NUCLEAR DATA EVALUATION AND EXPERIMENTAL RESEARCH OF ACCELERATOR DRIVEN SYSTEMS USING A SUBCRITICAL ASSEMBLY DRIVEN BY A NEUTRON GENERATOR*

S. CHIGRINOV, I. RAKHNO, K. RUTKOVSKAYA, A. KIEVITSKAIA,
A. KHILMANOVICH, B. MARTSINKEVICH, L. SALNIKOV, S. MAZANIK,
I. SERAFIMOVICH, E. SUKHOVITSKIJ
Radiation Physics & Chemistry Problems Institute,
National Academy of Sciences,
Minsk, Belarus

Abstract. The research in the field of creation of evaluated nuclear data libraries for fissile nuclides, investigation of nuclear reaction mechanism in the range of high energies and development of calculation methods for characteristics of an electronuclear reactor are being carried out at National Academy of Sciences of Belarus since early 70s. The possibility of using low energy accelerators to investigate physical characteristics of subcritical target/blanket systems follows from the mechanism of nuclear reactions in high (1GeV) and low (15-20 MeV) energy ranges as well as from features of nucleon-mesons cascade development. It was shown that the spallation neutron source can be simulated by neutrons escaping from heavy element targets bombarded by 14 MeV neutrons. It was a reason for creation of an experimental facility consisting of a subcritical target/blanket system driven by a high intensity (1.5-2.0 10^{12} neutrons/s) neutron generator.

1. INTRODUCTION

Possibility of using thorium for ^{233}U production is very important because of its high abundance and good nuclear data which improve physics characteristics of NPPs. The thorium fuel cycle can be used in modem nuclear reactors of all types with keeping up main design peculiarities and safety of nuclear power plants. Using thorium-uranium cycle in the frame of subcritical systems driven by high energy accelerators was considered in detail by C. Rubbia [1] and by H. Takahashi [2]. K. Furukawa proposed a THO -NES concept based on using Molten Salt Reactors and Molten Salt Breeders driven by accelerator [3].

It is obvious that many characteristics of the thorium-uranium cycle including a reprocessing technology are determined by accuracy of nuclear data in a wide range of energies and mass numbers, The research in the field of creation of evaluated nuclear data libraries for fissile nuclides, investigation of nuclear reaction mechanism in the range of high energies and development of calculation methods for characteristics of an electronuclear reactor are being carried out at National Academy of Sciences of Belarus since early 70s. During this period the neutron cross-section libraries for ^{233}U, ^{235}U, ^{238}U, ^{232}Th, ^{241}Am, ^{242}Am, ^{243}Am were created and included into the BROND-2 library (CJD, Obninsk, Russia).

During the last three years these investigations were supported within framework of the Project B-03 "Actinide Nuclear Data Evaluation" (ISTC, Moscow, Russia).

2. NUCLEAR DATA EVALUATION

In contrast to uranium-plutonium fuel cycle for thorium-uranium fuel cycle experimental and evaluated data are rather scarce which leads to different libraries of nuclear data and therefore to significant differences even in such integral characteristic like k_{eff}. One can see the differences in the Fig. 1 where the data on k_{eff} are presented by participants of neutron

* 1998 meeting.

benchmark on accelerator driven systems (ADS) with thorium-uranium cycle initiated by IAEA. It is seen that the k_{eff} values considerably differ from one participant to another depending on nuclear data library and computer code used.

The differences in cross-sections σ_f, σ_{n2n} and σ_{n3n}. taken from different libraries are presented in the Figs. 2 and 3 together with our evaluation performed using nuclear systematic validated for well experimentally investigated nuclei (^{238}U, ^{235}U, ^{233}U and others).

