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# A 14 MeV Neutron Source Based on Gas Dynamic Trap Concept. Status and Perspectives

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Besides the main physical problems of controlled fusion such as physics of alpha particles, ignition, etc, there exists a problem of a limited lifetime of structural materials under intensive bombardment by 14 MeV neutrons, degradations of their electrical and mechanical properties, accumulation of impurities, etc. At present, the development of the world fusion program is concentrated on the ITER project. However, even in the case of success of this project it cannot serve a function of high power neutron source for candidate material tests for future fusion power plant because of low fluence. Indeed, irradiation of one of the existing candidates on the role of a material for the first wall (ferritic-martensitic steel) with 14 MeV neutron flux of order of 2 MW/m$^2$ during 10 years will lead to the level of radiation damages of 200 dpa. The ITER will provide only about 2 dpa per year. Thus, the fusion reactor cannot be built without performing extensive program dedicated to qualify the materials to be used in the reactor core under high level irradiation by 14 MeV and secondary neutrons. In other words, the final goal of the controlled fusion program can not be achieved without urgent design and construction of a dedicated high power 14 MeV neutron source (NS). Among the problems to be studied it is worth mentioning the following ones: H, He, dpa production rates, neutron activation of materials, conductivity degradation, etc. The required 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 above mentioned properties.

The D-T reactions produce monochromatic neutrons with energy of 14 MeV. That is why the plasma based NSs look more attractive in comparison with the accelerator based NSs [1]. At present, the most well studied project of plasma NS exists in Novosibirsk. The project is based on the idea of oblique injection of fast atoms into a warm plasma confined in the so called Gas Dynamic Trap (GDT) [2]. The GDT is a mirror machine with high ($R\geq10$) mirror ratio and with collisional target plasma. Fast atoms passing through the plasma will be captured and converted into fast ions. As a result, the population of energetic sloshing ions appears in the trap. In the vicinities of turning points the longitudinal velocity of these ions turns to be zero. If one injects fast atoms of tritium into a deuterium plasma or a mixture of deuterium and tritium atoms into plasma (deuterium or even hydrogen), then strongly inhomogeneous 14 MeV neutron flux will be created in the range of turning points. It is important to take into account that for moderate energies of injected atoms (100 keV), the collisions of fast D and T ions will be mostly responsible for a 14 MeV neutron radiation. Because of that, the overfall of neutron flux densities between turning points and the mid-plane of plasma can be very large. The experiments performed on the GDT device with an injection of fast deuterium atoms with energies 15-17keV indeed have shown strongly inhomogeneous longitudinal distribution of neutrons of D-D reaction [3]. As it is seen in Fig.1, there is a reasonable agreement between the experiment and theory (solid curve).

A nonuniform distribution of the neutron flux along the axis of the magnetic trap is an important advantage of the GDT NS. According to our calculations, the total area of testing zone with high (of order of 2 MW/m$^2$) neutron flux density can be of order of 1 m$^2$ in this type of the NS. This value corresponds to requirements of material scientists. Thus, for the GDT NS case, the tritium consumption can be estimated in 150 g/yr. It is necessary to note that for the tokamak based NS, the first wall area can hardly be less than 20 m$^2$, and the neutron flux is uniform. Thus, such an approach will require about 3 kg of tritium per year (one should note that commercially available amount of tritium in the world is less than 5 kg/yr).

The experiments on the GDT device have already enabled to obtain several principal results. It was demonstrated that the MHD stability of plasma can be achieved in the axially symmetric magnetic field. Flute modes can be stabilized by using external anchor cells where the field line curvature is favorable for stability. If the favorable curvature of the magnetic field lines in the range of plasma expansion beyond the end mirrors is high enough, the MHD stability is observed. Another approach was demonstrated by installing an axisymmetric cusp in one of expanders. These experiments have

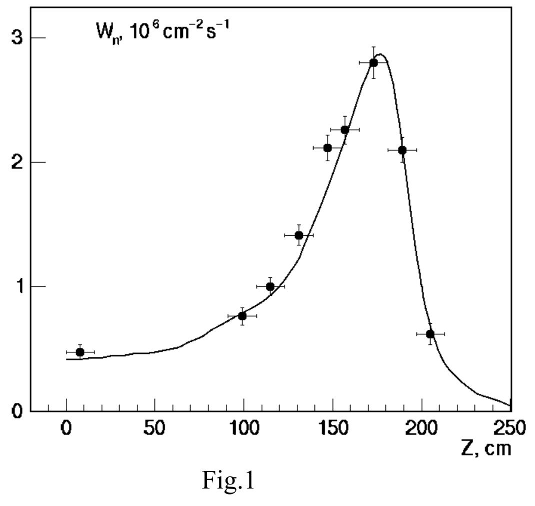

Fig.1

shown that the problem of MHD stabilization can be successfully solved. Recently, on-axis β exceeding 0.4 was obtained in the GDT near turning point of fast ions [3].

