SUB-CRITICAL ASSEMBLY DRIVEN BY A HIGH INTENSIVE NEUTRON GENERATOR FOR NUCLEAR SCIENCE AND TECHNOLOGY

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Abstract

In this paper a design of a small-scale set-up "Yalina" as a sub-critical assembly with thermal neutron spectrum driven by a high intensity ($I \approx 1*10^{12}$ n/s) neutron generator are described. At present experiments on neutron activation analysis, measurements of transmutation rates of long-lived fission products and neutron therapy investigations are being planned.

1. INTRODUCTION

In 1964–1988 research reactor IRT-2000 of Nuclear Power Engineering Institute of Byelorussian Academy of Science has been used as a neutron source for investigations in the field of reactor and neutron physics. With its shutdown and dismantling a problem with the neutron source for researches and applications become available.

2. EXPERIMENTAL SET-UP

The experimental set-up ″Yalina″ (Fig. 1) consists of a sub-critical assembly driven by a neutron generator and corresponding engineering systems: rabbit system, measuring and dosimetric devices, vital provision system, system of physical protection etc.

3. NEUTRON GENERATOR

The neutron generator NG-12-1 consists of a deuteron ion accelerator with magnetic separation of accelerated beam and rotating Ti-^{3}H target [1]:

- Maximal yield of neutrons - 10^{12} n/s
- Accelerating voltage - 250 keV
- Current of accelerated ions - 10 mA
- Diameter of the beam ~ 20–30 mm

The set-up enables us to carry out research using different sub-critical assemblies (arbitrary composition, geometry and neutron spectrum).

4. THE SUBCRITICAL ASSEMBLY

As the first stage the uranium-polyethylene sub-critical assembly (maximal multiplication factor ≈ 0,975) will be put into operation (Fig. 2). The core is a rectangular prism having base 400 × 400 mm^2 and height 570 mm. It is assembled from polyethylene blocks with the channels to place the fuel pins disposed in a rectangular lattice with pitch equal to 20 mm. Layout of the core of the sub-critical thermal assembly "Yalina" is shown in Fig. 3. There are four channels of ∅50 mm provided for location of detectors of neutron flux level monitoring system. A Pu-Be neutron source of sufficient intensity is provided to carry out control of nuclear chain reaction beginning from loading of the first portion of fissile material into core as well as sub-critical assembly operation. The fuel pins are made of UO_2–Mg allow with enrichment equal to 10% over ^{235}U. The sub-critical assembly contains 265 fuel pins. The fuel loading is almost optimal one. The sub-critical assembly has the reactivity compensation system. The device consists of remotely operating rods containing boron carbide.

For irradiation of investigated samples the experimental channels with diameter of 25 mm are available with radii 5, 10 and 16 cm. The core is placed into a well of a stack of graphite bricks (high purity graphite) serving as lateral reflector (300 mm thick). The sub-critical assembly is mounted on the movable platform, which allows movement of the assembly in two directions with respect to the ion beam axis. Two inclined channels were made in the graphite stack to dispose pipelines of the rabbit system. There is a possibility to place a lead target as a parallelepiped consisting of 12 fixed lead blocks with dimensions 80*80*50 mm^3 in the center of the core to increase the yield of neutrons.

