ASSESSMENT OF LIQUID BREEDER FW/BLANKET OPTIONS

‘Our goal is to select the best liquid breeder FW/blanket design for the US ITER Test Module Program’

ASSESSMENT AND DESIGN TEAM:

General Atomics	C.P.C. Wong
Consultant, Germany	S. Malang
Argonne National Laboratory	S. Majumdar
U. of California, Los Angeles	S. Smolentsev, M. Dagher, S. Sharafat, N. Morley, M. Abdou
U. of Wisconsin, Madison	M. Sawan
ORNL	S. Zinkle
Idaho National Laboratory	B. Merrill
UCSD	D. K. Sze
UC, Berkeley	P. Peterson, H. Zhao

TOFE MEETING
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OUTLINE

- FW/Blanket options
- Approach taken for the assessment
- Molten Salt FW/blanket designs
- Molten Salt Reactor Experiment
- Molten Salt blanket designs
  - Self-cooled and dual coolant configuration
  - Tritium breeding and shielding
  - Thermal-hydraulics
  - Safety

- Dual coolant Pb-17Li design
- Liquid breeder R&D Items
- Conclusions

ITER-TRITIUM BREEDING MODULE (TBM) BLANKET DESIGN OPTIONS

- He-cooled Ceramic/Be (China, EU, Japan, Korea, RF, US)
- He-cooled Pb-17Li (China, EU, Japan, Korea, RF, US)
- Water-cooled Ceramic/Be (China, Japan)
- Self-cooled Li with V-alloy (China, Japan, Korea, RF, US)
- Self-cooled and DC Molten Salt, DC Pb-17Li (Japan, China, US)

Concept coordinating parties

APPROACH TAKEN FOR THE ASSESSMENT

- **Reference design: max Γ_n = 5.4 MW/m^2 and heat flux=1 MW/m^2**
- **Utilize Reduced Activation Ferritic Steel (F82H) as the structural material**
- **Identify attractive liquid breeder blanket concepts**
- **Evaluate concepts that can be developed, qualified, and tested in the time frame of ITER**
- **Make scoping designs, layouts and first analyses and perform assessment of candidate concepts**
- **Identify R&D items**

MOLTEN SALTS
(Li_2BeF_4, $LiBeF_3$, FLiNaBe)

Pros

When compared to Li and LiPb:

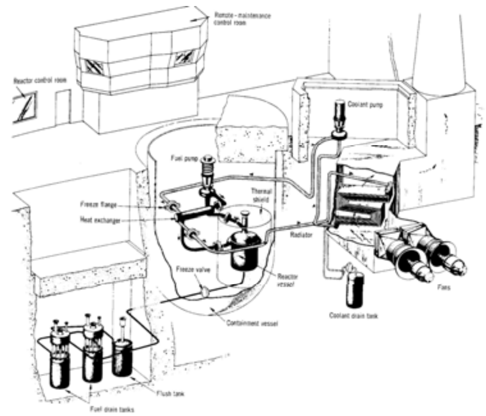
- **Reduced MHD effect**
- **Reduced chemical reactivity**

Cons

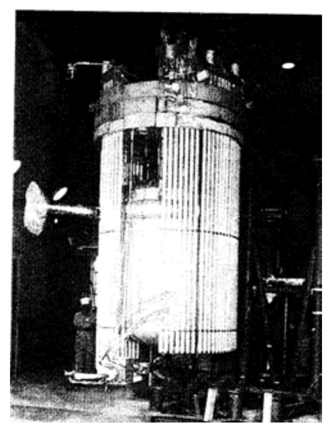
- **Need neutron multiplier for adequate TBR**
- **High viscosity, low Kth**
- **Needs REDOX control**
- **High melting point for Li_2BeF_4 (459° C) and $LiBeF_3$ (380°C)**
- **Thermophysical property data needed for FLiNaBe**

RELEVANT EXPERIENCE FROM MOLTEN SALT REACTOR EXPERIMENT (MSRE)

