THE GDT BASED NEUTRON SOURCE AS A DRIVER IN A SUB-CRITICAL BURNER OF RADIOACTIVE WASTES

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Transmutation of long-lived radioactive nuclear waste, including plutonium, minor actinides and fission products, represents a highly important problem of fission reactor technology and is presently studied worldwide in large-scale. Sub-critical systems seem to be a promising option for efficiently burning plutonium and minor actinides provided a sufficiently high-intense neutron source is available. For a number of years the Budker Institute of Nuclear Physics (Russia) in collaboration with the Russian and European organizations developed the project of a 14 MeV neutron source for fusion material irradiation and other applications. The projected plasma type neutron source is based on the Gas Dynamic Trap (GDT) which is a special magnetic mirror system for the plasma confinement. This poster presents different version of the GDT-based neutron source for hybrid fusion-fission sub-critical system for the transmutation of the long-live radioactive waste in spent nuclear fuel.

I. INTRODUCTION

Recently, the idea of coupling a sub-critical fission reactor and a DT-plasma device generating 14 MeV neutrons for the incineration and transmutation of long-lived isotopes has attracted increasing interest. Such DT-plasma surrounded by fission blanket provides some advantages as compared to ADS [1]. Firstly, one has to notice, that from a physics point of view, presence of 14 MeV neutrons in the generated spectrum provides additional flexibility with regard to the generation of additional neutrons via (n,2n), and (n,3n) reactions, as well as from ^{238}U fission, which is a threshold reaction. Moreover, the 14 MeV neutrons provide also greater incineration/transmutation capabilities of the system, since this permits even lower k_{eff}-regimes. Finally, the variable dimension of the neutron source (i.e., of the plasma) in a fusion-fission system opens new design possibilities for the sub-critical fission blanket, ultimately leading to more efficient incineration/transmutation machines.

The Budker Institute of Nuclear Physics has made the proposal of a powerful 14 MeV neutron source based on a gas dynamic trap (GDT) [2,3]. So, the question rises, whether the GDT based neutron source could be a candidate to efficiently drive such a sub-critical system too. The answers on these questions are the objective of the present paper.

II. THE GDT BASED NEUTRON SOURCE

The powerful 14 MeV neutron source on the base of the gas dynamic trap plasma device that confines deuterium-tritium plasma has been primarily developed as irradiation test facility for fusion material studies and for other application [3]. A research project of the Budker Institute aims at completing the database of the GDT in the high plasma parameter range, which is essential for the neutron source project. Figure 1 shows a schematic representation of the GDT-based neutron source proposed as irradiation facility for fusion material research. (“basic version” of GDT-NS) A system of magnetic coils generates an axially symmetric magnetic well along the axis of the vacuum chamber. In the central chamber the magnetic field confines the so-called target plasma in a gas dynamic regime, which is characterized by collisional particle losses into the end chambers of the device. An

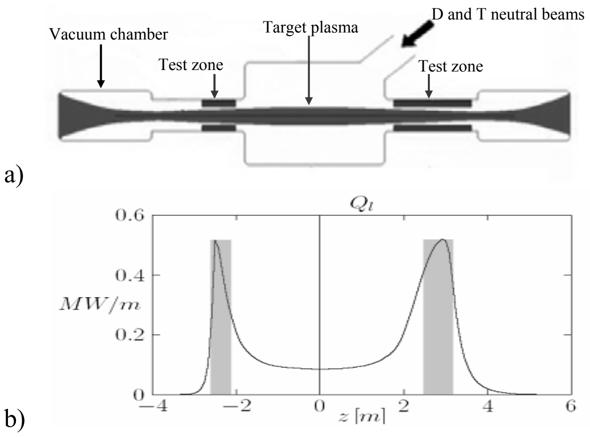


Fig. 1. (a) Schematic representation of the GDT-based neutron source as irradiation facility and (b) neutron power production per length.

inclined injection of high-energetic deuterium and tritium atoms produces deuterons and tritons oscillating back and forth between the hills of the magnetic field. The peaks of the fast ion density appearing near to their turning points represent the volumes of intense fusion neutron production.

