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ITER-based NNBI system for the Eos neutron source stellarator

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Introduction

The Problem:

Identify a beam injection system suitable for a sub-breakeven beam-target ("wet-wood burner" [1]) deuterium-deuterium (DD) neutron source using a stellarator optimized for fast particle confinement [2] as a target

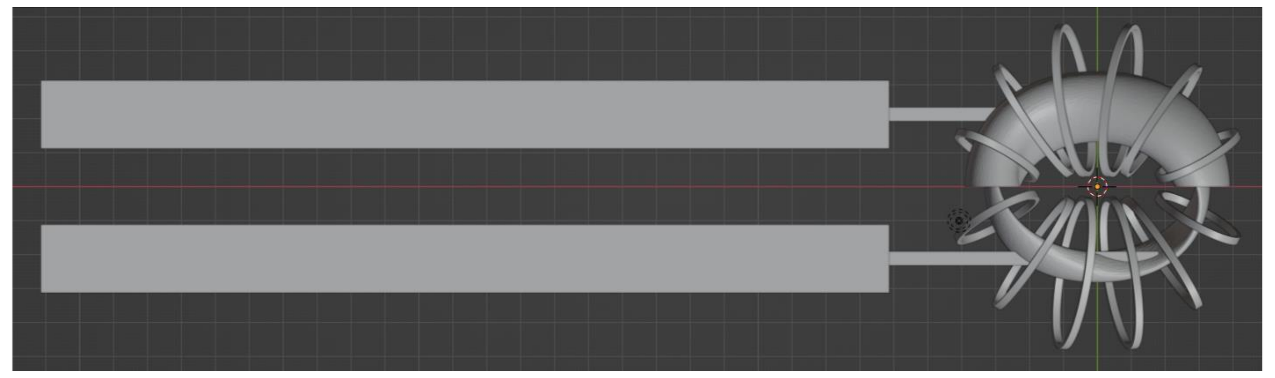
The Model:

Use a 1D slowing down model and energy-dependent fusion cross section to determine the beam parameters required for a useful neutron rate

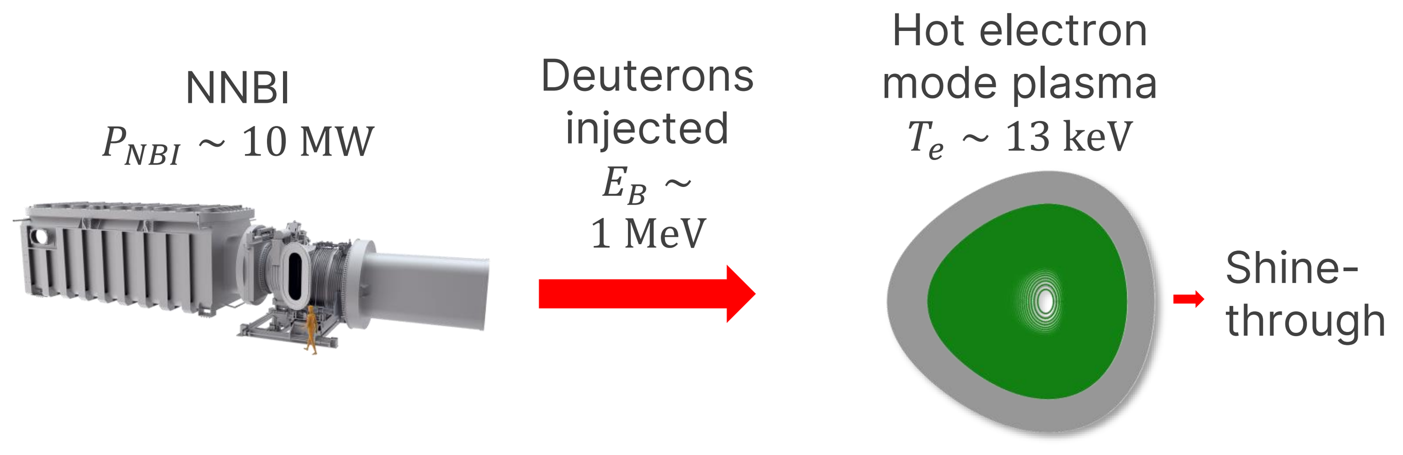
The System:

Negative-ion-based Neutral Beam Injection (NNBI) scaled from the ITER Heating Neutral Beams (HNBs) [3] are found to be appropriate

System Overview



25 m NNBI into 2.7 m radius stellarator



D-D → p-T:
2×10^{17} tritons/s:
Tritons are captured from exhaust; metal foil pump & cryo-distillation:
0.1 grams of tritium per day

