

BENCHMARK EXPERIMENTS ON THE CRITICALITY OF THE HEXAGONAL LATTICE WITH 21% ENRICHED URANIUM FUEL RODS AND THE BORON ABSORBER RODS IN WATER

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Benchmark criticality experiments for hexagonal lattice of fuel and absorbing rods in water were performed using “Giacint” critical facility of the Joint Institute for Power and Nuclear Research – Sosny of the National Academy of Science of Belarus. The fuel rods pitch is 21 mm and the absorber rods pitch is 63 mm with a triangular grid. The fuel composition – UO_2 with 21% uranium-235 enrichment. The absorber composition – B_4C . The moderator and reflector - H_2O . The criticality conditions obtained by adjusting the water moderator height in the studied lattices. The results of experiments on critical assembly have been analyzed by creating detailed calculation models and performing simulations for the experiments. The analyses used the MCNP-4C and MCU-PD computer programs. In addition, the impact of using different nuclear data files are examined.

1. Introduction

This paper presents the experimental and analytical parameters of criticality of the uranium-water critical assembly with a core based on 21% fuel rods and boron absorbing rods.

The experiments were performed using the “Giacint” critical facility of the Joint Institute for Power and Nuclear Research – Sosny (JIPNR-Sosny) of the National Academy of Sciences of Belarus [1]. The experimental results were analyzed in order to estimate whether they can be used as benchmark criticality data.

2. Critical assembly

The uranium-water critical assembly represents a grid (21 mm pitch) of fuel rods, containing UO_2 with 21% uranium-235 enrichment and a grid (63 mm pitch) of absorbing rods, containing B_4C , with water moderator and reflector. The critical assembly (Fig 1) is a thermal “open tank” critical assembly, comprising the core, the side reflector, the upper and lower end reflectors, and the control rods of the control and protection system (CPS).

The uranium-water critical assembly is located in the critical assembly's tank, which represents a welded stainless steel structure 2020 mm high and 1810 mm in diameter. The tank has a top flange to fix the aluminum hoods of the neutron detectors. The core of the critical assembly comprises fuel and absorbing rods, which are fixed in the spacing hexagonal grids from 10-mm aluminum alloy with holes arranged in the hexagonal grid with the pitch of 21 mm and supported by the



Fig 1. The uranium-water critical assembly

hexagonal plate from stainless steel, 16 mm thick, with holes for the control and protection system's controls. A hexagonal upper plate from 16-mm stainless steel is arranged above the fuel rod pitch; the plate also has holes arranged in the hexagonal grid with the pitch equal to the pitch of holes in the spacing grids. The spacing grids are arranged along the upper (bottom of the grid) and lower (top of the grid) edges of the core. The support plate is arranged ~800 mm from the bottom of the critical assembly's tank.

The side water reflector has tight hoods, around the core, with neutron detectors of the control and protection system, which are fixed to the flange of the critical assembly's tank. The critical assembly includes six control and protection system's controls, which contain composite rods formed by the fuel rod and the absorber element rigidly interconnected via the adaptor. The critical assembly reactivity decreases by moving the fuel rods downwards from the core and moving the absorber elements in their place.

The critical load was achieved with a hydraulic system of "Giacint" critical facility (Fig 2). The hydraulic system is used for critical assemblies with water moderator and intended for storage water moderator, the dosed moderator supply with certain speed in a critical assembly tank, working or emergency moderator discharge from a critical assembly tank, and utilization moderator after its use. As water moderator is used the distillate or a water solution of boric acid.

