Experimental facility for reactor experiments on study of spectral-luminescent characteristics of nuclear-excited plasma

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Abstract. The description of experimental facility and reactor ampoule device for carrying out the experiments on study of spectral-luminescent characteristics of nuclear-excited plasma formed by products of $6\text{Li}(n,\alpha)\text{T}$ nuclear reaction under conditions of neutron irradiation is given in paper.

1. Introduction
Direct conversion of nuclear reactions’ energy is a promising trend in the field of producing large amounts of light energy, including its most perfect form - coherent light. Exceptional features of nuclear power sources such as high power density, small size, the ability to effectively excite and ionize large amounts of active gaseous media at high pressures, give a certain potential advantages over other traditional methods of active media excitation [1]. There are two possible ways of nuclear energy conversion into the energy of coherent light emission: direct and combined nuclear pumping [2]. The efficiency of nuclear energy conversion into laser emission depends on the choice of the active gaseous media excited by the products of nuclear reactions. In this connection, the spectral study of optical emission of nuclear-excited plasma is of interest to solve the problems associated with finding of gaseous media with high efficiency of nuclear reactions energy conversion into energy of laser or spontaneous emission. This paper describes the ampoule device and experimental facility for study of spectral-luminescent characteristics of gaseous media, excited by the products of nuclear reactions in the IVG.1M research reactor. In the experiments on studies of the gaseous mixtures luminescence efficiency for ionization and excitation of gas mixtures was chosen $6\text{Li}(n,\alpha)\text{T}$ reaction which was not used before.

1. Experimental part
1.1. Methods of gas excitation by nuclear reactions’ products
For the effective excitation of gas media it is essential that isotopes interacting with neutrons must be in direct contact with gas medium. There are two possible methods of nuclear reactions energy use for ionization and excitation of plasma – use of surface sources of charged particles (inner surface of laser chamber is coated by thin layer of isotope $^{10}\text{B}$, $^{6}\text{Li}$, $^{235}\text{U}$ or its compound $^{235}\text{UO}_2$, $^{235}\text{U}_3\text{O}_8$) and volume

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sources of charged particles (gaseous isotope or its compound: \(^3\)He, \(^{235}\)UF\(_6\), \(^{10}\)BF\(_3\) include in composition of working mixture).

Figure 1 shows the scheme of experiment to study optical radiation of nuclear-excited plasma formed by nuclear reaction products. For the ionization and excitation of gas media in experiments performed at stationary reactor IVG.1M, was selected a reaction \(^6\)Li(n,α)\(^4\)He(2.73 MeV) + \(^3\)T(2.05 MeV)

\[
(\text{\textsuperscript{6}Li} + \text{n} \rightarrow \text{(\textsuperscript{4}He \text{ (2.73 MeV) + (\textsuperscript{3}T \text{ (2.05 MeV))}})}
\]  \hspace{1cm} (1)

The cross-section of this reaction is 945 barns \([3, 4]\). In addition, surface method using charged particles was selected for gas media excitation.

1.2. The scheme of reactor experiments on study of luminescence of gaseous mixtures

Figure 1 shows the scheme of experiments on study of optical emission of nuclear-excited plasma formed by nuclear reaction’s products during thermal neutrons interaction with charged particle’s sources.

Light radiation (4) from the ampoule, occurred in result of studied gas mixture excitation by nuclear reaction products is removed from the ampoule through quartz window (6) and, reflecting by hinged mirror (7) it gets to focusing lens (8). Then through optical fiber (9) the light directs to entrance of optical spectrometer (13) and entrance slit of monochromator (10) with photoelectric multiplier (11), operating in photon-counting mode. Luminescence spectrum obtained by optical spectrometer is recorded to computer (14).

The IVG.1M research reactor used as a source of neutron flux for nuclear reactions and excitation of gaseous mixture.

1.3. IVG.1M research reactor

The IVG.1M reactor – a water cooled heterogeneous research nuclear reactor on thermal neutrons with water moderator and beryllium neutron reflector.

The main parameters of the IVG.1M reactor:

- thermal power – 30 MW
- effective core size – 548 mm
- core height – 800 mm
- uranium-235 content in core – 4.6 kg
- thermal neutron flux density in center of experimental channel – \(3.5 \times 10^{14} \text{ n/cm}^2 \cdot \text{s}\).

In Table 1 the neutron flux at the reactor power 6 MW is presented.

| Energy group | from 0 to 0.67 eV | from 0.67 to 0.1 \times 10^6 eV | from 0.1 to 10 MeV | Integral flux |
|-------------|------------------|-----------------|------------------|--------------|
| Neutron flux, 1/(cm\(^2\)-s) | 1.087 \times 10^{14} | 0.42 \times 10^{14} | 0.22 \times 10^{14} | 1.5 \times 10^{14} |

1.4. Experimental bench

The LIANA experimental facility is designed to carry out studies on hydrogen isotopes mass-transfer processes in structural materials of fission and fusion reactors under neutron irradiation in the IVG1.M research reactor \([5]\). For reactor investigations of spectral-luminescent characteristics of nuclear-excited plasma the modernization of experimental facility was made. The modernization consists of: finalization of the exhaust system and a complete set of information measuring complex (IMC) with equipment and devices, which convert the measured optical characteristics of the light emission of nuclear-induced plasma in records of registration devices. Figure 2 shows a schematic diagram of the LIANA experimental facility after modernization. The developed additional systems marked with dotted lines.
Figure 1. Scheme of experiments on study of optical radiation of nuclear-excited plasma.

