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# Calculated Studies in Support of the Creation of a Uranium-Zirconium Hydride Critical Assembly with Low Enriched Uranium Zirconium Carbonitride Fuel

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## ABSTRACT

Uranium zirconium carbonitride UZrCN is a high density, high temperature fuel with high thermal conductivity, which has potential for use in various types of reactors, comprising research reactors, including of conversion HEU on LEU fuel. Within the Russian Research Reactor Fuel Return Program the Joint Institute for Power and Nuclear Research – Sosny of the National Academy of Science of Belarus is developing a uranium-zirconium hydride critical assembly with LEU UZrCN fuel, which will be placed on the Crystal critical facility. The critical assembly is a hexagonal lattice comprising a core, containing fuel and control rods assemblies with stainless steel claddings, surrounded by reflector assemblies and units. The fuel material is uranium zirconium carbonitride ($U_{0.9}Zr_{0.1}C_{0.5}N_{0.5}$) with ~ 12.0 g/cm$^3$ density, ~ 10.5 g/cm$^3$ uranium density and 19.75% uranium-235 enrichment. The moderator is $ZrH_{1.9}$ with 5.1 g/cm$^3$ density. Neutron absorber in control rods - natural $B_4C$. Each fuel assemblies contains zirconium hydride and 3 fuel rods in a niobium or stainless steel cladding. Side reflector: inner layer - cassettes with zirconium hydride and stainless steel claddings, outer layer - stainless steel units. This paper presents the configuration of the core and the reflector, the material composition and geometric dimensions of the components of the critical assembly, and the results of calculating by the MCU-PD and MCNP-4c codes.

## 1 Introduction

The purpose of this work is preliminary neutron-physical calculations to estimate the possibility of creating uranium-zirconium hydride critical assemblies at the Crystal critical facility [1, 2] using a set of fuel rods based on uranium-zirconium carbonitride with 19.75% enrichment on uranium-235, which were supplied in 2010 year in the Joint Institute for Power and Nuclear Research – Sosny of the National Academy of Sciences of Belarus by the Scientific Research Institute the Scientific Industrial Association "Luch" [3, 4].

## 2 Description of critical assembly

The critical assemblies with nuclear fuel based on uranium-zirconium carbonitride and a zirconium hydride moderator are hexagonal lattices with a pitch of 45 mm from fuel assemblies, fuel assemblies with control rods, cassettes with absorbing rods, zirconium hydride reflector's cassettes and steel reflector units.

*The fuel assembly of type 1 (type 2)* will have as cladding a thin-walled hexagonal tube made of stainless steel for a 44 mm wrench and a wall thickness of 0.4 mm. The fuel assembly will have stainless steel upper and lower end pieces. Hexagonal blocks of a moderator made of zirconium hydride $ZrH_{1.9}$ (density 5.1 g/cm$^3$), 15 mm high for a 43 mm wrench and a hole with a diameter of 28 mm from the center, will be installed inside the hexagonal tube. The total length of the zirconium hydride moderator in the fuel assembly is 600 mm. Stainless steel casing tube of diameter 27 mm and a wall thickness of 0.3 mm should be installed in the central cavity of a zirconium hydride moderator. Three fuel rods of type 1 (type 2) will be installed and fixed in the center of this tube with a 12.3 mm triangular pitch.

*The fuel rod of type 1 (type 2)* comprises a fuel core, cladding, and end pieces (Fig. 1). The fuel rod cladding has the outer diameter 12 mm and the wall thickness 0.6 mm. The fuel rod comprises tablets, 10.75 mm in diameter and 14.7 mm in height, from uranium-zirconium carbonitride $U_{0.9}Zr_{0.1}C_{0.5}N_{0.5}$. The core density is ~ 12.0 g/cm$^3$, the porosity not more than 12%, uranium content ~ 10.5 gU/cm$^3$.The enrichment by U-235 is 19.75%. The U-235 mass in the fuel rod is 96.6 g. The gaps between the fuel rod cladding tablets and the fuel rod cladding contain He under ~0.11 MPa. The total core height is 500 mm. The total length of the fuel rod is 620 mm. The material of the fuel rod clad and end pieces (plugs) is stainless steel (fuel rod type 1) or alloy NbZr-1 (fuel rod type 2).

