Ferritic Steel Lifetime Assessment and Self-Consistent Nuclear Parameters for ARIES-IFE-HIB

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ARIES Project Meeting
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PPPL

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Objectives

- Assess nuclear performance of structure-free blanket concept using ARIES design rules
  - Breeding potential of candidate breeders:
    - Flibe
    - Flinabe.
  - Lifetime of ODS ferritic steel (FS) protected with liquid blanket
  - Waste disposal rating **and** Helium production for structural components: shield, nozzles, feeding tubes.
- Estimate reduction in waste for thick liquid wall concept.

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Key Parameters

Target yield	458.7 MJ
Rep rate	4 Hz
# of pulses	126 million/FPY
Average source neutron energy	11.75 MeV
Neutron power	1286 MW
Neutron wall loading @ 0.5 m	410 MW/m^2
Penetrations coverage	3%
Plant lifetime	40 FPY
Availability	85%

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ARIES Requirements and Design Limits

Overall TBR	≥ 1.08
dpa* to FS structure	≤ 200 dpa
Helium production for reweldability of FS	≤ 1 He appm
WDR for Class C low level waste	≤ 1

* Thermal creep strength @ EOL is more restrictive than radiation damage, per M. Billone (ANL).

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Flibe vs Flinabe

- Flinabe has substantially lower melting point (~320 ^{o}C) compared to Flibe (459 ^{o}C) , offering low operating temperature and low vapor pressure.
- To provide very low vapor pressure in HIF beam tubes and protect structure against x-rays and target debris, Per Peterson (UCB) recommended Flinabe to create low temperature vortices.
- It is preferable to have single liquid composition everywhere (in chamber and beam tubes), if acceptable from perspectives of breeding and safety.

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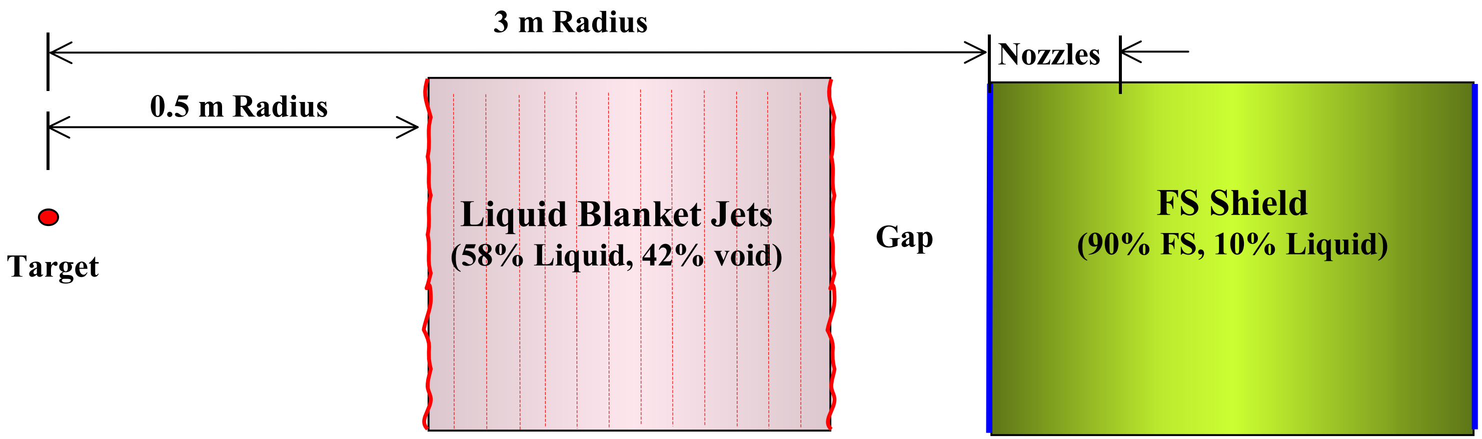
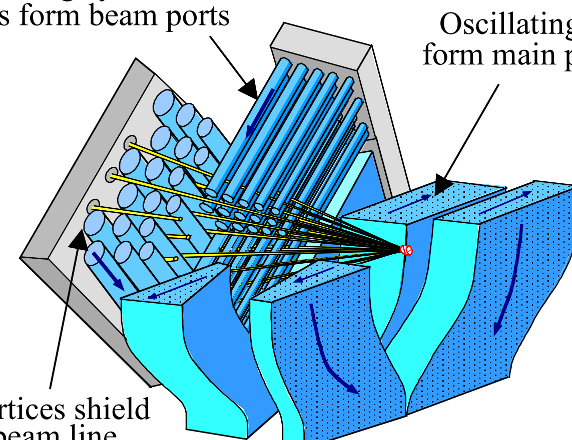
Schematic of Radial Build



- Flibe (BeF_2,$(LiF)_2$) and Flinabe (NaF, LiF, BeF_2) with natural Li.
- ODS nanocomposited# FS or 304-SS.
- Innermost layer of shield represents nozzles and feeding tubes.
- Point source and 1-D spherical geometry



G.R. Odette and D.T. Hoelzer, “Development of Nanocomposited Ferritic Alloys for High Performance Fusion First Wall and Blanket Structures,” article submitted to ANS FED newsletter, http://fti.neep.wisc.edu/FTI/FED/news0602.pdf (June 2002).