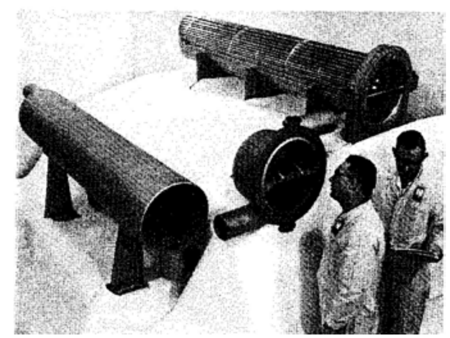
- **MSRE was an 8 MW(th) fission reactor**
- **Can be considered as a very successful MS development experience. It operated for ~5 years (1/65 to 12/69) and prepared the groundwork for a two region MS breeder fission reactor design**
- **We learned about the importance of chemistry control by REDOX with the use of Be**
- **Tritium control was a concern for MS fission reactor; fusion reactor will have a much higher production rate of tritium**
- **The MSRE initial operation experience will be relevant to the ITER MS test module program**



MSRE System arrangement



Heated core



Heat exchanger

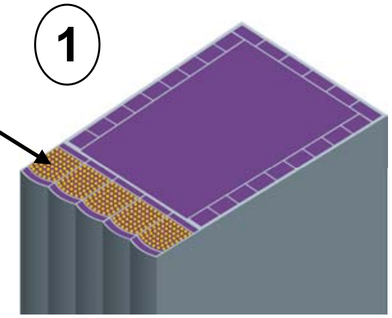
FOUR LIQUID BREEDER DESIGN CONCEPTS

Structural material: Ferritic Steel (F82H)

1. **Self-cooled FLiNaBe coolant and breeder, Be pebble bed multiplier (SC-MS-Be)**
2. **Dual Coolant, He and Li_2BeF_4, Be pebble bed multiplier (DC-MS-Be)**
3. **Dual Coolant, He and Li_2BeF_4, Pb slabs multiplier (DC-MS-Pb)**
4. **Dual Coolant, He and Pb-17Li (no multiplier) (DC-PbLi)**

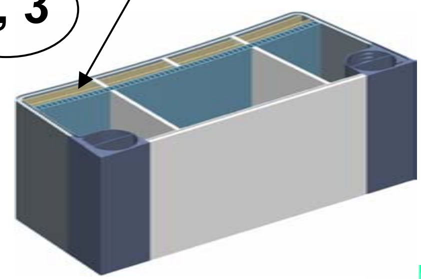
1

Be pebble bed



2, 3

Be pebble bed or Pb slab



(Be and Pb designs are similar but not identical)

