SOURCE OF RADIATION EMISSION WITH A PLASMA-PHYSICAL ACCELERATOR OF A LINEAR CONFIGURATION

Demin A.S., Polozkov S.D., Bedenko S.V.
School of Nuclear Science and Engineering, National Research Tomsk Polytechnic University, 634050, Tomsk, Russian Federation, email: asd47@tpu.ru

Introduction

The possibility of creating technical means for controlling the processes of accumulation and conversion of the energies of thermal and epithermal neutrons into the energy of monoenergetic photons emission due to neutron pumping of an active medium consisting of nuclei with long-lived isomeric states is studied in this work.

The system (Fig. 1) under study consists of an external pulsed source of D–T neutrons based on an extended gas-dynamic magnetic trap (denoted in [1] as Plasma Source Neutrons, PSN) and a subcritical blanket [2], which includes a variable-geometry neutron-collimation beam-shaping assembly (variable neutron-collimation Beam-Shaping Assembly, vBSA) [3] and an active medium.

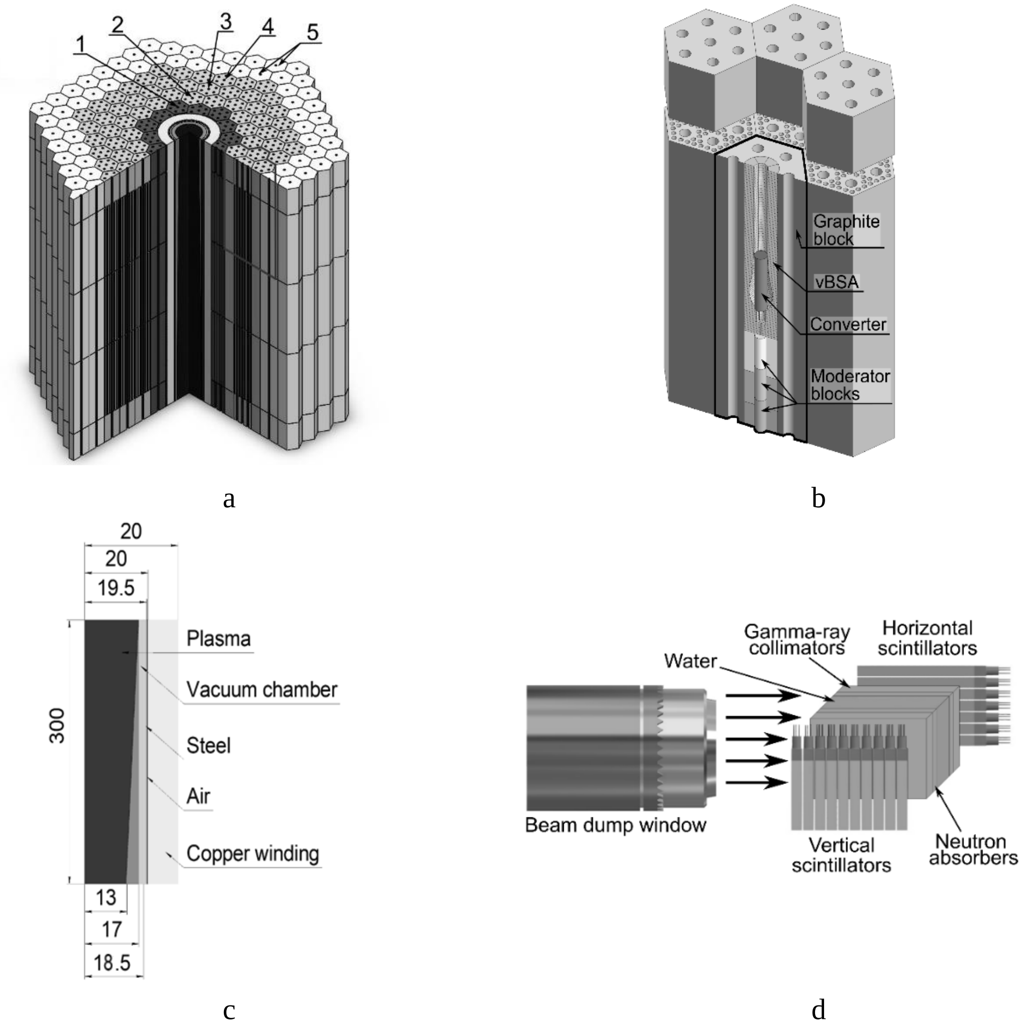


Fig. 1. Schematic view of the solution design for conjugate facility «blanket – PSN – vBSA»:
a – blanket with a modified paraxial region for PSN (1 – one row of columns of fuel-free blocks, 2-4 – three rows of columns with fuel blocks, 5 – reflector);
b – vBSA with active medium (converter);
c – cross section of the 3D PSN model;
d – vBSA exit window and TENIS system

The vBSA is a sophisticated configuration that consists of moderating blocks and selective plates, which are specifically designed to confine and shape a pulsed neutron flux. The objective of the vBSA is to convert the millisecond signature of the neutron flux into a monoenergetic photon emission, which is crucial for many scientific and medical applications.

Gadolinium oxide enriched in ^{155}Gd isotope is used as the active medium; as the main pump scheme, the channel of formation of ^{156}Gd isotope nuclei in the inverse state is studied, the de-excitation of which is accompanied by the emission of an intense gamma line with a wavelength of $\sim 10^{-4}$ nm [4].

