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The Program of Experiments at the Critical Assembly "Giacint" using LEU Nuclear Fuel on the Basis of UZrCN

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ABSTRACT

At critical facility "Giacint" are carried out experimental researches on the physics of nuclear reactors, criticalities of fissionable materials and nuclear safety, including work on replacement HEU on LEU nuclear fuel. New nuclear fuel will be created for research purposes at the critical facility "Giacint" on development of perspective cores for small size power and test reactors. The fuel consists of uranium-zirconium carbon nitride $U_{0,9}Zr_{0,1}C_{0,5}N_{0,5}$ with 19.75% enrichment by U-235. Density of uranium - more than 10,5 g/cm^3. The clad material is stainless steel or niobium. The fuel assembly for critical facility "Giacint" consists from seven fuel rods and does not have the clad. Fuel rods and fuel assemblies were tested for conformity to requirements of the technical specifications. For carrying out at critical facility "Giacint" of benchmark experiments with use of these fuel rods were developed uranium-water critical assemblies and critical assemblies without moderator and made their equipment. In the paper will be described named rods and fuel assemblies, geometry and composition specified critical assemblies and presented the program of experiments on them.

1.Introduction

The Joint Institute for Power and Nuclear Research – “Sosny” (JIPNR-Sosny) of the National Academy of Sciences of Belarus makes preparations at the critical facility "Giacint” for joint Belarusian-Russian-American experimental research in the physics of neutron multiplying systems, using new low-enriched nuclear fuel based on uranium-zirconium carbon nitride $U_{0.9}Zr_{0.1}C_{0.5}N_{0.5}$ with 19.75% uranium-235. This report describes the new nuclear fuel and the critical assemblies with water moderator and without a moderator to be investigated.

2.Critical facility "Giacint"

Critical facility "Giacint” is destined for basic research on the physics and safety of neutron-multiplying systems and applied research in a substantiation of development of new generation of different nuclear energy sources. It provides the experimental base for the development of fundamental and applied nuclear power engineering, including:

- fundamental research on the nuclear reactor physics and a radiation protection, criticality of fissile materials and criticality safety;

- applied research in a substantiation of development of new generation of reactor facilities of different destination;

- provisions of teaching and methodical experimental base for training specialists in field of nuclear power engineering and application of ionizing radiation.

Critical facility "Giacint” consists from the critical assemblies, control and protection system, hydraulic system, emergency caution system, temporary (operative) storage of nuclear fuel, radioactive materials and a radioactive waste, etc.

At critical facility "Giacint” critical assemblies with water or zirconium hydride moderator and without a moderator are assembled. There are sets of the fuel rods and the fuel assemblies containing uranium with various enrichment on uranium-235 (10, 21, 36, 75 and 90 %), reflector assemblies and blocks (on the basis of zirconium hydride, beryllium, polyethylene, stainless steel, etc.) and control and safety rods of the control and safety system (on the basis europium oxide, boron carbide (including enrichment to 85% on a boron-10), cadmium, etc.). On Figs. 1 and 2 are given photos of critical assemblies with water and zirconium hydride moderators.

Fig.1. Critical assembly
with a water moderator

Fig.2. Critical assembly
with a zirconium hydride moderator

The control and protection system of critical facility "Giacint” in all operating modes of the critical assembly since the first core charging of fissile material provides emergency protection on power level, a period of power doubling, and also the control of power level, a period of power doubling, reactivity, gamma radiation dose rate, moderator level in a critical assembly tank (for critical assembly with a water moderator), moderator temperatures in tanks of hydraulic system (for critical assembly with a water moderator). On Fig.3 the photo of a control board of critical facility "Giacint” is given.

Fig. 3. Control board
of the critical facility “Giacint”

The hydraulic system of critical facility "Giacint" is used only 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.