DC-Pb-17Li

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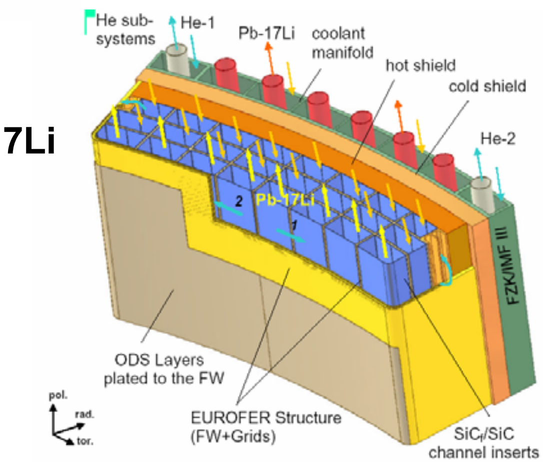
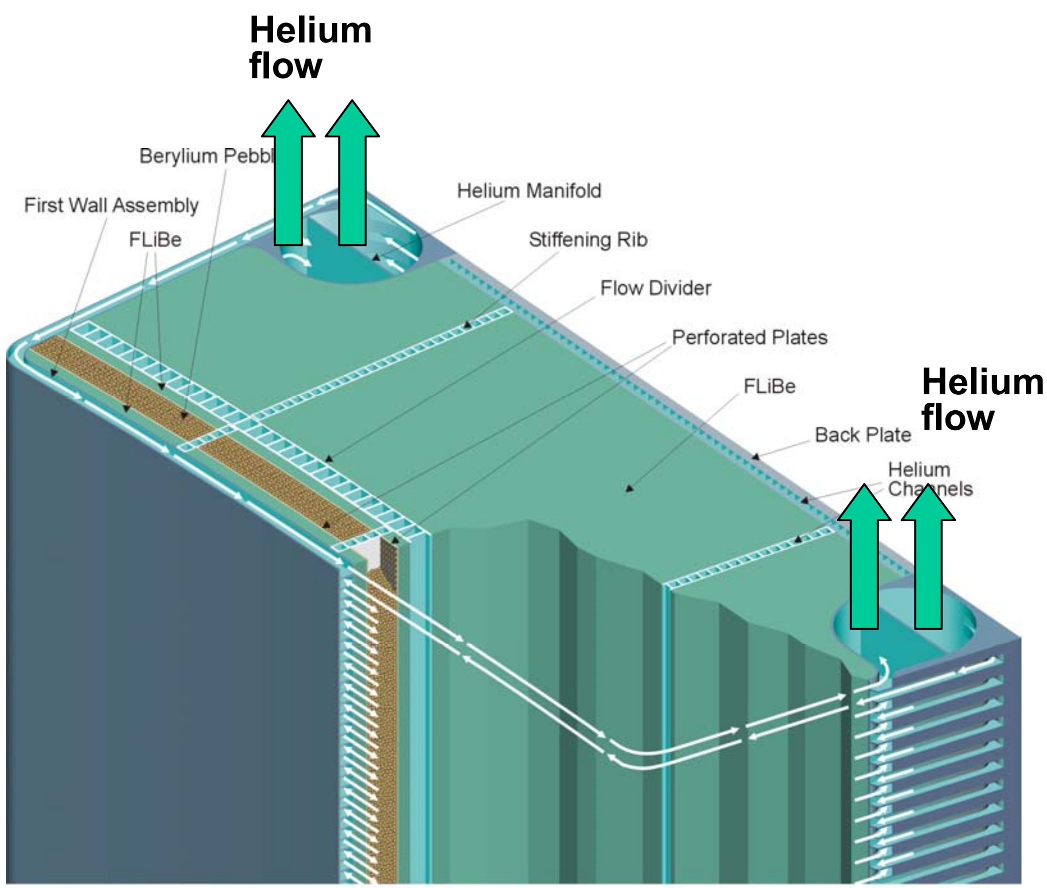
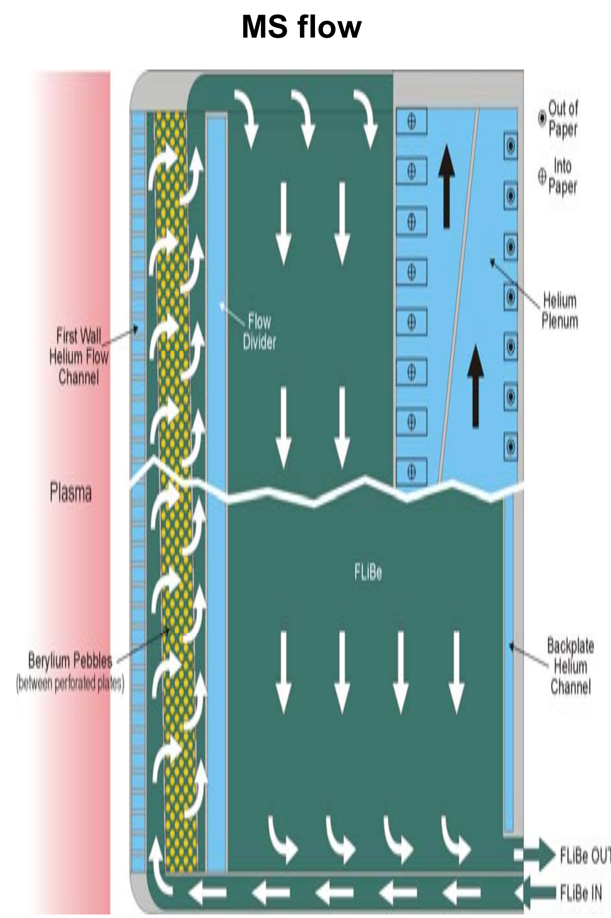