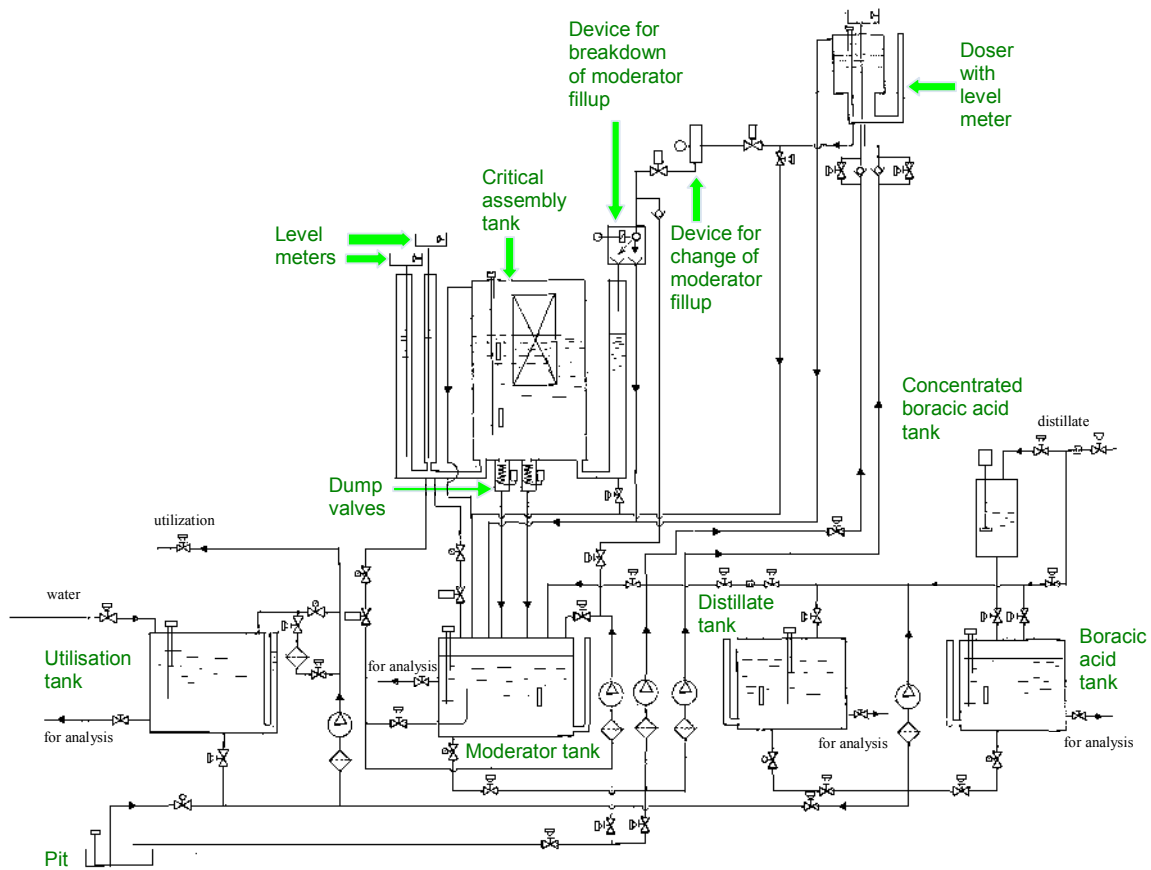


Fig 2. Hydraulic system of the "Giacint" critical facility

3. Elements of the core

Loading chart of uranium-water critical assembly shown in Figure 3.