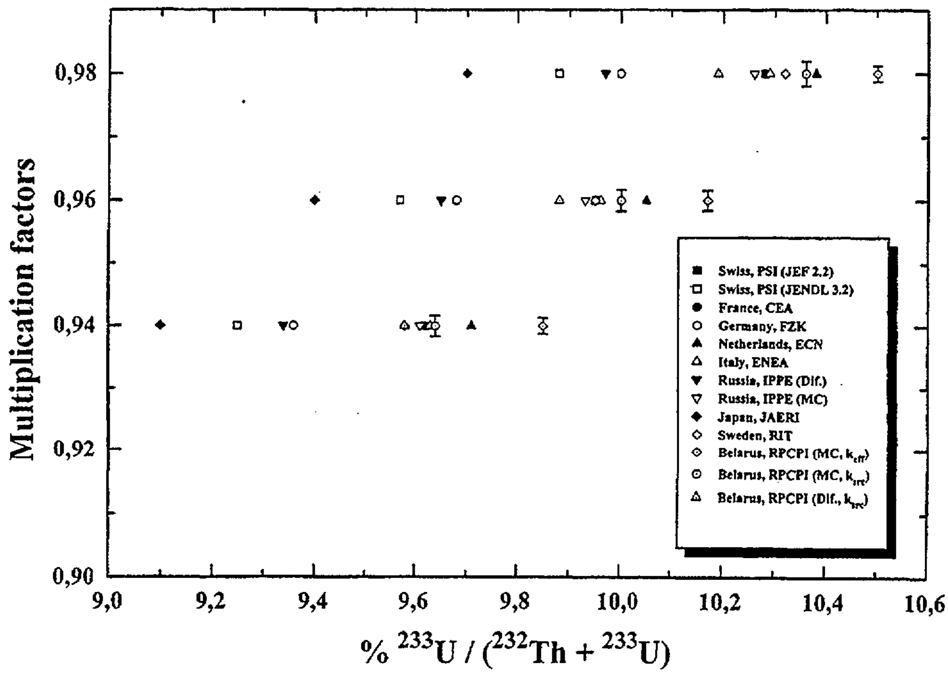

Figure 1. Results of IAEA benchmark on Th-U ADS.

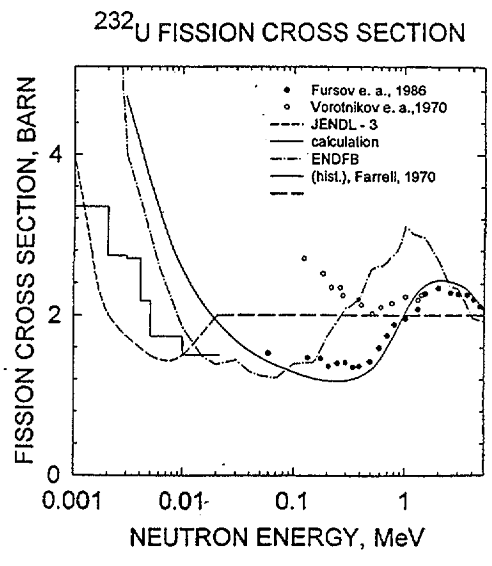

Figure 2. ^{232}U fission cross section.

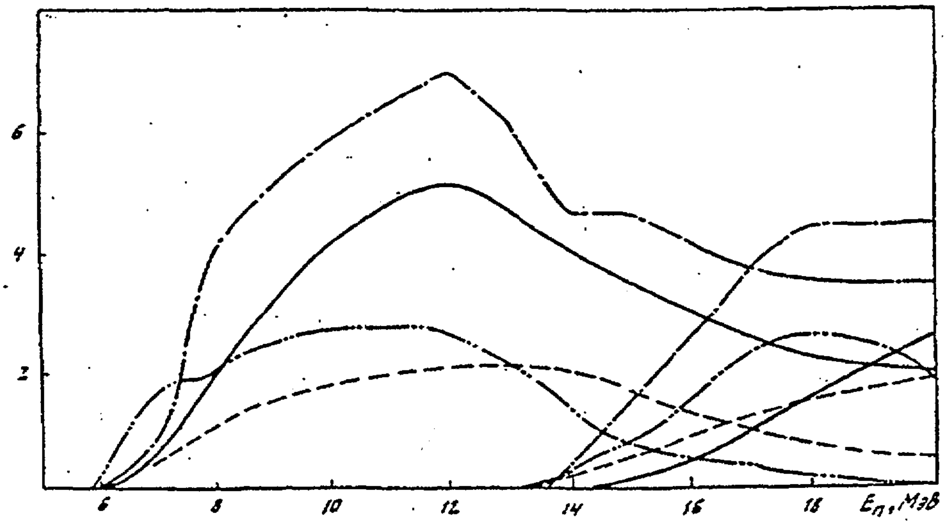

Figure 3. Comparison of evaluated (n,2n) and (n,3n) reactions cross-sections:
present evaluation ___
JENDL-2 evaluation -..-..-..-
JENDL-3 evaluation ------
ENDL-78 evaluation -.-.-.-.-.