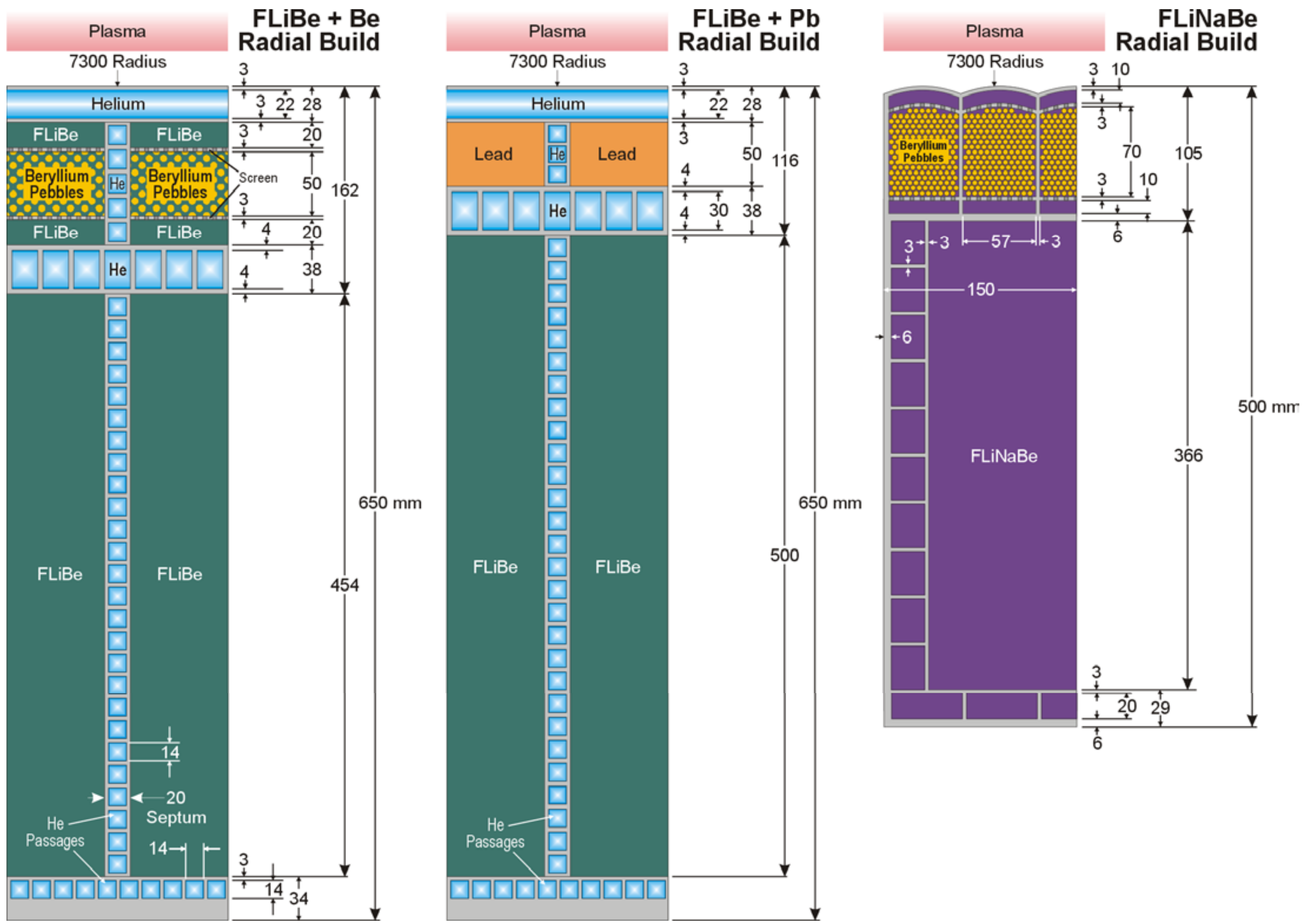
DC – He & Li_2BeF_4 + Be BLANKET CONCEPT (TYPICAL HE FLOW CIRCUIT FOR DC BLANKET)



