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

A.V.Anikeev[1], P.A.Bagryansky[1], A.A.Ivanov[1], E.P.Kruglyakov[1], K.Noack[2], A.D.Rogov[3], and Yu.A.Tsidulko[1]

[1] *Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia*
[2] *Forschungszenrum Dresden-Rossendorf, Dresden, Germany*
[3] *Joint Institute for Nuclear Research, Dubna, Russia*

1. Introduction

To become a long-term sustainable option for the world energy supply fission reactor technology has to solve the high-level waste repository problem. For this purpose, great R&D effort is made worldwide to develop new closed fuel cycle options and their technical solutions for minimizing the high-level waste that finally must be disposed. Long-lived fission products and, in particular, minor actinides (MA) are the components of the spent nuclear fuel which cause the most concern. Regarding the incineration of minor actinides, nuclear devices producing high-energetic (fast) neutrons by nuclear fissions and confining them without substantial energy moderation have the highest efficiency. Such devices can be built as fast reactors and as sub-critical nuclear fuel systems, the so-called driven systems, which are fed with neutrons from an external neutron source. Currently the accelerator driven spallation neutron source (ADS) [1] is favoured for this purpose because of the high neutron emission intensity achievable.

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. 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 larger 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 fact that the DT-plasma's energy is amplified by a factor greater than 5 in the sub-critical blanket allows to design compact fusion/fission systems, which might have attractive transmutation characteristics and are thought to have sufficiently reduced price due to compactness, simplified maintenance, reduced operating costs, etc.

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]. So, the question raises, 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.

2. The GDT based neutron source

The powerful 14 MeV neutron source on the base of the gas dynamic trap plasma device that confines a deuterium-tritium plasma has been primarily developed as irradiation test facility for fusion material studies and for other application [2]. 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. The basic version of the source (GDT-NS) dedicated for fusion material studies is an axially symmetric mirror machine of the GDT type, 10 m long and with a mirror ratio of 15. The idea of the source is extremely simple. If high energy deuterium and tritium neutral beams are injected at an angle to the axis of the trap into a “warm” plasma, then a population of fast sloshing ions is produced. Their density is strongly inhomogeneous along the axis with strong peaks close to the turning points. Nuclear reactions will mainly occur as result of fast-fast D-T collisions. As simulations show, in the vicinities of the turning points a 14 MeV neutron flux density of 2 MW/m^2 or even more can be achieved on the area of ~ 1 m^2 .

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 main goal of the optimization for the driver application of the neutron generator, apparently, has to be the maximal energy efficiency for the total neutron production in those part of the plasma device, which can be installed inside of the sub-critical system. In this sense, the configuration of the plasma device must have maximally long zone where the ratio of the neuron production to the fast ion energy losses is maximal. The calculations show that this ratio is maximal in the zone where the fast ions have the reflection point, so called “test zone” in terms of the previous application. (The energy loss takes place here due to the electron drag mainly, while the cold ion heating, the charge exchange losses and scattering resulting in the cone loss are minimal.) 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 1.5 m long test zones with the total useful neutron power of 1.5 MW under 100 MW of total electric power consumption.

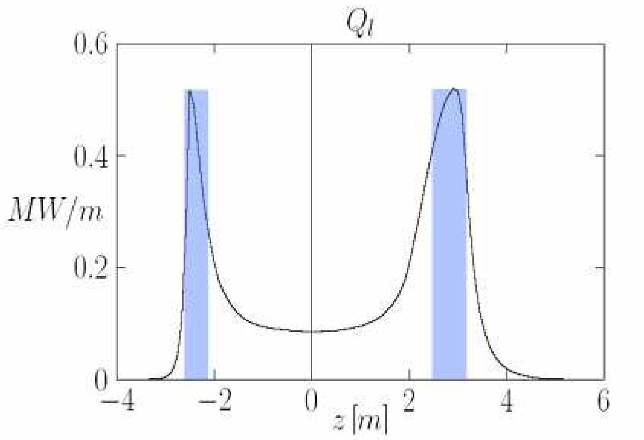

Fig.1 Neutron power production per length for the “basic version”. The test zones marked blue.

3. Calculation model and results

Neutron transport calculations were carried out by means of the MCNP-4C2 code and data package [3] for a model of a minor actinides burner. Our calculation model is very close to that used in Ref. [4], which is a slight modification of the model that was proposed by the NEA of the OECD as numerical exercise for a spallation based ADS [5]. Core and reflector data are those of an optimized reference system, which has been derived from an advanced liquid metal reactor. The cylindrical system shown in Fig. 2 is the basis for the various models, which were calculated. The core is loaded with uranium-free fuel composed of plutonium and minor actinides in a mass ratio, which is representative for the class of MA burners presently considered worldwide. Pb-Bi eutectic is used as spallation target, buffer and as coolant of core and reflector. The proton beam will be injected from above centrally onto the target. The isotopic nuclear densities of the material zones were taken from Ref. [4].