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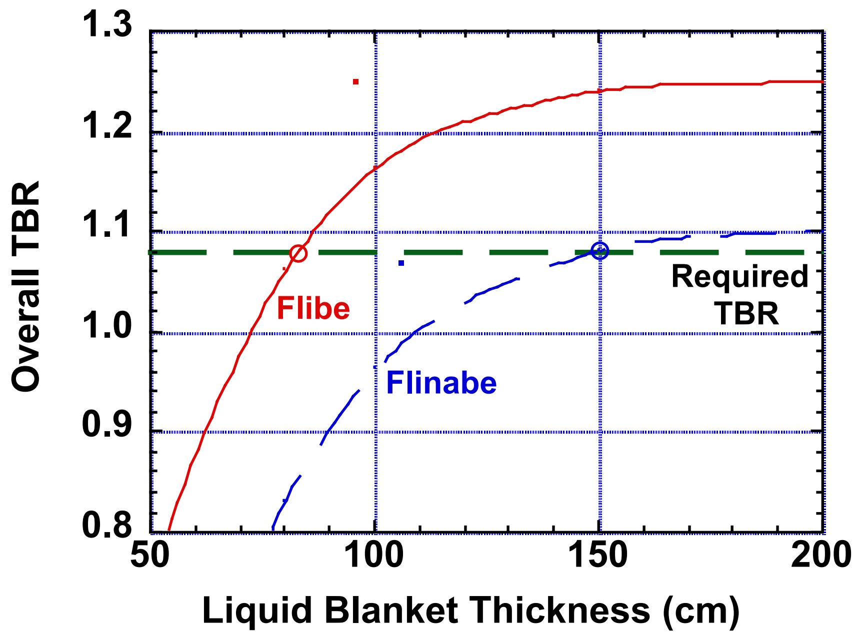
Flibe Breeds more Tritium than Flinabe



- 83 cm thick Flibe and 150 cm thick Flinabe meet ARIES breeding requirement (TBR ≥ 1.08).
- Enrichment does not enhance breeding of thick Flinabe.
- Nuclear energy multiplication amounts to ~1.25.
- ~10% of heating deposited in shield behind Flibe and 1% of heating in shield behind Flinabe.

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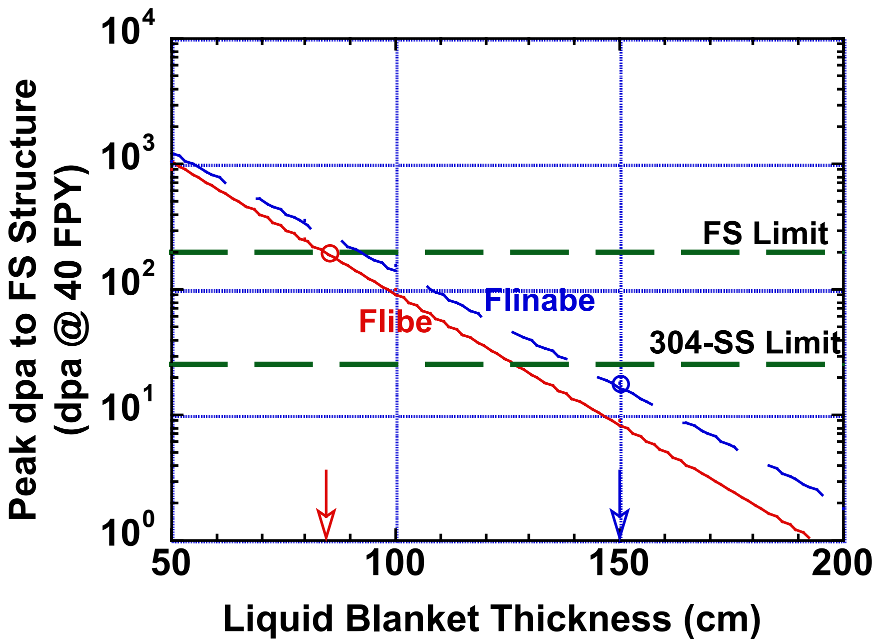
For Same Blanket Thickness, Flibe Provides Better Attenuation than Flinabe



- 85 cm Flibe blanket meets FS 200 dpa limit.
- 1.5 m Flinabe blanket provides better shielding and meets 25 dpa limit for 304-SS.

