Shielding Considerations for HIB With Pre-formed Channels

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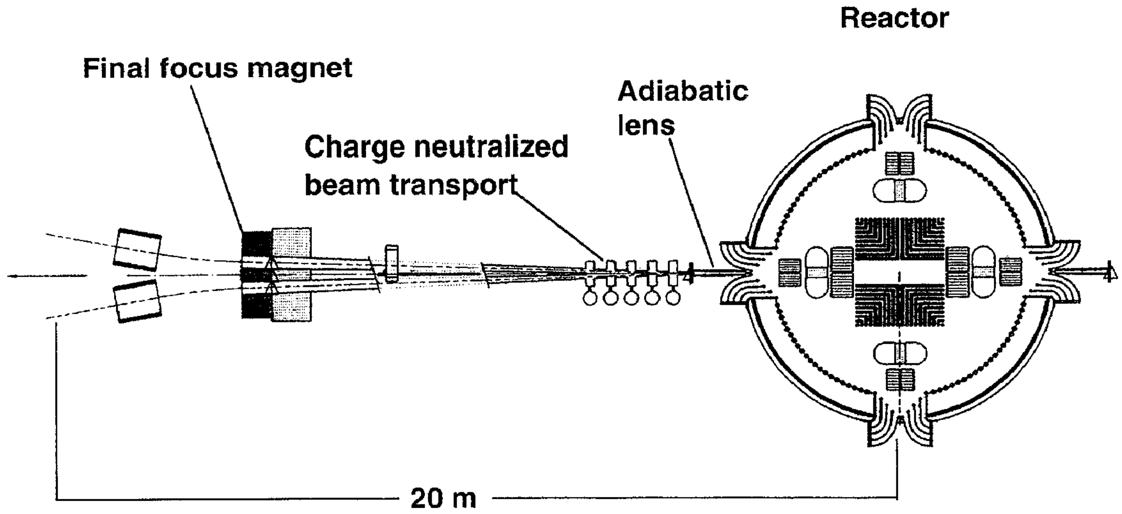
http://fti.neep.wisc.edu/FTI/ARIES/SEP2000/shield_mes.pdf

ARIES Project Meeting
18-20 September 2000
PPPL

Background

- Ion transport in pre-formed plasma channels has been considered as attractive option for HIB fusion power plants
- Point design of power plant developed in 1998-1999 based on modified HYLIFE-II liquid wall chamber
- At Yu's request, we have assessed recently impact on FF magnets and electrical insulators of using SOMBRERO-type blanket in place of Flibe jets

Liquid Wall Chamber with Flibe Jets



- Three Flibe jet assemblies (50 cm thick each) injected into chamber. Jets arranged alternately in horizontal and vertical directions
- Most of magnets and insulators will be in shadow of full 150 cm thick Flibe jets
- Parts of those components will be shielded by only 50 cm or 100 cm of Flibe (due to arrangement of slots in Flibe jets) resulting in hot spots
- Each jet assembly has 6 cm x 6 cm penetration for pre-formed plasma channels

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Shielding Concerns

- Neutron radiation affects sensitive components of beam transport system that include:
  - Insulators to prevent electrical breakdown between channels and target chamber wall
  - Adiabatic lens to focus ion beams into channels
  - Set of superconducting focusing magnets
  - Optics system for lasers that guides paths of channels

- Modest level of neutronics analysis performed to assess shielding requirements and damage level to those components (Results for liquid wall option published in 1999 ISFNT-5 paper)

Neutronics Assessment for SOMBRERO-type Chamber

- 1 m thick SOMBRERO blanket used with 3 m FW radius
- Damage to final laser optics exposed to direct streaming source neutrons can be reduced by placing them farther away from target @ 25 m or more
- Results normalized to a fusion power of 2580 MW and 40 FPY of operation

Electrical Insulator Design Limits

- Ceramic insulators used to provide electrical insulation in adiabatic lens and between channel and chamber wall
- Candidate materials include Al_2O_3, MgO, and spinel ($MgAl_2O_4$)
- Spinel is chosen as it offers lowest mechanical and structural degradation in nuclear environment among its class of solid ceramic insulators
- Radiation limit depends on amount of swelling that design can tolerate
- Fast neutron fluence is limited to 4×10^{22} n/cm^2 for 3% allowable swelling

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Direct Streaming Source Neutrons

- For 6 cm x 6 cm channels, direct source neutrons will stream through beam penetrations without affecting wall insulator if central opening is at least 10 cm wide at center of insulator

- Since conical insulator of adiabatic lens has 5-10 cm inner radius, source neutrons streaming through penetrations will not affect conical insulator

- Both insulators are in shadow of blanket relative to direct source neutrons emitted from target

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Impact of SOMBRERO Blanket on Insulator Shielding

