

**Joint Institute for Power and Nuclear Research – Sosny  
of the National Academy of Sciences of Belarus**

ISTC – Project B-070-98

**Experimental and theoretical investigation of transmutation  
of long-lived fission products and minor actinides in a subcritical  
assembly driven by a neutron generator**

**26 - th Quarter report**

Minsk -2005г.

**ISTC project B-070.**

**26-th Quarter report**

## 1. Results of technical development of the Project.

### Technical tasks 10, 11, 12, 13, 14, 17, 21, 27, 29, 30

In accordance with technical schedule of B-070 Project technical maintenance of neutron generator, target heat removal system, high voltage system and electric equipment, dosimetric control system, physical protection of nuclear materials system as well as servicing of special unit providing safe operation of rotating  $Ti^3H$  and  $TiD$  targets with 230 mm in diameter intended for neutron generation has been carried out during 26 Quarter.

To meet the technical requirements the speed of  $Ti^3H$  and  $TiD$  targets rotation was maintained in the limits of 300 – 560 rpm, when running the experiments it was set to be equal 560 rpm. The system of target heat removal allows to keep the target temperature at the level of 60 - 80°C by the circulation rate of cooling water about 3-5 l per minute thereby providing safe target operation from the point of view of radiation safety.

In the considered series of the experiments the following parameters of neutron generator were maintained:

Energy of deuterium ions (keV)	- 240
Ion beam current $D^+$ (mA)	- 1 – 2
Size of $D^+$ ion beam spot at the target (mm)	- 20 – 40
Dimension of $Ti^3H$ target (mm)	- 45
Flux of neutrons with $E_n = 14,1$ MeV (n/s)	- $(2 - 3)10^{10}$
Pulse duration ( $\mu s$ )	- 5 – 100
Pulse repetition frequency (Hz)	- 1 – 1000

### Maintenance of the subcritical assembly

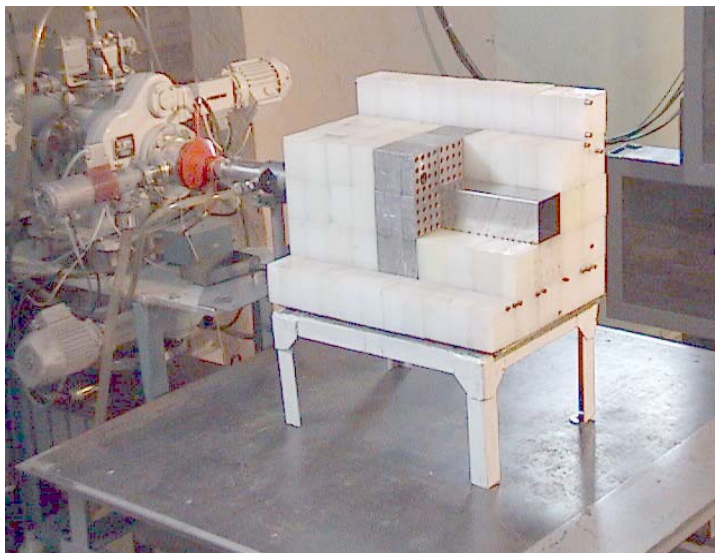
In accordance with the program of experimental investigations current maintenance of the subcritical assembly “YALINA” installation, systems of physical protection and video - observation has been carried out during 26-th quarter. Servicing of the system for pulse mode of neutron generator operation, remote system of radioactive samples delivery to the gamma-spectrometers, devices for fission chambers and  $^3He$  – detectors movement in radial and axial experimental channels of the subcritical assembly has been performed. The prevention and control of systems of neutron generator infrastructure has been permanently performed.

**The measurements of  $k_{ef}$  of “bare” (without reflector) assembly with polyethylene blocks partly replaced by lead blocks with application of pulse neutron source methods (DD-neutrons) have been performed.**

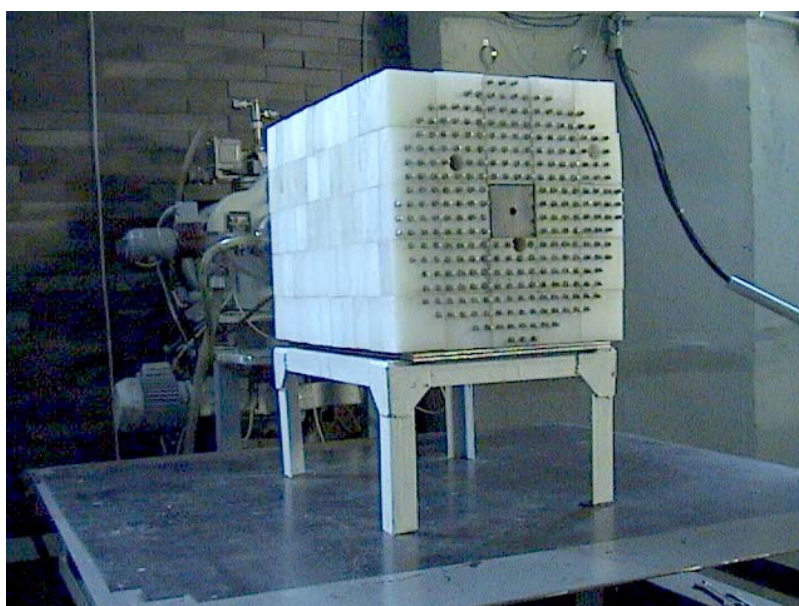
At central part of the “bare” assembly (280 fuel pins) lead blocks are situated with the holes for fuel pins location (Fig.1) with total length 110 mm instead of polyethylene blocks. Moreover in the modified assembly the corner polyethylene subassemblies were reconstructed (the subassemblies where measurement channels MI-MIV are located). With the purpose of  $k_{ef}$  increasing the subassemblies with axial holes with 50 mm in diameter were replaced by the solid ones with holes number corresponding to the number of fuel pins (Fig.2). Experimental channels were not changed.