Poloidal cross-section

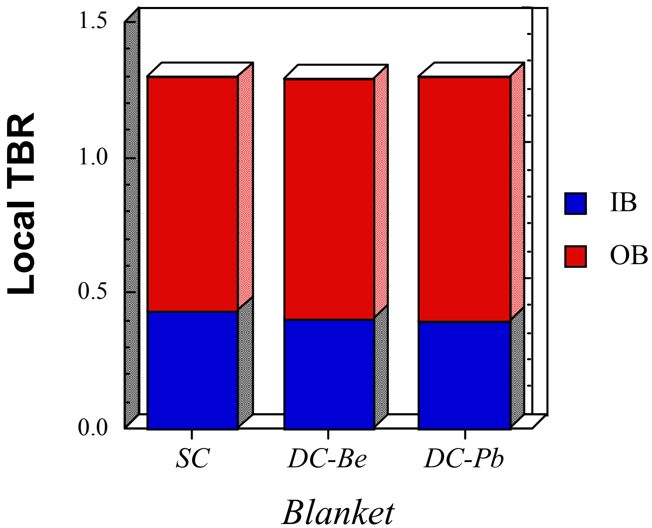


OUTBOARD MS BLANKET COOLANT CONCEPTS (MIDPLANE CROSS SECTIONS)



DC-MS-Be DC-MS-Pb SC-MS-Be

TRITIUM BREEDING POTENTIAL AND SHIELDING FOR MOLTEN SALT DESIGNS



	SC-MS-Be	DC-MS-Be	DC-MS-Pb
Inboard	0.432	0.406	0.399
Outboard	0.867	0.882	0.897
Total	1.299	1.288	1.296

- If neutron coverage for the divertor is 10% the overall TBR will be ~1.17 excluding breeding in divertor region. Breeding in divertor zone could add ~0.05.

- The blanket design concepts have the potential for achieving tritium self-sufficiency. Some design parameters can be adjusted (e.g., multiplier thickness, blanket thickness…etc.) to insure tritium self-suffiency based on calculations with detailed multi-dimensional modeling.

- With total B/S/VV radial build of 105 cm IB and 120 cm OB it is possible to achieve: shield as lifetime component, VV reweldable and magnets adequately shielded

MS DESIGNS THERMAL-HYDRAULICS ANALYSIS SUMMARY

Blanket parameters:

- Minimum MS T ~40° C above the melting point
- Try to design to maximum temperature of the FS structure < 550°C
- All interface temperatures < 550°C
- For SC-FLiNaBe ΔT=650-360°C, for DC He ΔT=450-300°C; Li_2BeF_4 ΔT=700-500°C

Results:

- DC design He velocity in the FW channels = 75 m/s; Li_2BeF_4 velocity = 10.8 cm/s
- Artificial wall roughening of FW He channels
- Using CCGT SC and DC designs can reach similar gross thermal efficiency of ~40%
- The SC FLiNaBe first wall T_{max}=680°C, an ODS-steel layer will be needed for the temperature > 550°C
- The DC Li_2BeF_4 multiplier designs will have a 1-2 mm thick frozen layer of MS at the secondary wall of the blanket, which is not acceptable. Therefore, a lower melting point MS like $LiBeF_3$ or FLiNaBe is recommended for the DC design

