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Nuclear facilities of the National Academy of Sciences of Belarus on the basis of highly enriched uranium.

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ABSTRACT

The investigations in the field of nuclear physics, development of numerical calculation methods for nuclear reactors, neutron physics and etc. are carried out at the Joint Institute for Power and Nuclear Research - Sosny (JIPNR-Sosny) since the 60s after putting into operation the research reactor and the critical assemblies. A large range of different configuration (geometry,composition) of critical assemblies have been constructed at the NAS Belarus during 25 years of studying neutronic of the special (fast and thermal) reactors. The Chernobyl accident brought a massive public reaction to nuclear efforts and the reactor ceased operation in 1987 and was shut down in 1991 and at present all investigations in these fields are being carried out on the basis of the subcriticall assemblies driven with high intensity neutron generator. The facilities with fast and thermal neutron spectra are fuelled with UO_2 and Umet. enriched to 10% -90% in ^{235}U.

1. Introduction

The investigations in the field of nuclear physics, development of numerical calculation methods for nuclear reactors, neutron physics etc. are carried out at the Joint Institute for Power and Nuclear Research - Sosny (JIPNR-Sosny) since the 60s after putting into operation the research reactor and the critical assemblies. A large range of different configurations (geometry, composition) of critical assemblies have been constructed at the NAS Belarus during 25 years of studying neutronics of the special purpose (fast and thermal) reactors. The Chernobyl accident brought a massive public reaction to nuclear efforts and the reactor ceased operation in 1987 and was shutdown in 1991 and all investigations using the reactor neutrons were interrupted. Closure of the reactor has led to new endeavors being undertaken at NAS Belarus including the coupling of a high-yield ($I \approx 10^{12}$ n/s) neutron generator to a sub-critical assemblies fuelled by highly enriched uranium.

2. Neutron generator.

According to the research program at the NAS of Belarus the experimental facility ″Yalina″ consisting of the sub-critical assembly with neutron thermal spectrum (source neutron multiplication factor Ms of the assembly is in the range of $10 \leq Ms \leq 50$), high intensity neutron generator and measurement systems were developed and put into operation in 2001 [1]. It is necessary to note that the principal scheme of the facility is very close to the scheme used in the ADS concept intended for energy production, transmutation of radioactive waste (MA and LLFP) and in that subcritical reactor are driven with high energy proton beam.

One of the main part of the facility is the neutron generator NG-12-1 (Fig. 1). It consists of a high-current deuteron accelerator, highly effective water-cooling rotating Ti^{3}H (TiD) 230 mm diameter target (Fig. 2) and has been operated since 1997 as intense continuous neutron source of (1.5-2.0) 10^{12} n/s at maximum with neutron energy 13.0 - 15.0 MeV and a continuous neutron source of (2.0-3.0) 10^{10} n/s at maximum with neutron energy 2.0- 3.0 MeV. The different type of ’’external neutron source – core” configurations can be arranged: in the case of using 230 mm diameter target the neutron source are placed outside of the core and for neutron source to place in the core centre the special neutron generator deuteron guides for 45 mm diameter TiD and Ti3H targets have been constructed (Fig. 2). When operating in the pulse mode the neutron beam pulse can be adjusted from 0.5μs up to 100μs and pulse repetition rate can be vary from 1 Hz to 10 000 Hz (Fig. 1).

Accelerator	H+ and D+
Beam energy	100-250 keV
Beam current	1 - 12 mA
Pulse duration	$(0.5\text{-}100) \cdot 10^{-6}$ sec
Repetition rate	(1-10 000) Hz
Spot size	≈2.0 - 30 cm
Ti3H target (230 mm):	
Rotating speed, rpm	560
Maximal yield of neutrons, n/s	$1.5\text{-}2.0 \cdot 10^{12}$
Neutron energy	13-15 MeV
TiD target (230 mm):	
Maximal yield of neutrons, n/s:	2-3.0 1010
Neutron energy	2.5-3.0 MeV