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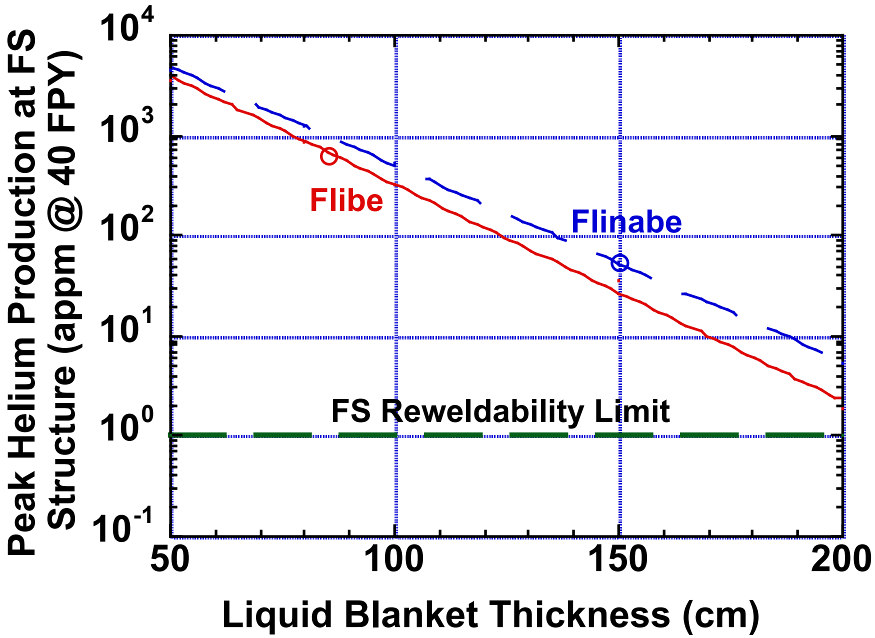
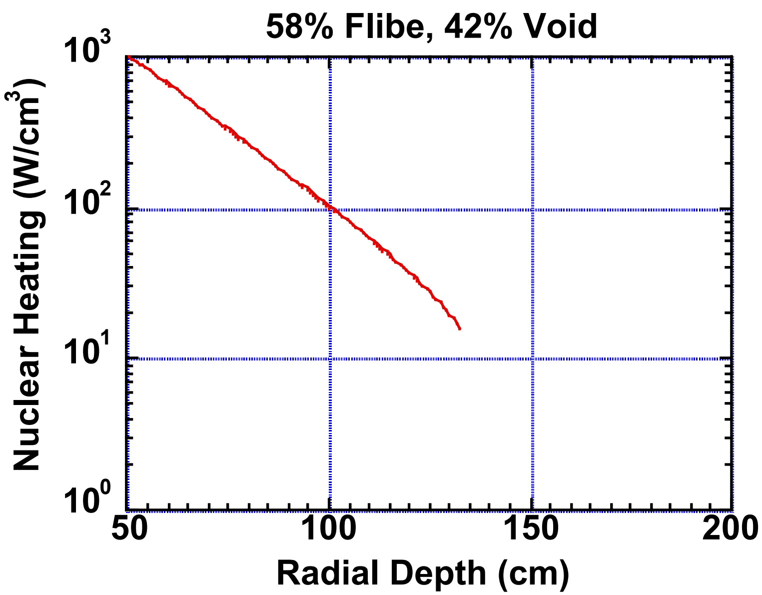
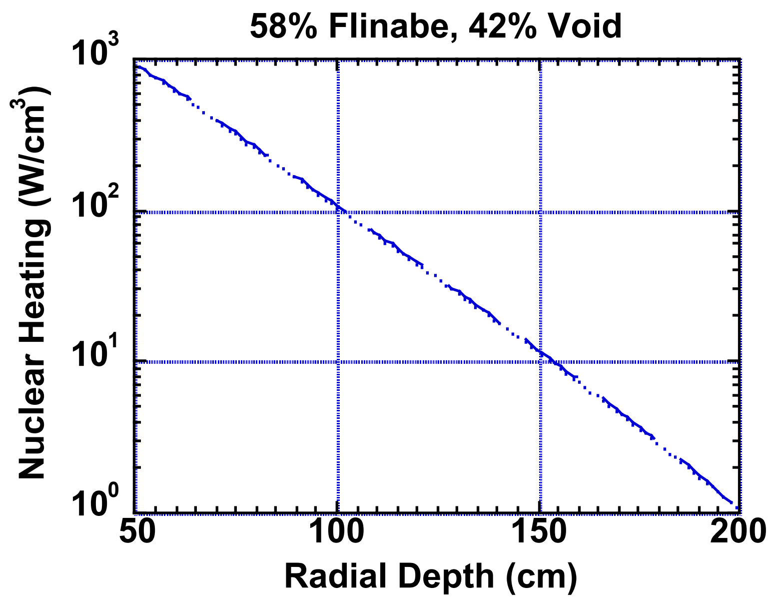
Helium Production is Excessive



Innermost shield layer/nozzles/feeding tubes cannot be re-welded at any time during operation.

Nuclear Source Term for Aerosol Calculations





- Heating evaluated at midplane per unit volume of actual blanket composition.
- For isochoric heating analysis, detailed heating in fine meshes and time-dependent nuclear heating will be computed upon request.

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Steel Composition (in wt%)

	ODS-12YWT-FS* (Experimental Alloy)	ODS M-F82H-FS**	304-SS#
Fe	83.818	87.891	70.578
C	0.052	0.04	0.046
N	0.014	0.005	0.038
O	0.16	0.13	–
Si	0.1	0.24	0.47
P	–	0.005	0.026
S	0.001	0.002	0.012
Ti	0.35	0.09	0.03
V	0.01	0.29	–
Cr	12.58	8.7	17.7
Mn	0.05	0.45	1.17
Co	–	0.0028	0.1
Ni	0.27	0.0474	9.3
Cu	0.02	0.01	0.2
Nb	0.01	0.00033	–
Mo	0.02	0.0021	0.33
Ta	–	0.08	–
W	2.44	2	–
Y	0.16	0.7	–

* R. Klueh et al., "Microstructure and Mechanical Properties of Oxide Dispersion-Strengthened Steels" fusion materials semiannual progress report for the period ending June 30, 2000 (DOE/ER-0313/28), pp. 123-130. Fe-12Cr-3W-0.4Ti-0.25Y_2O_3 (12YWT) experimental alloy.

