GAS DYNAMIC TRAP AS A HIGH POWER NEUTRON SOURCE FOR ACCELERATED TESTS OF MATERIALS

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Abstract

The urgency of design and construction of a 14 MeV dedicated neutron source which is absolutely needed to perform the material development and testing for future fusion power reactor is widely recognized. First of all, such a source makes it possible to collect information about mechanical, electrical and other properties of structural materials for DEMO design. About 10 years ago, material scientists have formulated criteria for the required parameters of such a source. In particular, 14 MeV neutron flux density was determined as 2 MW/m^2. However, in recent years, this requirement was strengthened till 4-5 MW/m^2. The paper presents different approaches to the problem how this increased neutron flux can be provided. It is shown that on the basis of the gas dynamic trap (GDT) concept the required neutron flux density can be achieved.

1. INTRODUCTION.

The fusion reactor cannot be built without performing extensive program of dedicated to qualify materials to be used in the reactor core under high power irradiation by 14 MeV and secondary neutrons. Among the problems to be addressed are the following ones: neutron activation, degradation of conductivity, swelling, etc. The materials either existing or to be created, should be of high mechanical endurance and should retain adequate electrical properties before the reactor shutdown. Besides, it is desirable to use low activated materials with properties mentioned above. Among the main currently available materials for the first wall there are ferritic-martensitic steels and vanadium alloys which have sufficiently long operating time. But even in this case, one should replace the first wall segments after a few years. If such segments will be irradiated within 10 years with a neutron load of the first wall of 2 MW/m^2 the level of radiation damages will exceed 200 dpa. Thus, even in the case of successful realization of the ITER project it cannot fulfill the required function of high power neutron source for testing candidate materials for future fusion power plant. Since it would provide only about 2 dpa per year. Therefore, it becomes clear that the requirement of material scientists to have dedicated high power neutron source with a flux density even higher than 2 MW/m^2 is absolutely necessary.

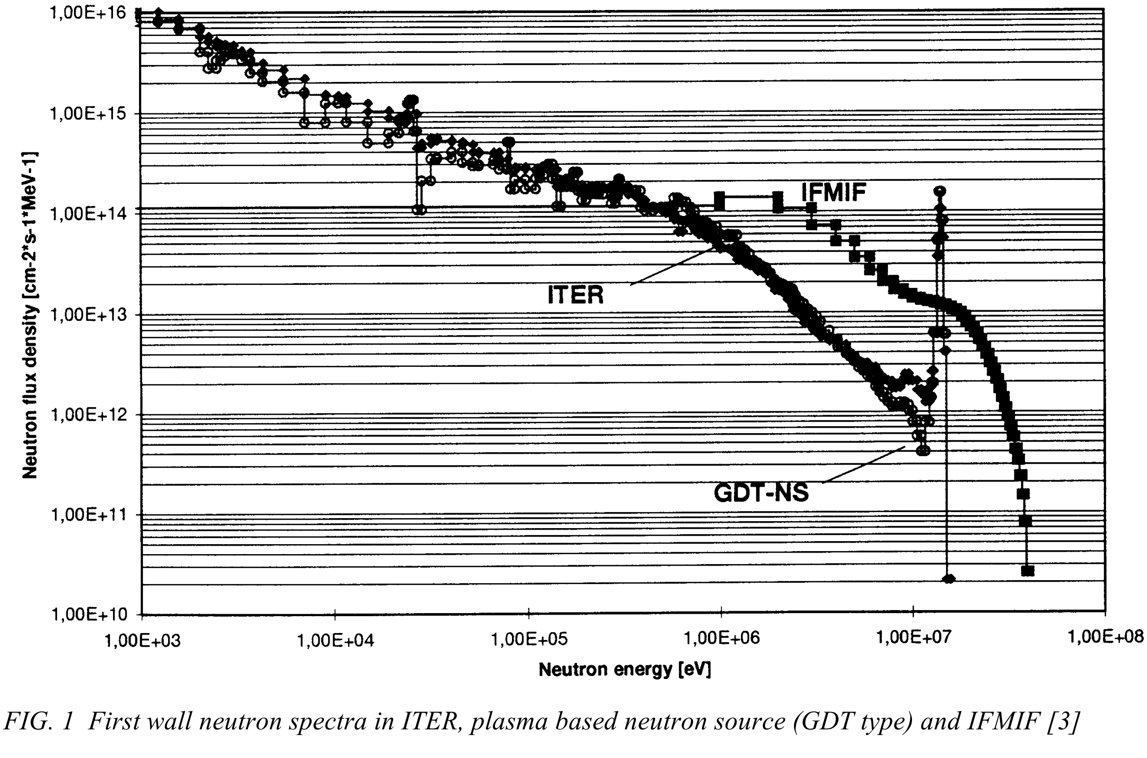

FIG. 1 First wall neutron spectra in ITER, plasma based neutron source (GDT type) and IFMIF [3]