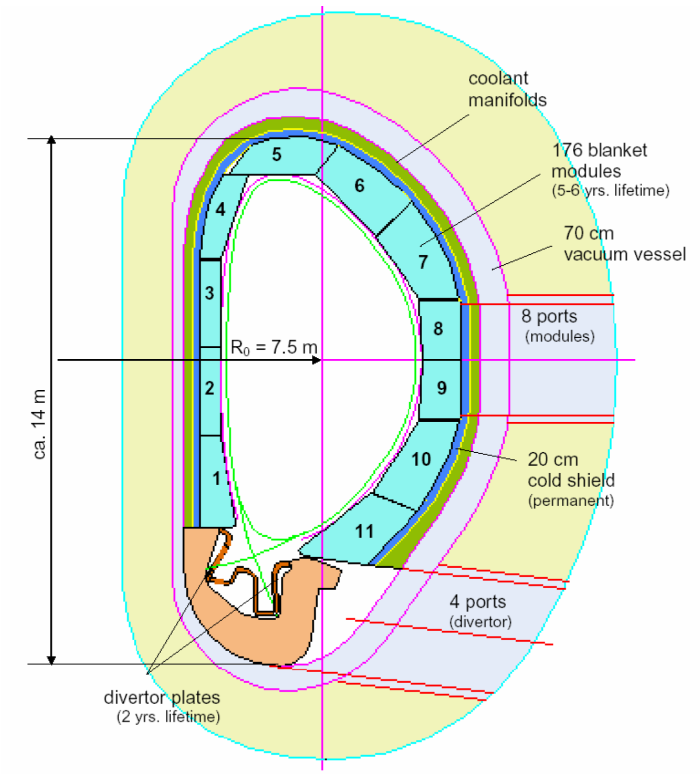
QUALITATIVE SAFETY COMPARISON OF SC AND DC MOLTEN SALT DESIGN OPTIONS

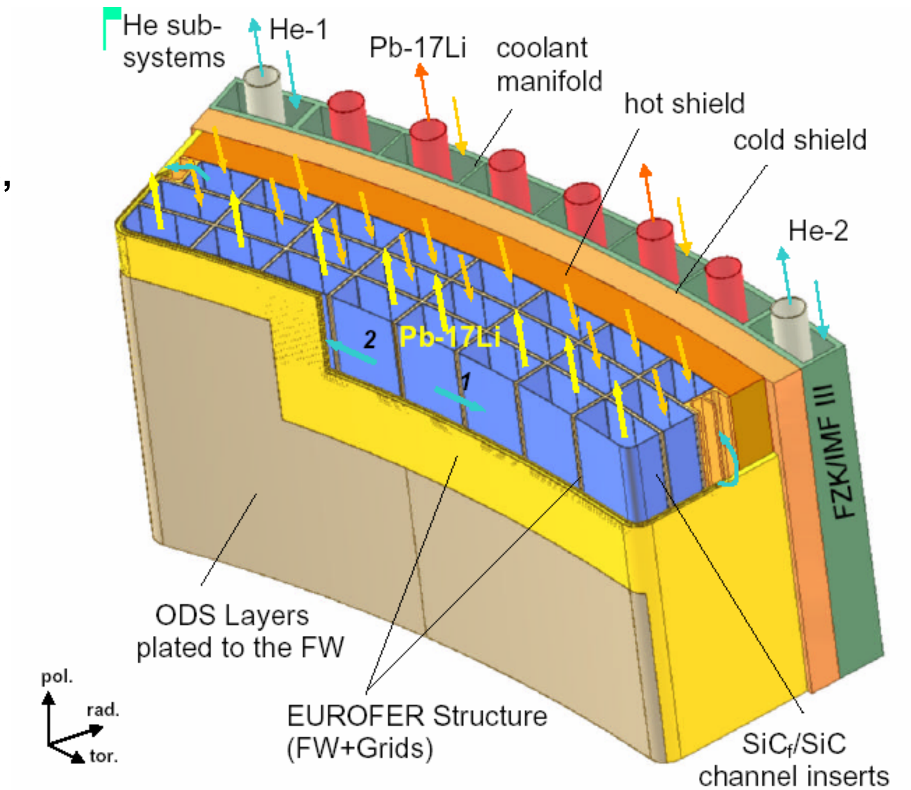
- Design specific safety issues (no clear safety advantage)
  - Self-cooled design
    - ★ FLiNaBe decay heat (Na-24)
  - Dual coolant designs
    - ★ Helium pressurization could lead to failure of radioactive material confinement barriers (vacuum vessel - VV, cryostat, confinement building)
- Common safety issues
  - Be multiplier tritium or Pb multiplier Po-210 and Hg-203
  - F82H decay heat
  - Radioactive inventories (tritium in F82H, F82H and MS radioactive isotopes)
  - Tritium permeation (pipe walls and heat exchangers)
  - Molten salt freezing could lead to loss-of-flow accidents

