EXTRAPOLATION OF GDT RESULTS TO A NEUTRON SOURCE FOR FUSION MATERIALS TESTING

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The achievement of 60% beta and near classical confinement in the Russian Gas Dynamic Trap (GDT) provides a basis for extrapolating to a 2 MW neutron source with 2 MW m^{-2} of 14 MeV neutron flux over an area of ~ 1 m^2. Such a source is needed for fusion materials development and qualification. We consider two axisymmetric configurations: a single mirror cell Deuterium-Tritium Dynamic-Trap Neutron Source (DTNS) and a Tandem-mirror Neutron Source (TNS). Compared to earlier US neutron source concepts, neither configuration utilizes complex minimum-B magnets or thermal barriers. In this paper we describe extrapolations from GDT with the same physical size, and the same dimensionless plasma parameters, but with higher magnetic field as well as higher neutral beam energy and power.

I. INTRODUCTION

Fusion power systems will require the development and qualification of materials to withstand both plasma and neutron bombardment. Plasma particles interact near the material surface whereas neutrons penetrate deep into the material [1]. After many years in a fusion device, neutron bombardment will displace each metal atom 100-300 times, (100-300 dpa It is thus not surprising that the characteristics of metals change in a fusion environment. This paper discusses a 2 MW magnetic mirror neutron source capable of generating neutron fluxes of ~ 2 MW/m^2 over an area of ~ 1 m^2. Such a source would be capable of testing material samples and blanket sub-modules without the need to breed tritium.

The investigation of plasma-material interactions is being carried out in plasma simulators and in fusion research devices to provide data for ITER and DEMO. Neutron-material effects are being investigated in fission reactors and spallation neutron sources. An accelerator-based (IFMIF) has been proposed by nuclear stripping of 30 MeV deuterons on a flowing lithium target [2]. Since these neutron sources do not generate a true 14 MeV fusion neutron spectrum, there is a need for a 14 MeV DT fusion neutron source. Three general types have been proposed: a rotating target neutron source (RTNS) [3]. A linear DT Dynamic Trap Neutron Source (DTNS) [4] and a tokamak based Fusion Nuclear Science Facility (FNSF) [5-6]. The characteristic features of these concepts are given in Table I. The key differences are the neutron flux, test area available, and tritium consumption per full power year (FPY). The neutron flux and test area of RTNS is very small. DTNS has higher flux and test area sufficient to test blanket sub-modules with low tritium consumption so as not to require tritium breeding. In contrast, FNSF has large area enabling full blanket module development, but these blankets must produce the tritium needed to operate.

TABLE I. Typical Characteristics of Materials Testing DT Neutron Source Concepts

	RTNS	DTNS	FNSF
Neutron Power (MW)	2e-5	2	200
Test Area (m^2)	1e-4	1	70
Neutron Flux (MW/m^2)	0.2	2	3
Tritium Burned FPY (kg)	~0	0.22	11

II. MAGNETIC MIRROR NEUTRON SOURCES

During the 1970's and 80's magnetic mirrors were considered as candidate DT neutron sources for testing materials [7]. These designs were all based on minimum-B magnets to provide MHD stability. While minimum-B systems demonstrate robust MHD stability properties they have several disadvantages. Because of mechanical forces, high magnetic fields and mirror ratio could not be achieved. . Furthermore, minimum-B magnets are relatively large so high heating powers are needed. Non-axisymmetry also introduces resonant and neoclassical radial transport. Finally, non circular plasma cross sections are prone to azimuthal asymmetries that drive radial transport. Several of these earlier designs employed complex thermal barrier concepts for improved efficiency. The neutron power of these designs ranged from 7 to 86 MW.

The present paper explores the feasibility of a mirror based axisymmetric coil design that would produce a few

MW of neutron power. These considerations are based on recent experimental results from the GDT device which has achieved 60% beta with classical collisional confinement [8] and extrapolates to a single-cell magnetic-mirror DT Neutron Source (DTNS).

It was discovered in the 1960's that an axisymmetric mirror, or simple mirror, is MHD unstable. This shifted research emphasis of research to minimum-B mirrors with everywhere good magnetic curvature. More recently several methods to achieve axisymmetric MHD stability have been proposed and demonstrated as summarized in Ref [9-10] and references there in. Most remarkable is the achievement of 60% beta , with classical confinement in the GDT device [8]. In this paper we assume that the GDT technique of applied radial electric field shear can be scaled to higher magnetic field and plasma temperature in a device of the same physical size and same dimensionless scale. A summary of such an extrapolation is indicated in Table II.