At present, a lot of proposals of high power and high flux 14 MeV neutron sources are known (see review papers [1,2]). They can be roughly subdivided into two groups: the accelerator-based neutron sources and plasma-based ones. The advantages of the plasma-based sources consist in production of adequate neutron spectrum (monochromatic neutrons with an energy of 14 MeV), larger area of testing zone and smaller neutron flux gradients. The first approach leads to inadequate neutron spectra (except for case of muon catalysis, but proposed device does not provide high enough 14 MeV neutron flux). As one can see in Fig.1 the plasma-based neutron source has the same spectrum of secondary neutrons as that in the ITER case. At the same time, the spectrum of D-Li source (the IFMIF project) differs significantly from that in the plasma-based one. In particular, a lot of neutrons are generated with energies larger than 14 MeV. This circumstance can lead to errors during the material tests. Besides, the volume of testing zone in any accelerator-based source is too small. Thus, accelerator-based sources cannot solve many problems of materials tests. Therefore, a plasma-based neutron source is then required.

2. PLASMA-BASED NEUTRON SOURCES.

Taking into account large tokamak sizes one can conclude that they will hardly be a basis of the 14 MeV neutron source. Besides too high construction and operational cost of such a source it will require too much tritium. If the first wall area is 200 m^2, the annual tritium consumption will be of the order of 30 kg/yr. At present, the world tritium production is only 5 kg/yr. Thus, one can conclude, that the neutron source can be built on the basis of either mirror machines or compact tokamaks with low aspect ratio (like START). Taking into account that minimum area of irradiated wall of compact tokamak cannot be made less than 15-20 m^2, one can estimate that in order to achieve the fluence of 20 $MW{\cdot}yr/m^2$ it is necessary to spend 20-28 kg of tritium. If one tries to increase the neutron flux density, say, by two times, this will be absolutely unreal because of the tritium availability problem. In the existing mirror-based project of the neutron source the area of the zone with intensive neutron flux of the order of 1 m^2 can be provided. Thus, the problem of too high tritium consumption does not persist in this case. At the moment, the most well developed project of the mirror-based neutron source exists in the Budker Institute of Nuclear Physics (Novosibirsk, Russia). This project utilizes an idea of oblique injection of fast atoms into a warm plasma confined in the so called Gas Dynamic Trap (GDT), - a mirror machine with high ($R>10$) mirror ratio. This principle does not require hot preliminary plasma with fusion parameters. The idea of such source has been presented in Ref. [4]. Fast atoms passing though the plasma convert into fast ions, so that the population of energetic ions appears in the trap. In the vicinity of the turning points the longitudinal velocity of energetic ions is close to zero and their density is therefore maximum here. If one injects fast atoms of tritium into deuterium plasma or deuterium and tritium atoms even into hydrogen plasma, 14 MeV neutron flux will be created mostly within the turning point ranges.

In the recent years, the GDT NS project was being developed in Novosibirsk. The studies are performed in several directions: experiment on the existing model of GDT in Novosibirsk, (mirror to mirror length is 7 m, magnetic field strength in mirror coils is 15 T, plasma density is up to 10^{14} cm^{-3}), conceptual design of the GDT NS and numerical simulations. The next step of the experimental studies is the so called «Hydrogen Prototype» device that is under construction. The main parameters of the HP are close enough to those of the neutron source, but it will work without tritium. Intensive

TABLE 1

Design parameters	GDT	HPNS	GDTNS
Injection energy, keV	15	30-40	65
Injection power, MW	4	18-24	60
Injection angle, degree	45	30	30
Magnetic field in mirrors, T	15	20	13
Magnetic field in the midplane, T	0.2	0.7-1.0	1.3
Plasma density in the midplane, cm^{-3}	10^{13}-10^{14}	$9{\cdot}10^{13}$	$1.16{\cdot}10^{14}$
Plasma radius in the midplane, cm	10	10	8
Electron temperature, keV	0.13	0.2-0.4	0.75

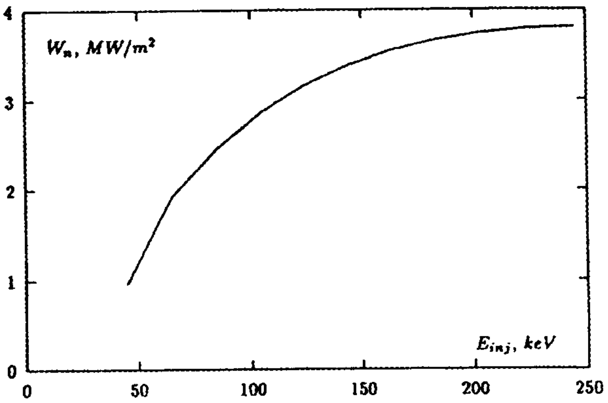

FIG.2 Neutron flux density in testing zone of GDT NS as a function of injection energy of deuterons and tritons

accumulation of physical database is produced with the aid of the GDT. In particular, the experiments have shown the ways of suppression of longitudinal electron heat conductivity, the ways to suppress MHD instabilities, etc. The experiments have already demonstrated the accumulation of sloshing ions on the density level above 10^{13} cm^{-3} (in the vicinity of turning points). This value is only one order of magnitude less than that required in the neutron source.