The idea to use the GDT based neutron source for driving a sub-critical system demands a new way how to optimize the GDT-NS parameters. In the frame of the possible application of the GDT based neutron generator for the material study, the main goal was to create a maximal neutron flux density at a surface close to the plasma surface in the testing zone under the given technical (and economic) limitations, in particular, the limitation of the power supply to ~ 60 MW. As result in the basic version we have two zones of 0.5 m long with the useful neutron power of about 0.4 MW in both sides (see Fig.1). The technical idea would be to surround both neutron production zones by a sub-critical system.

To maximally use the neutron production of the GDT one has to operate two MA-burners, one on each side of the device supplied with an intensity of about $S_{GDT/2}=0.98x10^{17}$ n/s. This value is considerably smaller than that aimed at for a commercial use of minor actinides burners. For such a facility the driver should deliver more than 10^{18} neutrons per second.

Therefore, one has to search for potentialities of improvements. One option is the increase of the electron temperature T_e of the GDT-plasma. This measure would reduce the energy loss rate of the high-energetic deuterons and tritons and, thereby, increase the fusion reaction rate considerably. Figure 2 illustrates the special situation with this plasma parameter for the case of the “basic version”. The diagram shows the total fusion neutron production power of the GDT-NS in dependence on the electron temperature. With the input parameters given at the beginning of this section the self-consistent mathematical model of the GDT device [4] yields the electron temperature of 3.5 keV. For the “basic version” a special cooling of the electrons down to T_e=0.75 keV has been introduced.

In addition to the increase of the electron temperature the GDT offers another possibility for improvement of its neutron source parameters. By modifying the external magnetic field the ratio of the emission intensities of both neutron production volumes can be varied. Moreover, these zones can be longitudinally extended, and, even certain axial profiles of the neutron intensity could be adjusted. The calculations show that for the “basic version” neutron source the additional one meter of the “test zone” produces 0.5 MW neutron power and “costs” 16 MW of electric power supply. According to this estimation the “basic version” was newly optimized and resulted in a “long version”, which has two 4 m long test zones with the useful 2 MW neutron power on each side and under 190 MW of total electric power consumption.

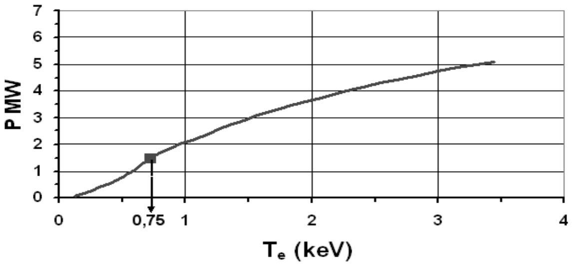


Fig. 2. Total neutron production power of the GDT-NS “basic version” vs electron temperature of plasma.

III. MA- BURNER CALCULATION MODEL

By means of the Monte Carlo code MCNP-4C2 [5] and the nuclear data library JENDL-3.3 neutron transport calculations were carried out for a minor actinides burner the scheme of which originally has been defined for an international numerical benchmark exercise for spallation based ADS [6]. Basic neutron characteristics of the system were calculated for the cases when operated with both the spallation source and the GDT neutron source.

The cylindrical system (one half) shown in Fig. 3 served as basis for the calculation models, which were used for studying the neutron physical characteristics of spallation and fusion driven burners. The core is loaded with uranium-free fuel composed of plutonium and minor actinides in a mass ratio of about 32:68. Lead-bismuth eutectic is the material of the spallation target, of the buffer and of the coolant. The proton beam is injected from above centrally onto the target. The geometric data and nuclear densities were taken from [6].

The D-T fusion source (basic GDT-NS) was simulated as homogeneous distribution in a voided