EU ADVANCED DUAL COOLANT DEMO BLANKET (CONCEPT FIRST PROPOSED BY 1997 ARIES-ST DESIGN)

Features:

- **Inboard/Outboard poloidally segmented blanket modules, each with two-pass poloidal Pb-Li flow.**
- **He in/out=300/480°C, Pb-Li in/out=460/700°C, $\eta_{\tau h}$=44% with CCGT.**

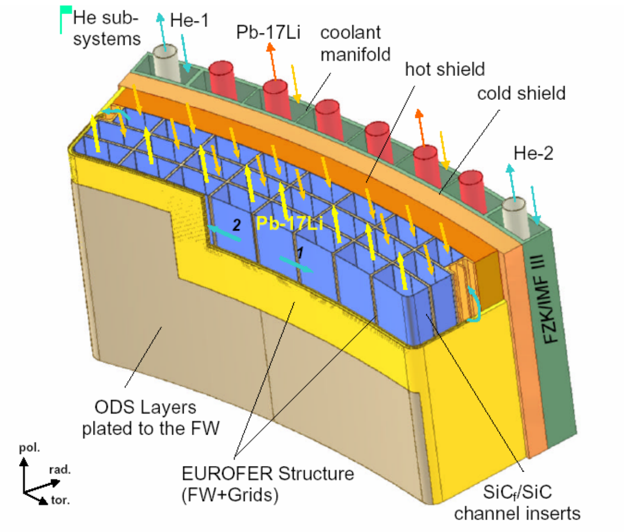




Ave. Γn = 2.27 MW/m², Max. ø = 0.59 MW/m²

KEY FEATURES OF DUAL COOLANT LEAD-LITHIUM CONCEPT (DC-PbLi)

- Helium cools the ferritic steel FW and structure and is used for FW/blanket preheating and possible tritium control
- Breeding Pb-17Li is circulating at low speed
- No separate neutron multiplier needed
- Use flow channel inserts (FCIs), wherever possible to:
  - Provide electrical insulation to reduce MHD pressure drop
  - Provide thermal insulation to decouple PbLi bulk flow temperature from wall temperature
  - Provide additional corrosion resistance since only stagnant PbLi is in contact with the ferritic steel structural walls



INITIATED LIQUID-BREEDER R&D ITEMS

- FLiNaBe melting point has been measured by SNL at 305 to 320°C
- FLiBe: tritium, thermofluid and REDOX studies under Japan-US JUPITER-II project
- SiC_f/SiC flow channel insert research initiated in EU, it needs to be organized in the US: fabrication, compatibility, MHD effects

CONCLUSIONS

- Using FS as the structural material, an assessment of four liquid breeder options has been completed
- Nuclear performance requirements can be satisfied by these designs
- SC and DC designs achieve CCGT thermal efficiency of ~40%
- SC-FLiNaBe design will need ODS-FS FW layer
- Lower melting point MS like FLiNaBe and $LiBeF_3$ should be considered for the DC designs to avoid a solid layer
- We will continue on the DC approach, which allows independent cooling of the first wall and blanket
- Critical issues have been identified: MS-REDOX, fundamental properties for FLiNaBe, FCI, FS/Pb-17Li, SiC_f/SiC and Pb-17Li compatibilities, tritium permeation, high temperature channel material and MHD effects