One of the most critical issues related to plasma confinement in mirrors is the danger of too large electron heat losses due to direct plasma contact to the end wall. However, for sufficiently high expansion of the magnetic field lines from the mirror to the end wall the theory [4] predicts strong reduction of the longitudinal heat losses. Indeed, the experiment has shown, that when the ratio of the field at end mirror to that at the end wall esceeds about 45, the end wall position does not influence upon the electron temperature at the central cell [5].

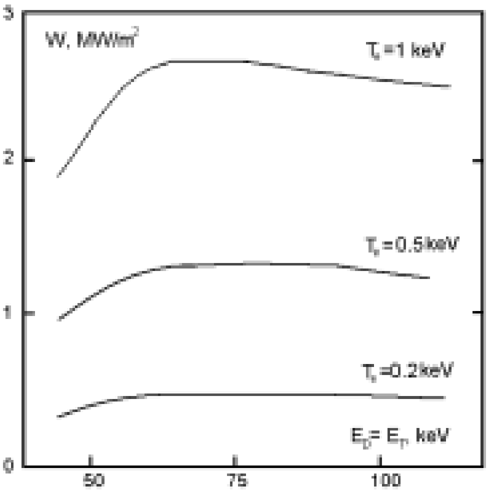

Fig.2

A lot of studies on optimization of parameters of neutron source were made on the basis of mathematical model of GDT plasma developed in Novosibirsk. Important results of these simulations are presented in Fig.2 where 14 MeV neutron flux density is shown as a function of energy of D and T beams injected into plasma. One can see that optimal injection energy is rather low and corresponds to 65 keV. This circumstance strongly simplifies the problem of neutral beam injection for GDT NS. Besides, the Figure demonstrates a very important role of plasma electron temperature. The reason of that is rather obvious: the higher electron temperature, the less deceleration of fast ions and the larger lifetime of these ions can be obtained.

| | |
|---|---|
| Plasma radius in the central part | 8 cm |
| Injection angle | 30° |
| Magnetic field strength in the end mirrors | 13 T |
| Mirror ratio | 15 |
| Injection energy | 65 keV |
| Electron temperature | 300 eV |
| Electron density in the central part | $1.2 \cdot 10^{14}$ cm$^{-3}$ |
| Density of fast ions in the central part | $0.42 \cdot 10^{14}$ cm$^{-3}$ |
| Electron density in the test zone | $3.0 \cdot 10^{14}$ cm$^{-3}$ |
| Density of fast ions in the test zone | $2.43 \cdot 10^{14}$ cm$^{-3}$ |
| Power consumption of injectors | 60 MW |
| Neutron flux density: in the test zone / in the central part | 420/16 kW/m$^2$ |

The curves shown were simulated for the case of strong electron heat losses to the end walls. As it is seen in the Table, even in the most pessimistic case, when the electron temperature is limited by the level of 300 eV (this level was experimentally observed in mirrors even with low expansion ratio), the level of neutron flux density will already be interesting for the material tests. But taking into account the successful experiments on suppression of electron heat losses one can conclude that significantly more high $T_e$ (and correspondingly neutron flux density) will be achieved.

At present, the works on modernization of the GDT device are in progress. According to results of simulations, an increase in NB injection power from 4 to 10 MW together with the growth of NB duration from 1ms up to 5ms (from physical point of view the steady state regime begins at 4-5ms) leads to an increase in the electron temperature up to 320eV. Correspondingly, the neutron flux density for D-T injection will achieve 0,45 MW/m$^2$. If this value will be obtained, one can discuss the full scale NS as a next step.

The problem of design of testing zone has been already studied earlier [6]. But up to now nobody touched the problem of the first wall heating. The main mechanism of heating is bombardment of the wall by alpha particles. The data shown in Fig.3 correspond to the case of plasma radius of 8 cm in the mid-plane and 4 cm in the range of testing zone.

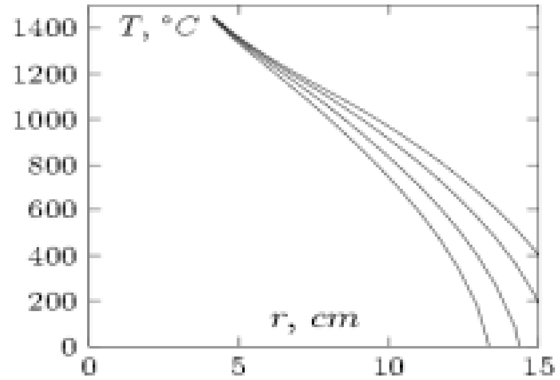

Fig.3

One can see that anyway in the range where the ratio of testing zone radius to plasma one is less than 1.5, all these curves give the same surface temperature (the curves correspond to the magnetic fields 5.3 T, 4.7 T, 4 T, 3.5 T. It means that the field in the end mirrors changes within 20-13T). It is seen that the working temperature of the testing zone surface without cooling is very high. As it is shown in [Ref.6], flowing off helium through the coaxial testing zone decreases the temperature of tested samples very significantly. From this fact it follows that the problem of cooling of the first wall can be solved.

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