Views on Neutronics and Activation Issues Facing Liquid-Protected IFE Chambers

L. El-Guebaly and the ARIES Team

Fusion Technology Institute
University of Wisconsin - Madison

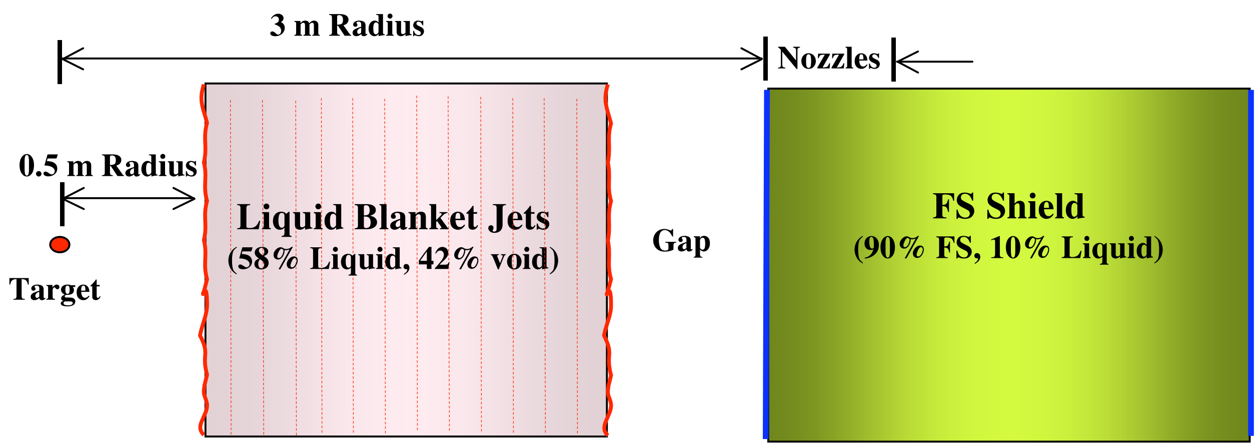
16th TOFE Meeting
September 14-16, 2004
Madison, WI

Objectives

- **Develop design space and operational windows for ARIES-IFE-HIB (no point design).**

- **Concerns:**
  - **Breeding potential of candidate breeders: Flibe & Flinabe**
  - **Ability of liquid wall to protect structure for 40 FPY**
  - **Activation level of structural components: shield & nozzles**
  - **Isochoric heating problems**
  - **Effect of radiation damage and cyclic fatigue on structure lifetime.**

Schematic of Radial Build



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

Key ARIES-IFE-HIB Parameters

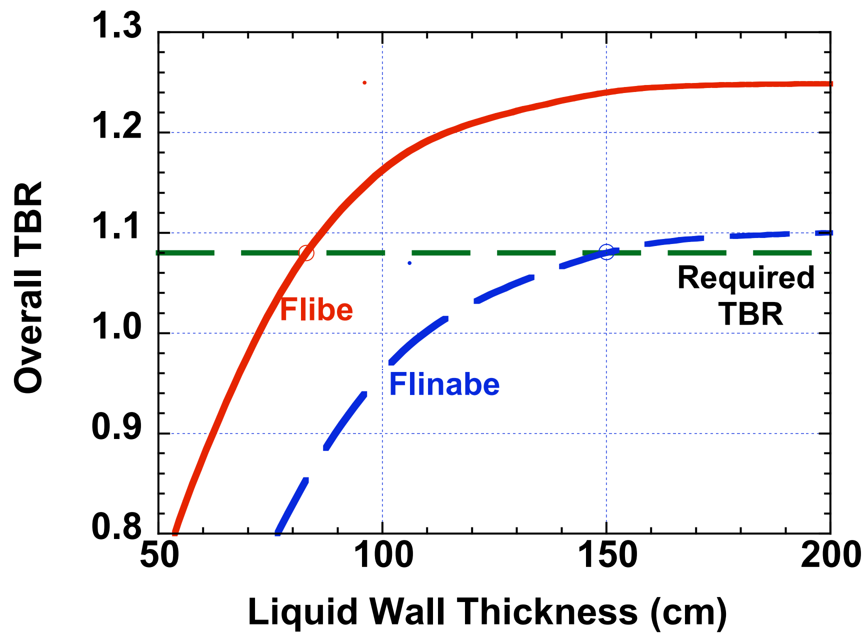
Target yield	**460 MJ**
Rep rate	**4 Hz**
# of pulses	**126 million/FPY**
Average source neutron energy	**11.8 MeV**
Penetrations coverage	**3%**
Plant lifetime	**40 FPY**
Availability	**85%**