The outside reflector of the critical assembly is a row of the zirconium hydride reflector cassettes and two rows of the steel reflector units.

The cladding of *zirconium hydride reflector cassettes* (Fig. 2) consist of a thin-wall hexagonal tube made of stainless steel for a 44-mm wrench, with the length 619 mm and the wall thickness 0.4 mm. The hexagonal tube is welded to the upper and lower end pieces. The hexagonal tube has 12 hexagonal units of the zirconium hydride moderator $ZrH_{1.9}$ (density 5.6 g/cm$^3$), each 50 mm high and 42.7-mm wrench. The moderator units have seven 8.3-mm holes spaced 14.5 mm apart; these holes house channel tubes made of stainless steel of the length 645 mm, the outer diameter 8 mm and the thickness 0.3 mm.

*The steel reflector unit* (Fig. 3) is made of stainless steel and fully meets the fuel assembly dimensions. The upper end reflector represented hexagonal units from stainless steel with 44 mm wrench and the height 62 mm, which were installed on the upper end parts of the fuel assemblies, the reflector's cassettes and the stainless steel reflector units.

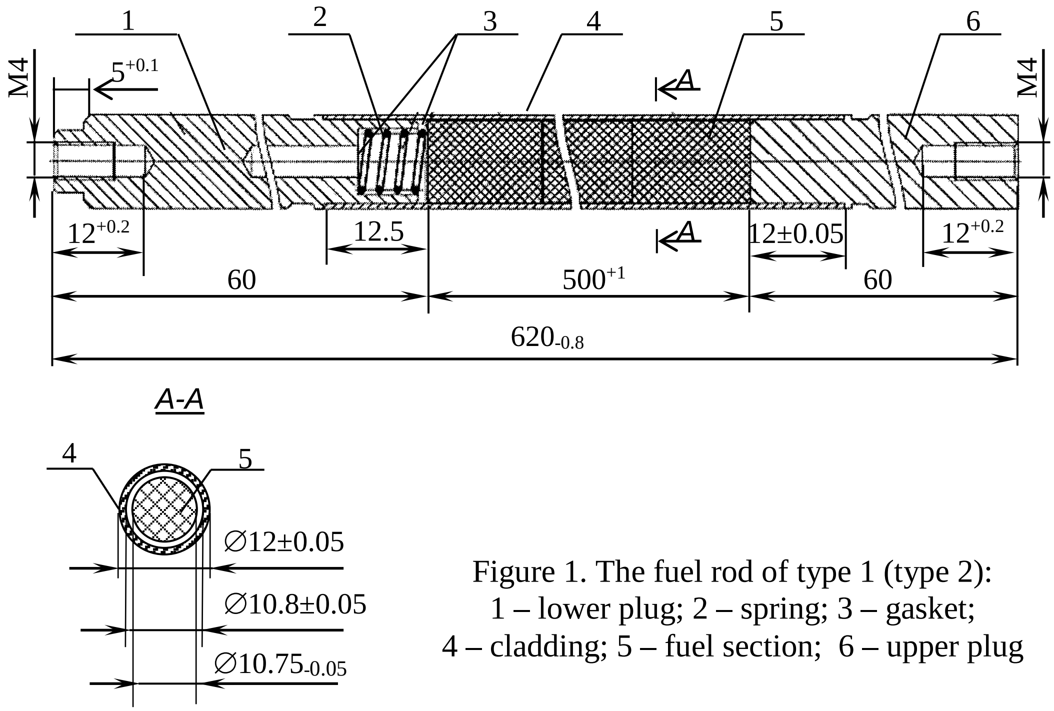


Figure 1. The fuel rod of type 1 (type 2):
1 – lower plug; 2 – spring; 3 – gasket;
4 – cladding; 5 – fuel section; 6 – upper plug

