

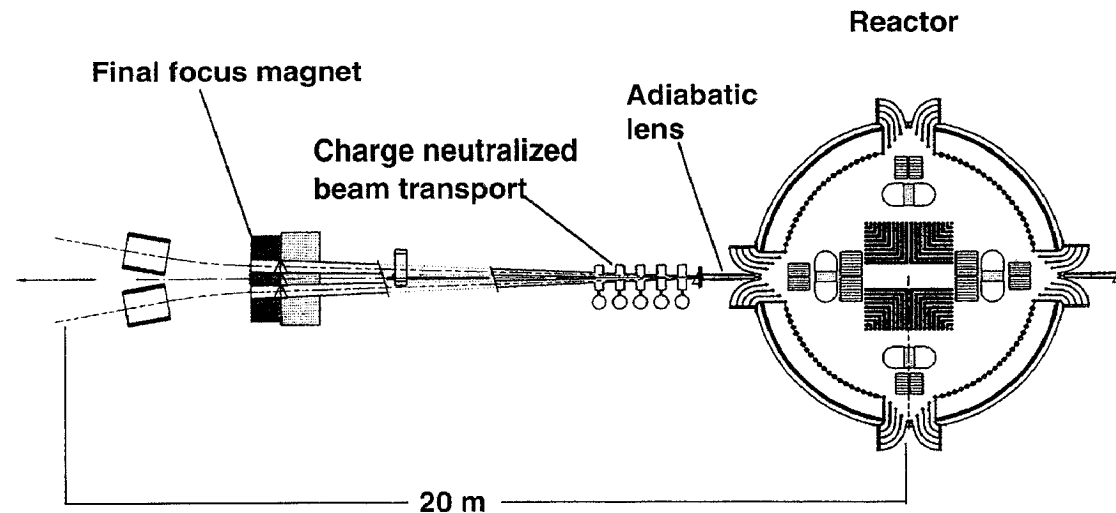
Shielding Analysis for a Heavy Ion Beam Chamber with Plasma Channels for Ion Transport

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Background

- Ion transport in pre-formed plasma channels considered as possible attractive option for ion beam fusion power plants
- A point design of a final focus and reactor system has been developed
- The target chamber considered is based on a modified HYLIFE-II reactor



Chamber description

- Thick curtains of Flibe employed to protect chamber wall
- Three Flibe jet assemblies injected into chamber forming a neutronically thick layer between target and FW
- Each assembly has a thickness of 50 cm
- These jets are arranged alternately in horizontal and vertical directions
- Each jet assembly has a 6 cm wide slot
- Slots in jet assemblies serve to define the 6 cm x 6 cm penetration for the pre-formed plasma channels used for ion beam transport to the target

Shielding Concerns

- Neutron radiation affects the sensitive components of the beam transport system
- Beam transport system includes
 - Insulators to prevent electrical breakdown between the channels and the target chamber wall
 - Adiabatic lens to focus the ion beams into the channels
 - Set of superconducting focusing magnets
 - An optics system for lasers that guides the paths of the channels
- Neutronics analysis performed to assess the shielding requirements and determine damage level in these components

Neutronics Assessment

- Most of magnets and electrical insulators will be in shadow of full 150 cm thick Flibe jets
- Parts of these components will be shielded by only 100 cm or 50 cm of Flibe due to arrangement of slots in Flibe jets
- Several conservative 1-D calculations performed to determine shielding requirements at hot spots
- Final laser optics exposed to direct streaming source neutrons
- Placement of laser metallic mirrors relative to target was determined
- Results normalized to a fusion power of 2580 MW (430 MJ target yield @ 6 Hz) and 30 FPYs of operation

Electrical Insulator Design Limits

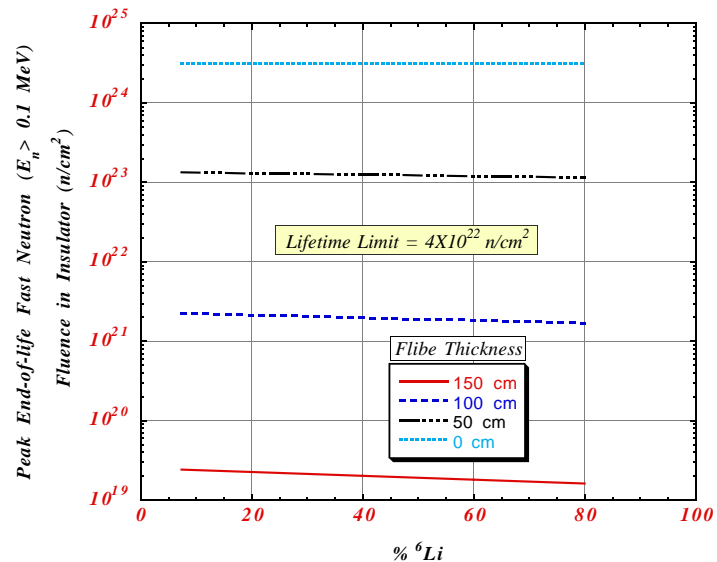
- Ceramic insulators used to provide electrical insulation in the adiabatic lens and between the channel and the chamber
- Candidate materials include Al_2O_3 , MgO , and spinel (MgAl_2O_4)
- Spinel is chosen since it offers lowest mechanical and structural degradation in a nuclear environment among its class of solid ceramic insulators
- The fast neutron fluence is limited to 4×10^{22} n/cm² for a 3% allowable swelling