ARIES-IFE Requirements and Design Limits

Overall TBR	**≥ 1.08**
dpa* to structure	**≤ 200 dpa for FS** **≤ 25 dpa for 304-SS**
He production for reweldability of FS	**≤ 1 He appm**
WDR for Class C low level waste	**≤ 1**

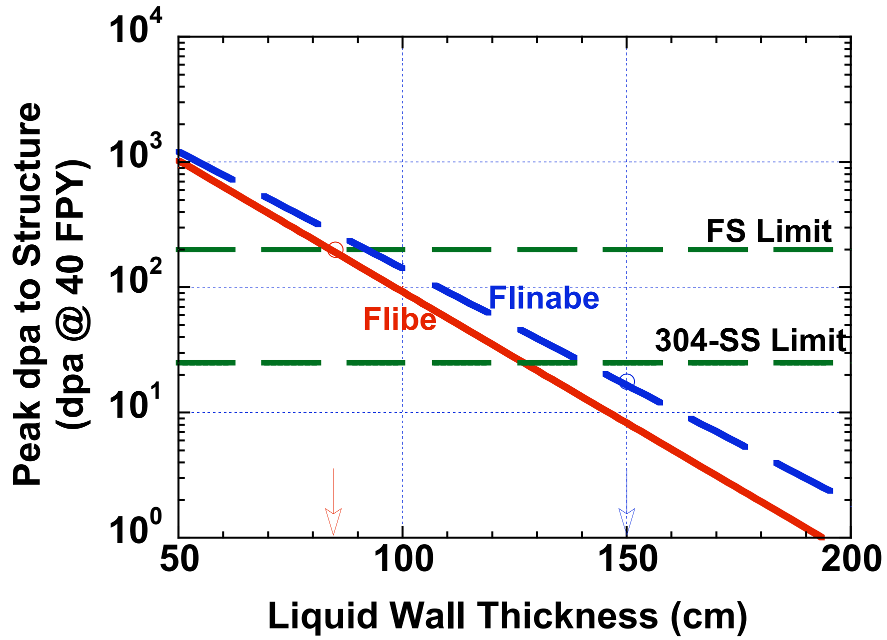
* Cyclic fatigue could be more restrictive life-limiting factor than radiation damage.

Flibe Breeds more Tritium than Flinabe



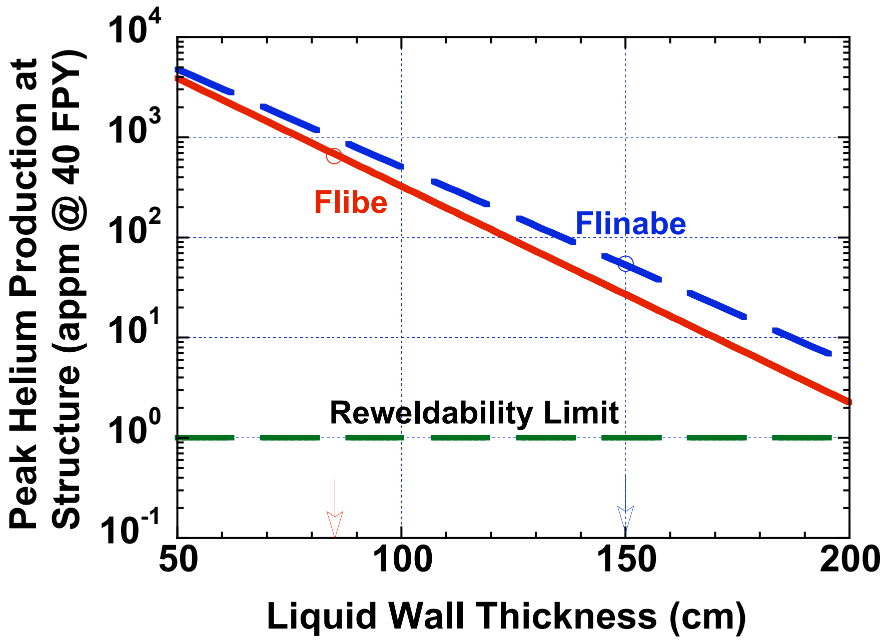
- 85 cm thick Flibe and 150 cm thick Flinabe meet breeding requirement.
- Enrichment does not enhance breeding of thick Flinabe.
- Nuclear energy multiplication amounts to ~1.25.

Flibe has Slightly Better Shielding Performance than Flinabe



- 85 cm Flibe blanket meets 200 dpa limit for advanced FS only.
- 1.5 m Flinabe meets dpa limits for both structures.

