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Development of the reactor lithium ampoule device for research of spectral-luminescent characteristics of nuclear-excited plasma

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HIGHLIGHTS

- The development procedure of the ampoule device for experiments with nuclear-excited plasma under neutron irradiation is described.
- The methods of nuclear reactions' energy conversion into the energy of optical radiation of nuclear-excited plasma are presented.
- A scheme of reactor experiments, the experimental facility and experimental device to carry out the reactor experiments are considered.

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ABSTRACT

This paper describes the development procedure of the reactor ampoule device to perform the experiments on study of spectral luminescence characteristics of nuclear-excited plasma formed by products of $^{6}Li(n,\alpha)^{3}H$ reaction under neutron irradiation at the IVG.1 M research reactor.

The methods of nuclear reactions' energy conversion into the energy of optical radiation of nuclear-excited plasma are presented. A scheme of reactor experiments, the experimental facility and experimental device to carry out the reactor experiments are considered in paper. The designed ampoule device is totally meets the requirements of irradiation experiments on the IVG.1M reactor.

1. Introduction

Spectral studies of optical radiation produced by nuclear-excited plasma are of interest to solve the problems associated with searching of the working gaseous medium with high conversion efficiency of nuclear reactions energy to the energy of laser or spontaneous radiation [1,2]. Such a medium can be used to extract the energy from fission or fusion reactors as optical radiation, and to control and adjust the reactor parameters [3,4].

Despite the fact that the study of optical characteristics of gaseous medium (based on noble gases and their mixtures) excited by ionizing radiation began more than 50 years ago, investigations in this area shall not be considered as complete [5].

Currently, at the Institute of Atomic Energy NNC RK (Kurchatov, Kazakhstan) the activities have been started to perform the reactor experiments on study of luminescence characteristics of gaseous medium excited by ionizing radiation.

In this paper the experimental facility and reactor ampoule device (AD) with experimental cell (with lithium layer inside) are detailed.

2. Experimental part

2.1. Methods of gas excitation by products of nuclear reactions

In experiments at fission reactors the direct excitation of active gaseous medium was performed, as a rule, using the products of exothermic nuclear reactions that occurred during the interaction of thermal neutrons with ^{10}B, ^{6}Li, ^{235}U, ^{239}Pu, ^{3}He nuclei [1,2]:

$$^{10}B + n \rightarrow {}^{7}Li\,(1.47\text{MeV}) + {}^{4}He\,(0.84\text{ MeV}) \quad (1)$$

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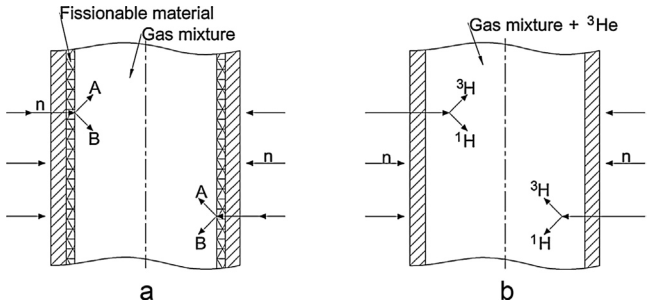

Fig. 1. Gaseous medium excitation methods: a – surface sources (Reactions (1)–(4)); b – volume sources (Reaction (5)).

$$^{6}Li + n \rightarrow {}^{4}He\,(2.73\ \text{MeV}) + {}^{3}H\,(2.05\ \text{MeV}) \quad (2)$$

$$^{235}U + n \rightarrow ff\,(99.8\ \text{MeV}) + FF\,(66.2\ \text{MeV}) \quad (3)$$

$$^{239}Pu + n \rightarrow ff\,(100.0\ \text{MeV}) + FF\,(71.5\ \text{MeV}) \quad (4)$$

$$^{3}He + n \rightarrow {}^{3}H\,(0.19\ \text{MeV}) + {}^{1}H\,(0.57\ \text{MeV}) \quad (5)$$

The cross-sections of these reactions for thermal neutrons comprise (in barns): 4010 (^{10}B), 945 (^{6}Li), 582.9 (^{235}U), 742 (^{239}Pu), 5400 (^{3}He) [6].

For effective excitation of gaseous medium it is necessary for the isotopes interacting with neutrons to be in direct contact with the gaseous medium.

There are two possible methods of plasma ionization and excitation by the energy of nuclear reactions:

use of surface sources of charged particles (the inner surface of laser chamber is coated by a thin layer of ^{10}B, ^{6}Li, ^{235}U isotopes or its compound $^{235}UO_2$ and $^{235}U_3O_8$ (see Fig. 1a));

use of volume sources of charged particles (gas or its compound ^{3}He, $^{235}UF_6$, $^{10}BF_3$ is included in the working mixture (see Fig. 1b)).

In this research a surface method and ^{6}Li(n,α)^{3}H reaction not used before were selected for gaseous medium excitation.