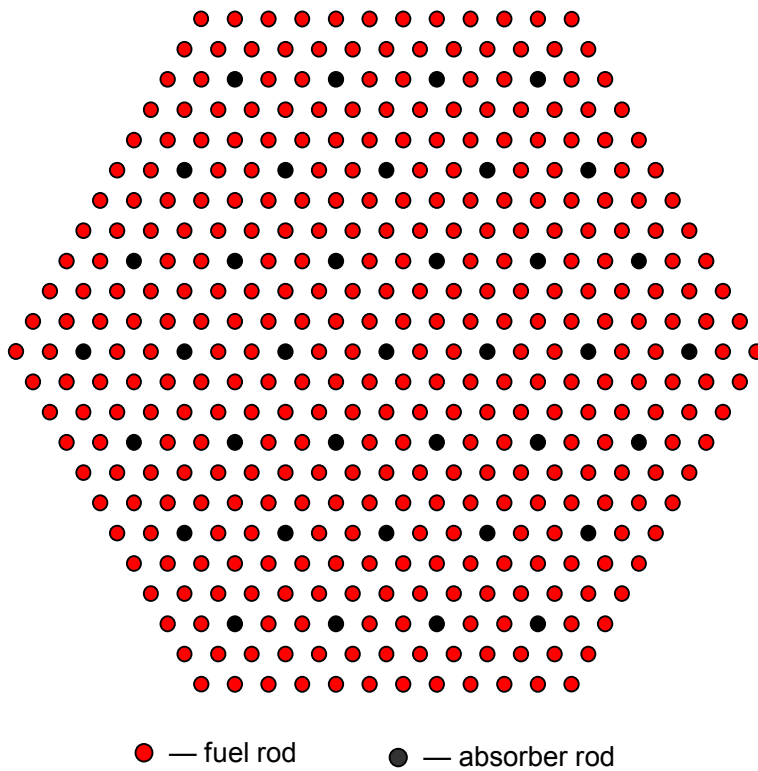


Fig 3. Loading chart of uranium-water critical assembly

The fuel rod (Fig 4) consists of a fuel core, cladding, two fixing devices, a spring and end parts, i.e., the upper and the lower plugs. The fuel rod cladding is made from stainless steel with the outer diameter 6.2 mm and the wall thickness 0.4 mm. The fuel core consists of tablets with the diameter 5.2-5.3 mm and the height 5-7 mm, made from uranium dioxide. The total height of the core is 500 mm. The average mass of fuel core is 109.776 ± 0.057 g. The average mass of uranium in the fuel rod is 96.358 ± 0.050 g. The average mass of uranium-235 in the fuel rod is 20.461 ± 0.014 g. The total length of the fuel rod is 651 mm. The fuel rod cladding has a 0.55-mm stainless steel wire coiled around the shell with the 100 mm pitch.

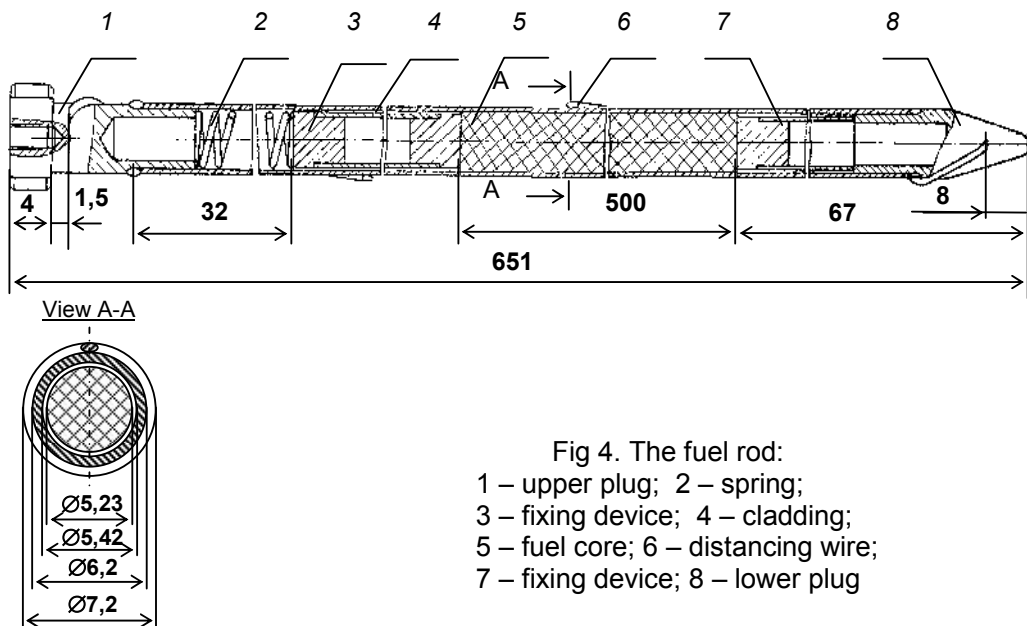


Fig 4. The fuel rod:

- 1 – upper plug; 2 – spring;
- 3 – fixing device; 4 – cladding;
- 5 – fuel core; 6 – distancing wire;
- 7 – fixing device; 8 – lower plug

The absorbing rod (Fig 5) represents a cylindrical stainless steel clad with the 6.2 mm diameter and the 0.4-mm thick wall, filled with the natural boron carbide to the 500 mm height; the mean boron carbide weight in the absorbing rod is 15.769 ± 0.053 g. The absorbing rod is sealed by welding the top (84 mm long) and lower (67 mm long) stainless steel plugs to the clad. The total length of the absorbing rod is 651 mm.

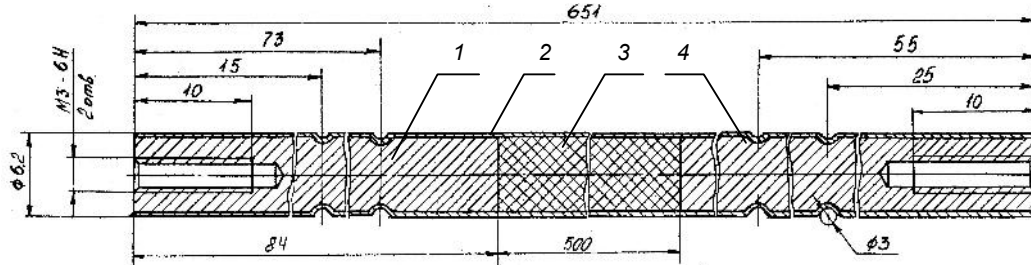


Fig 5. The absorber rod:
1 – upper plug; 2 – cladding; 3 – absorber core; 4 – lower plug

4. Neutron physical parameters of the uranium-water critical assembly

Table 1 represents critical assembly characteristics.