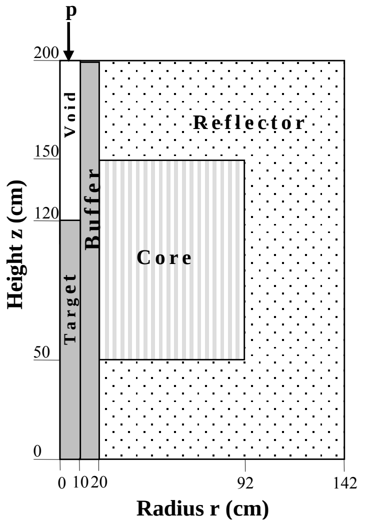
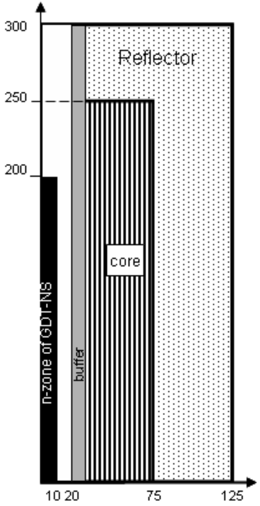


Fig. 3. Geometry model of the MA-burner with spallation target (a half of the system).

cylinder with radius r=10 cm, height h=50 cm and positioned in the centre of the system instead the beam target (see Fig. 3). The energy spectrum was the fusion peak with the mean energy of 14.1 MeV.

The stretching of the source volume in long version of the GDT-NS demands a corresponding elongation of the burner. As first step, the system shown in Fig. 4 was considered (a quarter is shown). Compared to system on Fig 3 the main changes are: the core height is 5 m; for technical reasons the radius of the inner hole was extended up to 20 cm; the buffer extends over the core height and its thickness was chosen 7.5 cm; the outer radius of the core 73 cm was determined so that $k_{eff} \approx 0.97$. The fusion source was simulated in the same way as described above, but now with a source cylinder of length 4 m. The material compositions were kept unchanged.

For each of the systems two types of transport calculations were performed – with a given outer source and a reactor criticality calculation.



Source (one side of GDT)

$L_{n\text{-}zone} = 4$ m, $r = 10$ cm

$P_{inp} = 150$ MWel

$P_{nusef} = 2$ MW

$S_{GDT}/2 = 9\text{x}10^{17}$ n/s

MA-burner:

Core height = 5 m

Inner core radius = 27.5 cm

Outer core radius = 73 cm

Inner channel radius = 20 cm

Buffer width = 7.5 cm

Fig. 4. Elongated MA-burner with a stretched GDT neutron source (a quarter of the system is shown).

IV. RESULTS AND CONCLUSIONS

The Table 1 gives the calculation results for different driven MA burners. In case of the GDT-driven systems it is taken into account that we have two neutron emission zones and each of them drives one burner, then one would have two MA burners generating double the nominal power. The results of the calculations with the external sources reveal a striking advantage of the fusion neutron source compared with the spallation source.

The project of the "basic version" of the GDT-based neutron source that has been proposed as irradiation facility for fusion material research turns out to deliver one order of magnitude less neutrons than would be necessary for a MA-burner of commercial scale.

TABLE I. The driven sub-critical MA burners

Source	ADS	GDT basic	GDT basic T_e~3.5keV	GDT long
P_{suppl}; MW	20	50	50	150
$P^n_{usefull}$, MW	0.25	0.44	1.4	4
S_n , n/s	$1.25\text{x}10^{18}$	$2\text{x}10^{17}$	$6.4\text{x}10^{17}$	$1.8\text{x}10^{18}$
P_{fis} , MW	263	87	288	1044
P^{el}_{out} , MW	105	35	115	418
Q= P^{el}_{out} / P_{suppl};	5.3	0.7	2.3	2.8
MA burning rate, kg/year (1LWRs=29kg/y)	36 (1.2)	23 (0.8)	75 (2.6)	144 (5)

An increase of the electron temperature of the GDT-plasma up to the self-consistent value would result in an increase of the Q-factor by a factor of about three. The realization of this possibility demands further plasma physics research.

The GDT neutron source offers the possibility for longitudinally stretching the neutron production volume. Thereby, the total strength and the energetic efficiency of the source can be substantially increased.

The most promising variant of a GDT-driven MA burner uses the optimized version of the GDT neutron source with two neutron emission zones that have been elongated to 4 m and requires a power input of 150 MW. In result, the system with the two MA burners driven by one "long" GDT neutron source can produce more then 1 GW of fission power with an energy multiplication factor *Q~2.8.* This system incinerates in 1 year a 144 kg MA that is produced by about 5 LWR´s in 1 year.

ACKNOWLEDGMENTS

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