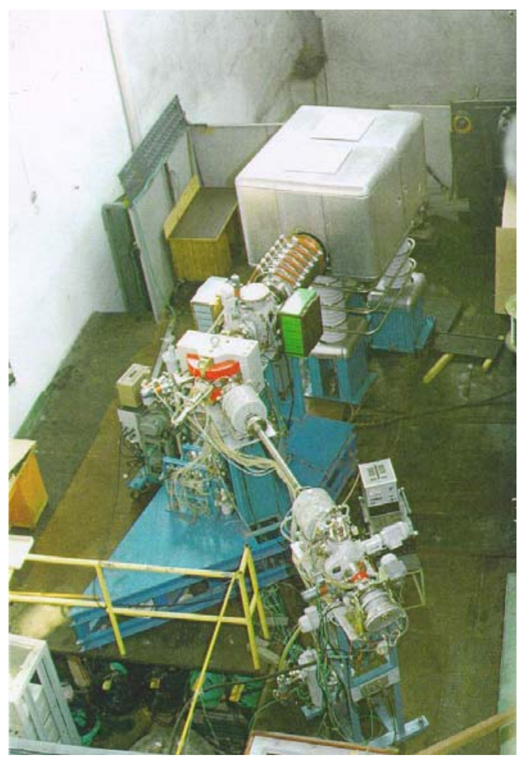
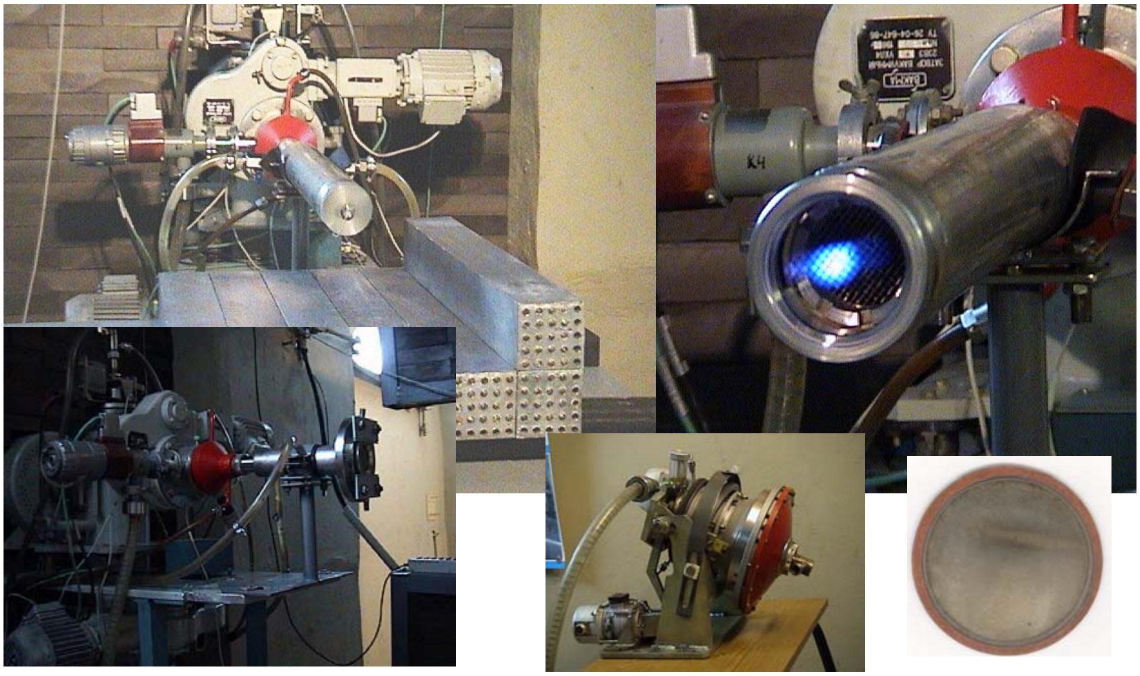


Fig. 1. Neutron generator NG-12-1 (D+3H→n+4He;D+D→n+3He)



D=230 mm **D=45 mm**

Fig.2 The Neutron generator deuteron guides for 45 mm diameter Ti^3H (TiD) targets.

