Isochoric Nuclear Heating and Design Implications

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http://fti.neep.wisc.edu/FTI/ARIES/MAY2003/lae_isochoric.pdf

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Contents

- Examples of time-dependent variation of nuclear heating in thick liquid wall and solid structure.

- Impact of instantaneous deposition of nuclear heating.

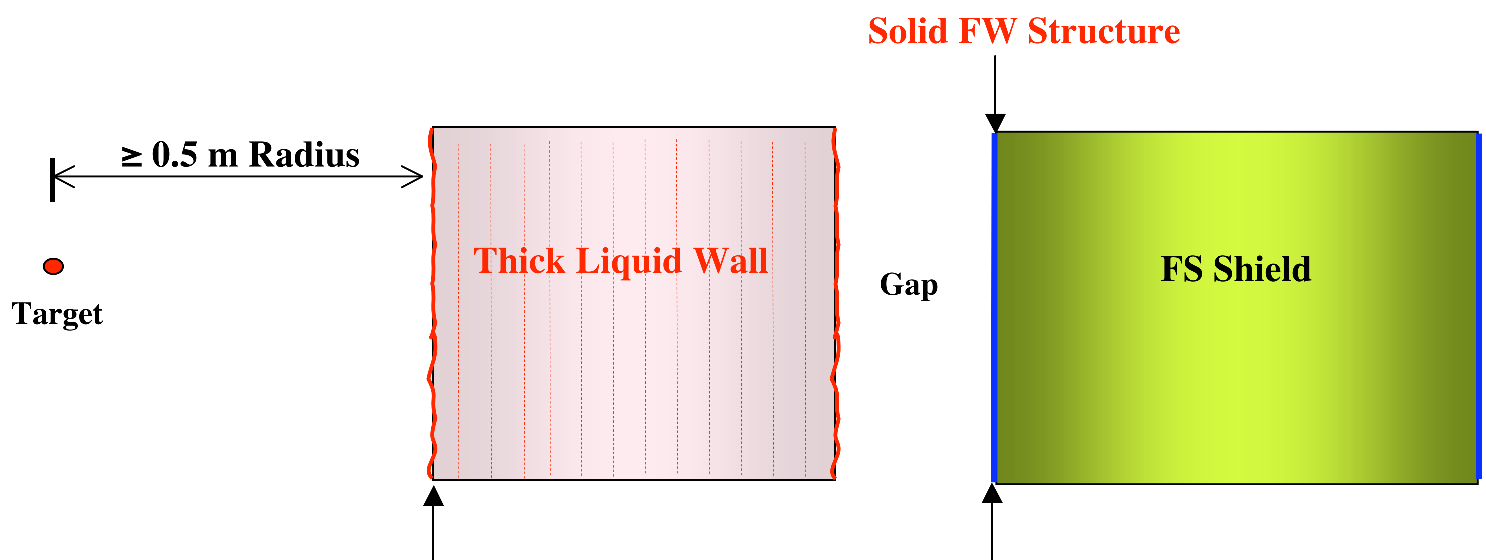
Is Time-Dependent Nuclear Analysis Essential for IFE?

- **In MFE**, fusion reactions are sustained for time much longer than neutrons time-of-flight (TOF) to FW and slowing down time in blanket
  - Steady-state calculation is sufficient for MFE.

- **In IFE**, fusion reactions occur during very short burn time (10-100 ps). Neutrons TOF and slowing down time are much greater than burn time (n's reach blanket surface in 10-150 ns and slow down in blanket in 10's of ns)
  - Time-dependent analysis is essential for IFE to evaluate instantaneous peaking of radiation effects.

- Over past 25 y, only HIBALL study (UW-1981) performed rigorous time-dependent heating and radiation damage analyses for IFE power plants.