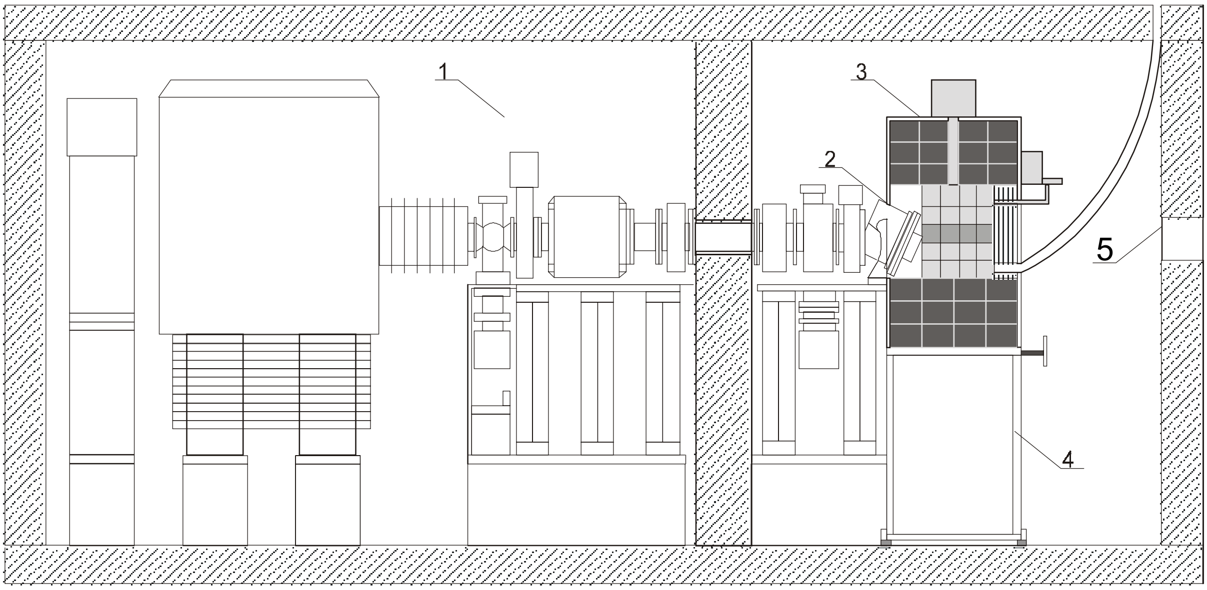

Fig. 1. The sub-critical facility "Yalina": 1 – the neutron generator; 2 – Ti-^{3}H target system; 3 –- the sub-critical assembly; 4 – movable platform; 5 – collimator.

Special attention was paid to aspects of nuclear safety of the sub-critical assembly. The proposed design and material composition of the sub-critical assembly allows to maintain pre-determined value of multiplication factor $k_{src} \leq 0.98$ for all possible variations of external factors (temperature, pressure, etc.) as well as in hypothetical case of flooding the room with water.

When elaborating the technical project the requirements being in service in the Republic of Belarus and defining conditions of nuclear as well as radiation and industry safety at all stages of creation and operation of the sub-critical facility were taken into account.

To ensure reliable and safe operation of the sub-critical facility the following main systems of vital support were provided for:

1 – control protection system; 2 – dosimetry monitoring system; 3 – alarm system; 4 – electricity supply system; 5 – physical protection system and security alarms; 6 – fire extinguishing system; 7 – water supply system; 8 – communication system; 9 – rabbit system.

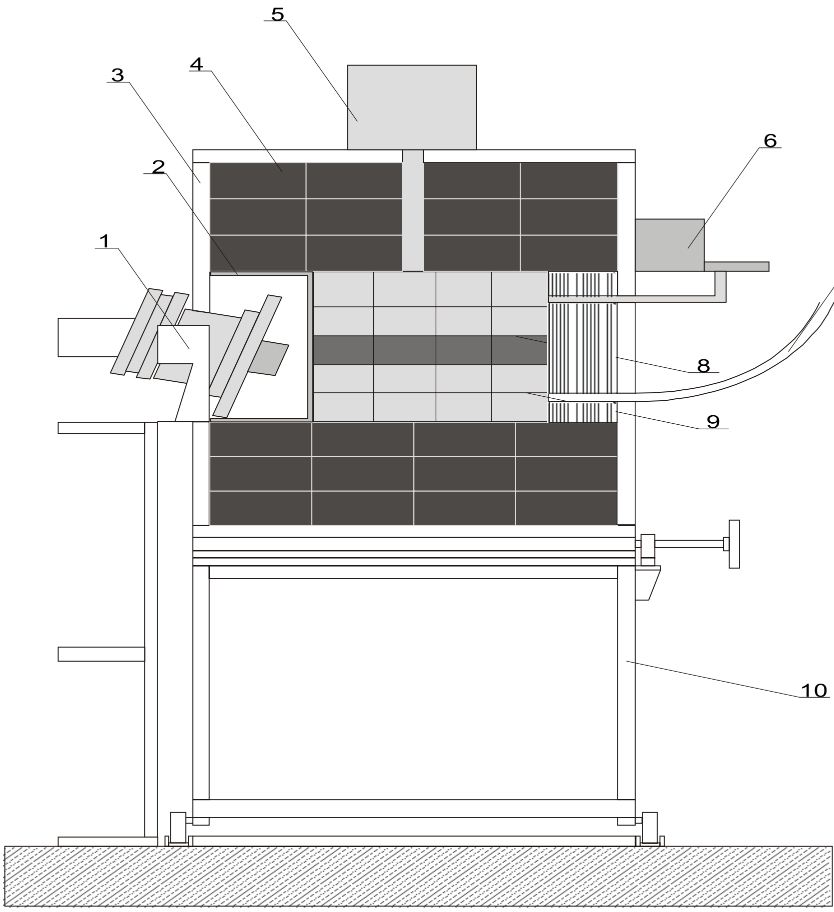

Fig. 2. The sub-critical assembly: 1 – target unit; 2 – shielding screen; 3 – cadmium screen; 4 – reactor type graphite reflector; 5 – container with starting Pu-Be neutron source; 6 – working mechanism of compensation rods; 7 – pipeline of the rabbit system, 8 – neutron producing lead target; 9 – core of the sub–critical assembly; 10 – movable platform.