- Wall insulator has peak end-of-life fast neutron fluence of $2x10^{22}$ n/cm^2 (< 4 x 10^{22} n/cm^2 limit for 3% swelling)

  ⇒ > 40 FPY lifetime

- Hot spots at insulator resulting from Flibe jets arrangement are eliminated for SOMBRERO blanket

- Flibe jets result in factor of ~10 higher damage at hot spots

Shielding Requirement for Insulator of Adiabatic Lens

- Insulator of adiabatic lens is shielded from source neutrons by:
  - 1 m thick blanket
  - 35 cm thick wall insulator
  - 10 cm steel electrode at chamber side of adiabatic lens

- Peak fast neutron fluence to adiabatic lens insulator @ EOL is factor of 100 below limit

Final Focusing Magnets

- Quadrupole magnets located at 10 m from adiabatic lens
- 4 superconducting coils surround 4 ion beam tubes
- Center of beam tube (with inner radius of 15 cm) is at 30 cm from channel axis
- Magnets are not in direct line-of-sight with source neutrons
- Adequate shielding should be provided to protect magnets against radiation
- ITER magnet composition used in analysis (316 SS, Nb_3Sn, GFF epoxy, LHe)
- Epoxy insulator dose limit (10^9 rad) is the most limiting factor that determines shielding requirements

Shielding Requirements for Magnets

- Magnet shielding is provided by SOMBRERO blanket and 35 cm thick wall insulator
- Radiation effects at magnet are one order of magnitude lower for SOMBRERO blanket compared to Flibe jets
- Additional shielding needed in front of quadrupole assembly is ~15 cm thinner for SOMBRERO blanket

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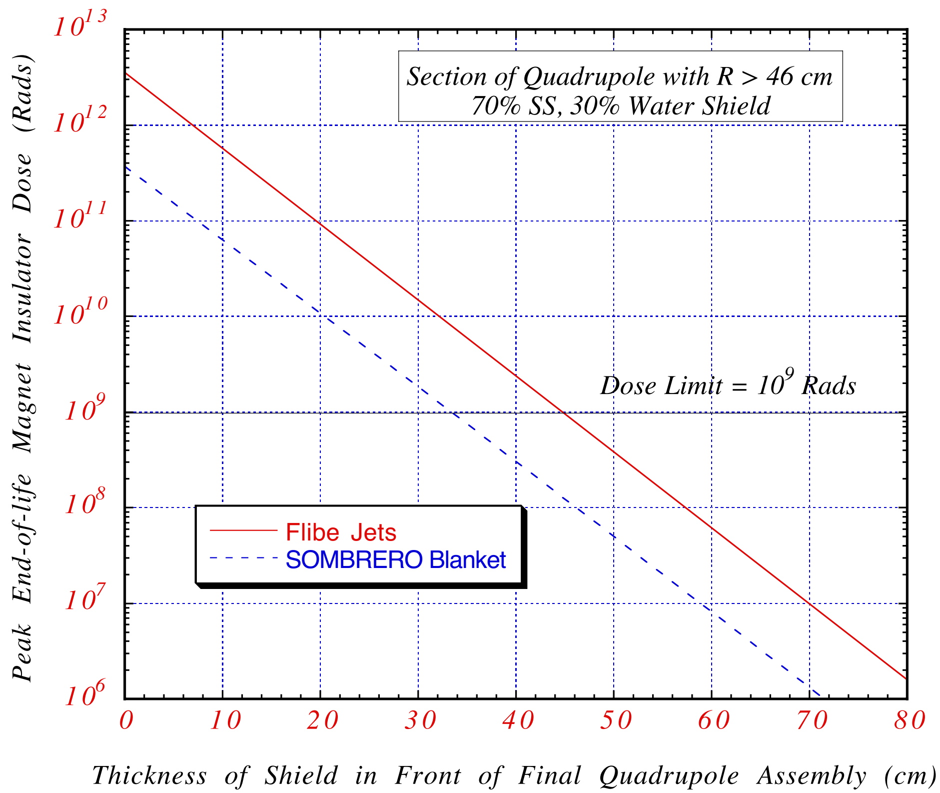
Additional Magnet Shielding Requirement



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Summary and Conclusions

- Neutronics analysis performed to assess shielding requirements for insulators and final focusing magnets for two blanket options: liquid and solid walls

- Source neutrons stream through channels without impinging on insulators and magnets as long as width of central channel opening is ≥ 10 cm

- SOMBRERO blanket provide better protection compared to Flibe jets:

  - Radiation effects at magnets and insulators are one order of magnitude lower, resulting in thinner magnet shield

  - Insulator lifetime is 40 FPY or more

  - Hot spots resulting from Flibe jet arrangement are eliminated

- More radiation resistant magnet insulator (e.g., GFF polyimide) will require thinner magnet shield

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