** IEA Modified F82H FS + 0.25wt% Y_2O_3, per M. Billone (ANL). Other elements include: B, Al, As, Pd, Ag, Cd, Sn, Sb, Os, Ir, Bi, Eu, Tb, Dy, Ho, Er, U.

\# Starfire report: C. Baker et. al, "Starfire-A Commercial Tokamak Fusion Power Plant Study," Argonne National Laboratory Report, ANL/FPP-80-1 (1980).

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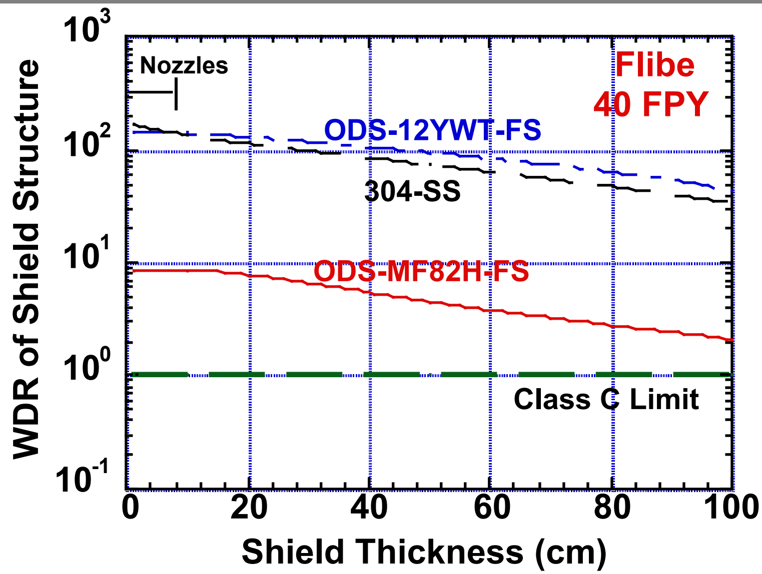
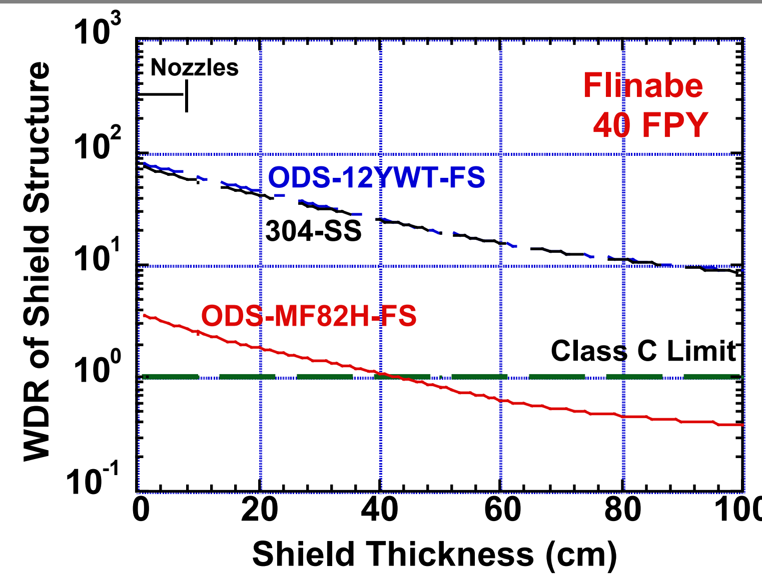
All Alloys Generate High Level Waste





- ODS-MF82H-FS offers lowest WDR.
- Thicker Flinabe blanket results in lower WDR.
- Main contributors to WDR: ^{94}Nb (from Nb), ^{99}Tc (from Mo), and ^{192n}Ir (from W).
- Potential solutions to meet waste requirement (WDR < 1):
  - Control Mo and Nb,
  - Thicken blanket.