When elaborating the technical project of the assembly the following main characteristics were determined:

The number of fuel pins ensuring $k_{max} \leq 0.98$ for the sub-critical assembly with chosen material composition and geometry as well as with lead target in central part of the assembly equals to 265 fuel pins**.** There is a regular set of detectors for neutron flux level monitoring system.

- Reactivity worth of a peripheral fuel pin **-** 0.22 $.
- Reactivity worth of a complete fuel subassembly containing 16 fuel pins and situated near the lead target - 5.42 $.
- Reactivity worth of a complete peripheral fuel subassembly **-** 3.25 $.
- Reactivity swing due to insertion of the lead target into central part of the sub-critical assembly **-** 1.49 $.
- Reactivity effect due to filling the sub-critical assembly with water - 0.54 $.
- Integral energy deposition rate for the assembly when operating with the Ti-^{3}H target (it is supposed that neutron intensity equals to10^{12} n/s) - 100 Wt .
- Temperature coefficient of reactivity with increase of temperature up to 100^0C - 0.2 $.
- Effective fraction of delayed neutrons β_{eff} - 0.00738.

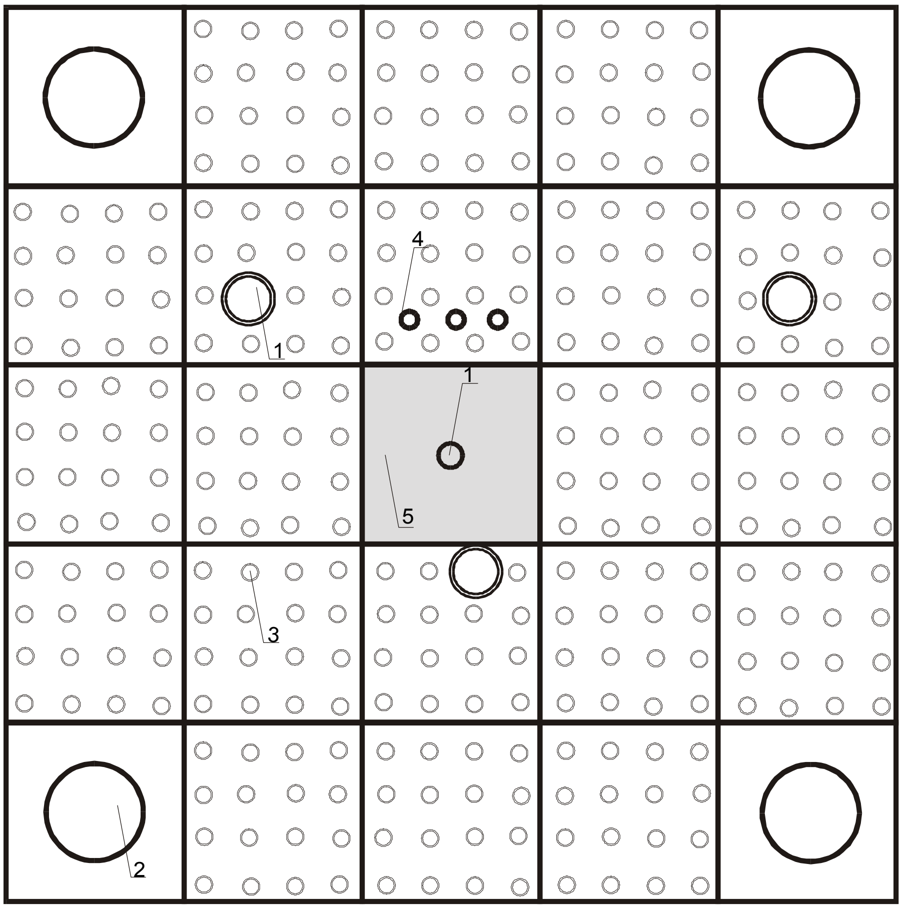

Fig. 3. The core of the subcritical assembly "Yalina": 1 – experimental channels; 2 – channels for neutron flux level monitoring system; 3 – fuel channels; 4 – channels for compensation rods; 5 – neutron producing target.

5. NEUTRONIC CHARACTERISTICS OF THE FACILITY

Calculations performed [2] have shown that in experimental channels of the sub-critical system different neutron spectra can be formed of about 3–5 10^8 n/cm^2 c. At present the assembly with thermal spectrum is constructed. Calculations have also shown that energy spectrum for the thermal assembly differs from any reactor spectra. Namely in the energy range from 1 to 10^4 eV dependence of neutron flux on energy is very weak which allows to get data on neutron cross sections for resonance region (Fig. 4). Measurements of energy spectra at different points inside the experimental channels will be performed by means of activation technique. For measurements of gamma ray spectra can be used three different HpGe detectors. Their characteristics are in the Table I.