The possibility of accumulating excess energy formed by a pair of stable isotopes of gadolinium ^{155,156}Gd was shown in [4]. Achievement of conditions of the inverse population of the levels of ^{156m}Gd nuclei of isotopically modified Gd_2O_3 and subsequent generation of photon emission was demonstrated in [5, 6].

The concept of a facility with a plasma-physical accelerator of linear configuration

The facility being studied consists of three parts, as shown in fig. 1. The first part is a subcritical blanket based on a multi-purpose high-temperature gas-cooled reactor unit of low power (HGTRU) [7], with a paraxial region modified under the Prompt-Subcritical Neutron scheme (fig. 1, a) [1, 2]. The second part (vBSA) (fig. 1, b) [3] with an active medium of Gd_2O_3 (converter) [6]. The third part is the PSN (fig. 1, c).

The blanket is constructed by assembling unified hexagonal fuel blocks (multiplicative part) and non-fuel graphite blocks (reflector). The PSN scheme is a cylindrical, axially symmetrical, extended vacuum chamber designed to hold high-temperature D−T plasma using a magnetic field. The diameter and length of the cylindrical chamber for the generation of D−T neutrons match the dimensions of the modified blanket region. The vBSA, with a cylindrical capsule of Gd_2O_3, replaces the upper fuel block (outlined in fig. 1, a) of the multiplicative part. Since the active medium is sensitive to the parameters of the neutron flux [6], the facility is equipped with a beam extraction window and a ThErmal Neutron Imaging System (TENIS) [8]. This system allows for the visualization and control of the neutron flux parameters inside the vBSA. TENIS, shown in fig. 1, d, is placed coaxially with the vBSA in the upper reflector.

Methodology

Certified programs, Serpent 2.1.31 (JENDL-4.0) and SolidWorks, were utilized to perform neutronic, thermophysical, and heat-hydraulic studies of the blanket parameters. For the first step, input sets of PSN parameters were taken from, specifically the optimal variant v8 and Table 2 of this work [2]. In the second step, hydraulic CFD modeling was performed for both the basic blanket loading option and the optimized option, taking into account the spatial energy distribution from the results of the neutronic and thermophysical simulations obtained in the first step.