2.2. Design of experiments

At spectral studies of the optical radiation produced by nuclear-excited plasma the measurements must be conducted directly at operating reactor. The difficulties associated with this process are in a biological shield under minimal losses of optical radiation and difficult spectral registration at the reactor. The first difficulty is solved by selection of specific design of experimental facility and AD; the second one is solved by application of photoelectric method of optical radiation registration.

Fig. 2 presents the scheme of experiment to study of optical radiation of nuclear-excited plasma formed by ^{6}Li(n,α)^{3}H nuclear reaction products. Optical radiation (6) from the ampoule, occurred in result of studied gas mixture excitation by nuclear reaction products is collected from the ampoule through quartz window (7) and, reflecting by hinged mirror (8) it gets to focusing lens (9). Then through optical fiber (10) the light directs to entrance of optical spectrometer (14) and entrance slit of monochromator (11) with photoelectric multiplier (12), operating in photon-counting mode. Luminescence spectrum obtained by optical spectrometer is recorded by computer (15).

2.3. Experimental ampoule device

To perform the reactor experiments upon the scheme presented in Fig. 2, the AD with surface source of charged particles was designed (see Fig. 3). As a source of charged particles a thin layer of lithium deposited on the inner surface of experimental cell of the

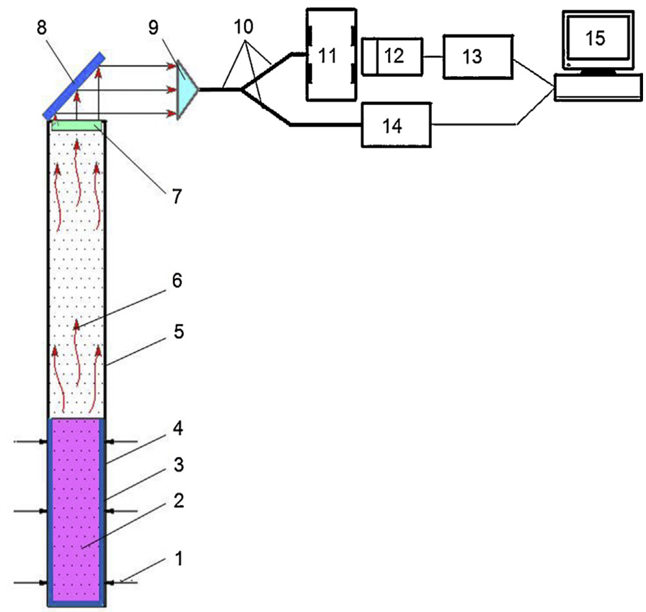

Fig. 2. Scheme of experiments on study of optical radiation of nuclear-excited plasma: 1 – thermal neutron flux; 2 – gas mixture exited by ^{6}Li(n,α)^{3}H reaction's products; 3 – Li layer; 4 – experimental cell; 5 – housing of ampoule device; 6 – optical radiation; 7 – quartz window; 8 – hinged mirror; 9 – collimator; 10 – optical fiber; 11 – monochromator; 12 – photosensor; 13 – oscillograph; 14 – optical spectrometer; 15 – PC.

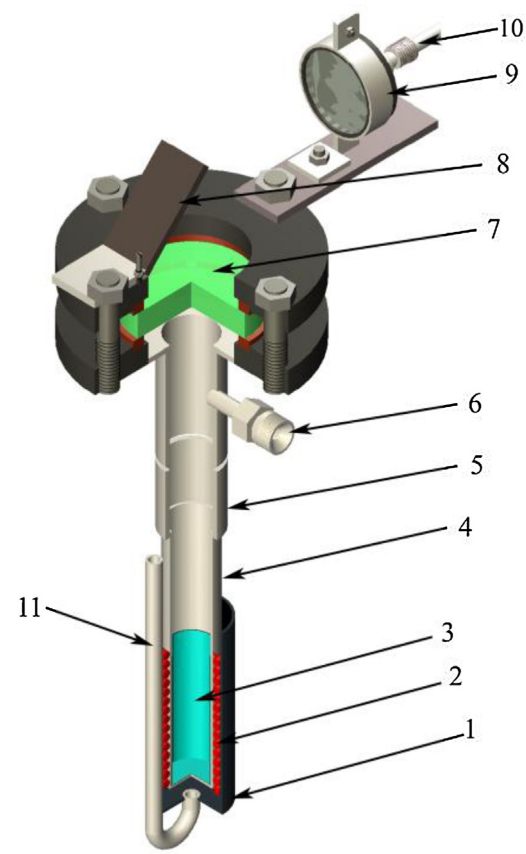

Fig. 3. Reactor AD for studies of optical radiation of nuclear-excited plasma: 1 – cooling casing; 2 – heater; 3 – (lithium) fissile materials thin layer; 4 – experimental cell body; 5 – AD body; 6 – gas mixture pumping and supply tract; 7 – quartz window; 8 – hinged mirror; 9 – collimator; 10 – fiber-optic lightguide; 11 – cooling tract.