EXTERNAL NEUTRON SOURCE FOR RESEARCH REACTOR BASED ON LINEAR ACCELERATOR AND BERYLLIUM TARGET*

V.P. Struev[1#], A.A. Bogdanov[1], A.G. Golovkina[1,2], Yu.V. Kiselev[1], I.V. Kudinovich[1,2], A.I. Laikin[1], S.M. Rubanov[1]
[1]Krylov State Research Center, Saint-Petersburg, Russia
[2]Saint-Petersburg State University, Saint- Petersburg, Russia

Abstract

Nuclear research reactor "U-3" of Krylov State Research Center was operated as an experimental tool to study a radiation shield of small nuclear power plants, radiation resistance of its equipment including control system elements. Reactor thermal output power is 50 kW. Currently reactor modernization is being carried out, in the framework of which neutron lighting system that consists of a linear electron accelerator "UEL-10D" (10 MeV) and a beryllium target is implemented. At the present time the neutron yield from the target experiments are going on, some obtained experimental results are presented. Optimal target sizes with a view to neutron yield were defined.

NUCLEAR RESEARCH REACTOR

Nuclear research reactor (NRR) "U-3" (Fig. 1, Table 1) has been operated since 1964. It's a multipurpose pool-type thermal reactor.

Table 1: Main Technical Characteristics of NRR "U-3"

Characteristic	Value
Design power level	50 kW
Reactor core	Cylindrical
Effective diameter	390 mm
Height	500 mm
Hexahedral lattice step	17 mm
Core charge	426 fuel elements (3408 g of U^{235})
Coolant	Distilled water (free convection cooling)
Coolant temperature out	39^0C
Coolant temperature in	36^0C

Reactor "U-3" has a unique possibility of radiation in neutronic and gamma fields thanks to the presence of the experimental channels taking out neutrons beam.

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#struevvp@krylov.spb.ru

Figure 1: Nuclear research reactor "U-3".

NRR "U-3" MODERNIZATION

Nowadays the reactor technical re-equipment process is almost finished. One of the aspects of the modernization is implementation of neutron lighting system based on the linear electron accelerator UEL 10-D (Fig. 2, Table 2) and beryllium target.

After re-equipment NRR "U-3" can effectively be used as a neutrons and gamma radiation source necessary in traditional problems of technical facilities radiation (to define their radiation resistance), isotopes conversion and crystals properties improvement under radiation. Also it's planned to carry out research in the field of ADS physics.

Table 2: Main UEL 10-D Accelerator Characteristics

Characteristic	Value
Accelerated electrons energy	10 MeV
Maximal average bremsstrahlung dose rate	1Gy/e
Frequency	50, 200, 250 Hz
Source electrons energy	50 keV
Maximal output impulse power	3.1 MW
Effective diameter of the focal spot on the target	≤ 2 mm

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Figure 2: Linear electron accelerator UEL 10-D.

ADS SYSTEM MOCK UP

ADS mock up is designed on the basis of NNR "U-3" with linear accelerator UEL 10-D and beryllium target. The experimental facility layout is presented in the Fig. 3.

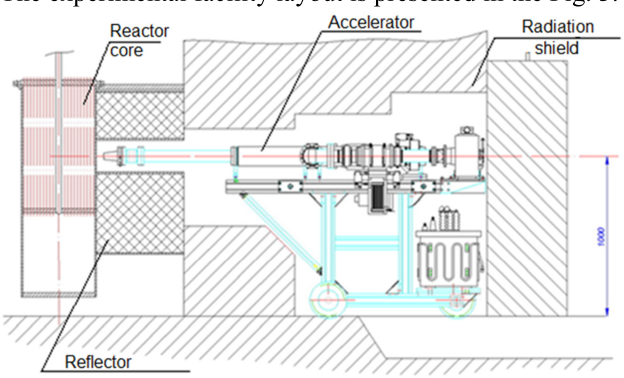

Figure 3: Layout of ADS mock up.

Beryllium target is gathered of the separate beryllium bushes with diameter 16.6 mm and height 70 mm. In order to decrease the absorption of bremsstrahlung generated by the accelerator, fuel rods are took out along the beam channel (Fig. 4).