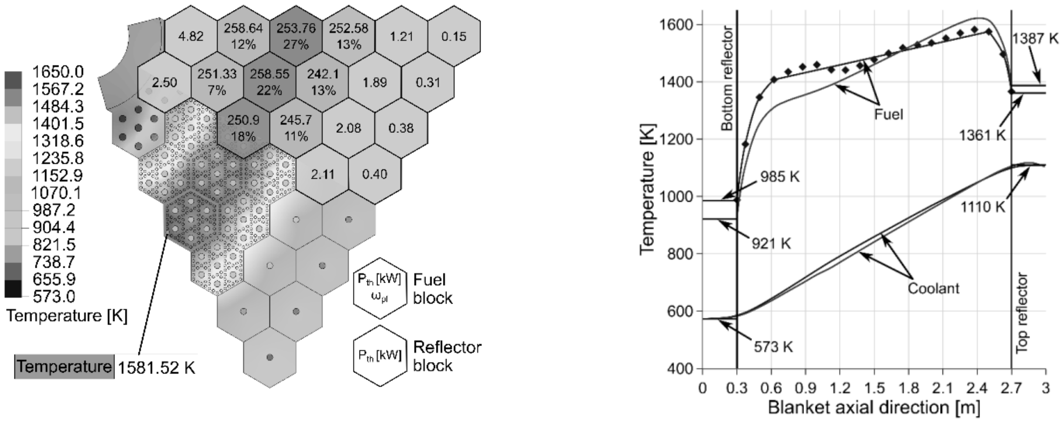
Results

At the first step in neutronic studies, the calculations of reactivity compensation were made by involving BPs and constant reactivity compensators. As a result, it was established that the best method of reactivity compensation was to cover the fuel pellet with a micronic-layer of ZrB_2. By utilizing a 100 μm thick ZrB_2 layer, the blanket can be transferred to a subcritical mode of operation with a subcritical multiplication factor of $k_{subcritical} = 0.95$. This corresponds to a neutron amplification value of 20.

Thermophysical and heat-hydraulic optimization of the blanket was performed according to the energy distribution profile along the radius by changing the volume fractions of the dispersed phase ω_{pf}, which was 17 % for the basic non-profiled load. The result of optimizing the blanket loading scheme is illustrated in fig. 2. Fuel blocks of rows 2–4 were loaded with fuel where were ω_{pf} = 7 %, 11−13 %, 18 %, 22 %, and 27 % (see fig. 2, a, upper region of the blanket sector).

Utilizing this blanket loading scheme results in a more uniform radial energy distribution profile, as depicted in the lower region of the blanket sector in fig. 2, a.

Note that for both non-profiled and profiled blankets, the maximum temperature is observed in the fuel columns of the third row at around 2.42 meters and is equal to 1622.66 K and 1581.52 K (see fig. 2, b). As shown in fig. 2, b, the axial offset of the temperature profile of the maximum-loaded column of the third row for both non-profiled and profiled blanket demonstrates a decrease in temperature gradients in both the multiplicative part and the areas where the PSN and vBSA are placed. In the region where the vBSA is located, the temperature change in the axial direction does not exceed 84.21 K for fuel and 157.13 K for helium.



a b

Fig. 2. Optimized neutronic, thermophysical and hydraulic parameters of the blanket:
a – radial relative power and temperature distributions;
b – axial temperature profile

Overall, the obtained parameters of the devices under study demonstrate satisfactory agreement with the parameters of reference facilities of this class.

Conclusions

This work presents a report on the feasibility study on creating an installation for controlling the processes of accumulations and conversion of the energy of thermal and epithermal neutrons into the energy of monoenergetic photons due to neutron pumping of the active medium formed by nuclei with long-lived isomeric states.

The synergy among the «blanket – PSN – vBSA» proposed in this study, which spatially combines vBSA, an active medium, and a subcritical blanket with PSN, creates a possibility to employ these systems in the development of a technique that generates radiation with parameters suitable for use in pulsed energy.

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