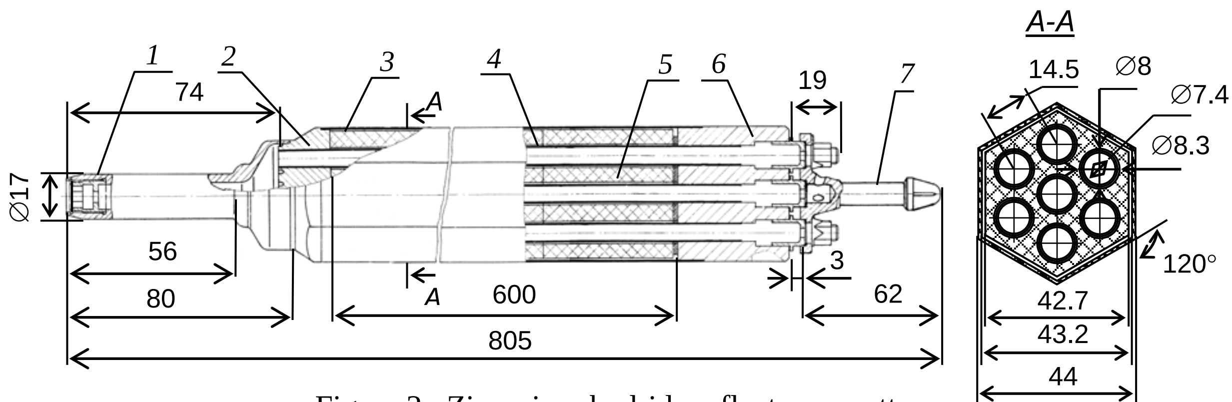


Figure 2. Zirconium hydride reflector cassette:
1 – shank; 2 – lower tube plate; 3 – tube; 4 – casing tube;
5 – zirconium hydride blocks; 6 – upper tube plate; 7 – head

Each critical assembly discussed below will be used six the actuating devices (ADs) of the control and protection system (CPS). In critical assembly 1, the actuating device consists of three fuel rods in stainless steel casing tube (diameter 27 mm, wall thickness 0.3 mm) and an absorber rod connected through a stainless steel adapter; in critical assembly 2 - only from the absorber rod.

*The absorber rod* will be a stainless steel tube with a diameter of 24 mm and a wall thickness of 1 mm, filled to a height of 500 mm with boron carbide powder with density of ~ 1.38 g/cm$^3$. Upper and lower stainless steel plugs 20 mm long will be welded to the tube sheath. The total length of the rod will be 540 mm.