Configuration	Grid pitch, mm	Fuel rods, pcs.	Absorber rods, pcs.	Water critical level*, mm	Water temperature, °C	Measurement reactivity margin, β_{eff}
1	21.0±0.1	360	37	541.2±1.0	15.3±0.1	0.000 ± 0,001
2				800.0±1.0		0.127 ± 0.010

* — the level was measured from the core bottom

Tab 1: Neutron physical characteristics of the uranium-water critical assembly

The reactivity margin of the critical assemblies are measured by the experimental unit “Reactivity Meter”, using the inverse kinetics method [2]. In order to exclude spatial effects of reactivity, the measurements were made using three ionization chambers, arranged at every 120° inside the side reflector of the critical assembly.

5. Calculation results

In creating the calculated model of the uranium-water critical assembly, the following assumptions were made:

- the calculated models of fuel and absorber rods are made symmetrical;
- the calculations were made ignoring the effects of the concrete walls, ceiling and floor of the room of the critical assembly, located at a distance over 2 m away from the critical assembly, and the effects of the neutron detectors, placed about 250 mm away from the core of the critical assembly.

The calculated model of the fuel rod is presented in Fig. 6, the calculated model of the absorber rod is presented in Fig. 7, and the calculated model of uranium-water critical assembly and the calculated model position of the fuel rod (absorber rod) in the core are presented in Fig. 8.

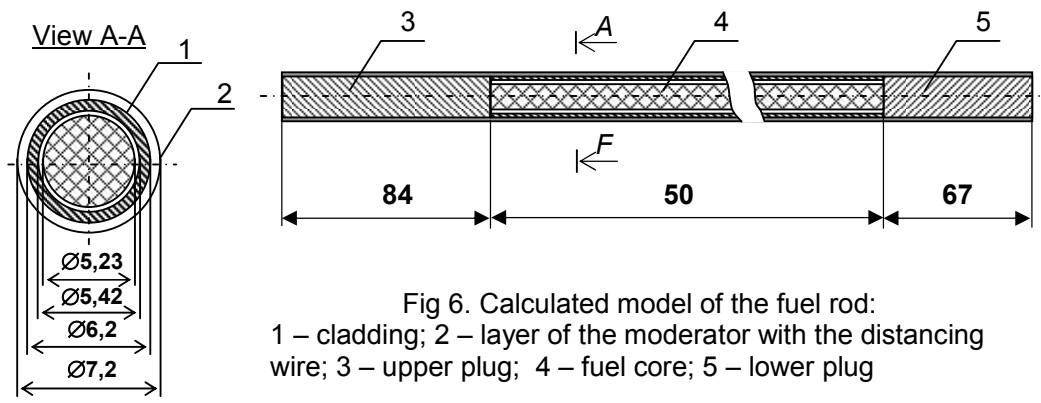


Fig 6. Calculated model of the fuel rod:
 1 – cladding; 2 – layer of the moderator with the distancing wire; 3 – upper plug; 4 – fuel core; 5 – lower plug

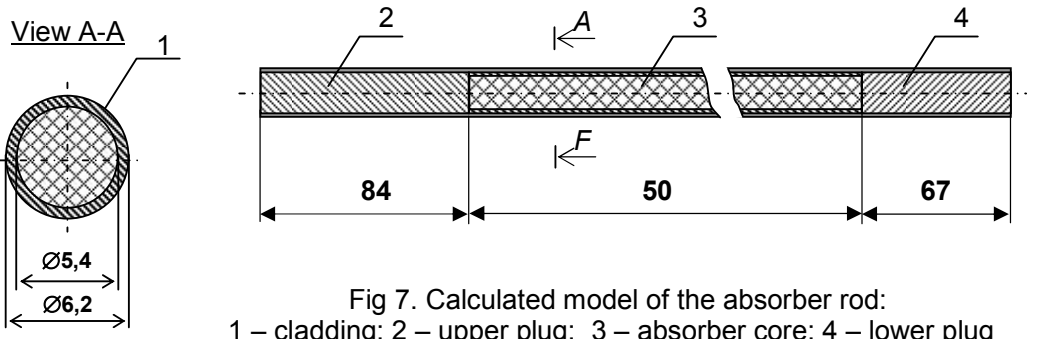


Fig 7. Calculated model of the absorber rod:
 1 – cladding; 2 – upper plug; 3 – absorber core; 4 – lower plug