“Long” target unit with DD or DT neutron-producing targets is situated inside the assembly in such a way that neutron birth point should be exactly at  $Z=0$ .

**The measurements of spatial distribution of neutron flux density with  $^{252}Cf$  – source at the  $Z = 70$  cm have been carried out.**



**Fig.1. The view of middle part of the assembly (part of polyethylene blocks were replaced by lead ones)**



**Fig.2. The view of “Bare” assembly (280 fuel pins) with lead blocks in the middle part instead of polyethylene ones. There are no measurement channels and fuel load map is somewhat different with respect to reference core.**

## **1. Measurements performed by DD neutron-producing target**

### **1.1. Measurements by pulse neutron source methods**

Small-size  $^3\text{He}$  detector enclosed in a cut out polyethylene holder (centering polyethylene plug is not at active part of the detector!) was placed in turn at center of EK2, EK3 and EK1 channels at point with  $Z=0$ .

The measurements have been carried out by amplitude of ion beam pulse  $\sim 4\text{V}$  (2 mA) ensuring initiation of starting pulse shaping for activation of the time analyzer.

By pulse measurements with application of DD target fair repeatability of results is observed by pulse repetition frequencies equal to 198 and 286 Hz and fixed  $\rho$  value by measurements in EK1-EK3 channels at  $Z=0$  (Table 1).

Magnitude of  $\rho$  estimated by means of Sjöstrand method is higher as previous than that estimated by Gozani method.

## 1.2. Measurements performed with application of Source Jerk Method

Detector  $^3\text{He}$  is placed at center of EK2 channel. Neutron-producing DD target is in “long” target unit at point  $Z=0$ . The channel width of time analyzer has been chosen under the condition of sufficient counting number at the channel after switching off the neutron generator -1 ms.

Ion current of neutron generator was set in such a way that counting rate by operating neutron generator should not be higher than  $10^5\text{s}^{-1}$  (100 counts at the channel with 1 ms width).

By further increasing of ion current it is necessary more correctly take into account dead time (by significant overload of the counter it could be unreasonable). The correct result can be obtained in this case only by means of proposed by our team method of delayed neutrons “tail” unfolding.

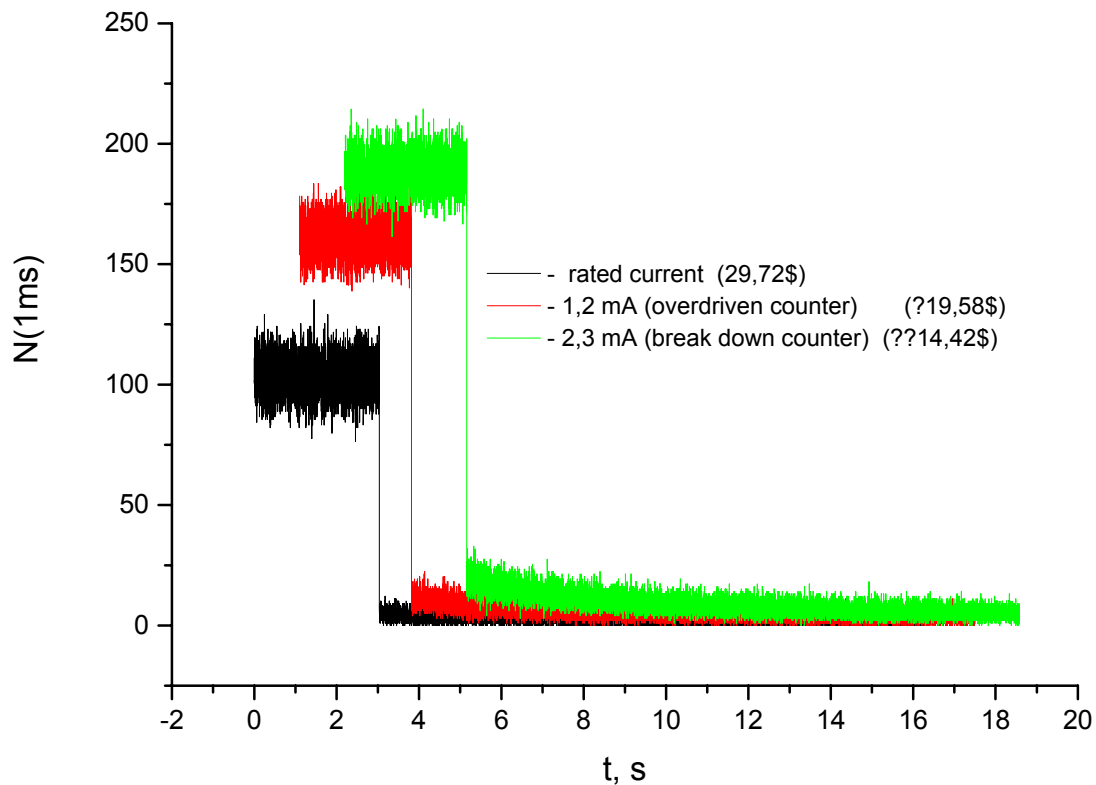
Three measurements performed (Fig.3) by different ion beams for fixed assembly configuration should give the same value of subcriticality level  $\sim 28\%$ .

Table 1

Dead time	Exponential fit after switching off			Linear fit before switching off		$\rho, \%$
	a	b	$\alpha$	a	b	
None	1.043±0.05	3.57±0.05	0.231±0.009		95.3±0.25	27.69
Yes	1.041±0.05	3.6±0.06	0.230±0.01	-0.183	103.1	29.72
None	2.82±0.06	8.62±0.08	0.259±0.006	0.228	143.3	17.62
Yes	2.84±0.05	8.718±0.078	0.26±0.006	0.239±0.2	161.96±0.3	19.58
None	4.67±0.08	13.81±0.098	0.241±0.005	-0.013	164.04	12.87
Yes	4.71±0.082	14.067±0.099	0.244±0.005	0.00002	188.9±0.3	14.42

By simple division of counting rates before switching off the neutron generator and 10 ms after that (after decay of fast neutrons) one can get 30%.