Direct Streaming Source Neutrons

- Direct source neutrons streaming through the beam penetrations in the Flibe curtains will not affect the lifetime of the insulator at chamber wall as long as a central opening of at least 10 cm wide is used at the center of the insulator
- Direct streaming neutrons will pass through without impinging on the insulator
- Since the conical insulator in the adiabatic lens has an inner radius ranging from 5 to 10 cm the direct streaming neutrons do not affect it
- Both electrical insulators are in the shadow of the Flibe jets relative to the direct source neutrons emitted from the target

Shielding Requirement for Insulator at Chamber Wall

- The insulator at the chamber wall is protected from the neutrons emitted from the target by the Flibe jets



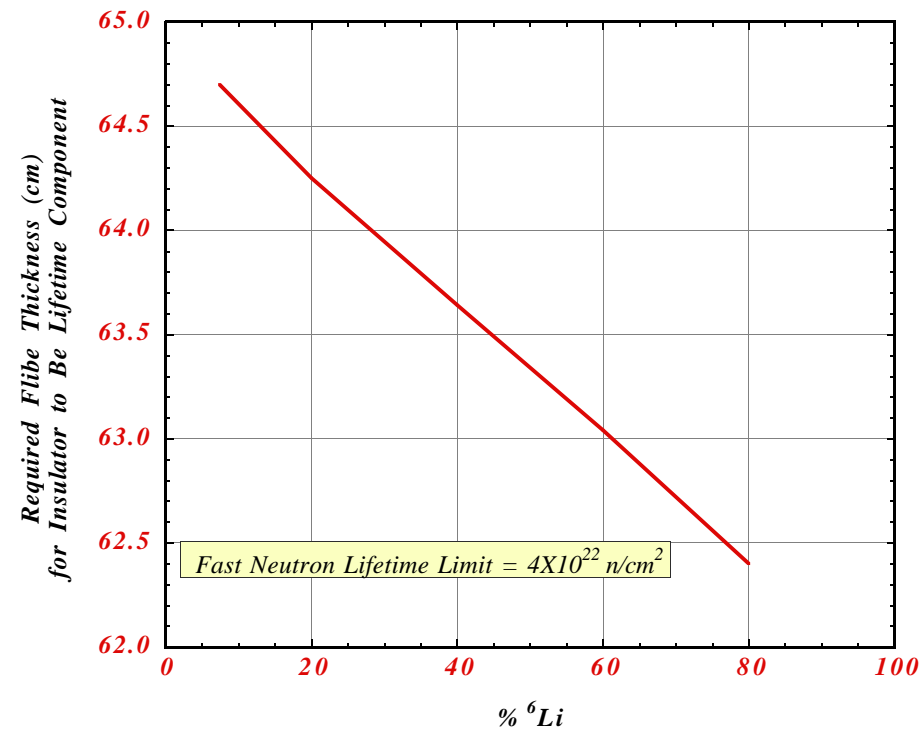
- Impact of enrichment on improving shielding performance is minimal

Shielding Requirement for Insulator at Chamber Wall

(continued)

- The peak end-of-life fast neutron fluence is lower than the 4×10^{22} n/cm² design limit for Flibe thicknesses of 100 and 150 cm
- Parts of the insulator protected by only 50 cm of Flibe will experience a peak end-of-life fast neutron fluence of 1.3×10^{23} n/cm²
- The fluence drops by an order of magnitude in 25 cm of the insulator
- If the design can accommodate swelling of ~10% at limited hot spots, the thickness of each Flibe jet assembly can be kept at 50 cm
- Alternatively, the jet assembly thickness should be increased

Required Flibe Jet Thickness



Required Flibe Jet Thickness

(continued)

- A reduction of only 2.5 cm in required thickness achieved by enrichment but TBR is reduced by 8%. Enriching the Li is not a viable solution
- Using 65 cm thick jet assemblies will be adequate for protecting the insulator
- Results are conservative since they are based on 1-D calculations with the target surrounded by the thin Flibe layer everywhere while in reality the thicker layers of Flibe elsewhere will reduce the contribution of secondary neutrons at the hot spots