3. Subcritical assembly with thermal neutron spectrum

The core of the sub-critical assembly is a rectangular parallelepiped with 40.0 cm width, 40.0 cm height and 60.0 cm length (Fig. 3). It is assembled of polyethylene sub-assemblies with 16 fuel rods per sub-assembly (Fig. 4) providing large flexibility of the core configuration. The sub-critical core is loaded with UO_2 fuel dispersed in Mg matrix (uranium is enriched to 10 % in ^{235}U). Fuel rods are arranged according to a square lattice with 2.0 cm spacing. Central part of the subcritical assembly is a neutron producing lead target of 8.0 cm width, 8.0 cm height and 60.0 cm length. The core of the assembly is surrounded by high purity graphite reflector 40.0 cm thickness and with thin (l = 1.5 mm) layer of Cd.

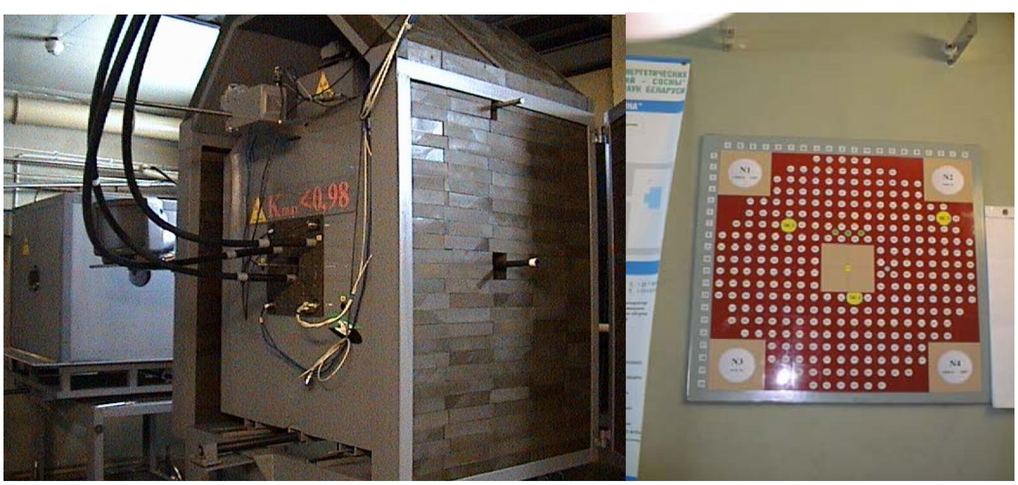


Fig. 3. Subcritical assembly with thermal neutron spectrum Keff. = 0.98

There are four channels 50 mm diameter at the corners of the core for housing the neutron's detectors for neutron flux monitoring system and 3 experimental channels 25 mm diameter at radii 5, 11 and 18 cm for placing different type of samples or ^{252}Cf source inside the core. The two axial and one radial experimental channels 25 mm diameter are arranged in graphite reflector. To decrease background the assembly is surrounded by borated polyethylene shielding of 25cm thickness. The Keff of the YALINA facility is ranging between ~ 0.9 to 0.98 for sub-critical configurations that correspond to load 216 and up to 280 fuel rods respectively (Table 1).

The ″Yalina″ facility can be used to study the physics of multiplying media with thermal neutron spectra at different subcriticality levels, large range of different configurations (geometry, composition) and external neutron sources (Cf-252, D(d,n)He-3, D(T,n)He-4).

Table 1.