By approximation of decay by exponent and steady state by linear function and by changing point of coordinate origin at the moment of neutron generator switching off one can get  $\rho = 29,72\%$  that agrees fairly with the results obtained by pulse neutron source methods of Gozani and Sjöstrand (Table 1). Decay constant of delayed neutrons  $\alpha$  was  $0.2313 \pm 0.00994 \text{ s}^{-1}$ .



**Fig.3. Results of the measurements performed by Source Jerk Method with DD target by different currents of neutron generator ion beam and invariable core configuration**

## **2. Measurements performed with application of DT neutron-producing target**

### **2.2. Measurements with application of pulse neutron source methods**

By running the experiments with DT target the ion pulse amplitude was reduced to 1.2 V (the lower amplitude would not be sufficient for starting the time analyzer).

To avoid the overload of  $^3\text{He}$  detector in experiments with DT target a series of measurements was performed with screening of active part of  $^3\text{He}$  detector by two layers of Cd with total thickness of 0.18 cm.

Detector was located in EK2 channel that is unfavourable condition for the measurements with DT target because high counting rate and dead time correction makes impossible to correct the counting rate. The value of  $k_{\text{ef}}$  obtained by overloaded measurement channel is always higher than actual one.

#### **2.1.1. Measurements with application of unscreened small size $^3\text{He}$ detector**

Two measurements have been performed: one by ion pulse amplitude 3V and second by 1.2 V. The comparison of trend of curves of  $^3\text{He}$  detector counting rate decay by pointed magnitudes of ion pulse amplitude (Fig. 4a) shows that in 1.2 ms after neutron pulse passing the shape of the curves is practically the same

The differences take place at the initial moment when detector is overloaded that is expressed in more flat course of the decay curves (it is especially remarkable in the case of amplitude 3 V).

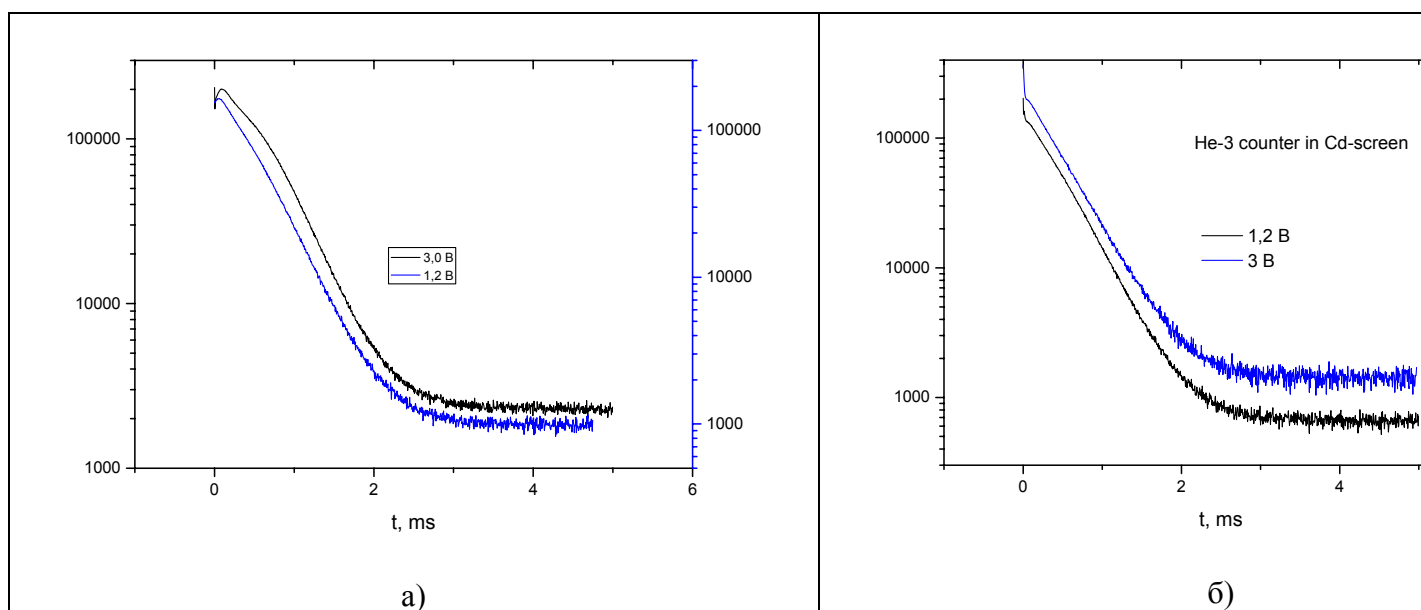
The results of processing of the pulse measurements data are presented in the Table 2. One can see that with decreasing of ion pulse amplitude (the detector load) the subcriticality value  $\rho$  approaches to the real one (obtained in measurements with DD target and normal detector load)

In this regard one negative fact should not be circumvented that while ion pulse amplitude is close to the threshold of starting pulses activating the time analyzer, more frequent start events of time analyzer occur due to pulse disturbances resulting in flattening of decay curve and reduction of  $\rho$  value.

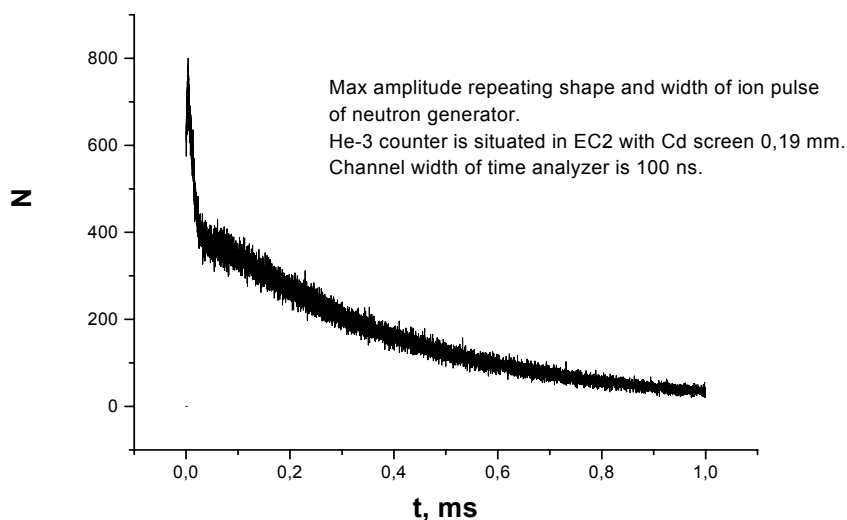
### 2.1.2. The measurements performed by $^3\text{He}$ detector screened by 0.19 mm Cd layer.