Shielding Requirement for Insulator in Adiabatic Lens

- The insulator in the adiabatic lens is shielded from the source neutrons by
 - 35 cm insulator at the chamber wall
 - The 10 cm steel electrode at the chamber side of the adiabatic lens
 - The Flibe jet assemblies
- The peak neutron fluence in the adiabatic lens insulator is a factor of 70 lower than that in the insulator region at the chamber wall
- Even for the limited areas protected by only 50 cm of Flibe, the peak end-of-life fluence in the insulator of the adiabatic lens is only 1.9×10^{21} n/cm² implying that it is a lifetime component

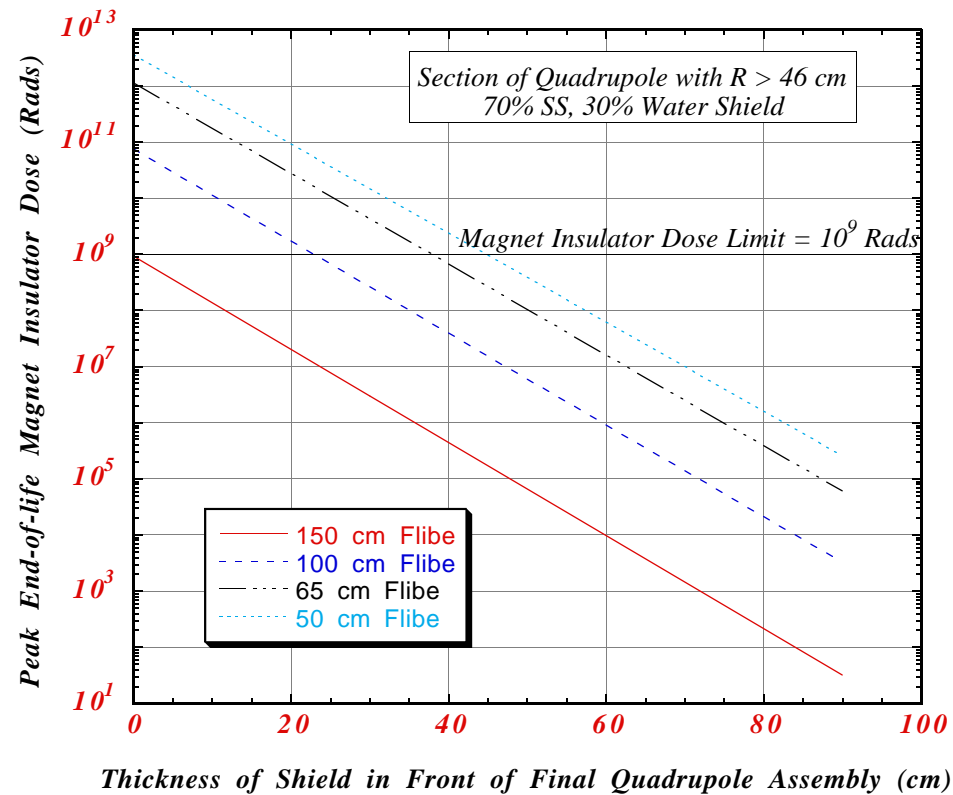
Final Focusing Magnets

- Final superconducting quadrupole magnets located at 10 m from the plasma adiabatic lens
- Four superconducting coils surround the four ion beam tubes
- The center of each of the four beam tubes with an inner radius of 15 cm is at 30 cm from channel axis
- Adequate shielding should be provided to protect the superconducting magnets from neutrons emitted from target
- The insulator dose limit (10^9 rads) is the most limiting parameter that determines the shielding requirement