The Facility « Yalina» Characteristics

Maximal yield of neutrons, n/s: D (T,n)^{4}He; En=13-15 Mev	(1.0-2.0)x10^{12}
D (D,n) He-3; En = 2-3 Mev	(2.0-3.0)x10^{10}
Cf-252, n/s	5.1x10^7
Accelerating voltage (Ed, keV)	250
Current of accelerated ions , mA	10-12
Beam spot size at the target , mm	20
Rotating speed, rpm	560
Pulse duration, μs	0.5-100
Pulse repetition, Hz	1-10 000
Core dimension:	40cmx40cmx57cm
Fuel	**UO_2 (enrichment 10%)**
Moderator	Polyethylene
Reflector	Graphite

A wide experimental program on the basis of the facility since that time has been already performed. The measurements of spatial neutron flux distribution, spectral indices, external neutron source importance, transmutation reactions rates (^{129}I,^{237}Np, ^{243}Am), neutron flux time evolution, multiplication factor Keff, source multiplication factor Ks for different levels of subcriticality of the assembly driven by neutron generator operating in continuous and pulse modes with Ti^3H, TiD targets and ^{252}Cf source placed at various positions inside the core have been done. The analysis of the sequence of experimental data has been performed with MCNP code and with different neutron libraries (ENDFB-VI, ENDFB-IV) [2]. The comparison of the theoretical and experimental data shows that in a number of cases they agree relatively well within error margins.

4. Booster (cascade) subcritical assembly

Further investigations at the National Academy of Sciences of Belarus will be performed in the framework of strategy of booster sub-critical systems driven by the neutron generator. The facility, named YALINA-BOOSTER (YALINA-B), will be put into operation by May of 2005. The basic idea of a fast spectrum booster coupled one-directional way to a thermal spectrum system is well known and consists in enhancement of the external neutrons source importance by placing a booster around the source located in the core center with the main sub-critical thermal part of the core surrounding the booster. The core of the assembly consists of booster (fast) zone (K^{f}_{eff} = 0.67) and thermal zone (K^{th}_{eff} = 0.95) separated by thermal neutron absorber (Fig.4,5). First zone of the booster is assembled of lead sub-assemblies with 33 fuel rods per sub-assembly, providing large flexibility of the core configuration.

- **Keff = 0,975 – 0,98**
- **Booster zone (Keff= 0,67):**
- dimension, cm 48x48x50
- Umet. is enriched to 90% in 235U
- UO_2 is enriched to 36% in 235U
- neutron flux density with energy:
- En >0,1 MeV, 10^9 n/(cm2 s)
- moderator Pb
- **Uranium load (kg) U-5–62.8;U-8 -54.5**
- **Intermediate zone:**
- thickness, cm 3
- material Umet (natural uranium) + B_4C
- moderator Pb
- **Uranium load (kg) -5 – 0.23; U-8 -31.8**
- **Thermal zone (Keff= 0,95) :**
- thickness, cm 24
- fuel : UO_2 is enriched to 10% in 235U
- moderator polyethylene
- reflector graphite
- Thermal neutron flux density:
- Ti^3H –target 10^9 n/(cm^{2}s)
- **Uranium load (kg) U-5 – 8.07; U-8 -72.6**
- **multiplication factor 50**
- **Total uranium load (kg) U-5 – 72; U-8 - 167**