As well as in the previous case the measurements have been made by ion pulse amplitudes 3V and 1.2 V respectively (Fig.4b).

The distinctive features of the measurements performed with the screened  $^3\text{He}$  detector are: linear decay of counting rate in semi - logarithmic scale almost through the total time interval and jump of amplitude at initial time of frequency sweep corresponding to pulse generation and practically resembling ion pulse of neutron generator by the shape and duration (Fig.5).



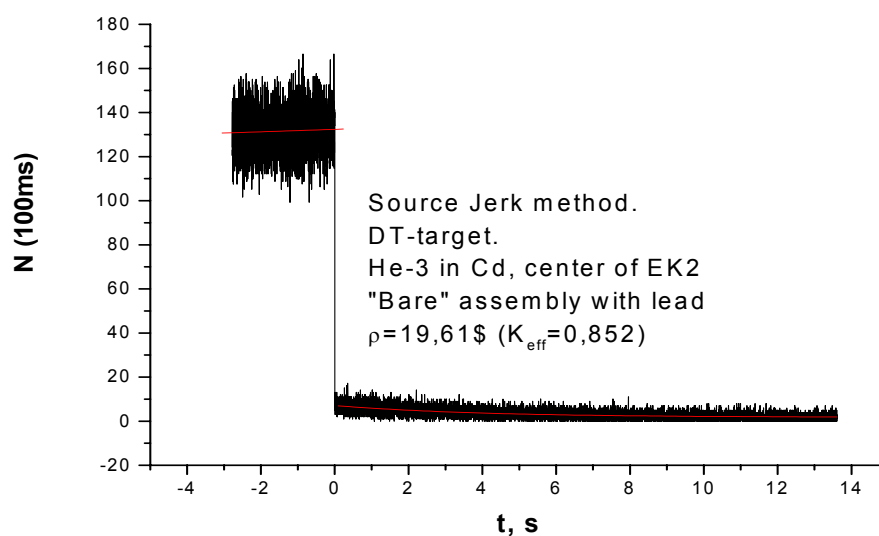
**Fig.4. Results of measurements by various amplitudes of ion pulse with application of  $^3\text{He}$  detector with Cd screen (b), and without it (a).**



**Fig.5. Time distribution of counting rates of  $^3\text{He}$  detector screened by Cd resembling shape and duration of ion pulse of neutron generator**

## 2.2. The measurements performed by Source Jerk Method with application of $^3\text{He}$ detector with Cd screening.

Usage of DT-target causes overload of the He-3 detector even at minimum ion current. Therefore the active part of the detector was screened by two layers of Cd (total thickness is 0.19 mm). Direct calculations from the curve of the changes of counting rate of the screened detector give the subcriticality value  $\rho = 19,61\%$  that differs significantly from the value  $29,7\%$  obtained at usage of DD-target which allows to operate without overload of the detector (Fig. 6).



**Fig. 6. Results of experimental measurements by Source Jerk Method with application of  $^3\text{He}$  detector with its active part screened by Cd at center of the EK2 channel of "bare" assembly with lead introduced to the core**

Table 2  
**Results of fitting of pulse measurements with DD- target in “long” target unit in “bare” (without any reflector) assembly with lead instead of polyethylene in middle part of the core**

Condition of the assembly, target type and location	Type and position of the detector	Pulse repetition frequency of neutron generator, Hz	Interval of fitting, ms	Fitting			Gozani method		Sjöstrand method
				a	b	$\alpha$	$k_{ef}$	$\rho, \$$	$\rho, \$$
“Bare” assembly 280 fuel pins Lead instead of polyethylene at middle part of the core “Long” target unit DD target at Z=0, 210 mm Pb-target	<sup>3</sup> He, EK1, Z=0	197.8	0.2 – 4.99	28.72±0.78	11707.6±14.7	2860.1±3.3	0.792	28.2	30.51
	<sup>3</sup> He, EK1, Z=0	286.1	0.2 – 3.47	42.4±1.43	11752±20.3	2864.5±4.72	0.796	27.6	29.84
	<sup>3</sup> He, EK2, Z=0	197.8	0.2 – 4.99	22.6±0.745	8710.6±14.4	2915.5±4.3	0.807	26.17	28.44
	He3, EK3, Z=0	197.8	0.2 – 4.99	33.38±0.83	12840.7±15.2	2810.3	0.800	27.1	29.38

**Results of fitting of pulse measurements with DT neutron-producing target in “long” target unit in “bare”  
(without any reflector) assembly with lead instead of polyethylene in middle part of the core**

Condition of the assembly, target type and location	Type and position of the detector	Pulse repetition frequency of neutron generator, Hz	Interval of fitting, ms	Fitting			Gozani method		Sjöstrand method
				a	b	$\alpha$	$k_{ef}$	$\rho, \$$	$\rho, \$$
“Bare” assembly 280 fuel pins Lead instead of polyethylene at middle part of the core “Long” target unit DT target at Z=0, 210 mm Pb target	$^3\text{He}$ , EK2, Z=0 unscreened, 3 V amplitude	192.3	1.2 – 4.99	2273.5±6.89	729181.4±5400	2723.8±5.49	0.833	22.64	25.55
	$^3\text{He}$ , EK 2, Z=0 unscreened, 1.2 V amplitude	192.3	1.2 – 4.99	985.9±4.58	351420.0±3909	2797.4±8.29	0.819	24.5	27.43
	$^3\text{He}$ , EK 2, Z=0 screened by Cd 0.19mm, 3 V amplitude	192.3	1.2 – 4.99	664.23±3.06	237867.4±2995	2850.5±9.37	0.821	24.2	27.12
	$^3\text{He}$ , EK 2, Z=0 screened by Cd 0.19mm, 1.2 V amplitude	192.3	1.2 – 4.99	287.63±2.264	95611.8±2038.9	2805.5±15.8	0.833	22.54	25.7

3. Measurements of neutron flux distribution by  $^{252}\text{Cf}$  source at  $Z \approx 70$  mm were performed in the assembly with lead blocks instead polyethylene ones at middle part of the assembly (Fig. 7).