These differences can undoubtedly result in different estimates of yields of proper isotopes for the fuel cycle, which is especially important for ADS with fast spectrum. Especially important for different estimates are fission and radioactive capture cross sections in resonance regions where their values can be extremely high. Nuclear data estimates in the regions are rather cumbersome. However using relevant systematic a self-consisted description of σ_t, σ_f, and σ_γ, have recently been obtained for ^{233}U in the energy range from 120 to 200 eV /G. Morogovsky, Fig. 4/.

Data of different libraries also differ in secondary neutron energy distributions for reactions (n, 2n), (n, n'), and (n, 3n), it is of special interest in the sense of spectrum formation for subcritical systems driven by high energy accelerators.

Large uncertainties in nuclear data required for thorium-uranium cycle and uncertainties in the region of intermediate energies are well known. In this regard for development of thorium-uranium cycle it is absolutely necessary to support any relevant experimental research and development of full modem evaluated nuclear data files. It should be also noted that the last changes made in such well known libraries like JENDL, JEF 2.2, ENDF/B-YI and other ones were made about five years ago and must be naturally expended to the region of higher energies. It is also necessary for estimates of performance of ADS.

3. EXPERIMENTAL RESEARCH

By now a lot of theoretical papers was published where basic aspects of ADS concept were discussed: production of energy, transmutation of radioactive waste, tritium production and incineration of weapon plutonium. The experimental research in this field is rather scarce because the experiments on available high energy accelerators are difficult and expensive, and in some cases even unfeasible. In this regard experimental research of various aspects of ADS on the basis of low energy ion accelerators are of great importance.

