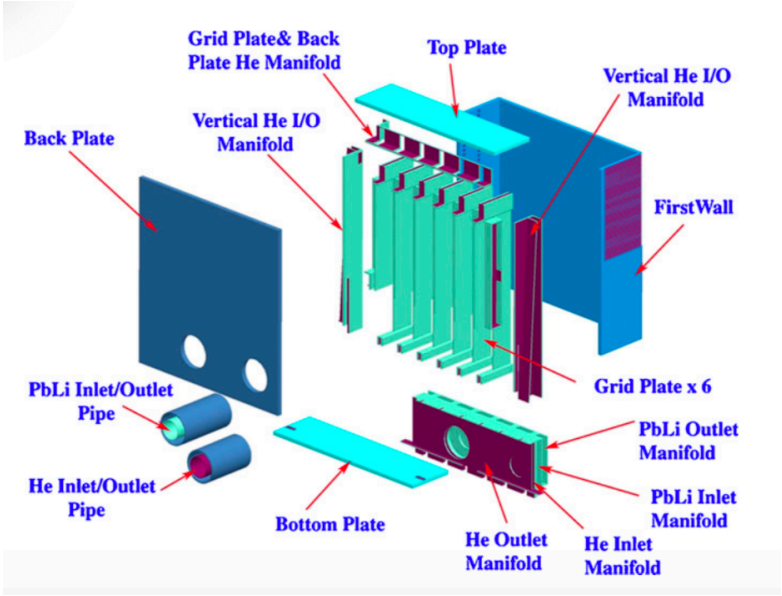
Disciplines involved in Fusion Blanket Design

Thermo-mechanics

Tritium Migration

Liquid Metal MHD

Computational Fluid Dynamics



Materials and Manufacturing

Thermal Hydraulics

Transients

Edge Plasma Physics

Nuclear Analysis

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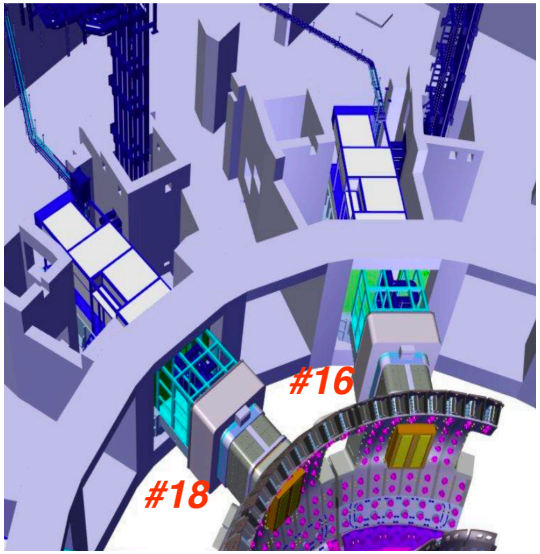
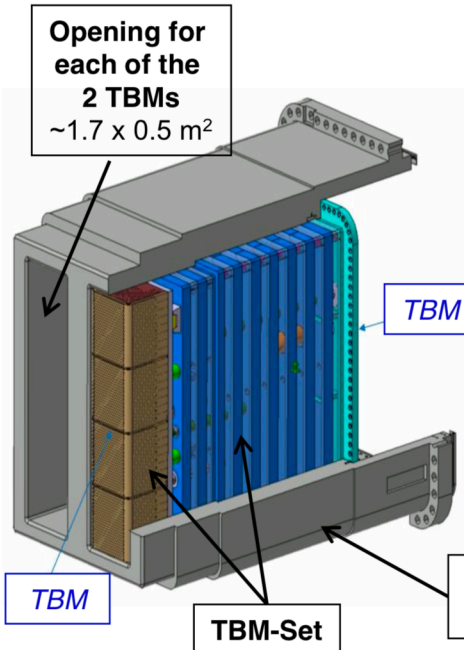
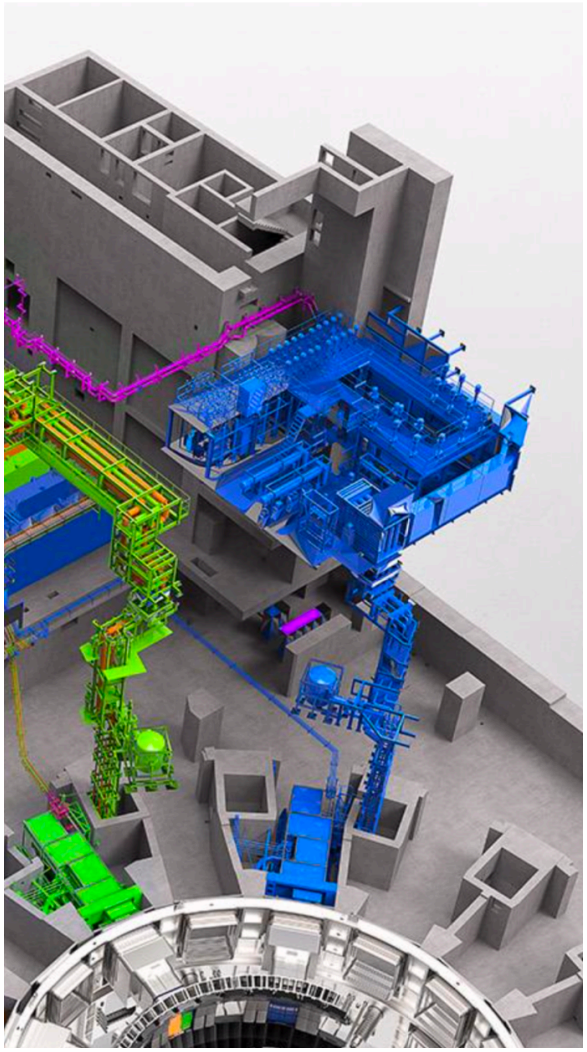
Test Blanket Modules on ITER

ITER will install 4 Test Blanket Modules on ITER (mini-blankets)
- Water Cooled Lead Lithium
- Water Cooled Ceramic Breeder
- 2 Helium Cooled Ceramic Breeder

The US is a non-procuring member for the TBM program







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What are Some of the Challenges We Wrestle With?

Solid breeders or liquid breeders? Is one better than another or are they just different?

Structural materials at high operating temperature and degradation over time

What is the best first wall cooling/material/plasma facing approach

Developing advanced helium cooling structures

Corrosion of RAFM steel by $Pb_{84}Li_{16}$ in a magnetic field, aluminization techniques

How do solid breeders behave when they are irradiated → Li consumption, Li migration, ceramic sintering and reconfiguration, tritium migration, etc.

Can we really provide electrical insulation for liquid metal breeders, how does the material behave with the liquid metal and under irradiation?

What is the tritium inventory within the fusion core, how does it move and where does it accumulate?

……..

Some Papers on Fusion Blankets and related

EU-DEMO Blanket: Federici et al, FED2019

JA-DEMO: Tobita et al, FST2019

CH Blanket: Songlin Liu et al, FED2019; Chenyu Xu et al, IEEE Trans Plas Sci 2018

ITER TBM: Luciano Giancarli et al, FED2018

Special Issue, FED2018 on US FESS-FNSF: https://www.sciencedirect.com/journal/fusion-engineering-and-design/vol/135/part/PB

Fusion materials and nuclear science research: Zinkle et al, FED2014

T. Ihli et al, FED2008

M. Abdou et al, FED2015