At critical facility "Giacint" there is system for acquisition, processing and storage experimental data meant for measurements of neutron-physical characteristics of critical assemblies analysis on the given stand, in particular has following experimental facilities and experimental devices:

- experimental facility for measurements radial and axial power density distribution in a core and uranium distribution on fuel rod length created on base device for fuel rod horizontal displacement, Ge-detector with multichannel spectrum analyzer, NaJ(Tl)-detector, multifunctional input-output module and PC;
- pulse neutron generator (max flux $1\cdot10^{10}$ neutron/s in pulse, pulse width $0.7\text{-}1.2\cdot10^{-6}$ s, neutron oscillation frequency 1-100 Hz);
- experimental facility for measurements radial integral power density distribution in a core created on base ionization chamber, current-voltage converter, multifunctional input-output module and PC;
- digital reactivity meter created on base three current neutron detectors with high-voltage power unit, current-voltage converter, multifunctional input-output module and PC;
- experimental device for analysis of neutron fluctuation in time domain (measurement absolute power of the critical assembly, kinetics parameter (β_{eff}/l), etc.) created on base pulse neutron detector with high-voltage power unit, preamplifier with pulse former, multifunctional input-output board and PC, etc.

The system for acquisition, processing and storage experimental data can be used at carrying out of following experiments at the critical facility:

- loading of critical mass (plotting of loading charts and inverse account curves);
- measurement of control and safety rod efficiency of control and protection system;
- control and safety rod calibration;
- definition of reactivity margin;
- measurement of reactivity effects;
- measurement of radial and axial energy release distribution on a core;
- measurement of the absolute power of the critical assembly;
- measurement of the kinetics parameter (p_{eff}/l);
- nondestructive check fuel rods and fuel assemblies with fissile material;
- validation neutron detectors, etc.

The system is created on the basis of the local network of PC, a subsystem of signal preprocessing and data acquisition, the experimental assemblies and devices.

3. LEU nuclear fuel for "Giacint" critical facility

LEU fresh fuel was design and produced for "Giacint" critical facility under Belarus-Russian –American cooperation on conversion nuclear fuel of research reactors. The low enriched fuel consists of uranium-zirconium carbon nitride $U_{0,9}Zr_{0,1}C_{0,5}N_{0,5}$ with 19.75% enrichment by U-235. Density of a fuel composition is not less than 12 g/sm^3, porosity - less than 12%, density of uranium - more than 10.5 g/sm^3, diameter of a tablet – 10.7 mm. Length of the uranium fuel part of rod - 500 mm, diameter of the fuel rod 12 mm, common length of the fuel rod -

620 mm (see Fig.4). Thickness of clad is 0.6 mm. The clad material is stainless steel or niobium.

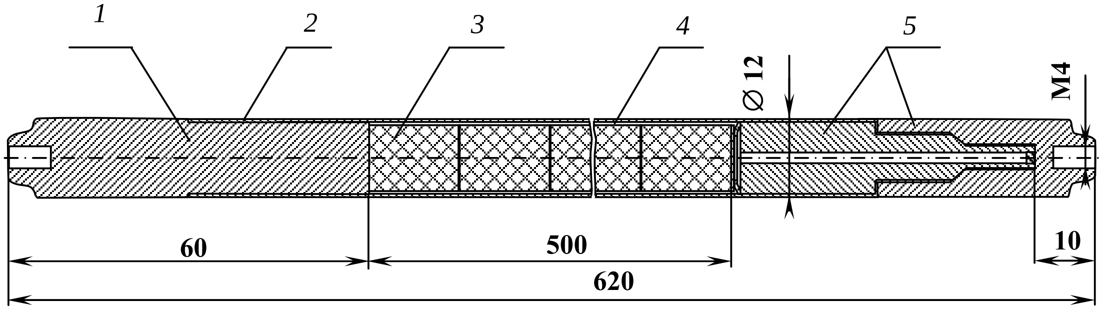
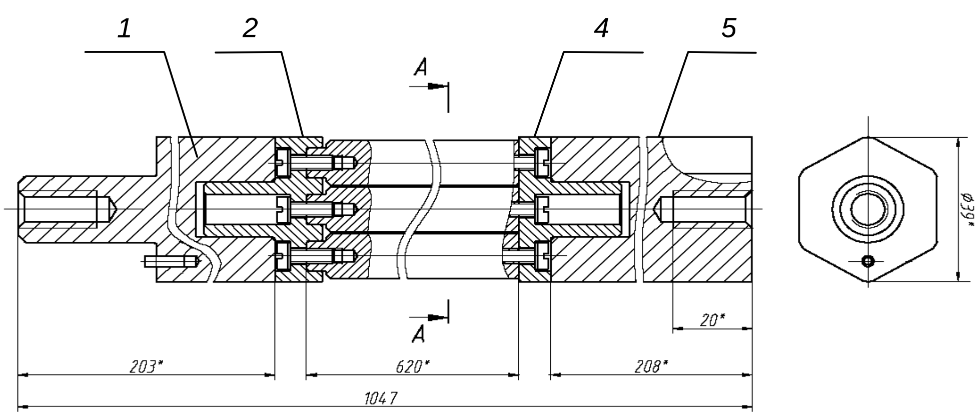