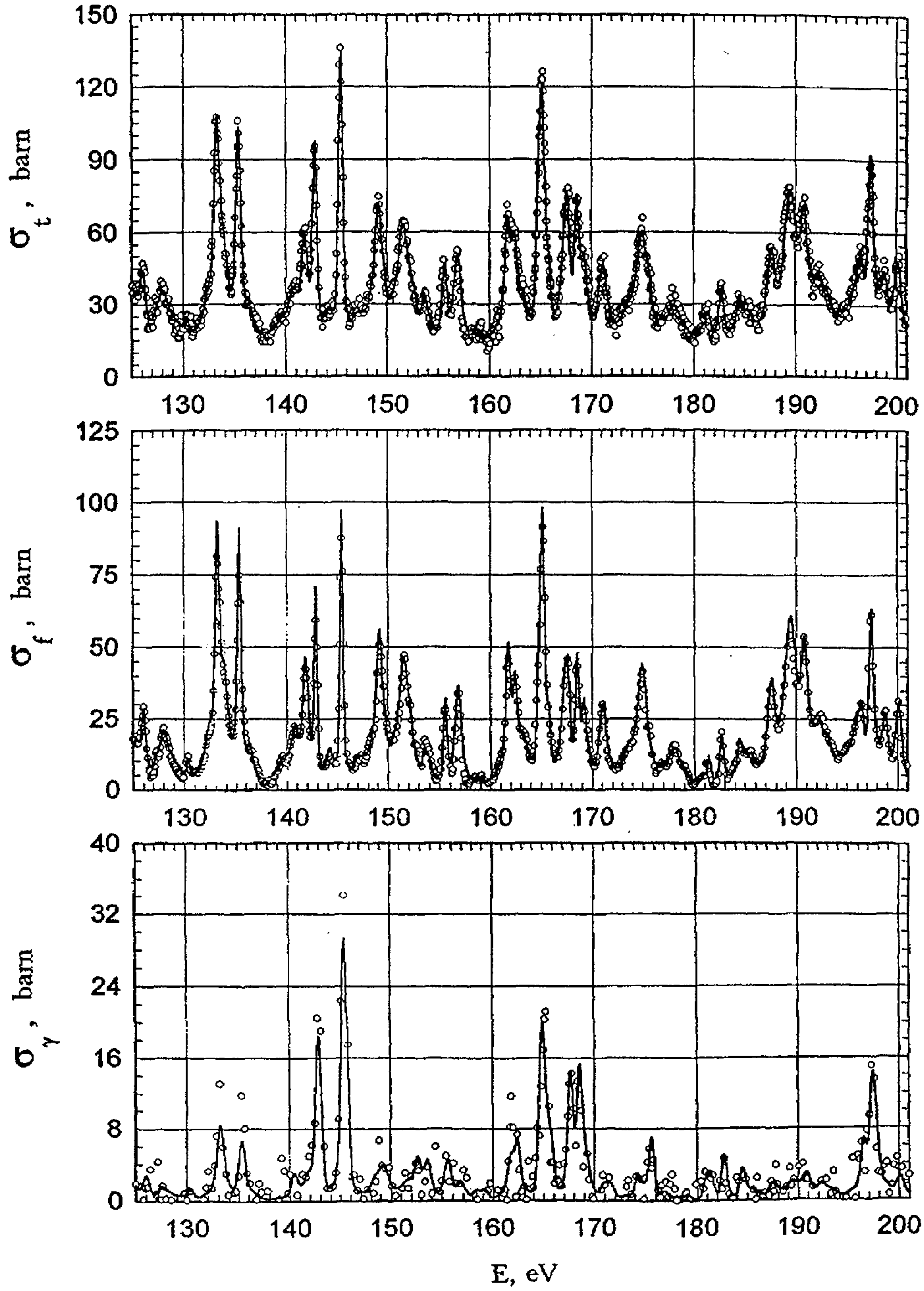

Figure 4. Comparison of experimental and calculated with MLBW parameters cross sections of ^{233}U.

The possibility of using low energy accelerators to investigate physical characteristics of subcritical target/blanket systems follows from the mechanism of nuclear reactions in high (≈1GeV) and low (≈15-20 MeV) energy ranges as well as from features of nucleon-mesons cascade development.

It was shown that the spallation neutron source can be simulated by neutrons escaping from heavy element targets bombarded by 14 MeV neutrons [8, 9]. It was a reason for creation of an experimental facility consisting of a subcritical target/blanket system driven by a high intensity (1.5-2.0 10^{12} neutrons/s) neutron generator (Fig. 5).

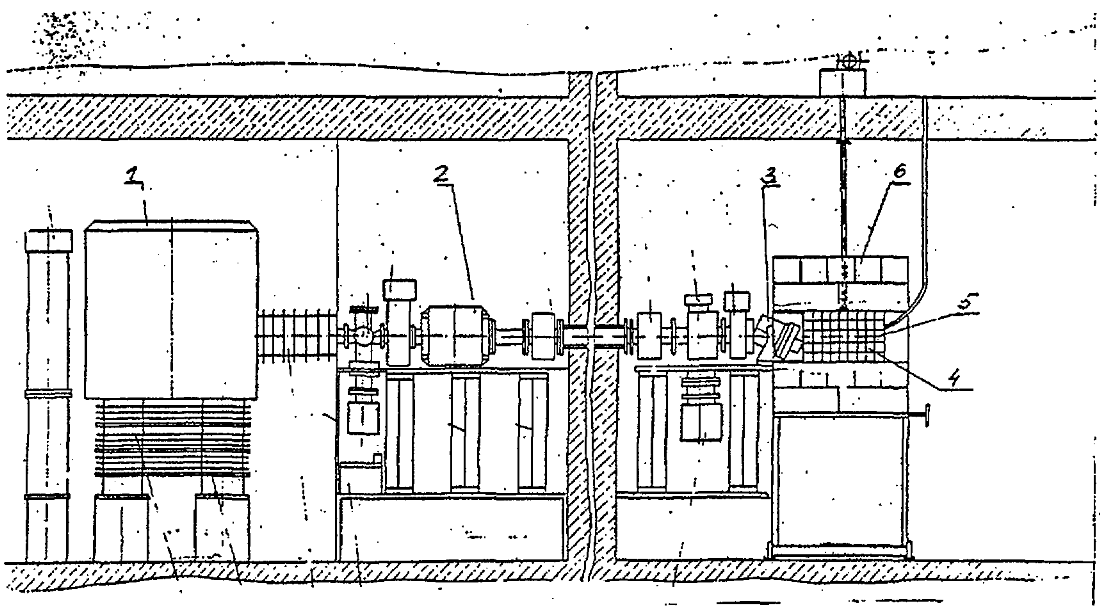

Figure 5. Subcritical uranium polyethylene assembly driven by neutron generator NG-12-1 (1-transformer, 2-magnetic analyzer, 3-target device, 4-core, 5-lead target, 6-graphite reflector).