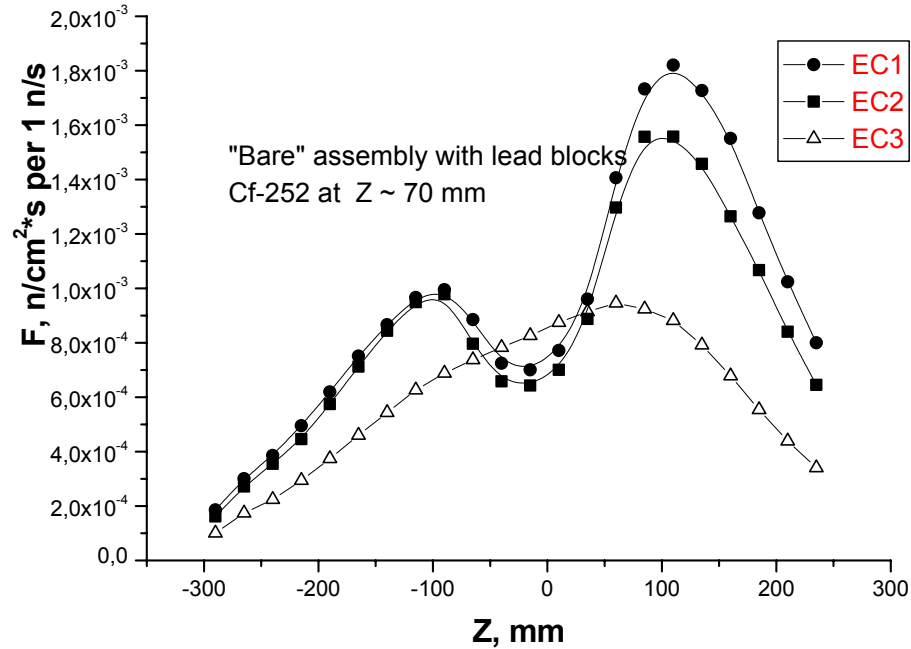


Fig.7. Axial distribution of neutron flux density in the experimental channels

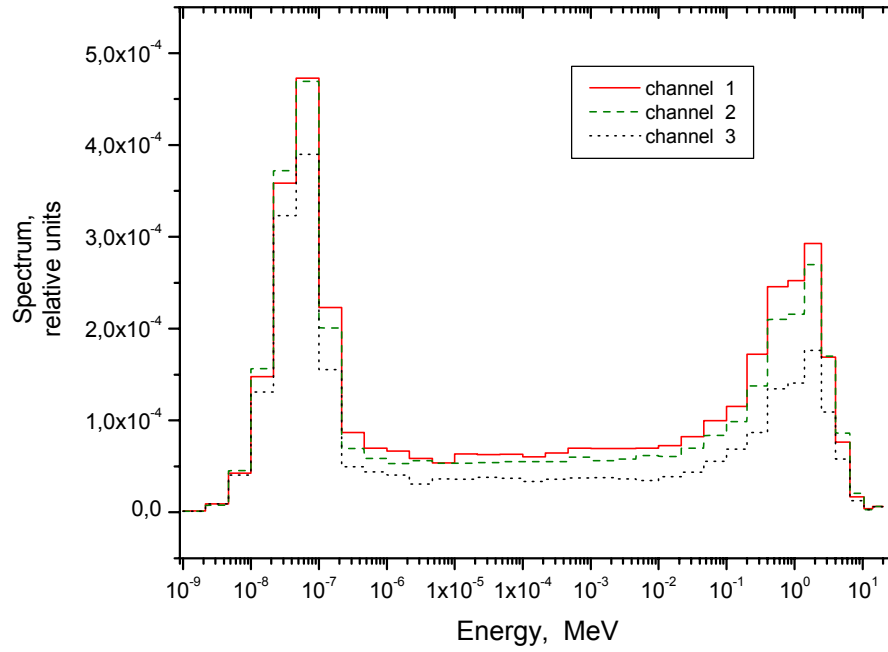
#### 4. The results of numerical simulation by MCNP-4B code

4.1. The calculations of neutron spectra in the experimental channels of the assembly have been performed:

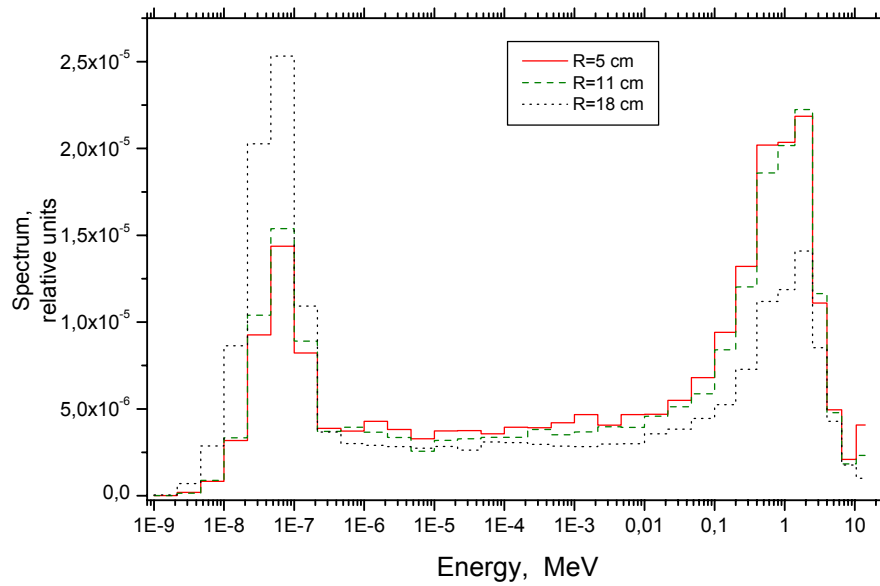
- 1) for DT mode of neutron generator operation by external location of neutron source;
- 2) for DD and DT modes by internal locations of neutron source

The results are presented in Fig. 8-10.