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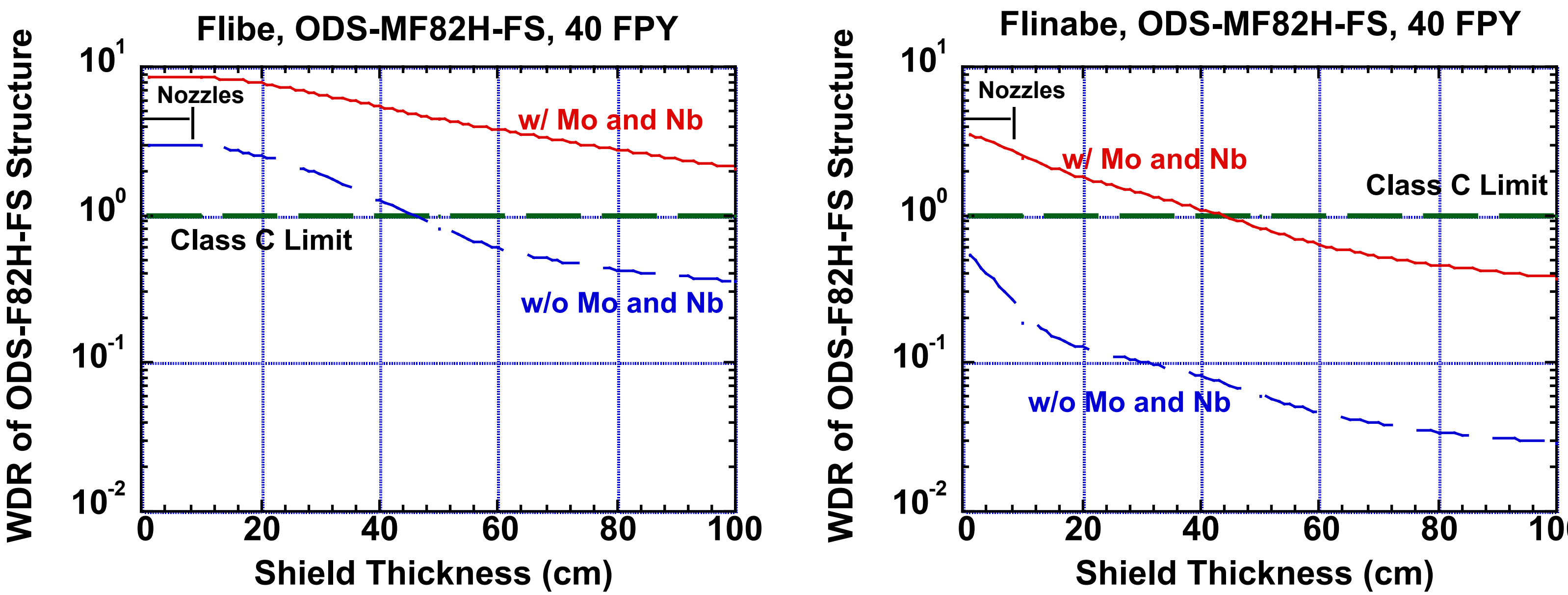
Effect of Mo and Nb on WDR



- In practice, Mo and Nb impurities cannot be zeroed out. Actual level depends on $/kg to keep Mo and Nb < 1 wppm.
- Flibe shield **with** Mo/Nb control should be > 50 cm thick to qualify as LLW.
- Flinabe shield **without** Mo/Nb control meets waste requirement if ≥ 45 cm thick.
- Nozzles/feeding tubes generate high level waste unless protected by thicker blanket **or** mixed with shield and disposed as single unit at EOL.

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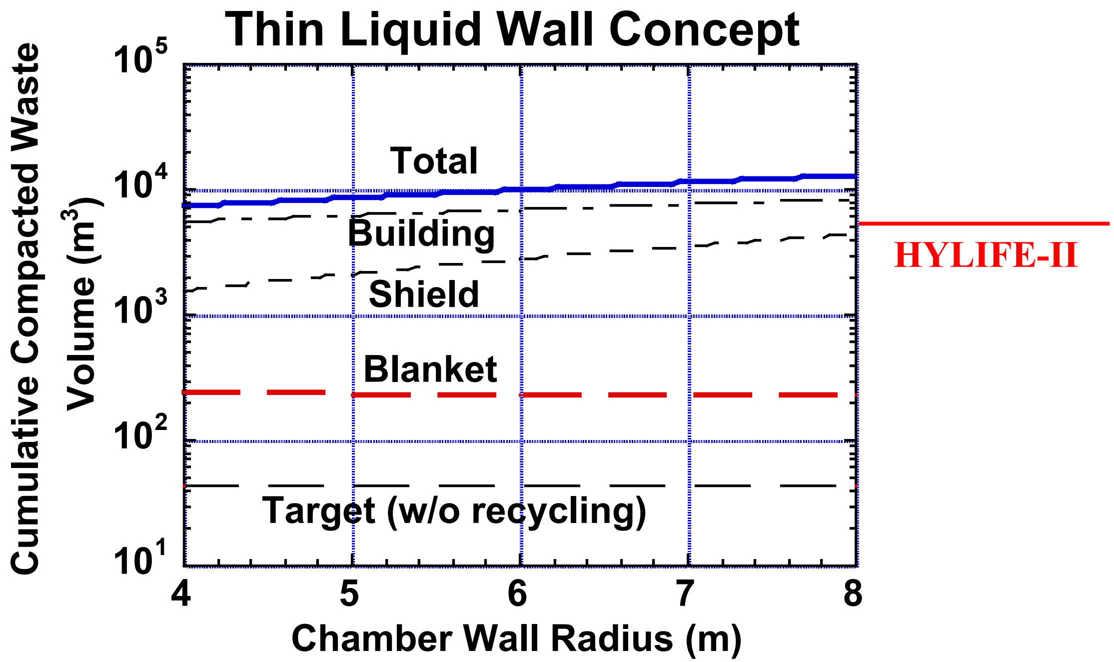
Revisiting Logic Behind Thick Liquid Wall Concept



- Thick liquid wall concept developed to eliminate blanket replacement, **reduce waste**, and increase availability by 10% ⇒ 20% lower COE, per R. Moir (UCRL-JC-115748, April 1994).
- In IFE solid wall designs, blanket generates only 2-4% of total waste

    ⇒ **Thick liquid wall concept offers <u>small</u> waste reduction.**

    (same conclusion made for MFE - APEX project)

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Conclusions

- Class C LLW requirement is more restrictive than breeding and dpa requirements.
- No breeding problem identified for Flibe and Flinabe.
- 85/150 cm thick Flibe/Flinabe blankets provide TBR of 1.08 and meet FS dpa limit.
- Helium production in FS is excessive and precludes FS reweldability during operation.
- All steels produce high level waste (WDR >> 1).
- ODS-MF82H-FS and Flinabe system offer lower WDR for FS structure.
- Low level waste can be achieved with combination of Mo/Nb control **and** blanket/shield adjustment.
- Nozzles/Feeding tubes need additional protection to qualify as LLW unless combined with shield.