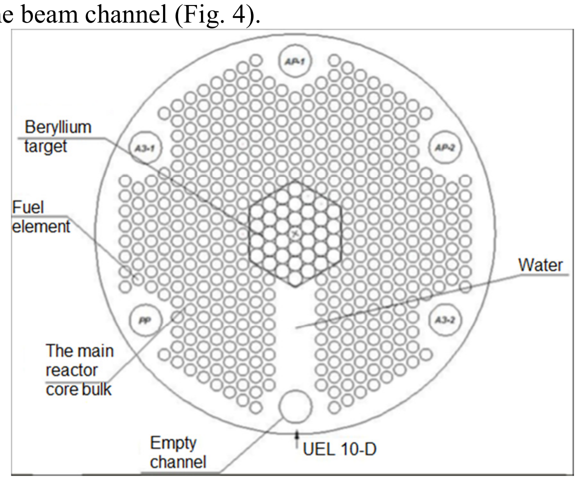

Figure 4: Reactor core with rods taken out along the beam channel.

DETERMINATION OF THE NEUTRON SOURCE CHARACTERISTICS

By now some experiment-calculated researches of external neutron source based on the accelerator UEL 10-D and beryllium target (with fuel taken out of the reactor core) were carried out.

Experiment Description

Experimental determination of the characteristics of neutrons flux from the target surface was fulfilled using activation method. Dysprosium and indium indicators were set up on the target surface and in the distance from it in order to register thermal and fast neutrons respectively (Fig. 5). The error of specific flux measurement with indicators is about 30%. In experiments accelerator work time was 10 min at the frequency 50 Hz – 25% of the available power.

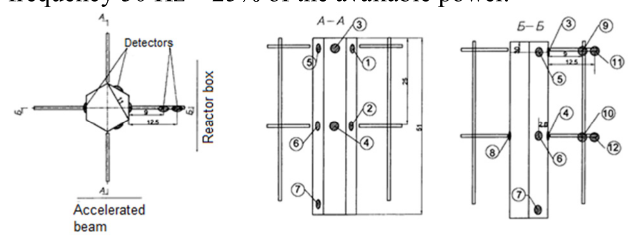

Figure 5: Detectors position layout.

Results of neutron flux density are presented in the Table 3 (detectors numbers corresponds ones in the Fig. 5).

Table 3: Measurement Results of Neutron Flux Density at the Detectors

No	Dy(β)/ therm	Dy(γ)/ therm	In(γ)/ therm	In(γ)/ 0.3 MeV	In'(γ)/ 0.3 MeV
Det 1	2.383	2.061	0.64	0.133	
Det 3	2.191	1.5	0.669		
Det 4	9.62	7.892	3.406	1.872	
Det 5	2.199	1.08	0.459		
Det 7	3.325	2.268	0.672		
Det 8	10.18	7.717	2.919	1.851	2.042
Det 9	0.24	0.238	0.146		
Det 10	2.406	1.922	0.644		
Det 11	0.103	0.078	0.043		
Det 12	0.612	0.385	0.265		

Calculation Results

For external neutron source calculation the Monte-Carlo simulation package FLUKA was used. The design scheme of the beryllium convertor is illustrated in Fig. 6.

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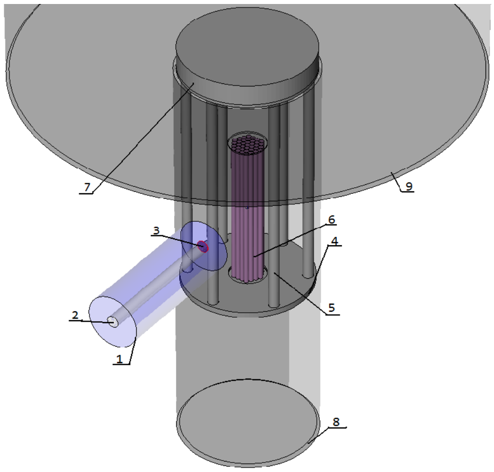

Figure 6: The design scheme of the beryllium converter arrangement in the center of the core. (FLUKA calculation model): 1 – iron housing of damper (100 mm); 2 – linac vacuum; 3 – tungsten target; 4, 7 – core support barrel; 5 – guide tube assembly; 6 – beryllium target; 8, 9 – aluminium reactor vessel.

Calculation results showed that the UEL 10-D accelerator electron beam intensity is $S_{\beta} = 3.36{\cdot}10^{14}$ e/sec. 25% of the bremsstrahlung spectrum has energy over the threshold energy for photonuclear reaction in Be.

The calculated value of bremsstrahlung on the target thickness is presented in Fig. 8. The optimal thickness of the tungsten target is 1 mm, the bremsstrahlung intensity in the forward direction with optimal target thickness is $3.85{\cdot}10^{14}$ γ/sec.

