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# Moderate Flux Version of 14 MeV Neutron Source Based on Gas Dynamic Plasma Confinement

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It is now generally recognized that further progress to a commercial fusion reactor will critically depend on the availability of materials which will have to operate for many years under the action of high flux of fusion neutrons without considerable degradation of the mechanical, electrical, and other properties. Another important requirement consists in the creation of new low-activated materials. High power 14 MeV neutron source is very important to study properties of structural materials of future fusion power plants.

One of the most promising approach to the creation of the neutron source is the concept based on the gas dynamic trap (GDT) [1]. The GDT is one of the simplest system for magnetic plasma confinement. As a matter of fact, it is an axisymmetric mirror machine of the Budker-Post type, but with a very high mirror ratio (R>10) and with a mirror to mirror length L exceeding a mean free path $\lambda_{eff} \sim \lambda/R$ for the ion scattering into loss cone. Thus, due to frequent collisions the plasma confined in the trap is very close to isotropic Maxwellian, and many instabilities can not excite, and plasma behavior is similar to a classical one. Besides, it is not necessary to create high temperature plasma. Using an oblique injection of fast deuterium and tritium atoms into a warm plasma one can obtain a population of unisotropic fast $D^+$ and $T^+$ ions which oscillate back and forth between the turning points near the end mirrors. For moderate energy of fast ions ($E_i$ < 100 keV) mostly the collisions of fast $D^+$-$T^+$ ions will be responsible for a creation of 14 MeV neutrons. Thus, strongly inhomogeneous neutron flux will be obtained with maxima in the vicinity of the turning points. An example of calculated distribution for one of the versions of the GDT NS is presented in Fig.1. An asymmetry is explained by special corrections of the magnetic field. By decreasing the derivative $|dB/dz|$ in the vicinity of the turning point one can increase the longitudinal size of the testing zone (see Fig.2). As estimations showed, one can obtain an effective testing zone area of the order of 1 $m^2$. For the required neutron flux density of 2 $MW/m^2$ the annual tritium consumption will be of the order of 150 gram. Besides, the electric power consumption in the case of the GDT NS will be rather moderate in comparison with other plasma based NSs [2]. Thus, the cheapest neutron source can be built on the basis of the GDT. At present, the mathematical model of plasma of the GDT has been built [3], the Fast Ion Transport (FIT) Code based on the Monte Carlo method has been developed for numerical simulations [4]. Additionally, the one-dimensional Fokker-Plank code FPM (Fast Particle Model) has been applied to «on-line» calculations of the global fast ions parameters [5]. At the moment, a lot of proofs have been obtained which demonstrate quite

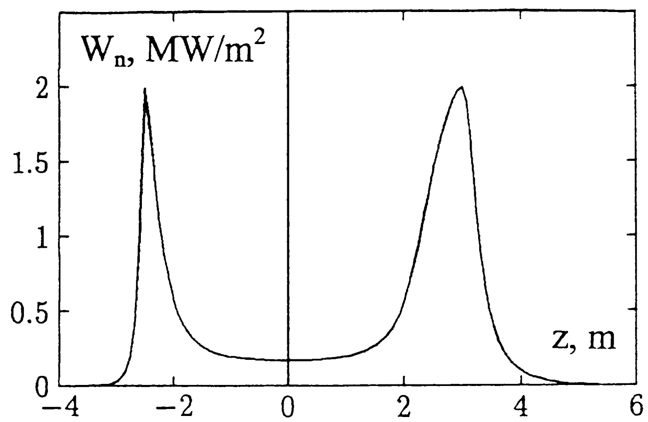

*Fig.1 Neutron flux density distribution along the trap*

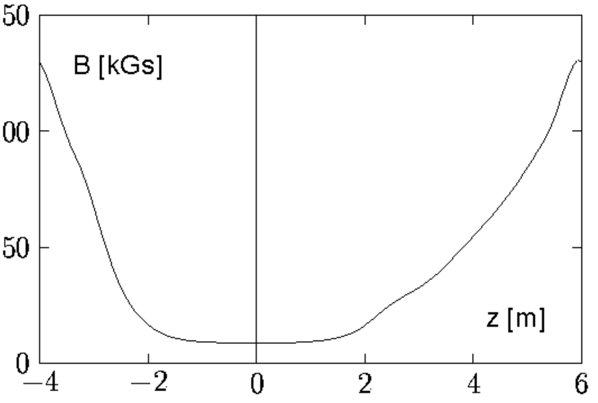


*Fig.2 Profile of magnetic field strength along the trap. The points of location of the end mirror coils are: Z=-4 m and Z=-6 m. Special correction of the field profile in the range Z>2 m was made.*

reasonable agreement between experimental data on the GDT device and results of numerical simulations. Fig.3 demonstrates an example of such agreement for the case of the experiment with injection of fast (E ~ 15 keV) deuterium atoms into target plasma of the GDT device [6]. As one can see in the Figure, the experimentally observed distribution of arising neutrons well corresponds to the results of simulations.