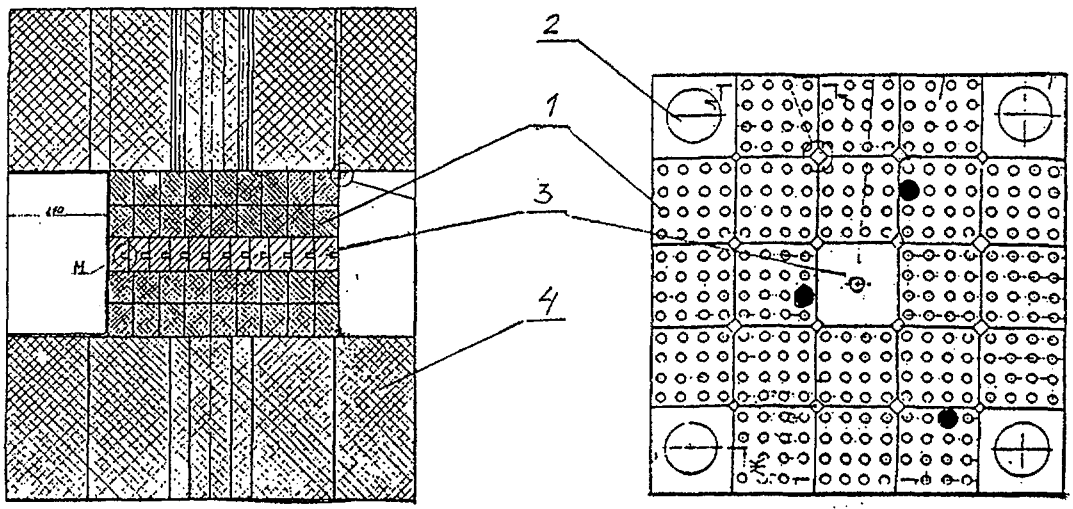

Fig. 6, Core of the subcritical assembly (1 - fuel subassembly, 2 - control subassembly, 3 - lead target, 4 - graphite reflector).

The target/blanket system includes a lead target for spallation neutron production and a subcritical assembly containing uranium rods with high enrichment, a moderator and experimental channels. Calculations have shown that it is possible to form different neutron spectra in experimental channels of the subcritical system: fast, resonance and thermal ones. In near future the subcritical assembly will be used for carrying out measurements in thermal and resonance spectra. The system measuring 4OOx4OOx600 mm^3 is assembled using cassettes with dimensions 8Ox8Ox600 mm^3 consisting of polyethylene moderator and fuel pins of UO_2 with enrichment equal to 10%. About 20 cassettes (i.e. 280 fuel pins) will be placed in the core of the target/blanket system to achieve the multiplication factor in the range of $0.9 < K_{eff} < 0.99$. The core is surrounded by a graphite reflector with dimensions 1000xl000x1200 mm^3, a cadmium layer I mm thick as well as borated polyethylene absorbing layer 0.5-1 mm thick (Fig. 6).

The subcritical assembly has three experimental channels located at a distance of 5.2, 10.5 and 16.6 cm from the assembly axis. The elements of the control system for neutron flux are placed in corners of the assembly.

It was shown by calculations that energy distributions of neutron flux density in the subcritical assembly differ from the spectra of thermal and fast reactors and are possibly characteristic of ADS with thermal spectrum.

The Fig. 7 presents the calculated neutron spectrum in the central part of the subcritical assembly. It is seen that neutrons with energies $E_n<0.5$ eV in the energy spectrum dominate and neutron flux varies slightly with energy in the range from 1 to 10^4 eV.