Thick Liquid Walls Could Protect FS Structure for Plant Life



<u>Arrival Time @ Liquid Surface</u>

	0.5 m Radius	5 m Radius
X rays	~0.1- 2 ns	~1 - 20 ns
n’s	~10- 20 ns	~100-150 ns
Ions	~20-200 ns	~0.2 - 2 μs

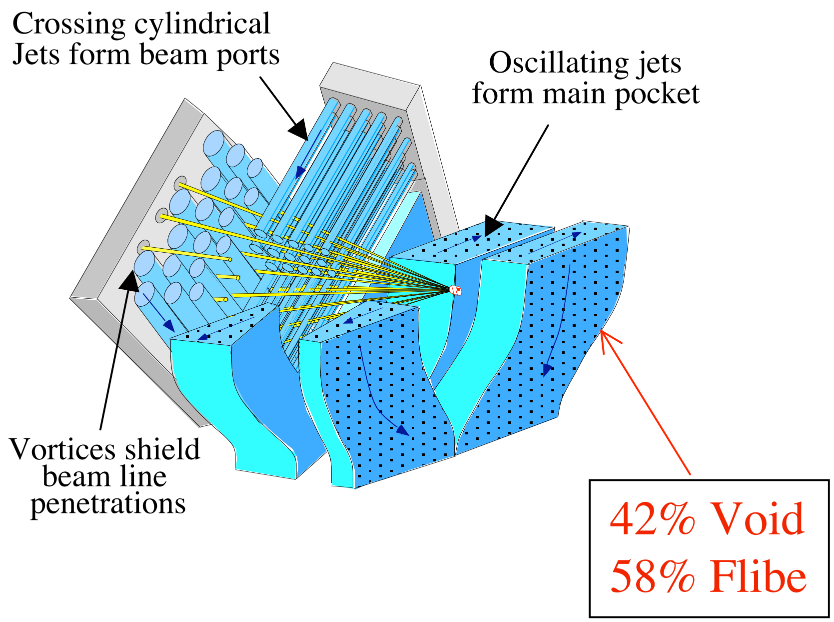
n’s spend tens of ns traveling through liquid before reaching FS wall

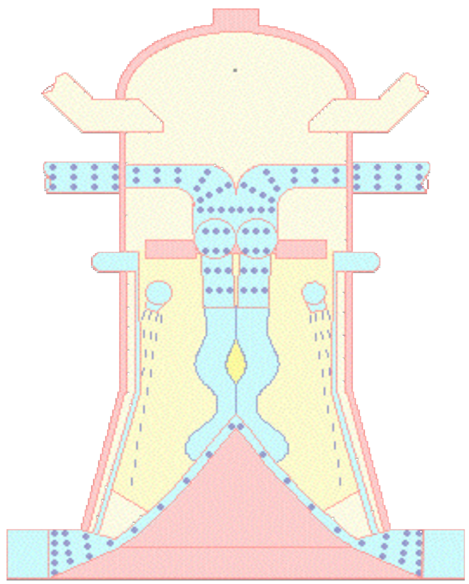
Evolution of Liquid Wall

- **X rays** rapidly deposit their energy at liquid surface (in μm's):
  - Vaporizing few microns
  - Producing vapor that rapidly blows off of liquid surface
  - Driving strong shock waves into liquid.
- Geometry of liquid hardly changes before neutron arrival.
- **Neutrons** deposit their energy volumetrically, causing rapid expansion of liquid.
- Vapor:
  - Cools down during expansion
  - Stops **ions**
  - Gets reheated by **ions**
  - Radiates heat, vaporizing more liquid

    ⇒ **ions** heat liquid indirectly.
- Hydro-motion leads to splash and break-up of liquid.