D-D → n-^{3}He:
2×10^{17} neutrons/s:
Tritons are bred from neutrons and ^{6}Li in blanket:
0.1 grams of tritium per day

The Model

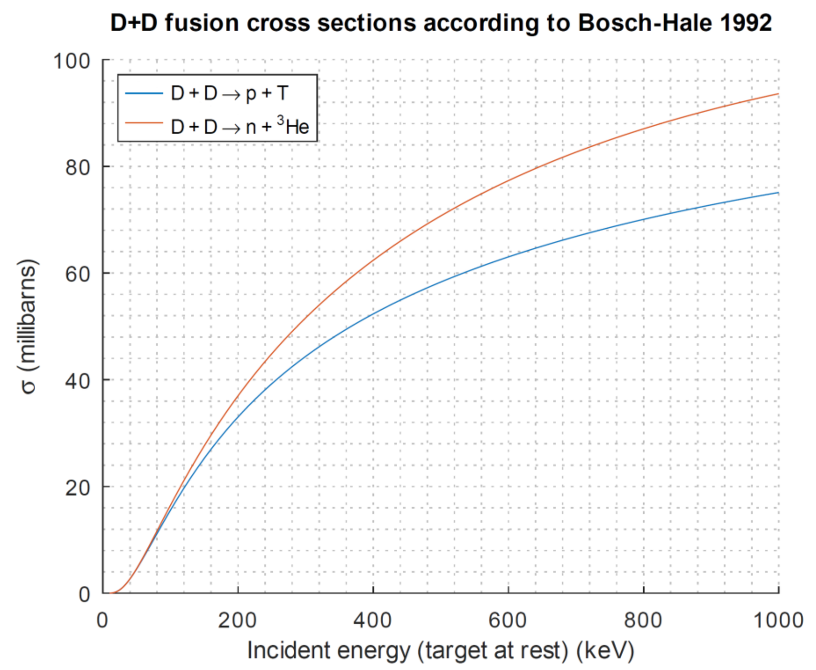
Assume injected particles are confined for many slowing-down times. Assume slowing down is collisional on electrons and ions. For a similar model, see [4]. Then fusion probability p_f is equal to:

$$p = \int_0^{E_0} dE \frac{n_\sigma \sigma(E) v_b(E)}{-((\partial_t E)_e + (\partial_t E)_i)}$$

where E is the energy of the beam particle starting at injection energy E_0, n_σ is the density of target (deuterium) plasma ions, $\sigma(E)$ is the fusion cross section, $v_b(E)$ is the beam velocity, $(\partial_t E)_e$ is the beam slowing rate on electrons, and $(\partial_t E)_i$ is the beam slowing rate on ions.

The fusion model

We used the model of Bosch and Hale [5,6].



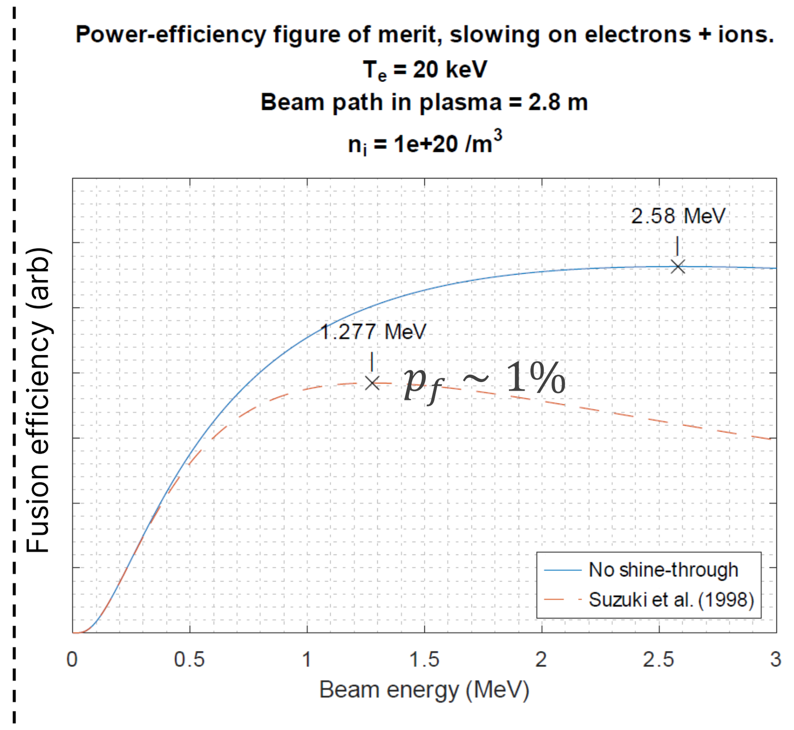
The slowing model

Slowing on electrons was taken in the appropriate limit [7,8]:

$$(\partial_t E)_e = -\frac{2}{\tau_{se}} E$$

Slowing on ions was taken in the appropriate limit [7,8]:

$$(\partial_t E)_i = -\frac{K}{\sqrt{E}}$$



The shine-through model

A power law was fit to the calculation of Suzuki [9]

$$\sigma_{stop} \propto E^{-0.767}$$

The optimal beam energy for fusion power efficiency, p_f/E_0, is shown at left, with and without shine-through.

Other features were considered in the design of the beam system, including thermal and beam β limits and auxiliary electron heating.

The NNBI System

The NNBI system makes heavy use of the ITER neutral beam design [3]:

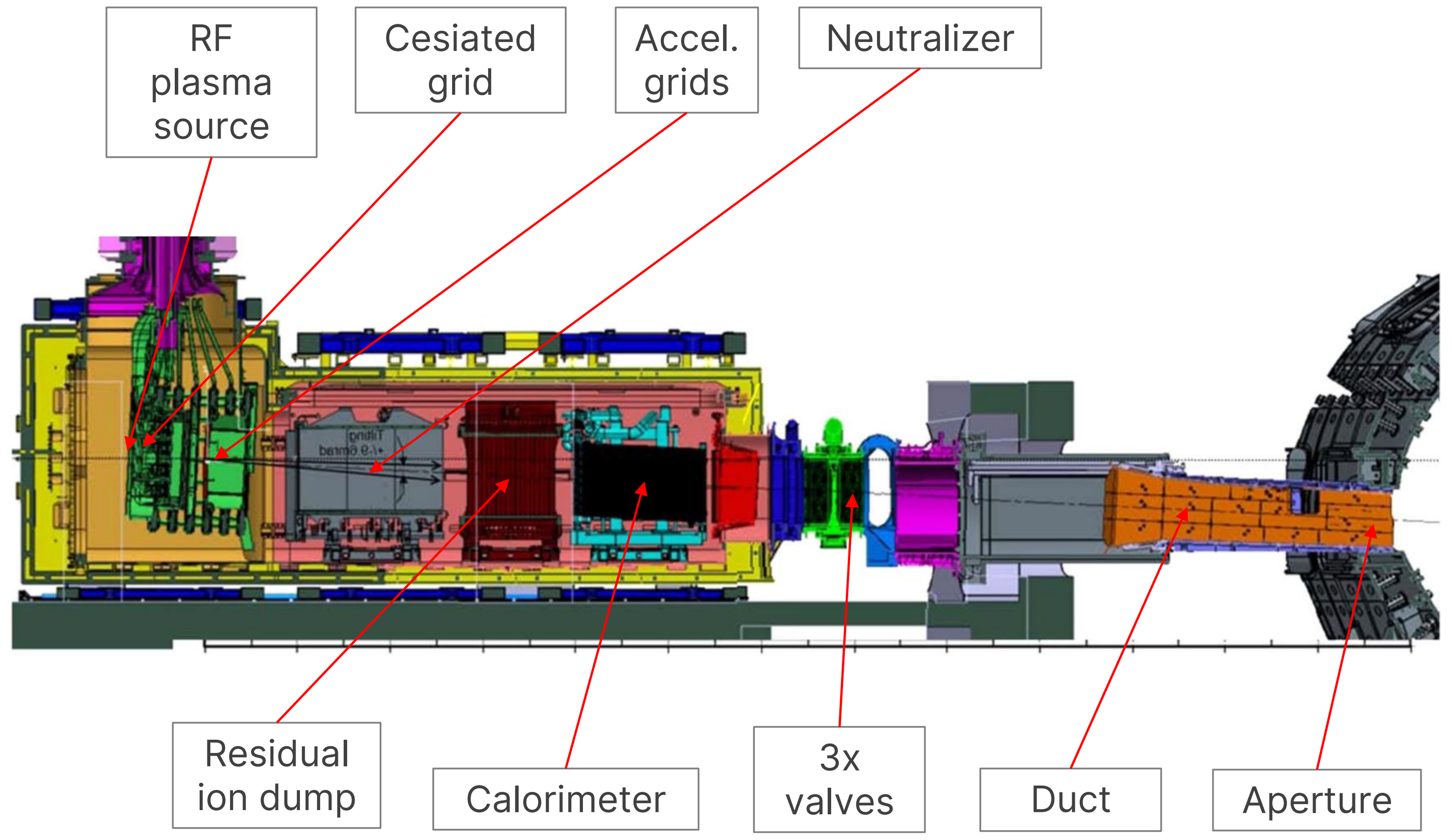


Diagram of the ITER HNBs [3]