Fig. 4. LEU fuel rod:
1 – top cap; 2 – clad; 3 – fuel core; 4 – space; 5 – bottom cap

In frame of uranium-235 equivalent exchange of HEU/LEU nuclear fuel, FSUE “SRI SIA “LUCH” produced 218 LEU fuel rods, including 168 in stainless steel clad and 50 in niobium clad. Features of the fuel rod technology:

- divergence of U-235 content from nominal value < 3%;
- unevenness of uranium content on height of the fuel core ± 5% of average value;
- fuel rod deflection density < 0.3 mm;
- fission product yield < 10-3;
- uranium pollution surface clad < 10-8 g/cm2;
- gas between fuel core and clad – He (pressure 0.11MPa).

The fuel assembly for “Giacint” critical facility consists from seven LEU fuel rods (see Fig.5). The fuel assembly does not have the clad. These fuel assemblies will be used for developing new low power nuclear reactor configurations cooled by gas or water. In particular, this nuclear fuel can be used at conversion HEU on LEU nuclear fuel in research reactors. Critical assemblies have been developed for performance of this purpose with/ without water moderator.



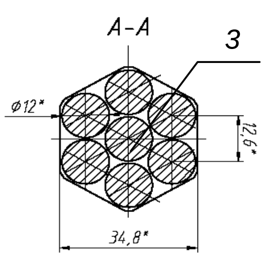


Fig. 5. Fuel assembly “Giacint” critical facility:
1 – bottom nozzle; 2 – bottom tube plate; 3 – fuel rod;
4 – top tube plate; 5 – top nozzle

4. Critical assemblies with water moderator

Critical assemblies with water moderator represent critical assemblies of the "open tank" type and include a core, a side reflector, upper and lower reflectors and the control and protection system actuating devices (CPS ADs).

Critical assemblies with water moderator are located directly in the tanks of the critical assemblies' (TCA), which is a welded structure, made of stainless steel. At the top, the tank has a flange used to fix aluminum hoods of neutron detectors.

The critical assemblies's core is made of fuel rods that are fixed in hexagonal distancing lattices made of an aluminum alloy and are supported by a hexagonal support plate made of stainless steel. The spacing lattices and the support plate are placed on steel pins, that are threaded on the bosses, welded to the TCA bottom. The distances between the plates are set by means of graded supports form steel pipes that are also put onto the pins. Nuts are threaded on the pins; the nuts help fix the entire structure securely to the TCA.

The spacing lattices are placed along the upper and lower edges of the core. The critical assemblies to be developed would represent hexagonal lattices of fuel rods in the water moderator. The critical assemblies are a lattices of fuel rods spaced 32.0 mm, 20.0 mm and 17.0 mm apart in the water moderator.

The loading charts and main characteristics of the critical assemblies 1-3 are given in Figs. 6-8.