TABLE I. Extrapolation to a neutron source (DTNS) with the same Physical and Dimensionless size as GDT. Physically 7 m mirror-to-mirror length, 15 cm plasma radius, 2 cm ion-gyro-radius, mirror ratio of 17, and 60% beta. B_o is magnetic field, NB is Neutral Beam, and Te is the electron Temperature

	GDT	DTNS	TNS
B_o, Tesla	0.3	1.2	1.2
NB Energy, E_b, keV	20	80	80
NB power, P_b, MW	5	40	20
T_e, keV	0.25	0.75	2.0
Neutron Flux, MW/m^2	0.4*	2.0	2.0

* If operated with tritium 80 keV neutral beam injectors

DTNS is a scaled up version of GDT with four time's higher magnetic field and neutral beam energy (Eb). The beam power is increased 8-fold to increase the electron temperature 3-fold at higher density which increases the neutron flux5-fold.

For the 0.25 keV electron temperature achieved in GDT, a neutron flux of 0.4 MW/m^2 could be achieved, near the 0.5 MW/m^2 projected for ITER. To achieve 2 MW/m^2, extrapolated from GDT, requires 40 MW of 80 keV neutral beam injection.

III. A TANDEM-MIRROR NEUTRON SOURCE (TNS)

A limiting aspect of the DTNS concept is the outflow of collisional warm plasma used to provide micro-stability to the neutral beam injected energetic ions which produce the neutrons. This plasma outflow is the major power drain that holds down the electron temperature. The electrons in turn cool the energetic ions. Thus the electron temperature determines the neutral beam power needed to produce a given neutron flux.

The tandem mirror electrostatic end-plug concept can reduce the outflow of warm plasma by creating positive potential peaks to confine warm ions. However sustaining the high end-plug plasma density requires neutral beam power. We use here as a basis of our considerations the GDT-SHIP concept and experimental data from the TMX experiment at LLNL [11]. For this evaluation we use the magnetic field axial profile illustrated in Fig. 1. The central field B_o is 1.2 T, the peak mirror field B_m is 20T and the plug minimum field B_p is 7 T.

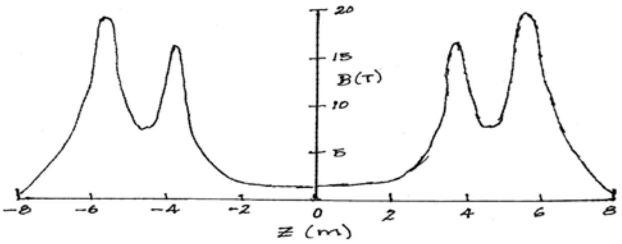

Figure 1. A Schematic of a TNS axial magnetic profile .

The aim here is to design a TNS that has both the same physical as well as normalized plasma parameters as the GDT experiment and performance similar to those routinely achieved in TMX. Just as in DTNS, TNS would utilize 80 keV neutral beams and a central magnetic field of 1.2 to match the GDT ion gyro-radius. To maintain a mirror ratio similar to GDT, the peak field is increased to B_m = 20 T. The plug minimum field is chosen to be B_m = 7 T for two reasons. First so the plug can sustain a high density plasma with a modest plasma beta to minimize Alfven Ion Cyclotron (AIC) fluctuations. The imbalance illustrated in Fig. 1 mirror peaks enables neutral beam injection at a mirror ratio of 1.3 to provide sufficient parallel energy to the injected ions to avoid AIC fluctuations. Finally, a mirror ratio of 3 (rather than 2) reduces the plasma potential ($5T_e/(R-1)$) that expels low energy ions forming an absence of low energy ions that drive loss cone DCLC micro--instabilities that would drain power.

Based on TMX data, the ratio of plug to central density is taken as $n_p/n_c = 4$. Higher values are possible but tend to limit the penetration of the warm plasma to the plug region needed to suppress DCLC fluctuations. A 4-fold reduction in plasma outflow enables the electron temperature to rise to 2 keV. To sustain the neutron production at a level of 2 MW/m^2 requires a neutral beam power of 20 MW (10 MW in the center cell and 5 MW in each end-cell). This reduces the total heating power by a factor of 2 (relative to DTNS) which more than compensates for the cost of a second high field mirror coil at each end. This TNS concept is being developed in the SHIP [12] configuration of the GDT facility.

IV. SUMMARY

This paper, illustrates a design basis for a 2 MW/m^2 DT Neutron Source (DTNS) with the same physical and dimensionless parameters as achieved in GDT. This is accomplished by increasing the magnetic field, neutral beam energy and power. Based on results from the simple tandem mirror experiment (TMX) we calculate that the same neutron flux can be achieved with half the neutral beam power and a quarter of the tritium reprocessing. These designs are based on technologies developed for ITER [13]. The two key physics issues that warrant further research are electron energy transport and more detailed understanding of the MHD stabilization physics. The major technology development needed is for steady state neutral beams, tritium reprocessing and tritium retention. These technologies are needed for all magnetic fusion systems. The linear geometry of the DTNS and TNS will ease construction, maintenance, operating, schedules as well as not requiring tritium breeding.

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