One should note that the GDT-based NS is one of the simplest NS projects from the engineering viewpoint because of axisymmetric geometry of magnetic system and moderate energetics. Besides, physical approach to plasma confinement in GDT is based on quite conservative assumptions. To optimize the main parameters of the neutron source special mathematical model of plasma was developed [5]. This model includes the solution of kinetic equations for plasma ions and energetic sloshing ions. The model also includes all limitations for plasma parameters linked with exitation of micro- and MHD instabilities. It also takes into account the longitudinal and transverse losses. Note that dimensionless plasma parameters of the neutron source are close enough to those attained in the stable regime at 2XIIB device [6].

The main self consistent parameters of the neutron source calculated for the case of fully superconducting magnetic system were presented in Ref. [7]. These parameters are shown in Table1 together with the parameters of the existing GDT device and of the HP which is under construction at present. The maximum neutron flux density in the case of the version presented in this Table was 1.8 MW/m^2.

3. GDT-NS VERSIONS WITH ENHANCED NEUTRON FLUX DENSITY.

Taking into account recent progress in the neutral beam injectors technology and the progress in production of strong (up to 20 T) magnetic field with the aid of usual superconductors [8], we revised the results of our previous calculations. One of the aim of the revision was to study the conditions at which the GDT-based neutron source is capable of producing neutron flux density of the order of 3-4 MW/m^2. The dependence of 14 MeV neutron flux density on the injection energy of D-T

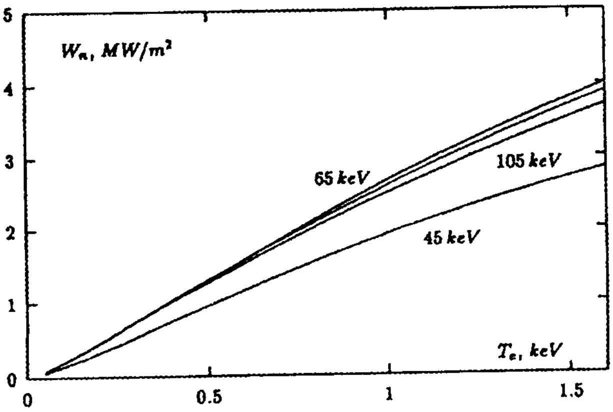

FIG. 3 Optimized neutron flux density as a function of electron temperature (the unmarked curve corresponds to the injection energy of neutrals equaled to 85 keV).

mixture is presented in Fig.2 ($n_t/n_d = 1.28$). The electron temperature of the order of 10^{-2} E_{inj} is assumed (it is rather well established that under this conduction the microturbulence is not excited in a mirror plasma). In this case, maximum neutron flux density can be achieved for the injection energies of the order of 250 keV.

As it is seen in Fig. 3, even more than 4 MW/m^2 can be achieved with smaller injection energy of D-T mixture if the electron temperature will be a little higher than 10^{-2} E_{inj}. Figure 4 demonstrates the important role of the electron temperature. One can see that even more than 4 MW/m^2 neutron flux density is achievable with the electron temperature of 2 keV. At present, such value of the temperature has not been obtained in mirror machines. However, the possibility to suppress the longitudinal electron thermal conductivity was experimentally demonstrated in the GDT [9].

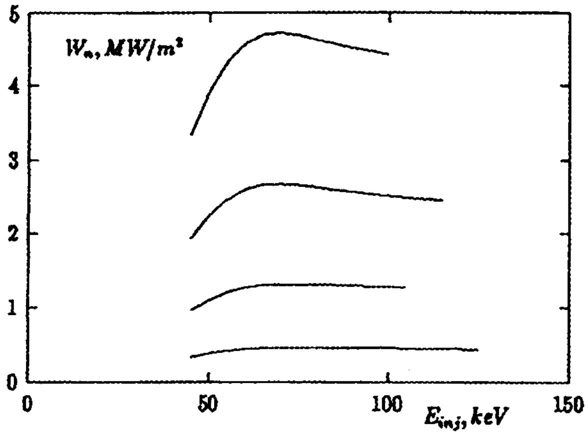

FIG. 4 Neutron flux density as a function of injection energy of D and T beams at different electron temperatures (200 eV, 500 eV, 1 keV, 2 keV). The lower curve corresponds to T_e =200 eV, upper one to T_e=2 keV

4. CONCLUSIONS

Among the plasma-based neutron sources the axisymmetric GDT NS looks like the simplest one and not so expensive as others. Any other source cannot compete with the GDT NS in the range of neutron flux densities of the order of 3-5 MW/m^2 because even on this level of the flux densities the annual tritium consumption of the GDT NS does not exceed several hundred grams.

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