However, plasma parameters required for the high power GDT neutron source, at present, are far enough from those obtained on the existing GDT device. In particular (see, for example, Ref.[7]), to achieve the required level of the neutron flux density, one should obtain high enough electron temperature. There exists an opinion that too high heat losses due to direct plasma contact to the end wall do not permit to have high temperature of electrons in mirror machines. Really, in the experiments on 2XIIB [8] the record electron temperature was only 260 eV in spite of very high ion temperature. Thus, the difficulties with longitudinal heat losses really exist for classic mirror machines. As to the gas dynamic trap, in this case, due to very high ratio of magnetic field strength in the end mirror and in the wall of expander there is a possibility to suppress the longitudinal electron heat conductivity. Such a possibility has been really demonstrated experimentally on the GDT device [9]. But, unfortunately, the maximum electron temperature in the GDT experiments is below 130eV.

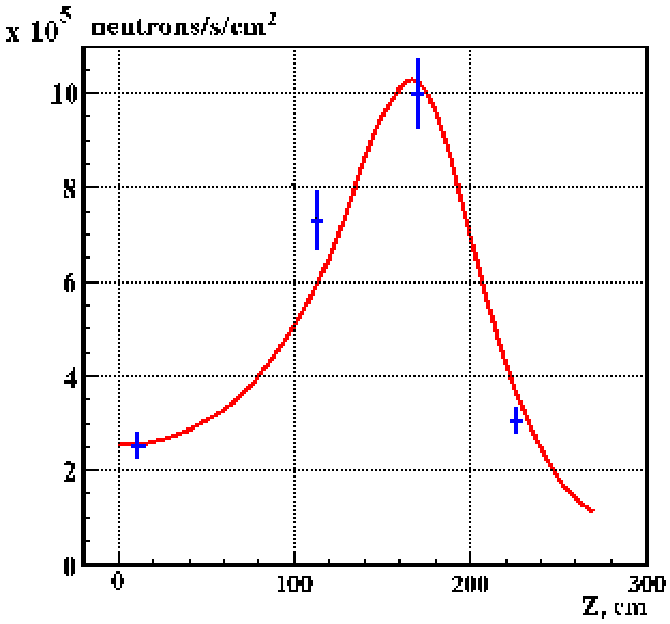


*Fig.3 Experimental distribution of the neutron yield along the axis of the GDT device. Neutrons are obtained as a result of fast-fast deuterons collisions. Results of numerical simulations by the Monte Carlo method presented by solid line.*

As it was shown in [7], the neutron flux density in the GDT NS strongly depends on the electron temperature. In particular, these calculations show that even higher than 4 MW/m$^2$ neutron flux density can be obtained. The main objection against this statement consists in the following. It is not obvious that codes worked out for the GDT NS will give exact predictions when required plasma parameters differ significantly from existing ones. Thus, first of all, one should demonstrate a feasibility of high electron temperature in exact accordance with numeric computations. The degree of confidence to the results of computer simulations becomes very high when the most significant parameters differ from those presently available not more than two or three times.

The results of calculations for moderate versions of neutron source are presented in Table 1. The maximum magnetic strength in the end mirror is taken to be 13 T. It means that fully superconducting magnetic system can be used.