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Importance of Results and What needs to be done

- Nuclear assessment is important to feasibility of thick liquid wall concept.
  Results show impact of thick liquid wall on: FS lifetime
  Waste level
  Reduction in waste volume.
- Design-specific analysis needed to meet LLW requirement for nozzles and shield using:
  - Nb and Mo impurity control
  - Thicker blanket (adjust TBR)
  - Thicker shield.
- Need feedback from materials community on acceptable Nb and Mo impurity level **and** impact on FS unit cost.

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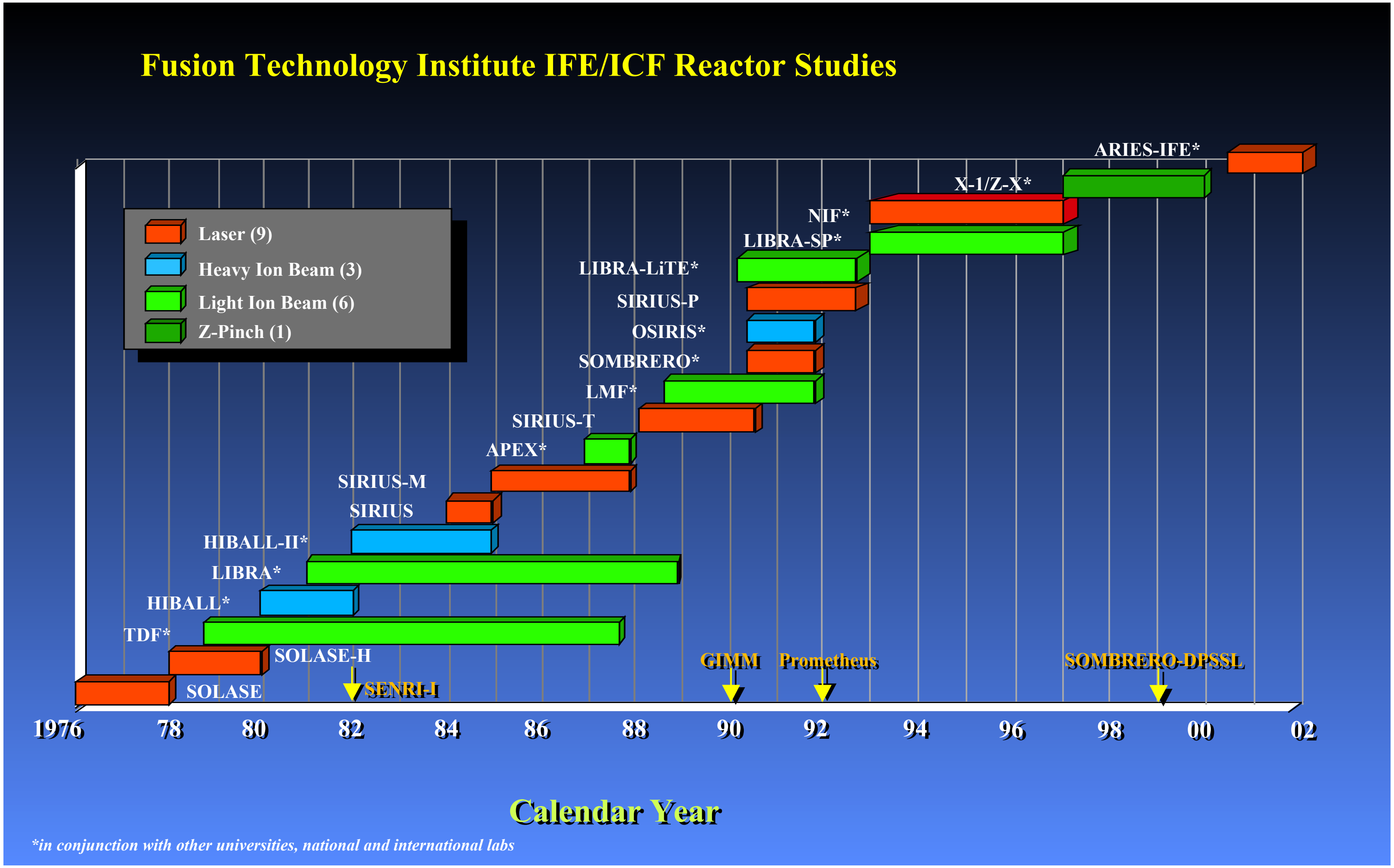
UW IFE Designs