Excessive Helium Production at Chamber Structure



Problem: Innermost layer of shield and nozzles cannot be rewelded at any time during operation.

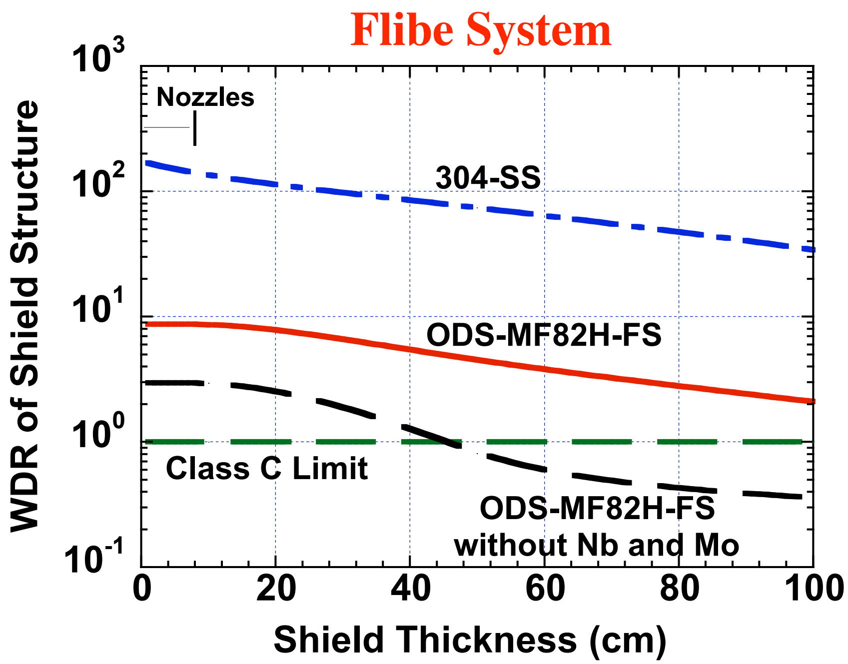
Steel Composition (in wt%)

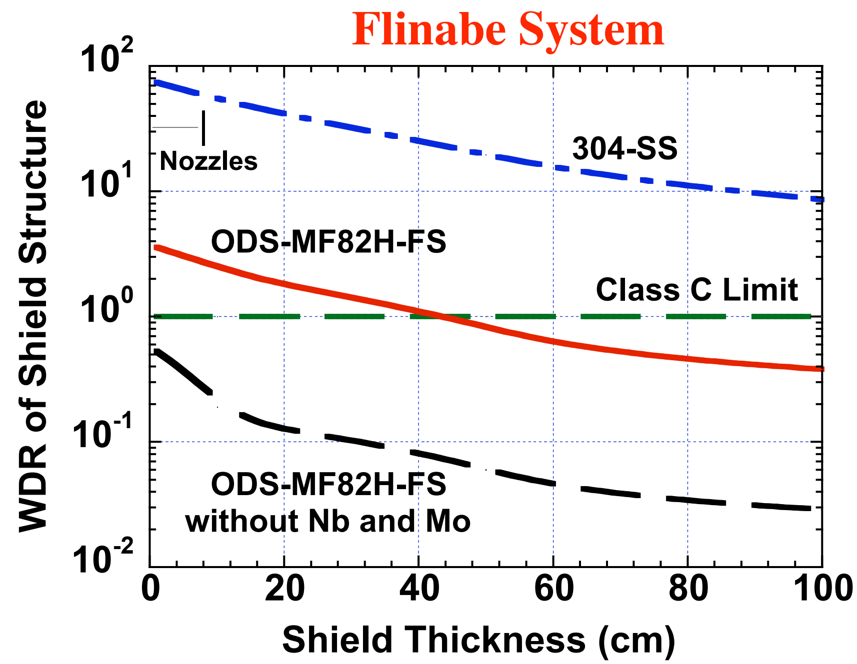
	ODS M-F82H-FS*	304-SS#
Fe	87.891	70.578
C	0.04	0.046
N	0.005	0.038
O	0.13	–
Si	0.24	0.47
P	0.005	0.026
S	0.002	0.012
Ti	0.09	0.03
V	0.29	–
Cr	8.7	17.7
Mn	0.45	1.17
Co	0.0028	0.1
Ni	0.0474	9.3
Cu	0.01	0.2
Nb	0.00033	–
Mo	0.0021	0.33
Ta	0.08	–
W	2	–
Y	0.7	–

* 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.