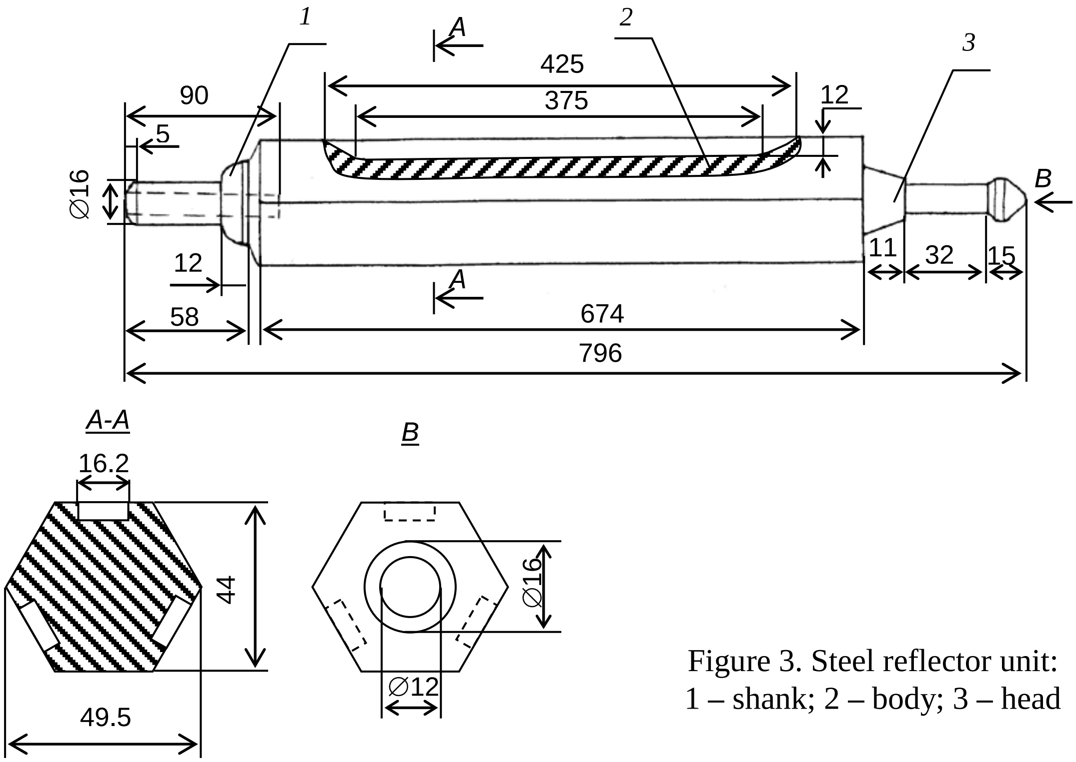


Figure 3. Steel reflector unit:
1 – shank; 2 – body; 3 – head

## 3 Analytical model of the critical assembly

Analytical model of the critical assembly is presented on Figure 4; analytical model of the fuel assembly of type 1 (type 2) — on Figure 5.

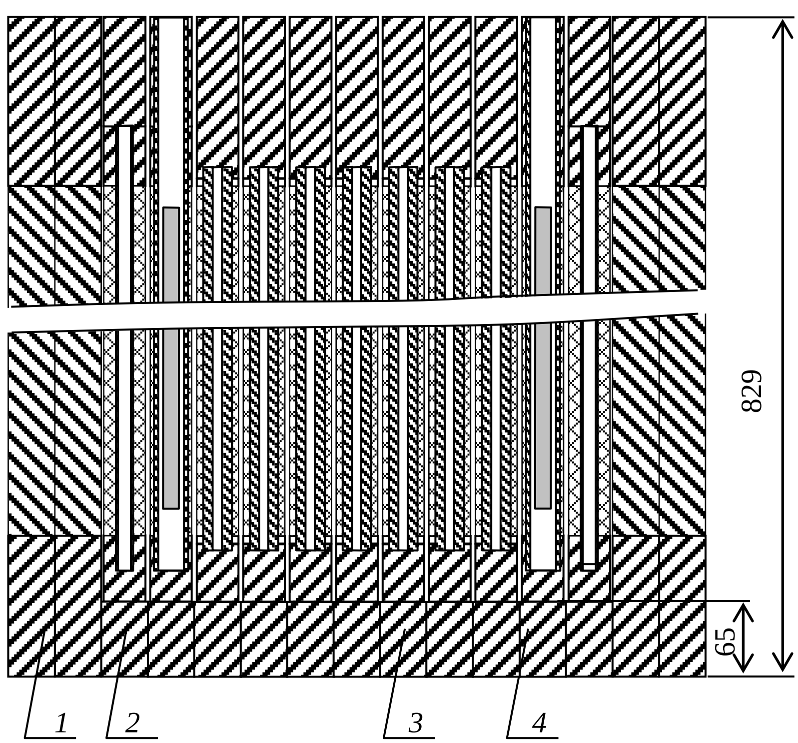


Figure 4. The analytical model of the critical assembly: 1 – analytical model steel reflector unit; 2 – analytical model zirconium hydride reflector cassette; 3 – analytical model of the fuel assembly; 4 – analytical model of the cassette with AD of CPS

