A Materials Evaluation D-T Neutron Source Based on an Axisymmentric Gas Dynamic Trap Magnetic Mirror
A white paper submitted to the OFES DOE Renews Process

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I. OVERVIEW

This white paper proposes a means of closing a major gap in scientific and technological understanding needed to build a fusion DEMO facility following success in ITER: the urgent need for materials that withstand heavy neutron bombardment [1]. Here we suggest the gas Dynamic Trap Neutron Source (DTNS) [2]-[4] as a steady state facility to evaluate materials at a level of $\sim$ 2MW/m^2. In contrast to IFMIF [5], the DTNS has a D-T neutron energy spectrum and can test larger and more samples, but consumes tritium ($\sim$ 100 grams per full power year). In contrast to tokamak based concepts [6]-[9], DTNS is simpler and smaller in size and consumes less tritium, unless the tokamak breeds tritium, However, tokamaks can test larger components.

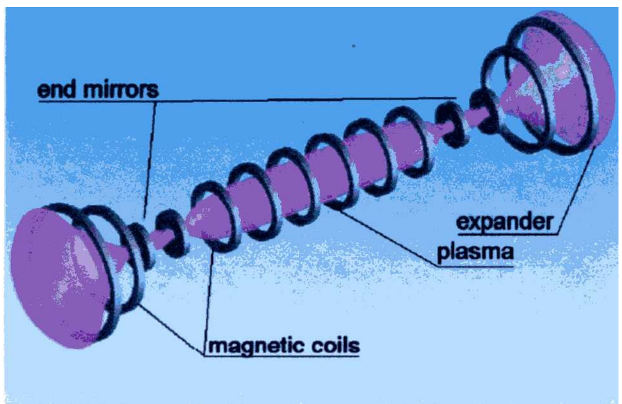

FIG. 1: The DTNS central section is 10 m long and 16 cm in diameter with a mirror ratio of 15. DTNS is powered by 30 MW of 70 keV neutral beams injected at 30 degrees.

Compared to previous high Q mirror reactor concepts [10] the DTNS does not require thermal barriers, uses circular coils rather than minimum-B coils, and does not require significant technology development. In 2008 an Assessment of the Status of Magnetic Mirror Research was completed [11]. The assessment concentrated on recent results from facilities in Russia (GDT) and Japan (GAMMA-10) as well as on new theoretical concepts.. The recent GDT results of 60 % central beta [12]-[13] indicates that an axisymmetric mirror system could form the basis of a Deuterium-Tritium Neutron Source (DTNS) for material testing. The axisymmetric mirror configuration has substantial physics and engineering advantages over past minimum-B thermal-barrier mirror system designs.

II. RECENT GDT RESULTS

The GDT axisymmetric mirror device [11]-[13] achieves a MHD stable central plasma beta of 60 %. The plasma has an electron temperature of 0.2 keV, ion energy of 10 KeV and density of 10^{20}m^{-3}. The plasma energy confinement time of $\sim$ 2 ms, is dominated by electron drag, and is adequate for DTNS operation at higher density and energy. GDT operates at the beta required for DTNS but a factor of 3-4 lower electron temperature. DTNS would have higher power neutral beams (30 vs 3.5 MW and 70 vs 20 keV) and thus would have higher ion energy ($\sim$ 40 keV) and thus higher electron temperature ($\sim$ 0.75 keV).

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III. THEORETICAL ANALYSIS

Theoretical analysis is key to assessing the extension of the present results to DTNS

1. MHD Stability: While sufficiently high betas have been achieved in agreement with theory, analysis of additional stabilization effects such as finite Larmor radius could broaden the operating range of DTNS.
2. Trapped Particle Modes: Trapped particle modes can localize in regions of bad curvature, even with connections to regions of good curvature but are not observed in GDT. Stability analysis of these modes with DTNS parameters is underway.
3. Micro-Stability: GDT is not impacted by Drift Cyclotron Loss Cone (DCLC) modes or Alfvén Ion Cyclotron (AIC) modes (although evidence of weak AIC modes are observed). The stability of these modes needs assessment at DTNS parameters.
4. Electron Temperature The electron temperature measured by Thomson scattering in GDT reaches 0.2 keV with 3.5 MW of neutral beam power [12]. DTNS operates at 0.75 keV with 30 MW of heating power. Mirror scaling predicts these electron temperatures would be achieved, but further analysis is warranted.

IV. INTERNATIONAL COLLABORATION AND ENGINEERING DESIGN

US collaboration with GDT and GAMMA-10 is desirable. The GDT team is increasing the neutral beam power from 3.5 to 5 MW. They have also begun experiments to increase confinement by beam injection into small axisymmetric end cells, with promising initial results. An upgrade of GDT, to reduce the extrapolation to DTNS, would include doubling the magnetic central field to 0.6 T and doubling the neutral injection power to 10 MW. Together with diagnostic additions this would decrease the extrapolation to DTNS. GAMMA-10 is implementing higher ECH power and Thomson scattering to provide a better understanding of electron physics.

A DTNS conceptual engineering design has been carried out in Russia [3]-[4] and at Karlsruhe Germany. There is also a large commonality between DTNS and previous source designs carried out by LLNL, U.Wis., Novosibirsk, and Karlsruhe [14]. An independent US DTNS design effort should be undertaken based on US technology capability.

V. SUMMARY

The axisymmetric mirror D-T neutron source could evaluate the behavior of materials and sub-components to 14 MeV neutron bombardment at a level of $1-2$ MW/m^2 over a surface area of $\sim 1\text{m}^2$. Higher levels are available for smaller areas. Next steps include analysis to project present GDT results to DTNS parameters as well as examination of conceptual engineering issues. A favorable outcome could enable initiating a fast paced start of construction in 2012 with operation beginning in 2017. This testing would help close gaps regarding materials qualification for DEMO (Greenwald Report Gaps 10 and 13 [1]), and responds to Initiative 7 concerning a Materials Qualification Facility.

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