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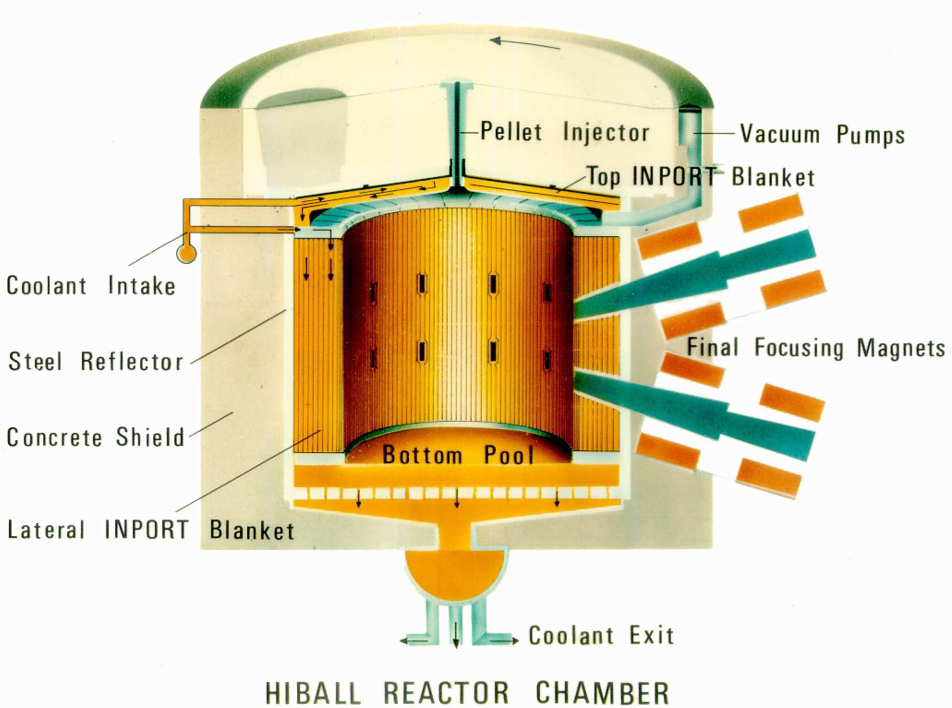
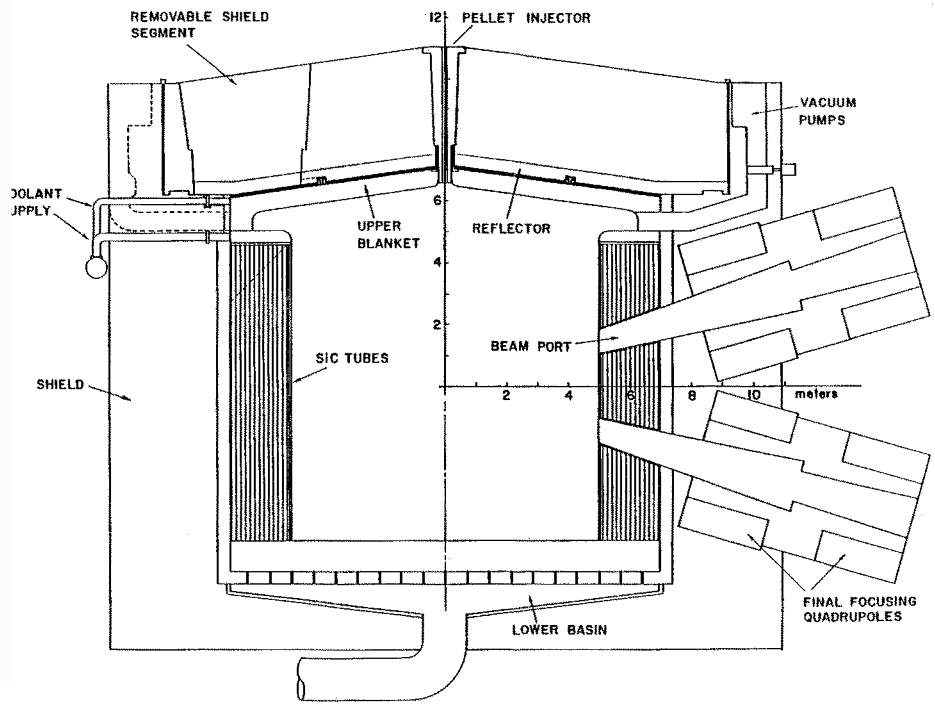
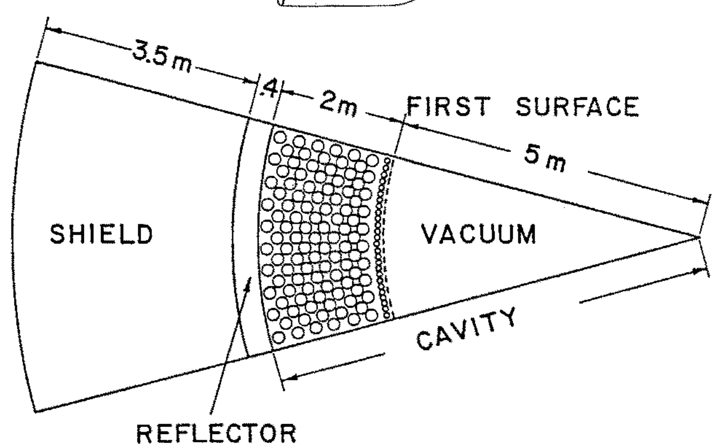
UW IFE Design - HIBALL (1981)







- Many **INPORT*** units ⇒ high surface area for condensation.
- LiPb seeps through woven, porous SiC **flexible** tubes.
- Axial tension applied on tubes to limit motion.
- **Concerns**: vaporized LiPb exerts high impulse load on tubes, uncertainties in applied tension, possible change in SiC porosity, possible deviation from circular tube shape.