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

All Steel Alloys Generate High Level Waste





- 304-SS generates very high level waste.
- Main contributors to WDR: ^{94}Nb (from Nb), ^{99}Tc (from Mo), and ^{192n}Ir (from W).

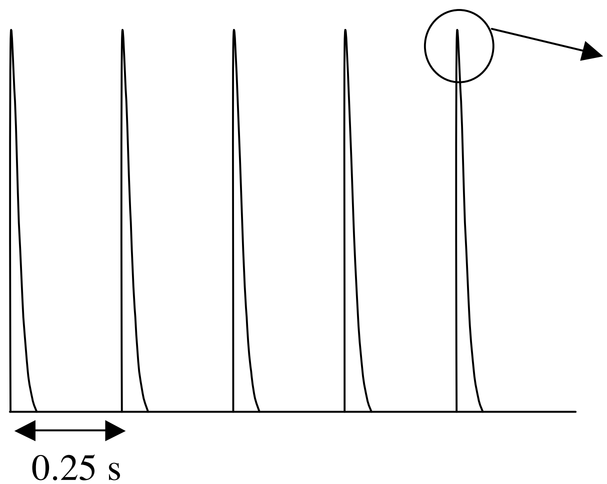
Potential Solutions for Waste Problem

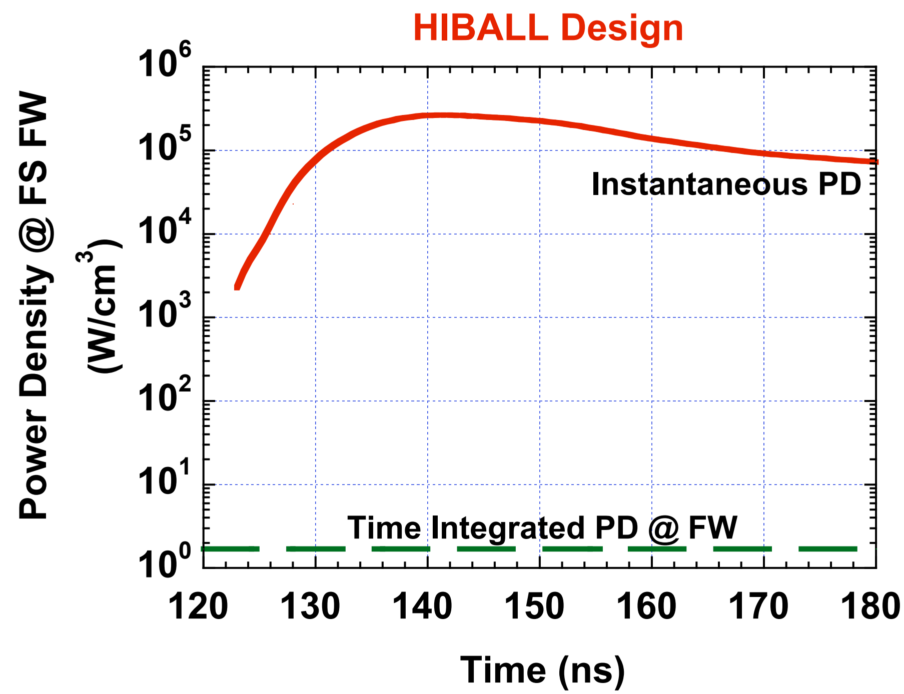
- **Thicken blanket and deplete Flibe/Flinabe (cost?),**
- **Average WDR over thicker shield (> 50 cm),**
- **Control Mo and Nb for Flibe system in particular (cost?).**

- In practice, Mo and Nb impurities cannot be zeroed out. Actual level depends on $/kg to keep Mo and Nb << 1 wppm.

- Nozzles generate high level waste unless mixed with shield and disposed as single unit at end of life.

Isochoric Heating





- FS temperature fluctuates 4 times per second.
- Nuclear heating will induce stresses on the order of 10 MPa in FS
- Fatigue from cycling and repetitive shock wave could:
  - Cause internal cracks
  - Shorten structure life
- When combined with radiation damage, fatigue life could be more restrictive than 200 dpa limit.

Concluding Remarks

- No breeding problem identified for Flibe and Flinabe.
- Excessive helium production at structure precluding FS reweldability during operation.
- Steel-based structure produces high level waste (WDR >> 1), mandating:
  - Thicker blanket with depleted lithium (cost ?)
  - Shield > 50 cm thick, and/or
  - Nb and Mo impurity control (cost?).
- Nozzles need additional protection to qualify as low level waste unless mixed and disposed with shield.
- Combined effect of radiation damage and fatigue on structure lifetime should be addressed in future studies.