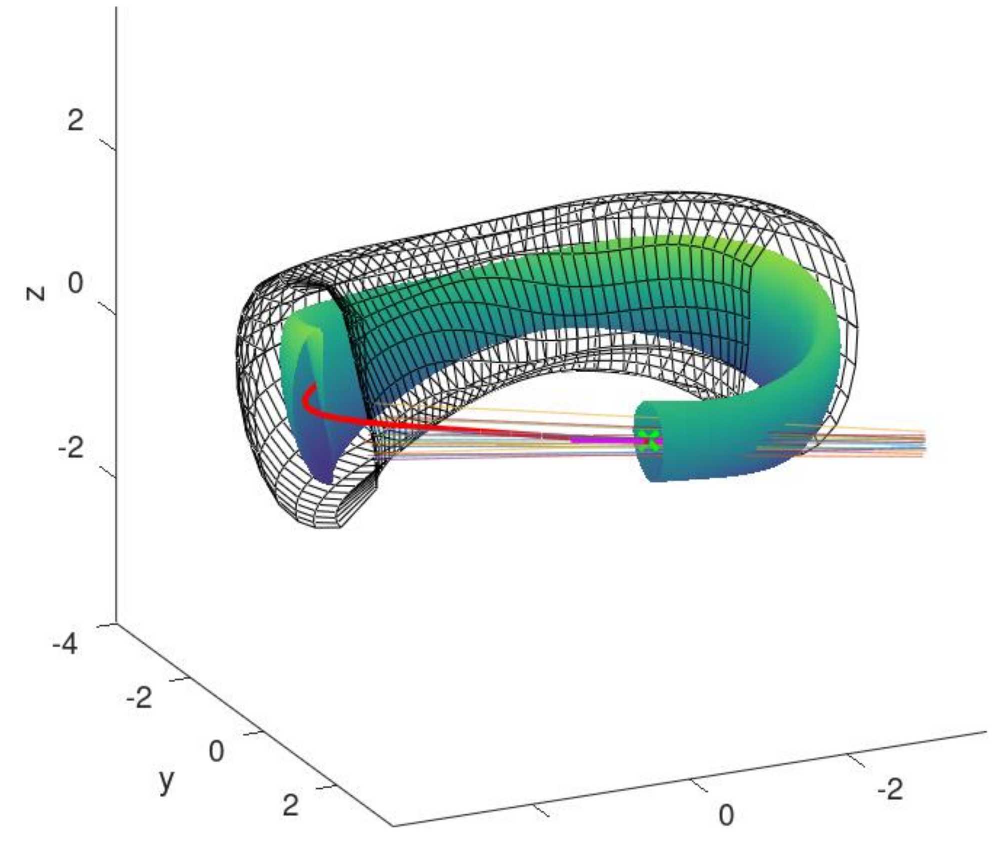
Neutral beam system parameters		
	ITER HBN	Neutron source
Species	Deuterium	Deuterium
Injection energy	1 MeV	1 MeV
Power	2x 16.7 MW	2x 5 MW
Sources	8	2
Grid segments	4	1
Length	25.4 m	16.5 m
Aperture	160x100 cm^2	40x40 cm^2

The ITER HNB can be scaled down in *power* trivially: Beam particles are generated and accelerated in parallel beamlets.

The ITER HNB can not be scaled down in *length* as trivially, but certain components are long because of power (ion dump, calorimeter) and neutron flux (duct).

The ITER HNB aperture is set to be steerable, not minimum size for divergence. Aperture can be smaller.

The ITER HNB divergence is set from focusing on the ion dump channels; decreases in length after this point yield a tighter beam.



Rendering of Monte Carlo sampled beam trajectories into a stellarator plasma. A PPPL collaboration using ASCOT [10] and BEAMS3D [11] is ongoing via the INFUSE program.

Conclusion

An NNBI system coupled to a stellarator optimized for fast ion confinement can produce an economically useful neutron rate

The NNBI system operates at similar energy, species, and power density to allow significant re-use of ITER HNB research

The ITER HNB can be scaled down in power trivially

Research is ongoing to adapt the ITER HNB to a beam-target DD neutron source

References

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