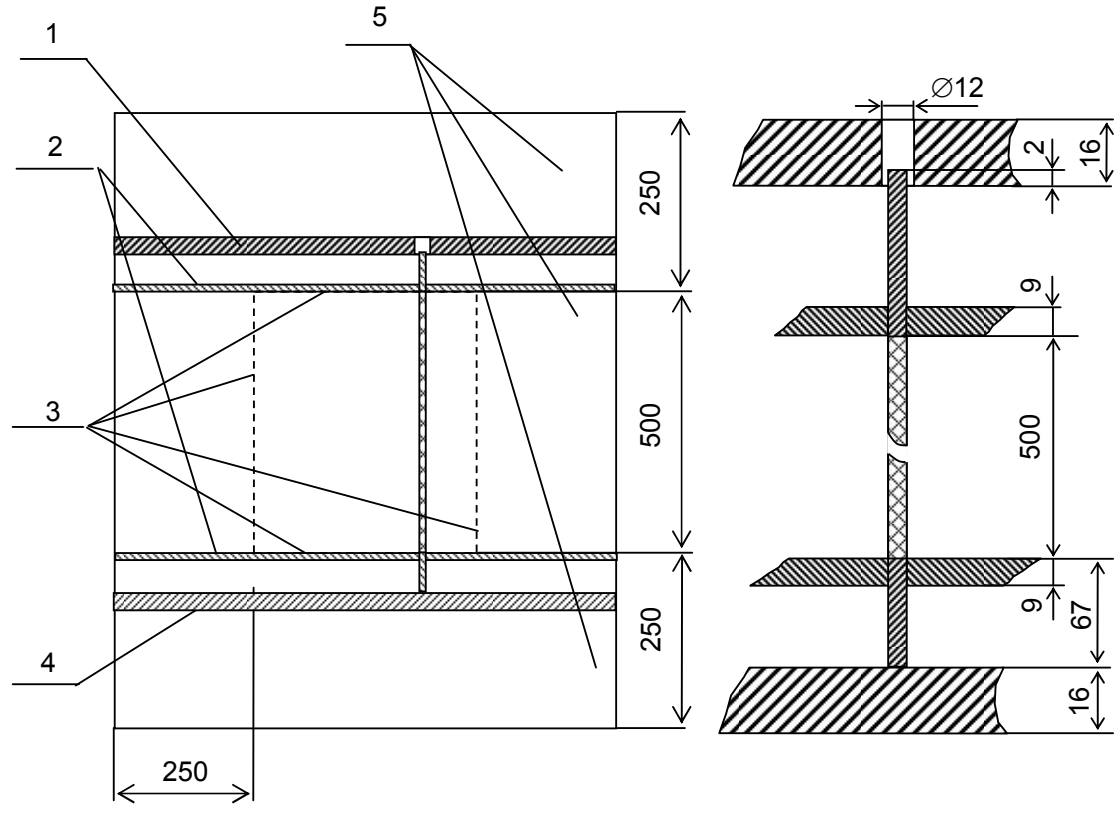


Fig 8. The calculated model of uranium-water critical assembly (moderator level 800 mm) and the calculated model position of the fuel rod (absorber rod) in the core:
 1 – upper plate; 2 – spacing grids ; 3 – core border; 4 – support plate; 5 – water moderator

For the estimation of experimental results, analytical models for each critical assembly have been constructed by using program codes MCNP-4c [3] with the ENDF/B-V nuclear data library and MCU-PD [4] with the MCUDB50 nuclear data library. The calculated values of the effective neutron multiplication factor K_{eff} , is presented in Table 2.

Configuration No.	K_{eff}	
	MCNP-4c (ENDF/B-V)	MCU-PD (MCUDB50)
1	1.00202 ± 0.00025	1.00094 ± 0.00051
2	1.00329 ± 0.00008	1.00245 ± 0.00057

Tab 2: Calculation results for uranium-water critical assembly

5. Conclusions

The experimental data received at the critical facility "Giacint" on the uranium-water critical assembly with a core based on 21% fuel rods and boron absorbing rods can be used at verification of computer codes by various libraries of the nuclear data.

6. References

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