* **In**hibited flow **Por**ous **T**ubes

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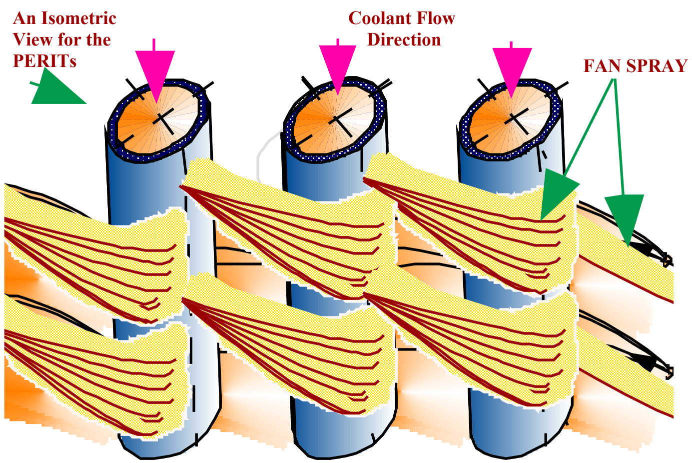
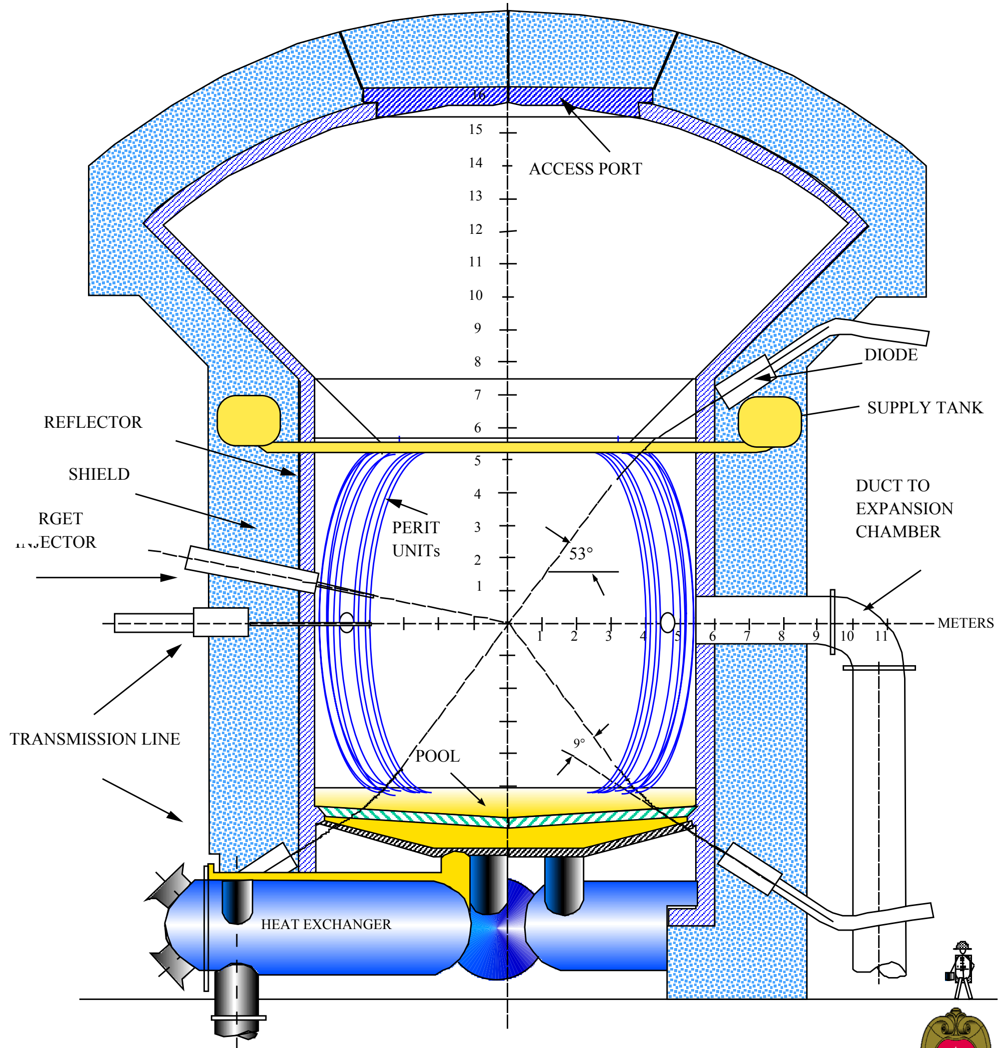
UW IFE Design - LIBRA-SP (1995)



PERIT Unit

- Two rows of **PERIT*** unit:
  - Perforated to maintain wetted surface through jet fan spray
  - Rigid to withstand shock waves.
- LiPb coolant/breeder and FS tubes.

* **Pe**rforated **Ri**gid **T**ube



Cross-Section of the LIBRA-SP Target Chamber

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