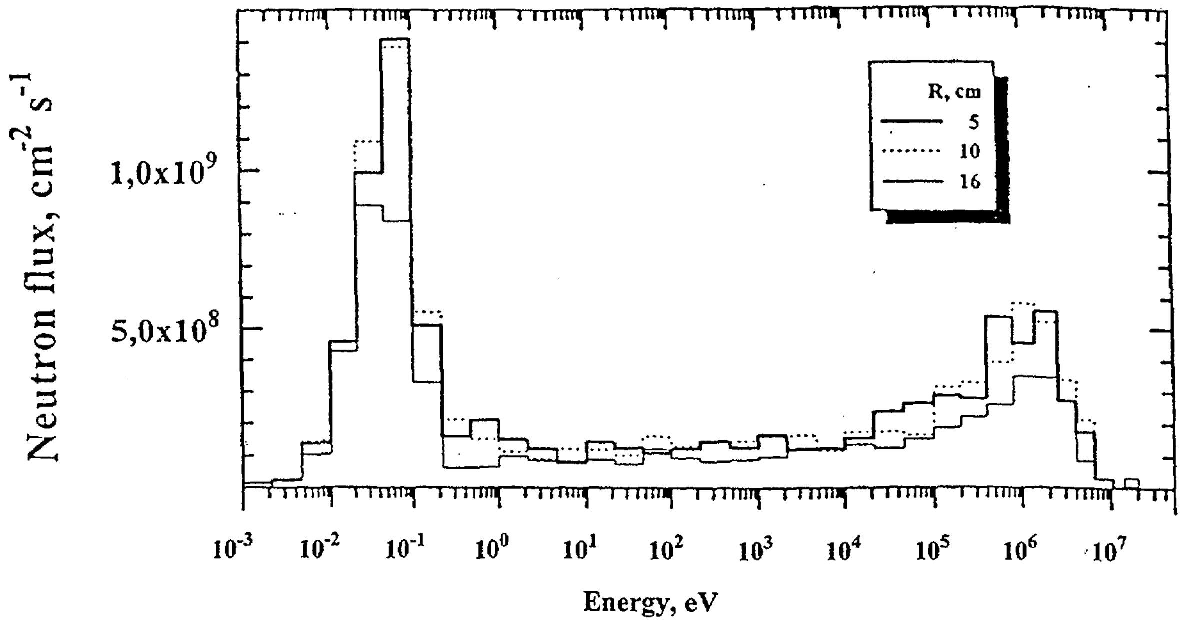

Figure 7. Calculated neutron energy distribution for the subcritical assembly driven by the neutron generator. Normalization was performed per 10^{12} neutrons per second.

Taking into account the neutron flux energy dependence as well as cross-sections σ_γ, and σ_{n2n}, for ^{232}Th and σ_f for ^{233}U one should expect that ^{232}U accumulation rate in ADS with thermal spectrum will be lower than that in thermal reactors.

Weak dependence of neutron flux density in the region of energies of 0.5 eV$<E_n<$10 keV gives the possibility to obtain experimental data on contribution of resonance region into transmutation rates of LLFP and MA where the values of cross-sections can be rather high.

We performed preliminary estimates for possibility of measuring transmutation rates of some LLFPs and MAs. The estimates revealed that in the assembly for a number of LLFPs and MAs reaction rates are high enough for the transmutation rates to be measured successfully (Table I).

Table I. Reaction rates of some LLFPs and MAs.
$\Phi = 10^7 n/cm^2 \times s$; $t=10^4 s$; $\varepsilon=0,1$

No.	Target	σ , barn (therm)	m, g	N, n+A--A'	S_{imp}	Activity, A, Bk
1	Zr-93	2.6±1.4	1.0	1.7×10^9		9.3×10^7
2	Tc-99	20.0+1 22.9±1.3	1.0	1.2×10^{10}	1.4×10^5	6.3×10^8
3	Sn-126	0.297	0.1	1.4×10^7	2.7×10^5	1.1×10^8
4	1-129	27+2.2	1.0	1.3×10^{10}	8.6×10^7	6.6×10^6
5	Cs-135	8.710.5	1.0	3.9×10^{10}	1.2×10^7	4.3×10^7
6	Cs-137	0.11±0,033 0.25±0,02	0.001	4.8×10^3	63.0	3.2×10^8
7	Th-232	7.4	1.0		$3*10^6$	4.1×10^3
8	U-233	σ_f=522.6	1.0		3×10^s	3.6×10^8
9	Np-237	σ_c=169±3 σ_f=0.0019± 0.003	1.0	4.3×10^{10} 4.8×10^6	8.0×10^6 2.4×10^2#	2.6×10^7
10	Am-241	σ_C=832+20 σ_f==3.15	0.001	2.1×10^8 7.9×10^5	1.1×10^6 $2.5\times10^{2\#}$#	1.3×10^8
11	Am-243	σ_c=79.3±1.8 σ_f=0.2±0.11	0.1	2.0×10^9 5.0×10^6	1.6×10^7 2.5×10^6#	7.4×10^s