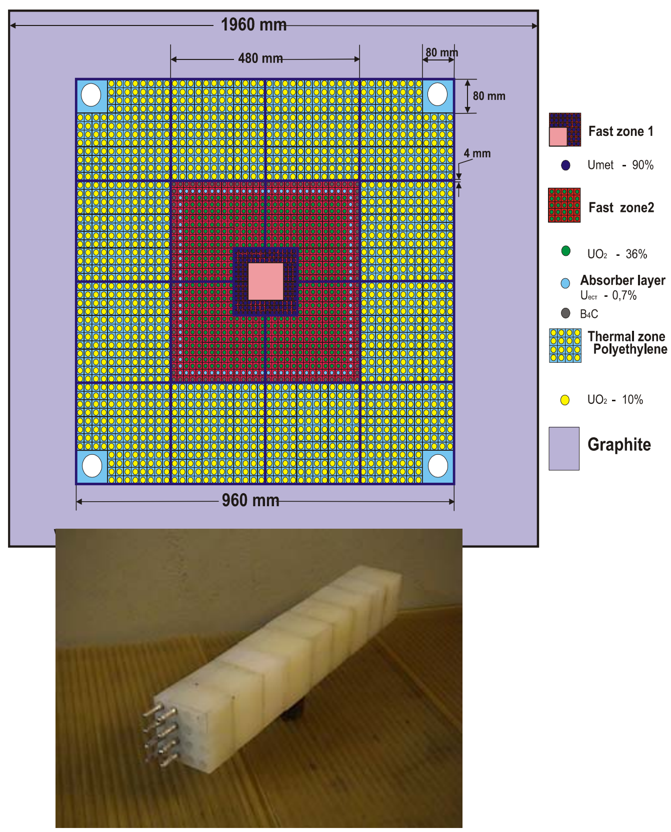


Fig.4. Cross-section, main parameters of the booster sub-critical assembly Yalina-B and polyethylene sub-assembly.

The zone with metallic uranium enriched to 90 % in ^{235}U has a square lattice with pitch equal to 1.14 cm. Second booster zone is arranged of lead sub-assemblies with rods of uranium dioxide enriched to 36 % in ^{235}U. This part of the booster has square lattice with pitch equal to 1.6 cm. There is a neutron producing lead target at the core center.
The thermal neutron absorber layer of 3 cm thickness consists of natural uranium rods and B_4C rods and has the same pitch equal to 1.6 cm. The construction of the biggest part of sub-critical assembly - thermal zone, is identical to the core of the facility with thermal neutron spectrum. The main parameters of the facility are presented in the Fig. **4** and multiplication factor Keff of such combined sub-critical assembly according to calculations performed by code MCNP, is equal to Keff = 0.975. One of the main feature of the facility is that in YALINA-B neutron spectrum in the booster zone, time response (e.g., response of ^{235}U fission rate to the source pulse) as well as the neutron lifetimes are very close to those in SAD – subcritical facility with MOX fuel driven by 660 MeV proton beam that now is being under construction at Joint Institute for Nuclear Research (Dubna, Russia) [3].

Fig. 5. General view of the booster sub-critical assembly.

YALINA-B and SAD have a high degree of synergy, since the YALINA-B experiment is expected to provide valuable results that will feed into and help define the SAD scientific programme.

The fast zone of the facility can be considered as a volume neutron source in contrast to YALINA and MASURCA [4] experiments. From this point of view the booster zone is closer to the spallation lead target of the SAD and TRADE [5,6] projects. The following experimental programme is of special interest and includes:

- Measurement of the MA (^{235}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{242}Am) fission rates in fast neutron spectrum:
- Studying the coupling properties of the spallation target (booster zone) and reflector, blanket, shielding.
- Studying the influence of shielding on physical parameters of the fast spectrum core.
- Development of reactivity monitoring techniques for subcritical systems with fast neutron spectrum
- Validation of calculation codes, libraries used to describe the subcritical core.

- Experimental determination of kinetic parameters and response to external neutron pulses for different sub-criticality levels.

5. Conclusion

The experimental facilities YALINA and YALINA-B allow to deliver valuable data in the following fields: measurements of transmutation rates of fission products and minor actinides, investigation of spatial kinetics of the sub-critical systems with external neutron sources, validation of the experimental techniques for, e.g., sub-criticality monitoring, neutron spectra measurement, safety research on sub-critical systems and technological applications such as neutron therapy, neutron activation analysis, production of isotopes for calibration of gamma spectrometers etc.

Moreover it is of great interest and importance to perform both theoretical and experimental investigations of possibility to substitute highly enriched uranium for low enriched one without essential changes of neutronics of the sub-critical assembly, driven by a neutron generator operating both in continuous and pulse modes. In particular, in cooperation with Argonne National Laboratory a project on use of LEU in the referenced assembly is under consideration. This project can include study of use LEU to replace HEU without penalizing the assembly performance. Different fuel forms and specifications can be considered to maintain the original performance.

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