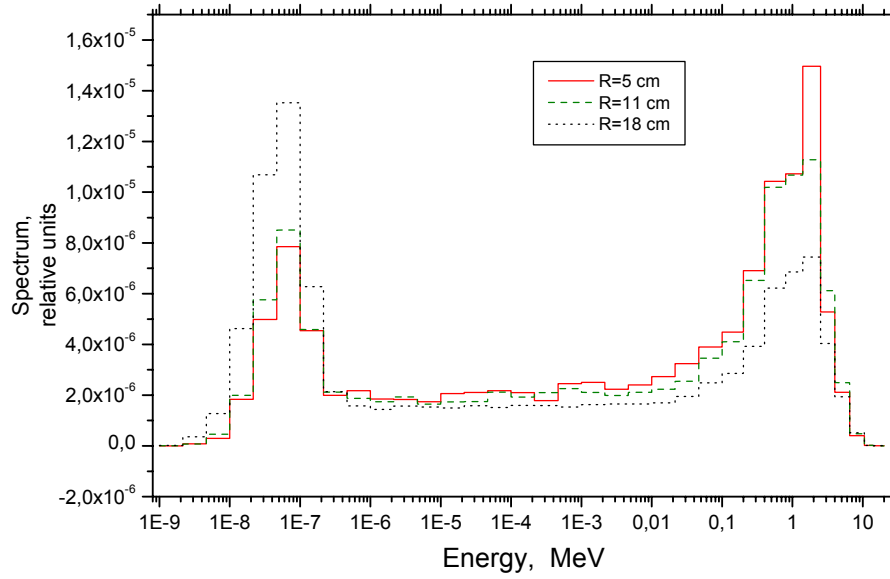
4.2. The calculations of neutron flux in the experimental channels of the assembly have been performed. The results are presented in Fig. 11-16.



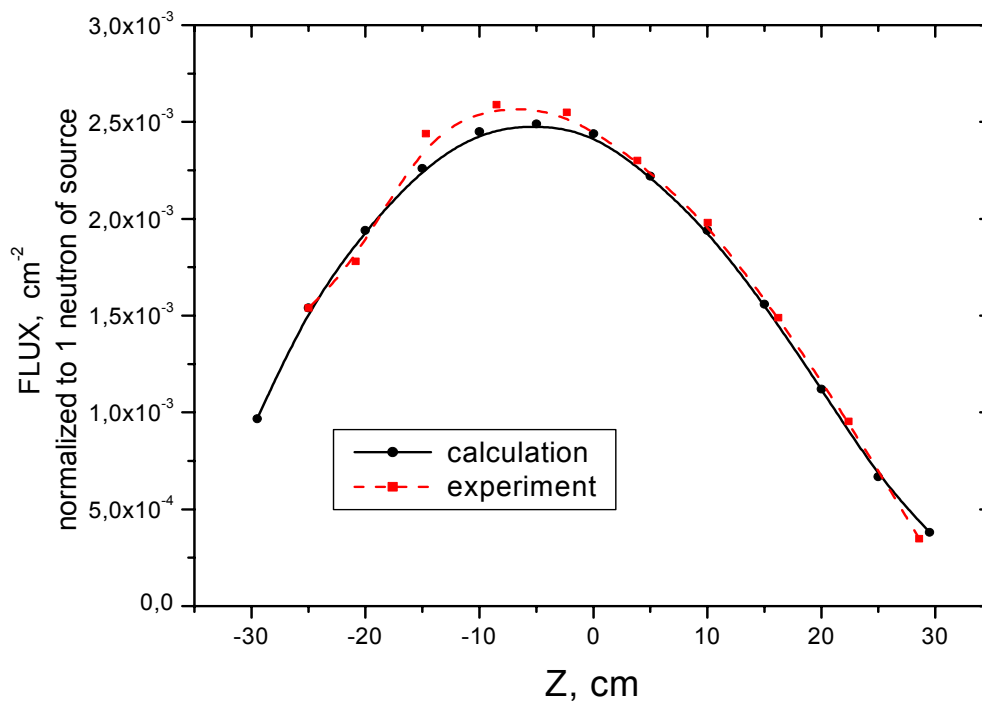
**Fig.8. Neutron spectra in the experimental channels by source DT,  $z = -38$  cm**