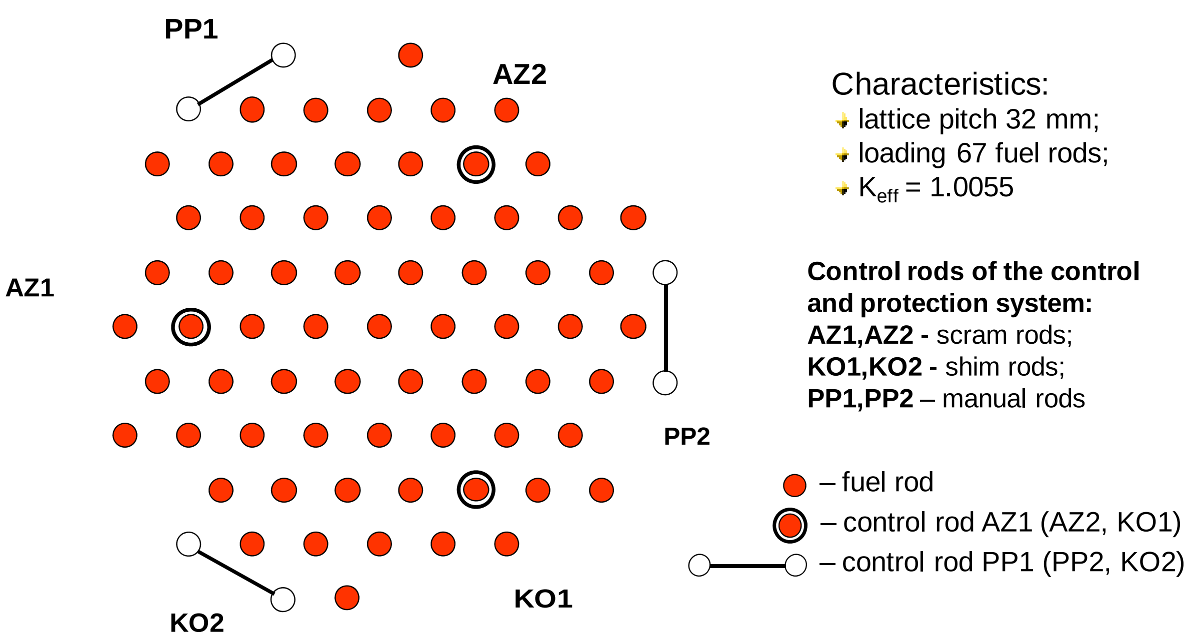


Fig. 6. Critical assembly 1

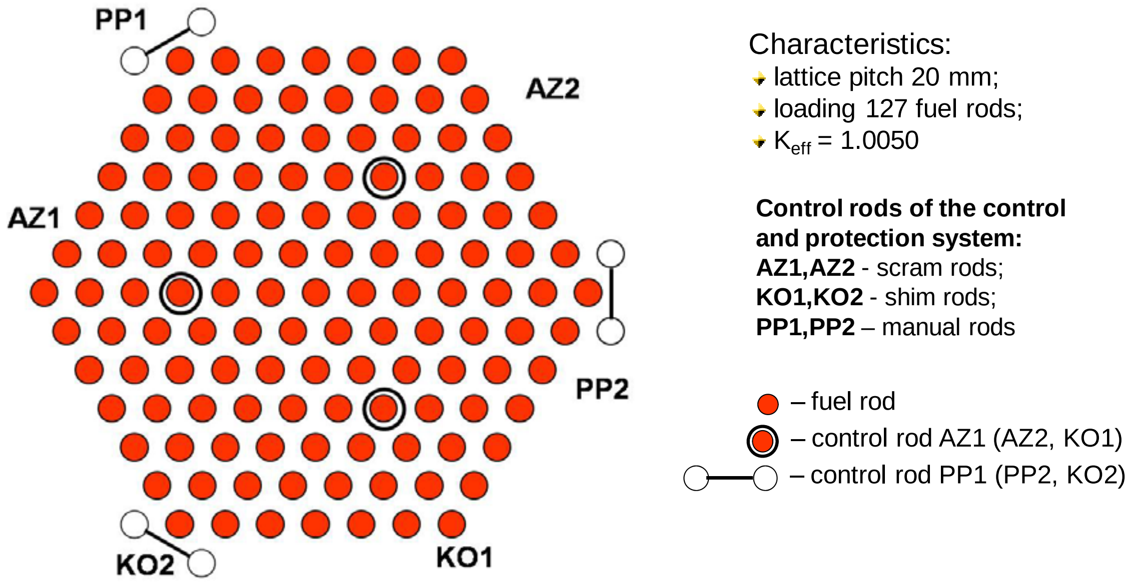


Fig. 7. Critical assembly 2

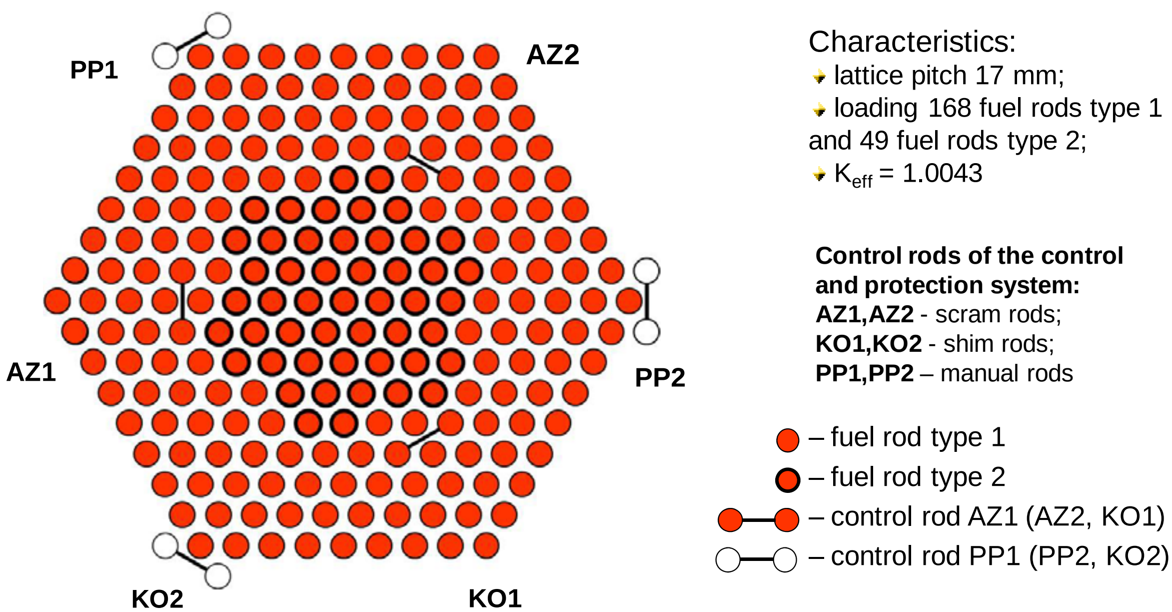


Fig. 8. Critical assembly 3

5. Critical assemblies without moderator

A critical assembly without moderator is a critical assembly without a tank used in fuel assemblies without a clad, comprising an active zone, a side reflector, upper and lower end reflectors, and actuating devices (AD) of the control and protection system (CPS)

The critical assembly will be placed on a special support frame. The critical assembly has a stainless steel support plate, attached to the special support frame. The support plate has holes, drilled in the form of a hexagonal grid with a 35.7 mm pitch, for inserting fuel cassettes and reflector cassettes. The neutron detectors are arranged around the critical assembly on special poles.

The loading charts and the basic characteristics of critical assemblies 4-6 without moderator are given in Figs. 9-11.