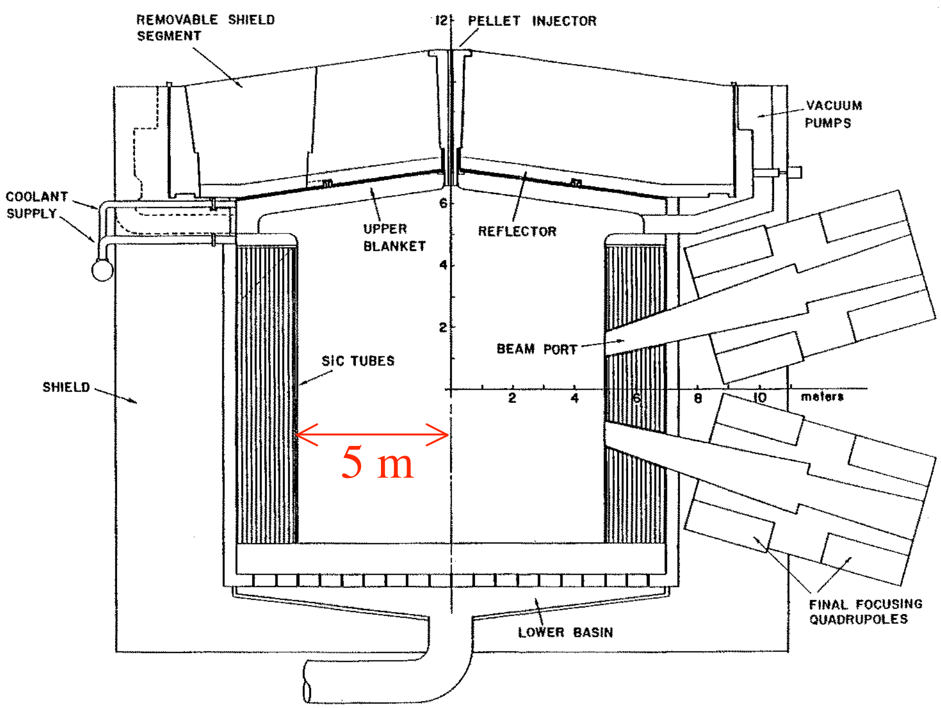
HYLIFE Design Allows Flibe Jets Disintegration Between Shots

