Shielding and Breeding Considerations for ST-Based HTS-FNSF Design

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The shielding and tritium breeding assessments for the ST-based fusion Nuclear science facility (FNSF), being addressed at the University of Wisconsin-Madison through a national collaborative effort led by the Princeton Plasma Physics laboratory, represent key elements for achieving the design engineering objectives. These include adequate protection of the electrically efficient high-temperature superconducting (HTS) magnet against radiation and tritium self-sufficiency using outboard-only blanket as much as practically possible.

HTS magnets are potentially attractive for fusion applications due to the high operating temperature (20-40 k) (that reduces the cryogenic heat load), high current density, and high magnetic fields at coil (approaching 20 T). The most capable, radiation-resistant HTS option for ST applications is REBCO that could tolerate up to 3×10^{22} n/m^2 fast neutron fluence ($E_n > 0.1$ MeV) and allow 5 mW/cm^3 of peak nuclear heating without damaging the HTS magnet.

Numerous shielding and cooling materials have been examined to select the optimal shield that primarily protects the inboard magnet of the 3 m major radius device. The plasma generates 560 MW of fusion power and 1.1 MW/m^2 machine average neutron wall loading, producing significant neutron fluence (~6 MWy/m^2) at the outboard midplane for blanket and materials testing during the 10 year of operation. The potential impact of the candidate inboard materials (ferritic steel, tungsten carbide, hydrides, water, borated water, and heavy water) on shielding the magnet as well as reflecting neutrons to the outboard blanket to enhance the tritium breeding ratio (TBR) has also been assessed.

The blanket of choice is the dual-cooled lithium lead (DCLL) blanket – the preferred blanket concept in the US for future devices. High-pressure helium coolant and flowing LiPb remove the surface and nuclear heating and circulate to external heat exchanger and tritium extraction systems. Our 3-D neutronics model included the details of blanket internals, the long-leg divertor configuration, five outboard test modules, and several H/CD ports. An additional effort was made to examine the need for a thin inboard blanket to achieve an overall TBR in excess of unity with a wide margin.