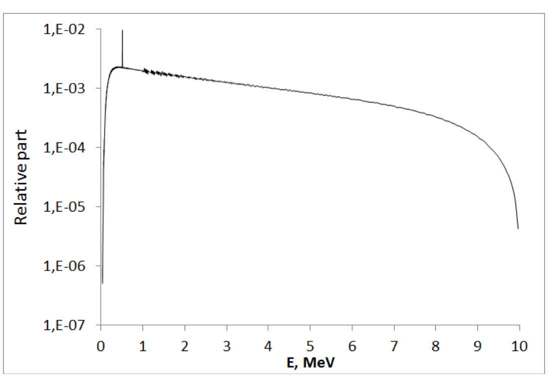

Figure 7: Bremsstrahlung spectrum (n=$5{\cdot}10^{7}$).

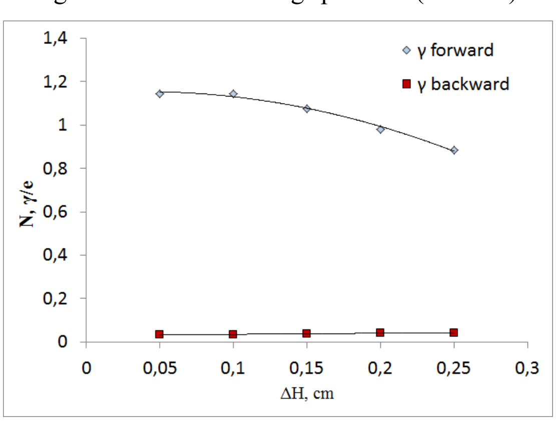

Figure 8: Yield of γ-bremsstrahlung in dependence of the tungsten target thickness in forward and back directions.

Comparison of Calculation Results with the Experiment

Comparison of specific neutrons flux calculation in FLUCA results with the experimental results for dysprosium and indium indicators is presented in Fig. 9, a) and b). Taking into account the measurement error we can conclude that calculation and experimental results are in a good correspondence.

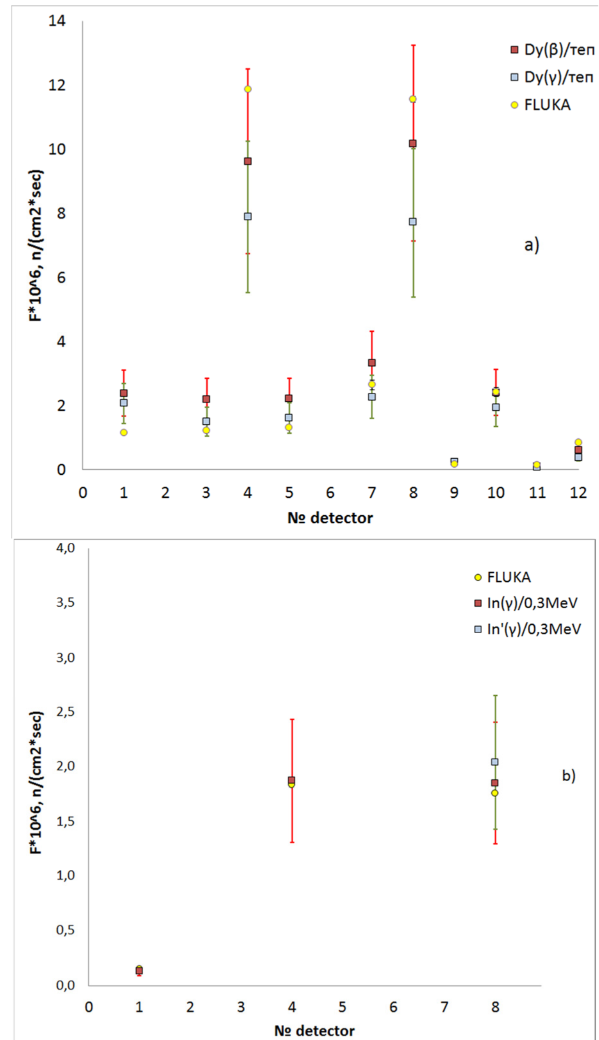

Figure 9: Comparison of specific neutron flux for two indicators types: a) Dy, b) In (n = $3{\cdot}10^{8}$).

CONCLUSION

On the basis of nuclear research reactor “U-3”, linear electron accelerator and beryllium target the ADS mock-up was created. The calculation model of Be target irradiated by electrons beam was developed. Experiments and calculations on neutron yield from the beryllium target were carried out. The results showed a good correspondence in the error limits. The specific neutron flux value reaches $8{\cdot}10^{6}$ n/cm^2·sec and $2{\cdot}10^{6}$ n/cm^2·sec in average.