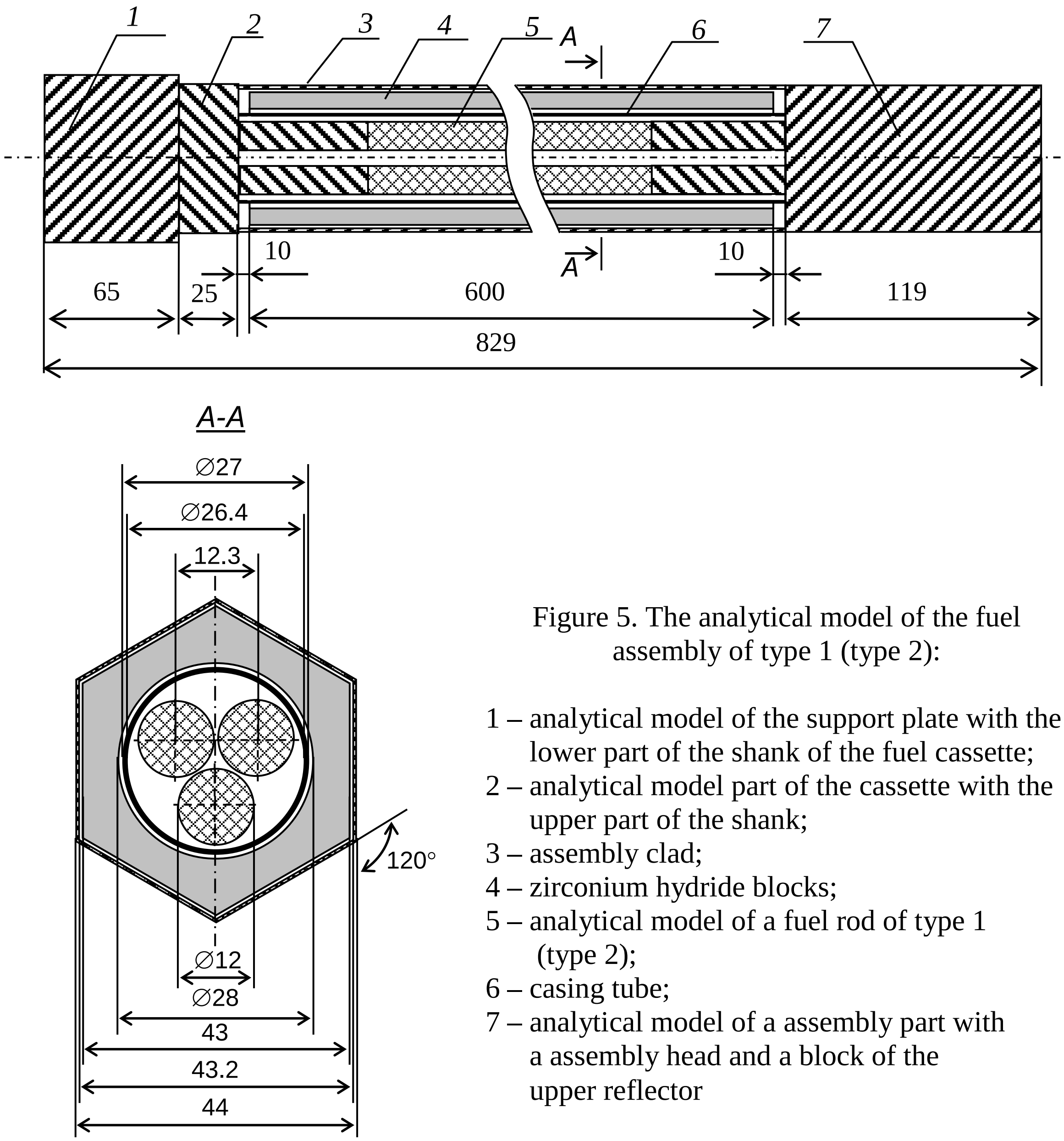


Figure 5. The analytical model of the fuel assembly of type 1 (type 2):