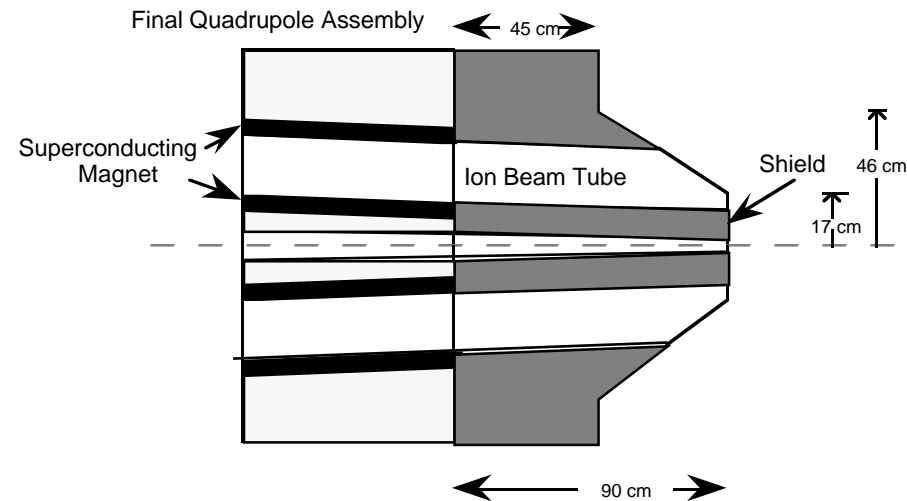
Shielding Requirements for Magnets

- Additional shielding needed in front of the quadrupole assembly
- A central conical penetration with a minimum radius of 5 cm should be employed to eliminate any of the direct source neutrons from impinging on the quadrupole assembly
- The shield provided in front of the quadrupole unit should have a thickness of 90 cm up to a radius of 17 cm with thickness decreasing to 45 cm at 46 cm radius. Penetrations should be provided in the shield to allow for passage of the ion beams

Additional magnet shielding requirement



Shield configuration for the final quadrupole assembly

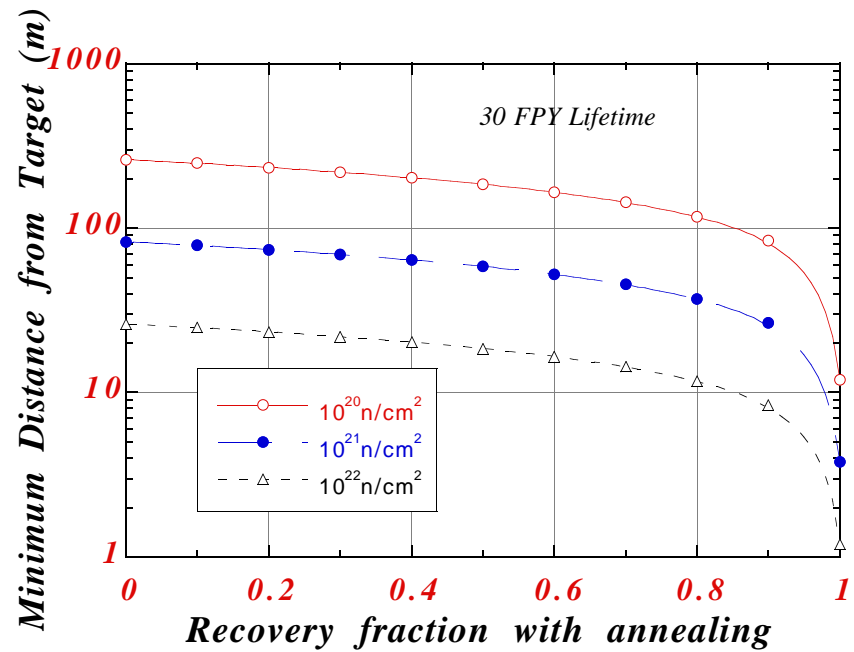


- This design is conservative
 - Magnet is more than 12 m away from Flibe jets and impact of the 6 cm wide gaps in jet assemblies on magnet damage peaking will be significantly diluted
 - No credit taken for additional shielding provided by the baffle chamber and pumping units located between adiabatic lens and final focusing magnets
- Multi-dimensional calculations needed to confirm these results

Placement of Final Laser Mirrors

- Dielectric coated mirrors are more sensitive to neutron radiation than metallic mirrors
- The sensitive dielectric mirrors are removed from the line-of-sight for target neutrons by using grazing incidence metallic mirrors
- The lifetime of the GIMM is limited by mirror deformation from swelling and creep that leads to defocusing of the laser beam
- The fast neutron flux at the GIMM is contributed mostly by direct source neutrons
- The minimum distance from the target for the metallic mirror to be a lifetime component was determined as a function of fluence limit and damage recovery fraction with annealing
- Experimental data on radiation damage to metallic mirrors are essential to allow for a more accurate prediction of the GIMM lifetime

Minimum distance of final metallic mirror from target



Summary and conclusions

- Neutronics analysis performed to assess shielding requirements for insulators and final focusing magnets in a modified HYLIFE-II target chamber that utilizes pre-formed plasma channels for heavy ion beam transport
- Spinel is chosen as insulator material since it offers the lowest property degradation in a nuclear environment
- Direct streaming neutrons pass through without impinging on the insulator
- Lithium enrichment in Flibe has minimal effect on improving shielding performance
- Using 65 cm thick jet assemblies provides adequate shielding for the insulator units
- Additional shield with a thickness ranging between 45 and 90 cm needs to be provided in front of the final focusing quadrupole unit
- Neutronics calculations were performed to determine the constraints on placement of final laser mirrors