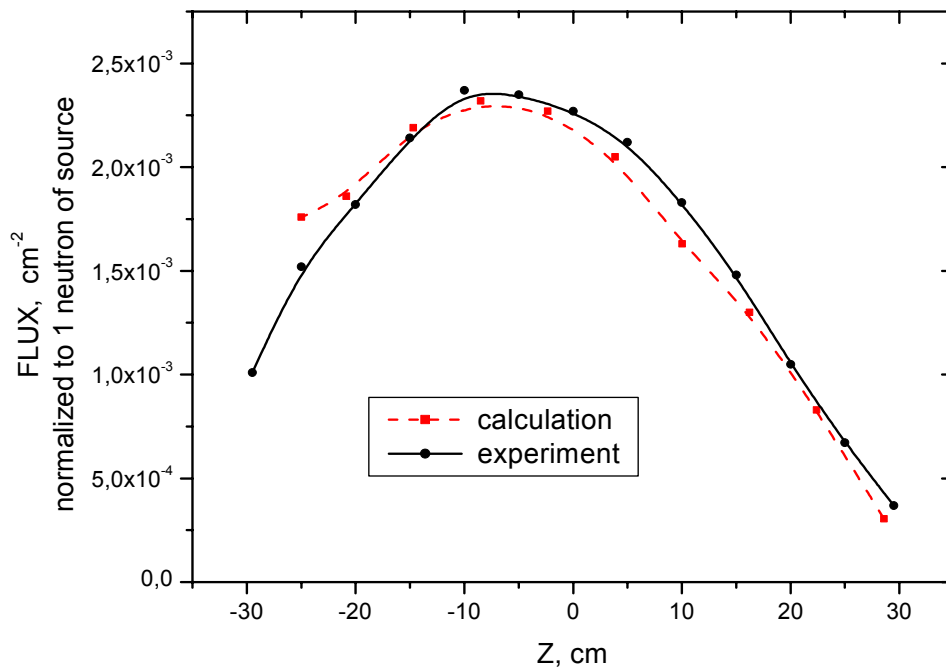
**Fig.9. Neutron spectra in the experimental channels by source DT,  $z = 0$  cm**



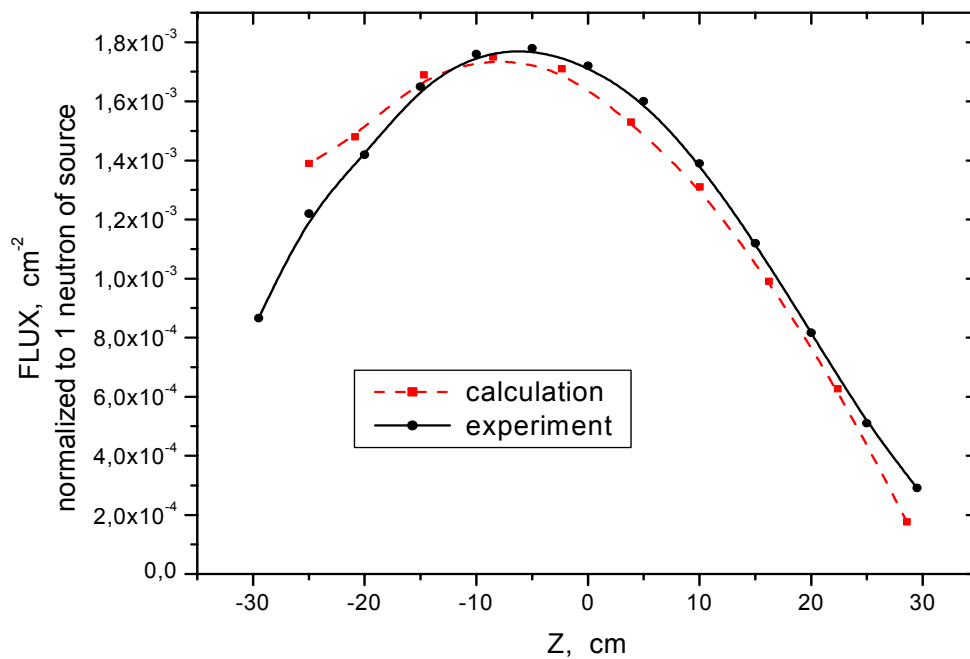
**Fig.10. Spectrum of neutron in the experimental channels at source DD,  $z=0$  cm**



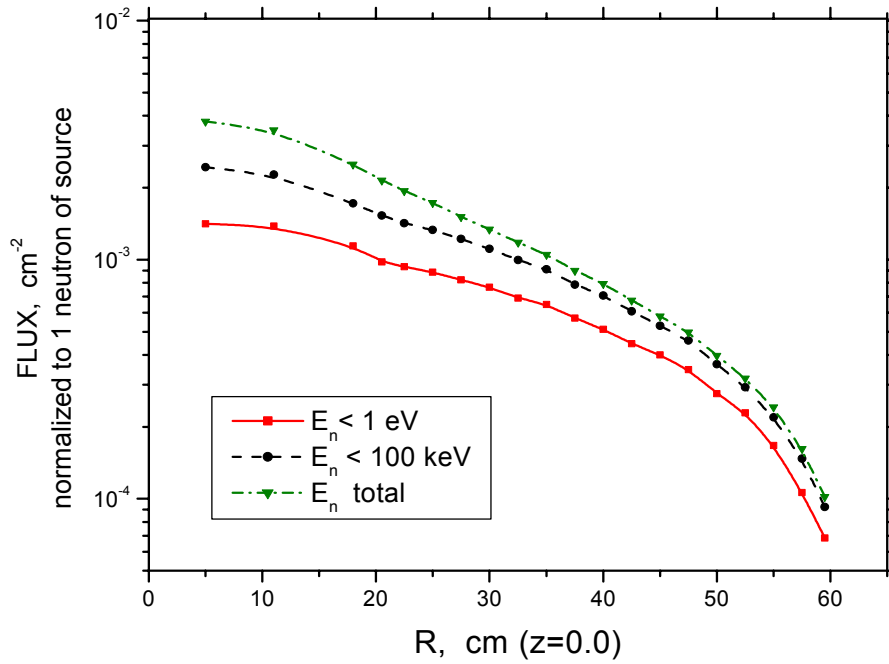
**Fig.11. Comparison of the experimental results with those of numerical simulation of neutron flux in experimental channel E1 by DT - mode,  $E_n < 100$  keV. Neutron source is located outside the core.**