1 – analytical model of the support plate with the lower part of the shank of the fuel cassette;
2 – analytical model part of the cassette with the upper part of the shank;
3 – assembly clad;
4 – zirconium hydride blocks;
5 – analytical model of a fuel rod of type 1 (type 2);
6 – casing tube;
7 – analytical model of a assembly part with a assembly head and a block of the upper reflector

## 4 Results of preliminary neutron-physical calculations

A series of preliminary neutron-physical calculations made. The Figure 6 shows loading configuration of uniform critical assembly 1 with fuel assemblies of type 1 and fuel assemblies control rods. The Figure 7 shows loading configuration of critical assembly 2 with fuel assemblies of type 1 and type 2 and cassettes with the ADs of CPS. The Table 1 presents the composition of these critical assemblies. The calculated values of the effective neutron multiplication factor $K_{eff}$, the effective delayed neutron fraction $\beta_{eff}$ and the prompt neutron lifetime L, calculated by different programs, are presented in Table 2. The results of ADs of CPS efficiency calculations of the critical assembly 2 are presented in Table 3.

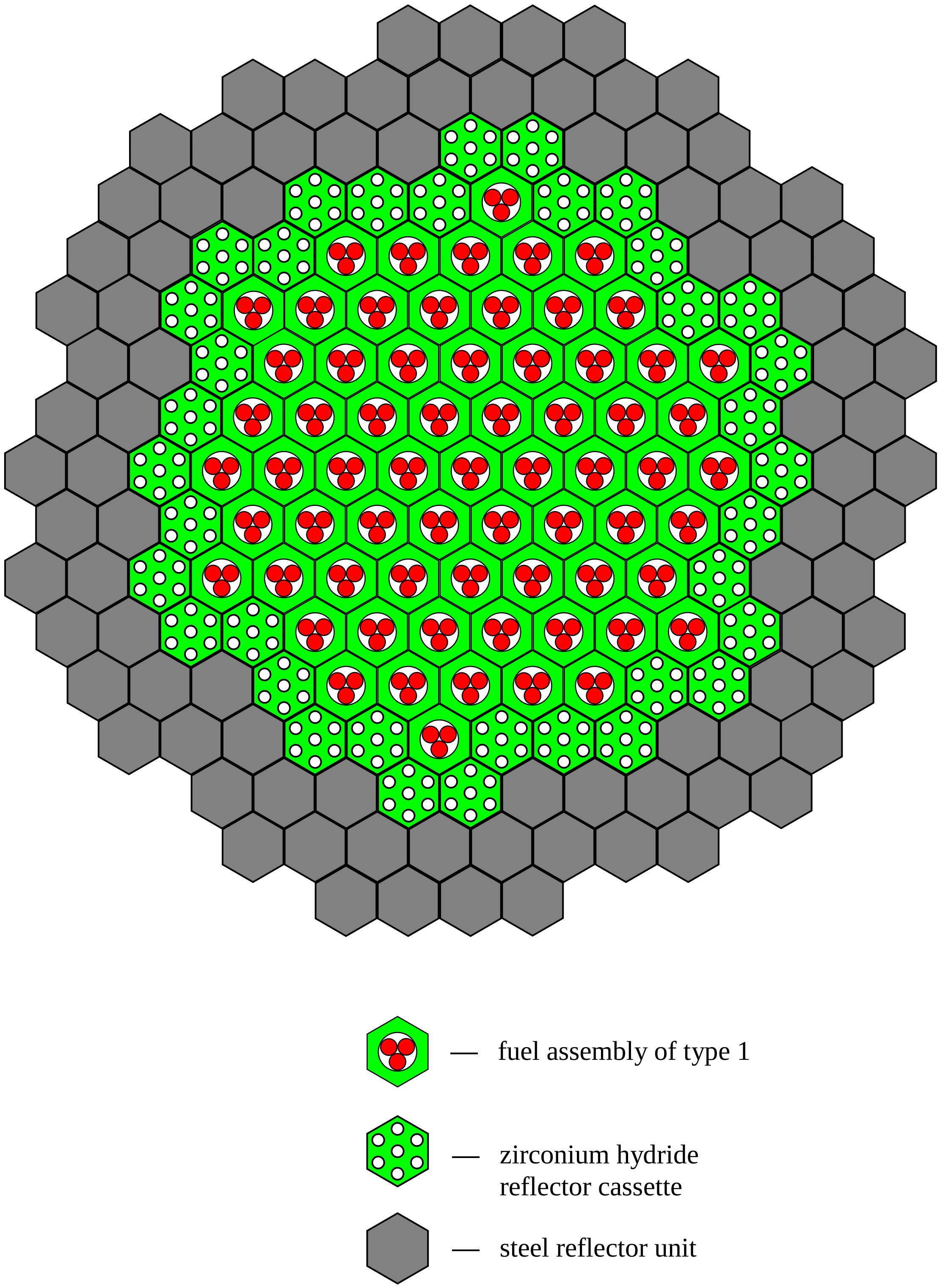