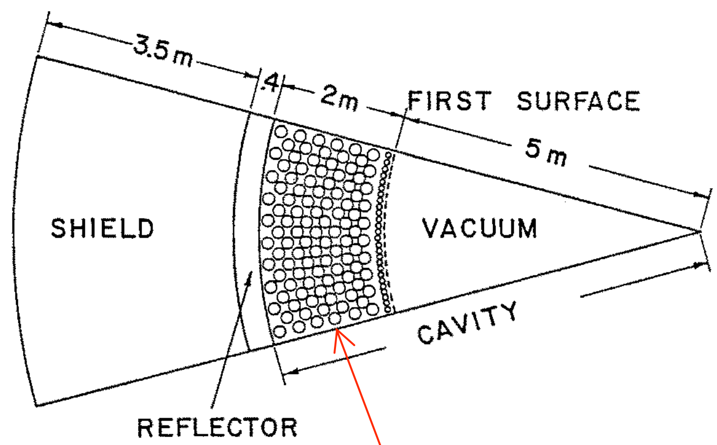




HYLIFE-II

HIBALL's Porous SiC Tubes Prevent LiPb Columns from Disassembly Between Shots

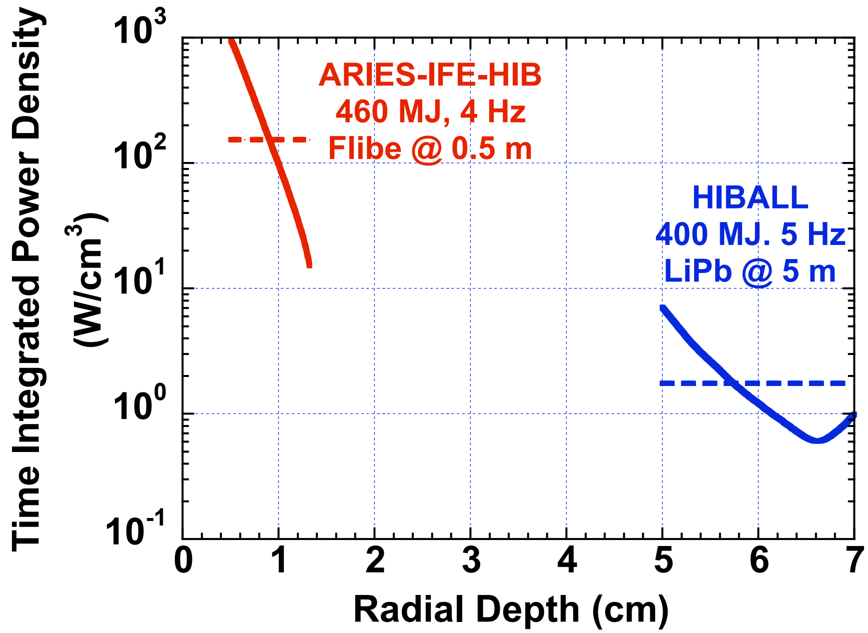




400 MJ Target
10 GeV Bi^{++} ions
5 Hz

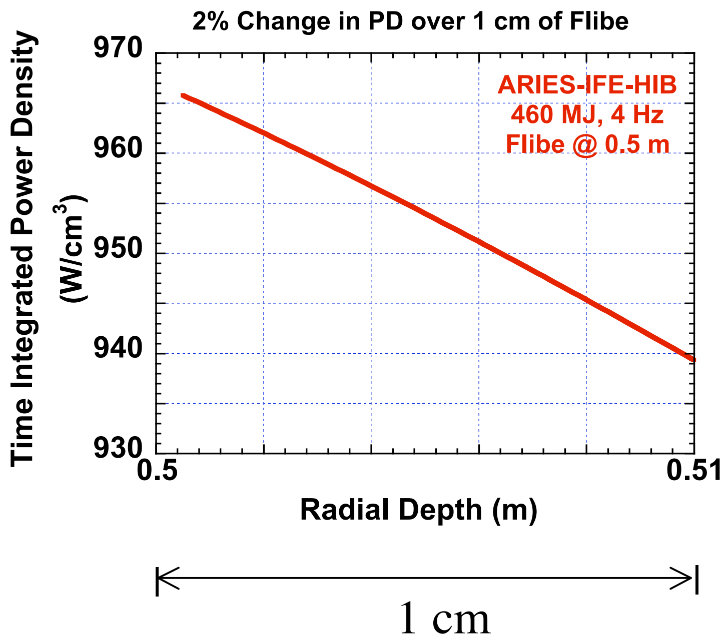
66% Void
33% LiPb
1% SiC

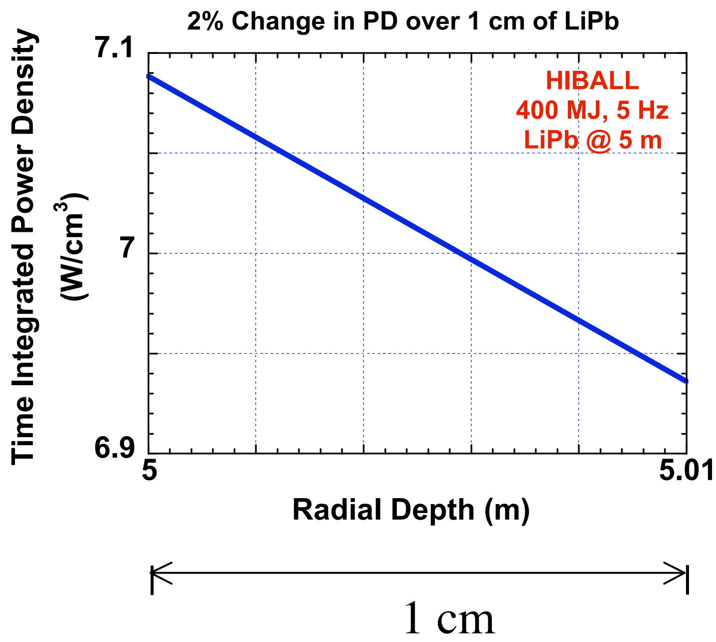
Time Integrated Energy Deposition in Thick Liquid Walls



Time integrated, space average power density (PD) is ~150 W/cm^3 for ARIES-IFE-HIB and ~2 W/cm^3 for HIBALL