Yield of nuclide - 1%; the number of decayed nuclei during the time of the measurement is 10%; γ-quantum yield per one decay is 0.5;
NA - number of nuclei formed in (n,γ)-reactions;
Sj_{mp} - number of registered impulses.

From the data presented in the table one can see that if neutron flux at thermal point equals approximately to 10^7 n/(cm^{2}s) it is possible to measure reaction rates in the spectrum of the subcritical assembly driven by the neutron generator. When performing activation measurements with samples irradiated in cadmium containers one can obtain information on average cross sections for ^{232}Th and ^{233}U in the energy range with little variation of neutron flux versus energy. It is very important for updating of evaluated nuclear data libraries.

The measurements of energy spectra at different points inside experimental channels will be performed by means of activation technique having different advantages comparing to other ones. In the energy range 30keV-15MeV the measurements will be performed by means of solid-state nuclear track detectors and thin-film break-down counters.

It will allow define optimal conditions for transmutation and get information on average cross sections for the energy spectra (like resonance integrals for reactor systems) which can be characteristic ones for energy systems driven by accelerators. In addition it is possible to measure the spectral indices σ_i/σ_f [5, 6, 7] for different isotopes.

The experiments on measurement of transmutation rates of LLFP and MA in different neutron will allow to make conclusions about trends of subsequent investigations, estimate discrepancies in evaluated nuclear data files for fission products and minor actinides as well as to compare results obtained by means of computer codes with experimental data. It is also possible to carry out experiments for research of peculiarities of dynamics of target/blanket systems driven by high energy accelerators.

The work on updating of existing evaluated nuclear data libraries and experimental research in the ADS region will be carried out at the subcritical assembly driven by the neutron generator in near future. The work will be supported by National Academy of Sciences of Belarus as well as ISTC under Project B-070

REFERENCES

[1] RUBBIA, C., et al., A realistic plutonium elimination scheme with fast energy amplifying and thorium-plutonium fuel,CERN/AT/95-53(ET).

[2] TAKAHASHI, H., CHEN, X., "Accelerator driven cross-progency nuclear fuel cycle" Intern. Conf. on Evaluation of Emerging Nuclear Fuel Cycle Systems, Global'95, Versailles, France (1995) 1436.

[3] FURUKAWA, K., et al., Thorium molten salt nuclear energy synergetics, J. Nucl. Sci. Tech., 27, (1990) 1157.

[4] MASLOV, V. M., KIKUCHI, Y., Systematic Study of Neutron Induced Reactions of the Actinide Nuclei, JAERI-Research 96-030, (1996)

[5] KOLAR, W., G. CARRARO, G. NASTRI, "Total neutron cross-section of ^{233}U from 0.7 to 300 eV.", (Proc. Intern. Conf. Nuclear Data for Reactors, Helsinki, v. 1, (1979) 387)

[6] NIZAMUDDIN, S., J. BLONS, Single-level analysis of the ^{233}U fission cross section for neutron energies between 6 and 124 eV, Nucel. Sci. Eng., 54, (1974) 1 16.

[7] WESTON, L. W., GWIN, R., G. DE SAUSSURE et al, Measurement of neutron fission and capture cross sections for ^{233}U in the energy region 0.4-2000 eV, Nucl. Sci. Eng., **34** (1968)

[8] CHIGRINOV, S., et al., "Experimental research of the transmutation of long-lived fission products and minor actinides in the subcritical assembly driven by neutron generator", (Proc. of the second Int. Conference on Accelerator-Driven Transmutation Technologies and Applications, Kalmar, Sweden) (1996) 737-741.

[9] BAKHANOVICH, L. A., et al, Evaluation neutron data for ^{233}U, INDC(BLR)-001, Vienna, (1993).