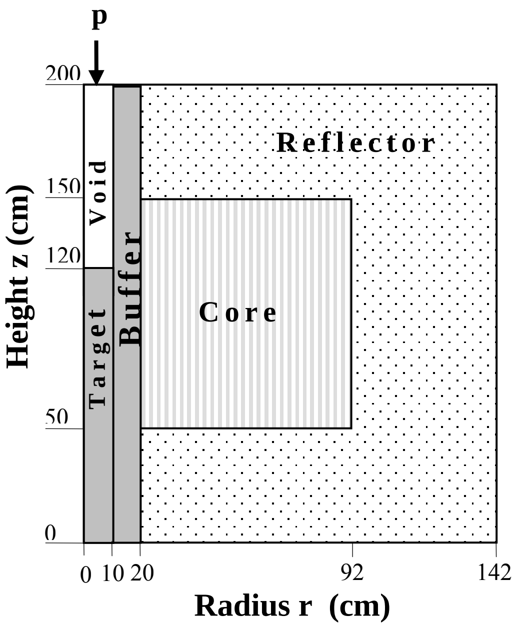

Fig. 2: (r,z) geometry model of the actinides burner with spallation target, from Ref. [4].

Neutron transport calculations were done for several configurations: **A** – the configuration as shown in Fig. 2; **B** – the configuration in Fig. 2, but, without target and buffer and with the DT fusion source that was modelled as homogeneous cylinder with radius r=10 cm, height h=50 cm (for the “basic version”) and positioned in the centre of the system; **C** – the configuration of system B, but, with buffer; **D** –the “long version” where we enlarged the system C in relation to the 1.5 m source height. For each of the systems two types of transport calculations were performed – with a given outer source and a reactor criticality calculation. The first pre-calculations of the MA burner with the different driven system were presented in detail in Ref. [6].

The most important integral parameter is the effective multiplication factor k_{eff}, which is defined as the maximum eigenvalue of the so called stationary reactor equation. For a sub-critical system is $k_{eff}<1$, whereas for a stationary (critical) reactor is just $k_{eff}=1$.

Other important parameter of a sub-critical reactor system are:

M_{eff} – mean number of neutrons emitted from fission reactions in a fission chain that was initiated by one fission neutron of the sub-critical reactor. This quantity is designated as multiplicity of a fission neutron and is related to k_{eff} by $M_{eff} = k_{eff} / (1 - k_{eff})$.

h_{fis} – Mean energy released by fissions per source particle in MeV (“fission heating”). With this quantity the fission power P_{fis} released in the core, can be calculated for a given source intensity S according to: $P_{fis} = S \cdot h_{fis}$.

P_{el}^{out} – the electrical output power of the system, where an efficiency of 40% was assumed for the conversion of thermal to electric power.

Q – the energy multiplication factor. For MA burners working with fast neutron spectra, where the fission represents the greater part of the transmutation reactions, Q may also be used to characterize their transmutation efficiencies.

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.

Table 1. Integral parameters of various burner variants.

	A	**B**	**C**	**D**
Reactor: k_{eff}	0.95856	0.95008	0.95817	0.95867
M_{eff}	23.1	19.0	22.9	23.2
Driven system	ADS	GDT-DS	GDT-DS+B	GDT-DS long
h_{fis} , MeV/neutron	1316	2119	2710	3827
S, neutron/s	12.5×10^{17}	1.8×10^{17}	1.8×10^{17}	3.5×10^{17}
P_{fis} , MW	263	60 (×2)	77 (×2)	204 (×2)
P_{el}^{out}, MW	105	48*	62*	163*
P_{el}^{inp}, MW	20	60	60	100
Q= P_{el}^{out} / P_{el}^{inp}	5	0.8	1	1.6

* for system with 2 burner

Table 1 gives the calculation results. The accuracy of the results was sufficiently high. For instance, the statistical errors of the k_{eff} values are not greater than 2×10^{-4}.

4. Conclusions

The most promising variant of a GDT-driven MA burner uses the optimised version of the GDT neutron source with two neutron emission zones that have been elongated to 1.5 m and requires a power input of 100 MW. In result, the system with the two MA burners driven by one "long" GDT neutron source can produce about 400 MW of fission power with an energy multiplication factor $Q\sim2$.

Acknowledgment

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