Figure 6. The loading configuration of the critical assembly 1

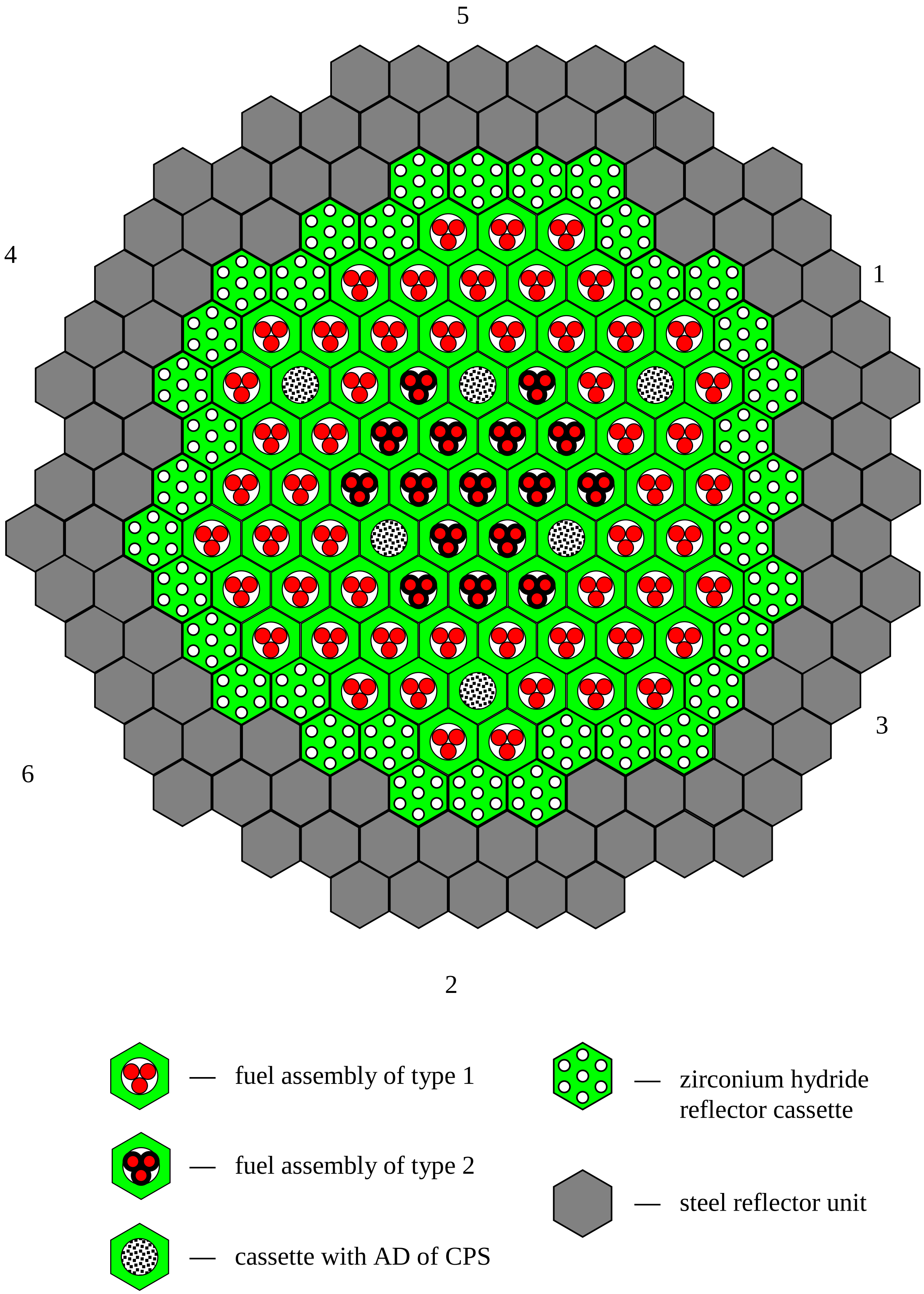


Figure 7. The loading configuration of the critical assembly 2

Table 1. The composition of the critical assemblies

| Critical assembly | The core composition, pcs. | | | The side reflector composition, pcs. | |
|---|---|---|---|---|---|
| | Fuel assembly of type 1 | Fuel assembly of type 2 | Cassette with AD of CPS | Zirconium hydride reflector cassette | Steel reflector unit |
| 1 | 67 | — | — | 36 | 90 |
| 2 | 54 | 16 | 6 | 36 | 90 |

Table 2. The calculated neutron-physical characteristics of the critical assemblies

| Critical assembly | $K_{eff}$ | | $\beta_{eff}$ | L, s | |
|---|---|---|---|---|---|
| | MCNP-4c [5] (ENDF/B-V) | MCU-PD [6,7] | MCU-PD [6,7] | MCNP-4c [5] (ENDF/B-V) | MCU-PD [6,7] |
| 1 | 1.00880 ± 0.00008 | 1.00938 ± 0.00023 | 0.007762 ± 0.000002 | $2.254 \cdot 10^{-5} \pm 2.68 \cdot 10^{-9}$ | $2.057 \cdot 10^{-5} \pm 3.33 \cdot 10^{-9}$ |
| 2 | 1.00716 ± 0.00008 | 1.00444 ± 0.00014 | 0.007722 ± 0.000002 | $2.426 \cdot 10^{-5} \pm 2.85 \cdot 10^{-9}$ | $2.291 \cdot 10^{-5} \pm 2.23 \cdot 10^{-9}$ |

Note. Confidence intervals for a probability of 0.67.

Table 3. ADs of CPS efficiency of the critical assembly 2