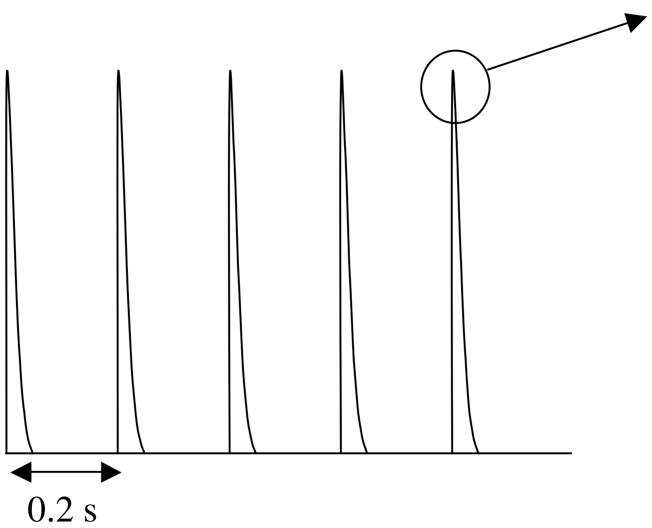
Neutrons Deposit Their Energy Volumetrically, Unlike X-rays and Ions

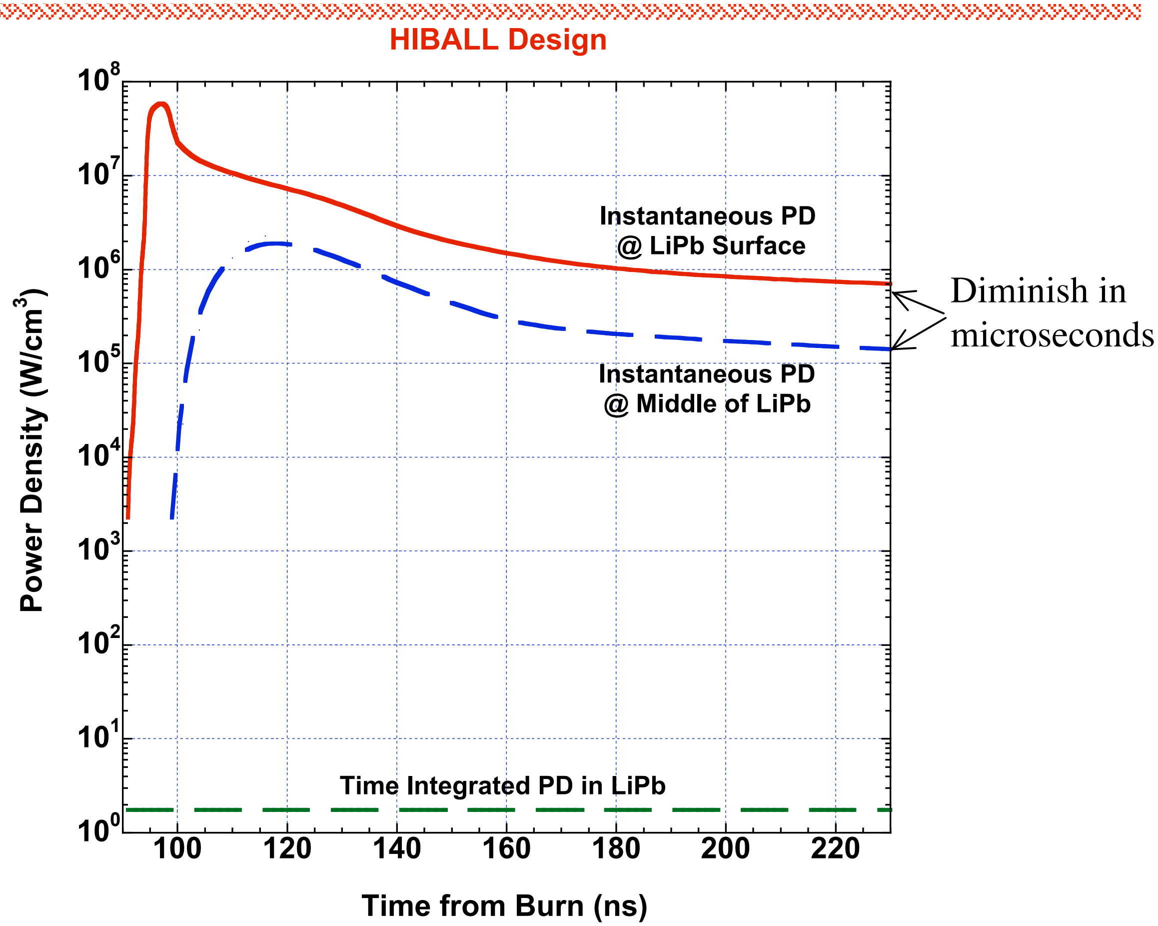




First cm of liquid exhibits slight change (~2%) in nuclear heating distribution, unlike x-ray and ion energy deposition that diminishes after few microns