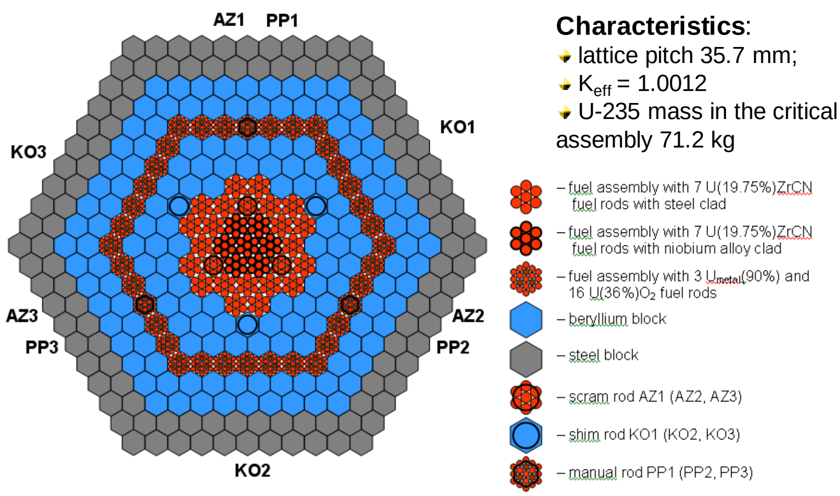


Fig. 9. Critical assembly 4

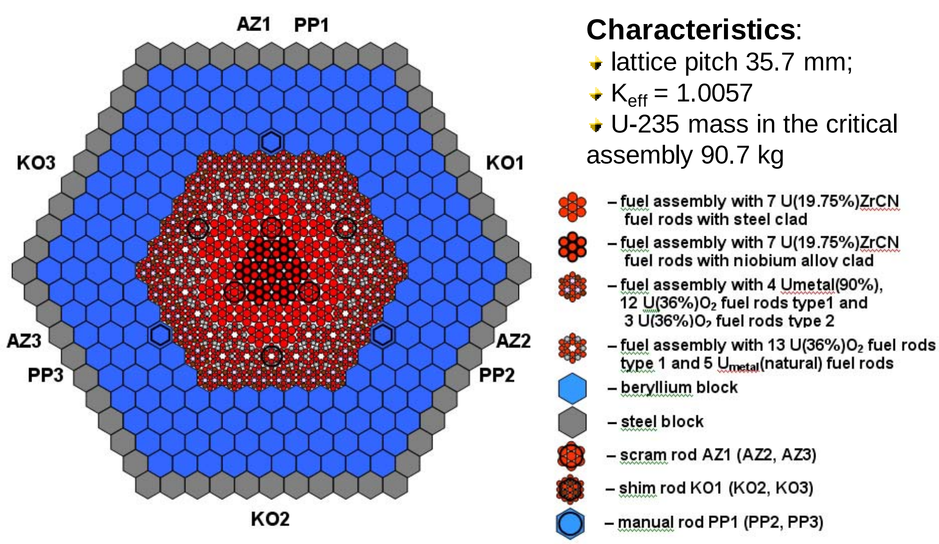


Fig. 10. Critical assembly 5

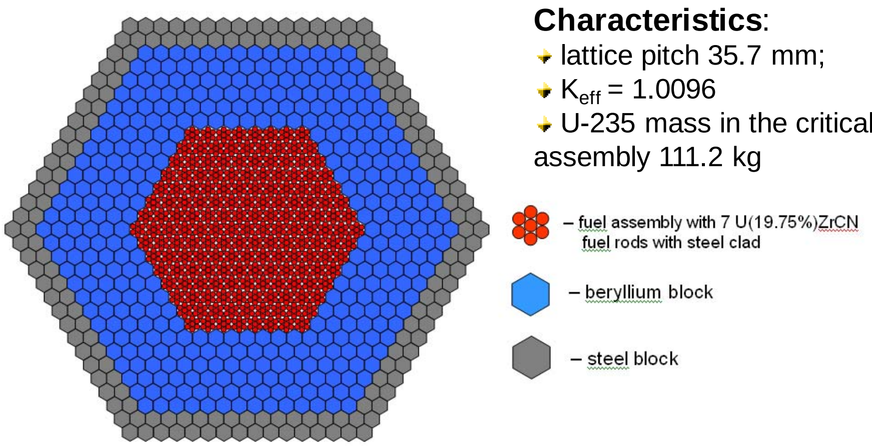


Fig. 11. Critical assembly 6

6. Conclusion

The joint Belarusian-Russian-American experimental research to be performed at the critical facility "Giacint" in the JIPNR-Sosny will help produce benchmark data on physical characteristics of neutron breeder systems with low-enriched nuclear fuel, based on uranium-zirconium carbon nitride. The produced data could be used for validation and verification of mathematical codes and nuclear data libraries for developing reactors with this nuclear fuel.