Figure 2. Scheme of LIANA experimental facility for experiments on study of spectral-luminescent characteristics of gaseous mixtures.

1 – experimental ampoule device; 2 – monochromator with PEM; 4 – digital oscillograph; 5 – computer; 6 – mass-spectrometer; 8, 17, 20 – manual operated valves; 9 – tank; 10 – gas mixture purification system; 11 – gas mixture preparation system; 12 – nitric trap for for-vacuum pump; 13-for-vacuum pump; 14 – high-vacuum pump; 15 – pressure sensor; 16 – gas regulator; 18 – vacuum-meter VDG-1; 19 – mechanical vacuum valve.

The LIANA experimental facility consists of ampoule device with experimental cell (where the investigated sample of gas mixture is placed) and operational unit (marked with red line in Figure 3). Operational unit consists of vacuum system, ampoule device gas feeding system and informational and measuring complex. Vacuum system allows prepare the facility to work, to create the necessary conditions for experiments and prepare the investigated gaseous mixture of three gases of different concentrations and pressures. Exhaust system provides pumping of investigated gaseous mixture from tank to experimental cell of AD through filtration system. Filtration system was included in exhaust system especially to remove impurities (N₂, CO₂, O₂, H₂, etc.). These impurities appear in gaseous mixture during experiments preparation and lead to decreasing of luminescent properties of gaseous mixture. Purification includes a blowing of gases through absorbing device (titanium and copper oxide with temperature of 923 K). Informational and measuring complex provides control and operation of facility’s parameters during experiments (see Figure 3).
1.5. Experimental reactor ampoule device
To perform reactor experiments upon the scheme presented in Figure 2, the ampoule device (AD) was specially designed with surface source of charged particles (see Figure 3). As source of charged particles as was stated above the natural lithium coating by thin layer to the inner surface of experimental cell of the ampoule device was used (natural composition of lithium isotopes $^6\text{Li}$ (7.5 %) + $^7\text{Li}$ (92.5 %). Given below are technical characteristics of ampoule device (Table 2).

![Figure 3. Scheme of modernized IMC of LIANA facility.](image)

| Item                              | Value                  |
|-----------------------------------|------------------------|
| AD length, mm                     | 2300                   |
| AD diameter, not more, mm         | 40                     |
| Experimental cell’s length, mm    | 200                    |
| Experimental cell’s diameter, mm  | 20                     |
| Fissionable material              | natural Li             |
| Lithium layer thickness, µm       | 50                     |
| Analyzed gases and mixtures       | He, Ar, Ne, Kr, Xe     |
| Electric heater capacity, from W  | 400                    |
| Thermocouple’s material (ChA)     | chromel-alumel         |
| Analyzed pressure of gases in AD, atm | from 0.05 to 1       |
| AD, experimental cell body’s material | stainless steel 12Ch18Ni10Ti |

1.6. Technique of reactor experiments
Reactor experiments to study spectral luminescent characteristics of gaseous mixtures excited with nuclear reaction $^6\text{Li}(n,\alpha)^3\text{T}$ products will be carried out using the designed ampoule device according to the following scheme:

- Ampoule device is loaded in experimental channel of IVG.1M reactor. Thus, AD experimental cell was placed at the level of reactor core center.
- Hereafter, the estimation of reactor reactivity change made by ampoule is carried out and thereafter all necessary technological procedures on preparation of loaded irradiated ampoule device and LIANA bench to carry out reactor experiments were conducted.
Then, prior to reaching the targeted level of power with a reactor, the studied premixed gas accumulated in the reserve storage (9) (see Figure 2) is supplied into the ampoule device capacity up to required pressure.

After this, the reactor is set on the targeted level of power and the measurements of light fluxes are carried out. The light radiation occurred as a result of excitation of studied gas mixture by nuclear reaction products influenced by neutron flux, withdraws from the ampoule through quartz window and is fed to optical spectrometer input and entrance slit of monochromator with PMT operating in photon counting mode using a collimator and optical fiber cable (with two light valves).

Then, luminescent spectrum are recorded at stationary level of power, whereafter IVG.1M reactor is set on the succeeding stationary level of power and the following measurements of light fluxes are carried out.

When luminescent spectrum of gas mixture at all studied stationary levels of reactor power are measured, the planned reactor shutdown will be done.

**Figure 4.** Scheme (a) and view (b) of reactor ampoule device for investigations of optical radiation of nuclear-excited plasma. 1 – fiber-optic lightguide; 2 – collimator; 3 – hinged mirror; 4 – quartz window; 5 – gas mixture pumping and supply tract; 6 – ampoule device body; 7 – experimental cell body; 8 – cooling casing; 9 – heater; 10 – (lithium) fissile materials thin layer; 11 – cooling tract.

**Conclusion**
Conducted out-of-pile experiments with designed ampoule device showed the reliable operation of temperature regulation and stabilization systems and also systems of studied gaseous mixtures supply and pressure control in ampoule device. Thus, the designed ampoule device completely meets all requirements of reactor experiments and is ready to conduct experiments for studying optical radiation of nuclear-excited plasma produced by nuclear reaction products in neutron radiation field of IVG.1M reactor.

**Acknowledgements**
The work supported by the Ministry of Education and Science of the Republic of Kazakhstan, Grant #2068/GF4.

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