| ADs of CPS | Efficiency, $\beta_{eff}$ | |
|---|---|---|
| | MCNP-4c (ENDF/B-V) | MCU-PD |
| 1 | 1.078 ± 0.015 | 1.025 ± 0.045 |
| 3 | 2.677 ± 0.015 | 2.573 ± 0.046 |
| 1, 2 and 4 | 3.480 ± 0.015 | 3.449 ± 0.049 |
| 3, 5 and 6 | 8.742 ± 0.016 | 8.486 ± 0.050 |
| 1, 2, 3 and 4 | 6.328 ± 0.015 | 6.224 ± 0.050 |
| All ADs of CPS | 12.940 ± 0.016 | 12.679 ± 0.054 |

Note. Confidence intervals for a probability of 0.67.

## 5 Conclusion

The performed neutron-physical calculations showed the possibility of creating on the Crystal critical facility uranium-zirconium hydride critical assemblies using a set of fuel rods based on uranium zirconium carbonitride with 19.75% enrichment on uranium-235, which were supplied from the Scientific Research Institute the Scientific Industrial Association "Luch" at the Joint Institute for Power and Nuclear Research – Sosny of the National Academy of Sciences of Belarus in 2010 year. This critical assembly models the physical features of small-sized reactors with zirconium hydride moderator and can be used to obtain benchmarks of data on criticality and other neutron-physical characteristics of neutron multiplying systems of this type.

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