Instantaneous Nuclear Energy Deposition Exceeds Time Average PD @ Liquid Surface by ~7 Orders of Magnitude

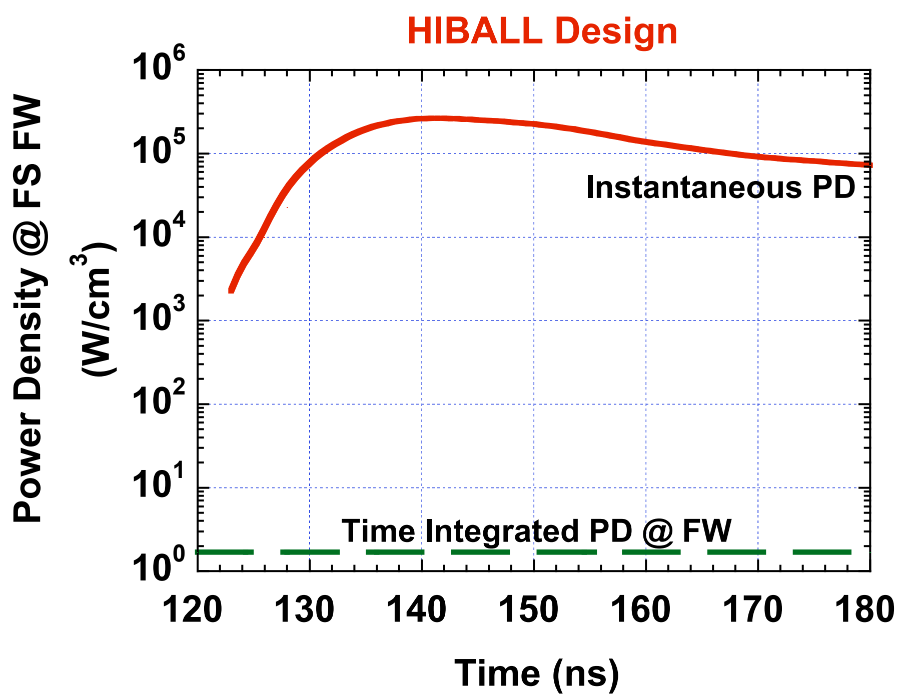




Large instantaneous energy deposition heats up liquid volumetrically and results in strong pressure wave that breaks-up liquid wall

At FW FS Structure, Instantaneous Nuclear Energy Deposition Exceeds Time Average PD by ~5 Orders of Magnitude

- FS temperature fluctuates 5 times per second.
- Nuclear heating will induce stresses on the order of 10 MPa in FS, per Hassanein (ANL).
- Inertial effects are not likely to be an issue.
- For these low stresses, fatigue in unirradiated FS should not be an issue, per Blanchard (UW).
- Fatigue in irradiated material is expected to be OK as well, but needs to be quantified.
- **Assessing FS lifetime**:
    1. Quantify fatigue effects in unirradiated material
    2. Assess radiation damage effects (e.g., 200 dpa @ EOL)
    3. Quantify fatigue effects in irradiated material.



Instantaneous nuclear energy deposition combined with 200 dpa may shorten FW service life

Conclusions

- Instantaneous nuclear heating:
  - Peak spreads out almost uniformly over few cm
  - ~20 ns duration of peak in liquid
  - 10^7 peak to average ratio
  - ~10^5 lower peak heating compared to x-rays and ions
     surface effect of nuclear heating can be neglected.
- Nuclear energy deposition heats-up thick liquid volumetrically and breaks-up liquid geometry.
- Instantaneous deposition of nuclear heating in FW structure 5 times per second produces relatively low stresses in FS.
- Impact of radiation damage on fatigue life needs to be quantified.