Table 1

| | | |
|---|---|---|
| Plasma radius in the central part | 8 cm | 8 cm |
| Injection angle | 30° | 30° |
| Magnetic field strength in the end mirrors | 13 T | 13 T |
| Mirror ratio | 15 | 15 |
| Injection energy | 65 keV | 65 keV |
| Electron temperature | 200 eV | 250 eV |
| Electron density in the central part | $1.2 \cdot 10^{14}$ cm$^{-3}$ | $1.1 \cdot 10^{14}$cm$^{-3}$ |
| Density of fast ions in the central part | $0.32 \cdot 10^{14}$cm$^{-3}$ | $0.37 \cdot 10^{14}$cm$^{-3}$ |
| Electron density in the test zone | $2.5 \cdot 10^{14}$cm$^{-3}$ | $2.8 \cdot 10^{14}$cm$^{-3}$ |
| Density of fast ions in the test zone | $1.87 \cdot 10^{14}$cm$^{-3}$ | $2.29 \cdot 10^{14}$cm$^{-3}$ |
| Power consumption of injectors | 60 MW | 60 MW |
| Neutron flux density: in the test zone / in the central part | 230/7 kW/m$^2$ | 350/10 kW/m$^2$ |

It is necessary to add several comments to the data presented in the Table 1.

1. For 30° injection the turning points correspond to mirror ratio R=4. Thus, the distance between the turning points will be about 5 meters (see Fig.1). There is no problem in this case to shield end mirror against irradiations by neutrons.

2. The efficiency of injection is estimated as 50%. (28-29 MW from 60 MW is trapped in the target plasma).

3. Strong mechanism of electron cooling is supposed. Due to this mechanism electrons can not be heated higher than 200-250 eV.

But even in this pessimistic case, the level of neutron flux density has been already interesting for material tests. Such a pessimistic is hardly probable in reality.

Table 2 shows an increase in the neutron flux density with growth of the electron temperature.

Table 2

| | | | | | |
|---|---|---|---|---|---|
| $T_e$, eV | 200 | 250 | 300 | 400 | 500 |
| $W_n$, kW/m$^2$ | 230 | 350 | 435 | 715 | 1000 |

The calculations were made with the fixed power consumption of NB injectors, fixed magnetic field strength in the mirror coils (13 T) and with the fixed mirror ratio (15). At present, there is no doubts that $T_e$ = 250÷300 eV will be obtained. It is naturally, that this step will be made on the GDT-Upgrade. As computer simulations show, three important changes should be done on the GDT device: increase in the magnetic field strength at the mid plane from 0.2 up to 0.35 T, increase in the NB injection power from 4 up to 10 MW, and increase in the beam duration from 1 ms up to 3 ms. As it follows from calculations, these measures will lead to the increase in the electron temperature up to 260 eV. If it is obtained, the neutron source with a moderate neutron flux density of order 350-430 kW/$m^2$ can be constructed. Of course, it is the most pessimistic estimation of the flux density level. In reality, one should wait for significantly higher neutron flux density, since in the GDT case, the problem of suppression of the longitudinal electron heat conductivity will hardly be very serious.

## References:

1. I.A.Kotelnikov, V.V.Mirnov, V.P.Nagorny, D.D.Ryutov, In: Plasma Physics and Controlled Fusion Research, **2**, IAEA, Vienna, p.309, (1985).
2. E.P.Kruglyakov, Transactions of Fusion Technology, **v.35**, „ 1T, Fuste 8(1), p.p.20-29, (1999).
3. I.A.Kotelnikov, D.D.Ryutov, Yu.A.Tsidulko et al, Preprint of the Budker Institute of Nuclear Physics „105, Novosibirsk, (1990).
4. K.Noack, G.Otto, S.Collatz, Transactions of Fusion Technology, **v.35**, „1T, p.p.218-222, (1999).
5. A.A.Ivanov, A.N.Karpushov, Preprint 96-2, Budker Institute of Nuclear Physics, Novosibirsk, (1996).
6. A.V.Anikeev, P.A.Bagryansky, A.A.Ivanov, et al., Proc. 26th EPS Conf. on Controlled Fusion and Plasma Physics, Maastricht, Nederlands, **v.23J**, p.p. 1781-1784.
7. A.A.Ivanov, E.P.Kruglyakov, Yu.A.Tsidulko, 17th IAEA Conf. on Fusion energy, Extended Synopsis, IAEA-CN-69, p.291, FTP/31, Yokohama, (1998).
8. F.H.Coensgen, T.A.Casper, D.L.Correll, et al. Proc.Intern.School of Plasma Phys. «Piero Capdirola», Bologna, Editrice Compasitori, p.p. 477-487 (1991).
9. A.V.Anikeev, P.A.Bagryansky, P.P.Deichuli, et al., in: Proc. 23rd EPS Conf. on Plasma Physics and Controlled Fusion, Kiev, **20C**, pt.2, p.p. 688-691 (1996).