TABLE I. CHARACTERISTICS OF HPGE DETECTORS USED FOR GAMMA SPECTRA MEASUREMENTS ON SUB-CRITICAL ASSEMBLY “YALINA”

Type of detector	Energy region (keV)	Resolution for Co	
		122 keV	1332 keV
Planar detector	10 – 1000	0.5	
Coaxial HpGe 20%	40 – 10000	0.9	1.8
Coaxial HpGe 80%	40 – 10000	1.1	2.1

Apart from thermal neutrons, (d,t) 14 Mev neutrons as well as (d,d) 3 MeV neutrons can be used for investigations on experimental set-up “Yalina”.

6. CONCLUSIONS

The design of the sub-critical set-up with "Yalina" as sub-critical assembly with thermal spectrum driven by the high intensity neutron generator ($I \approx 1*10^{12}$ n/s) is described in this paper. Instead of the former dismantled research reactor IRT-2000 this set-up can be used for number of investigations with neutrons:

1. Measurements of transmutation rates for some long-lived fission products and minor actinides.
2. Neutron activation analysis of geologic samples for investigation of rare earth elements.
3. Neutron therapy of cancer tissues.
4. Active methods of non-destructive assay of nuclear materials.
5. Creation of radioactive sources.

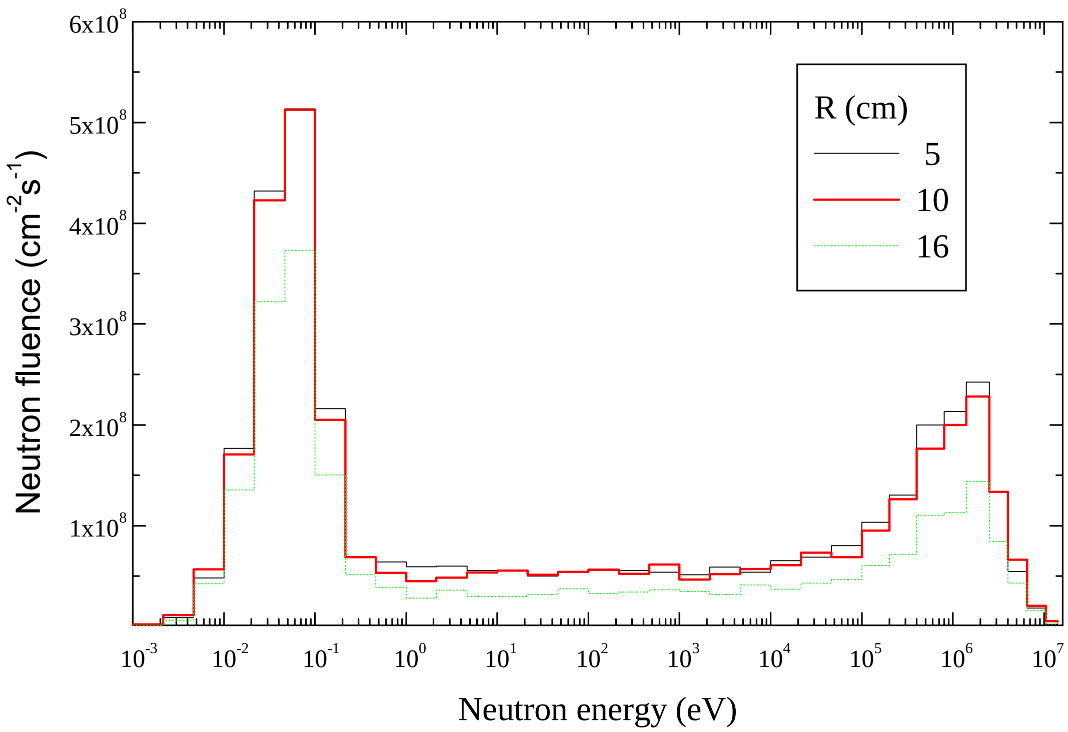

Fig. 4. Neutron spectra averaged over sample volumes in the experimental channels of the sub-critical assembly with thermal spectrum driven by the neutron generator. It is supposed that neutron source intensity equals to 10^{12} n/s.

REFERENCES

[1] BOULYGA S., GOULO V., ZHUK I., et al., “Neutron generator NG-12-1 – a basic installation for research in neutron center of the National Academy of Science” Preprint-21, The Institute of Radiation Physics and Chemistry Problems, Minsk (1998) 35p.

[2] BRIESMEISTER J., (Editor) “MCNP – a general Monte Carlo N-particle transport code” version 4B, LA-12625-M (1997) 736 p.