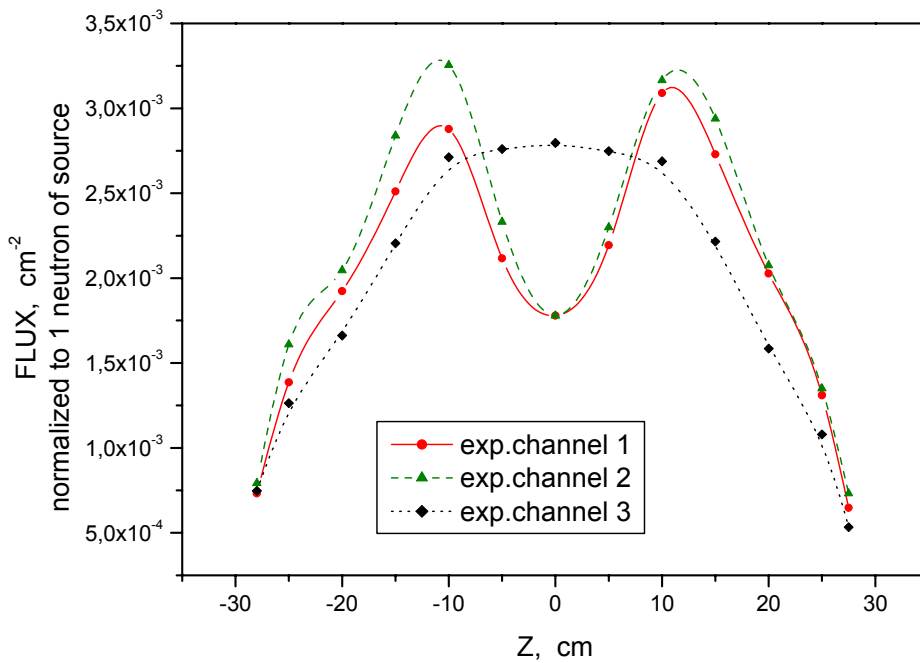
**Fig. 12. Comparison of the experimental results with those of numerical simulation of neutron flux in experimental channel E2 by DT –mode,  $E_n < 100$  keV. Neutron source is located outside the core.**



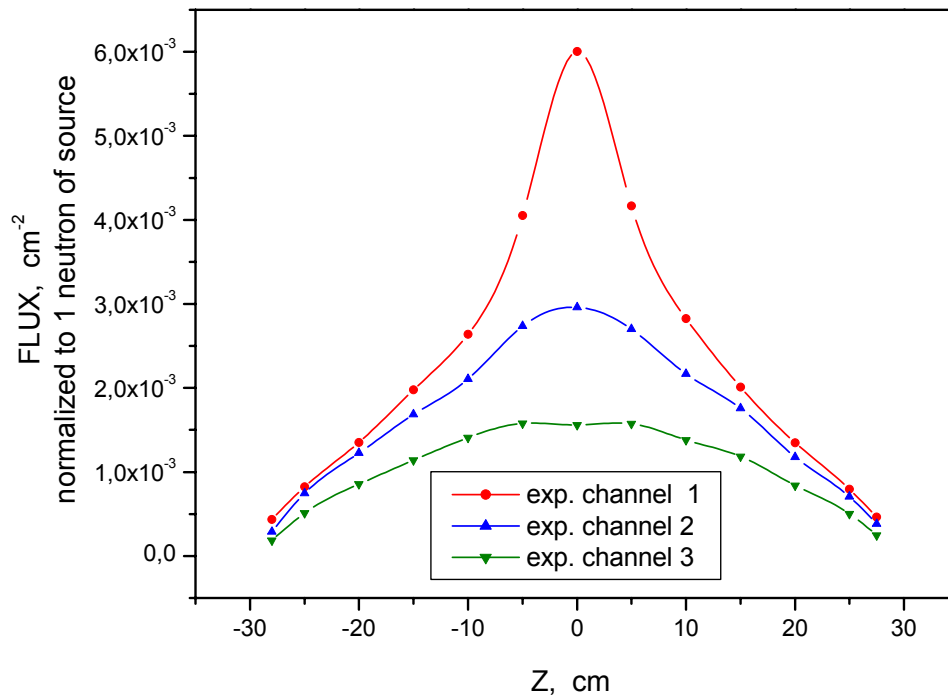
**Fig.13. Comparison of the experimental results with those of numerical simulation of neutron flux in experimental channel E3, by DT – mode,  $E_n < 100$  keV. Neutron source is located outside the core.**



**Fig.14. Radial distribution of neutron flux density  
(results of numerical simulation by MCNP – 4B code)**



**Fig.15. Axial distribution of neutron flux density in the experimental channels  
( $E_n < 1$  eV), DT**



**Fig.16. Axial distribution of neutron flux density in the experimental channels ( $E_n > 0.75$  MeV), DT-mode.**

5. **Calculated value of multiplication factor  $k_{ef}$  with taking into account the effective part of delayed neutrons  $\beta_{ef}$  is:  $0.92589 \pm 0.0009$ ; without taking into account  $\beta_{ef}$  :  $0.91888 \pm 0.00096$ .**

### Cooperation with the collaborators.

Experimental program “YALINA” is being discussed with Drs. Dr. W. Gudowski (RIT, Sweden), C. Broeders (KfK, Karlsruhe, Germany), E.Gonzales (CIEMAT, Spain), Y.Kadi (CERN), A.Stanculescu (IAEA). Second Steering Committee Meeting SAD/YALINA-B was held in Minsk 24-25 January 2005. The experts taking part at the meeting recommended:

1. to prepare the Formal proposal to the ISTC for continuation of the YALINA experiments. The proposal should have strong synergy components with SAD project.
2. to calibrate the YALINA detectors at MOL facility (Belgium)
3. The SAD/YALINA collaborators create a group of young students/researchers/engineers to join experimental work at YALINA and SAD. The seed of this group already exists.
4. SAD/YALINA collaborators submit proposals for Research agreements and Research contracts to IAEA for the CRP on ADS.

### Travels

Dr. S. Chigrinov participated in the International Workshop on MUSE Program, 16 - 25 October 2004, Rome, Italy and discussed the continuation of the SAD-YALINA-B experimental program with Drs. Dr. W. Gudowski (RIT, Sweden), C. Broeders (KfK, Karlsruhe, Germany), E. Gonzales (CIEMAT, Spain), F. Meller, F.Fugeras (Cadarashe, France).

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