RUSSIAN PROGRAM OF MINOR ACTINIDE NUCLEAR DATA MEASUREMENTS AND EVALUATION

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Abstract

The proposed programme consists of five subprograms of the MA nuclear characteristics measurements and their evaluation. The measurements will be performed with the different methods using different installations (nTOF, Pb-slow down spectrometer, tandem generator, irradiation in high flux reactor, benchmark experiments at BFS). Nuclear characteristics (σ_f, σ_c, α, resonance integrals and parameters, central reactivity coefficient etc.) will be measured for 22 isotopes of Np, Pu, Am, Cm, Bk and Cf in four energy range of neutron spectra: thermal region, resolved resonance region (1 to 100 eV), unresolved resonance region (0.1 to 100 keV) and fast spectrum region (0.1 to 30 MeV).

The measured data will be evaluated and prepared as a file compatible with existing nuclear data libraries.

Introduction

It is commonly accepted now that a long term sustainable nuclear power (NP) is impossible without solution of the problem of the radioactive waste (RW) incineration and especially of minor actinides (MA) burning. For R&D of all these reactors it is necessary to know the nuclear characteristics (fission, capture and absorption neutron cross sections, resonance parameters and integrals, etc.) of all isotopes of minor actinides (Np, Pu, Am, Cm, Bk, Cf) in four range of neutron spectra: thermal region, resolved resonance region (1 to 100 eV), unresolved resonance region (0.1 to 100 keV) and fast region (0.1 to 30 MeV). The main bulk of these data were obtained about twenty to thirty years ago and they are very incomplete at the moment [1-5].

We suggest the comprehensive program of MA nuclear data measurements and evaluation. The differential, integral and benchmark measurements will be performed in the framework of the Program. The values σ_f, σ_c, α, resonance integrals and parameters, void and Doppler-effects etc. will be measured in the energy range $0.1eV < E < 12$ MeV for 22 isotopes of Pu, Am, Cm, Cf and Bk. The obtained data will be evaluated and prepared for using in the worldwide nuclear data libraries.

The programme consists of five ISTC subprojects which are all submitted now to ISTC.

1. High Precision Measurement of MA Nuclear Data in Resonance Neutron Energy Range

(G.V.Muradyan, Russian Research Center "Kurchatov Institute", Moscow, ISTC # 3176)

It is planned to measure fission $\sigma_f(E)$, capture $\sigma_c(E)$ and absorption $\sigma_a(E)$ cross sections as well as the ratio $\alpha(E)= \sigma_c/\sigma_f$, resonance integrals (RI) and resonance parameters (RP) with accuracy of 3 to 5% for MA isotopes in the energy ranges presented in Table 1. Measurements will be performed at linac FAKEL (Kurchatov Institute, Moscow) using an original method of measuring γ-rays multiplicity caused by the fission, capture and scattering of neutrons.

Table 1.

Isotope	Measuring characteristics*)	Energy range (eV)
^{237}Np	$\sigma_c(E)$, RIC	0.5 to 2000
^{238}Pu	$\sigma_c(E)$ RIA	0.5 to 30 0.5 to 300
^{241}Pu	$\alpha(E)$ RIF, RIC $\sigma_f(E)$	0.5 to 200 0.5 to 300 0.5 to 2000
^{241}Am	RP RIF, RIA $\sigma_f(E)$	0.5 to 5 0.5 to 300 0.5 to 2000
^{242m}Am	RP RIF, RIA $\sigma_f(E)$	0.5 to 5 0.5 to 300 0.5 to 2000
^{243}Am	$\sigma_\gamma(E)$ RIF, RIA $\sigma_f(E)$	0.5 to 10 0.5 to 300 0.5 to 2000
^{243}Cm	$\sigma_\gamma(E)$, RP, RIF, RIA	0.5 to 10
^{244}Cm	$\sigma_f(E)$, $\sigma_\gamma(E)$, $\alpha(E)$ RIF, RIC	0.5 to 200
^{245}CM	RP, $\sigma_a(E)$, $\alpha(E)$ RIF, RIA $\sigma_f(E)$	0.5 to 20 0.5 to 300 0.5 to 2000
^{246}Cm	RP, $\sigma_c(E)$, RIC	0.5 to 50.
^{247}Cm	$\sigma_a(E)$ RIF, RIA $\sigma_f(E)$	0.5 to 100 0.5 to 300 0.5 to 2000
^{251}Cf	RP, RIF, RIA	0.5 to 5.

*)RP – resonance parameters; RIC – capture resonance integral;

RIF - fission resonance integral; RIA - absorption resonance integral.

2. Measurement of fission cross section energy dependence of MA in high neutron energy range (I.V.Ivanin, Russian Federal Nuclear Center VNIIEF, Sarov, ISTC # 2952)

It is planned to measure fission cross section $\sigma_f(E)$ in the neutron energy range E=40 keVto12 MeV with accuracy 3 to 5 % for MA-isotopes presented in Table 2.

Table 2.

ISOTOPE	***Achieved accuracy %***	**Required accuracy %**	
		ADS-burners	**Fast Lead Cooled Reactors**
^{237}Np	7	5	2
^{238}Pu	10	5	5
^{241}Am	10	5	3
^{242m}Am	15	5	5
^{243}Am	10	5	3

Measurements will be done at accelerator LU-50 (VNIIEF, Sarov) by nTOF technique using fission chambers.

3. **Measurement of cross sections of fast and resonance neutrons induced fission of MA for their transmutation with ADS**
(B.I.Fursov, Institute of Physics and Power Engineering, Obninsk, ISTC # 1749)

Two types of experiments with isotopes

^{241}Am, ^{242m}Am, ^{243}Am,
^{243}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{248}Cm.

are planned:

1. Measurement of fission cross-sections of **Am** and **Cm** isotopes in the neutron energy range E=5 to 30 MeV using neutrons produced in reactions *t(p,n), d(p,n)* and *t(d,n)* at tandem generator (IPPE, Obninsk).

2. Measurements in the neutron energy range E=1eV to 50 keV using lead slow down spectrometer (100 tons lead cube at INR, Troitsk).

4. Measurement of transmutation properties of MA irradiated in the intermediate reactor neutron spectrum

(Yu.G.Toporov, Research Institute of Atomic Reactors, Dimitrovgrad, ISTC # 2925)

The nuclear characteristics of the following six groups of minor actinide isotopes are planned to be measured:

^{238}U,
^{237}Np,
^{240}Pu, ^{242}Pu, ^{244}Pu,
^{241}Am, ^{242m}Am, ^{243}Am,
^{242}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{248}Cm,
^{249}Bk,
^{250}Cf, ^{251}Cf, ^{252}Cf.

The measurements include the MA irradiation in the intermediate neutron spectrum (E =0.1 to 100 keV) of SM-3 reactor (RIAR, Dimitrovgrad) and complete radiochemical and isotopic post irradiation analysis.

5. Benchmark experiments on MA transmutation at BFS critical facilities for justification of ADS-burners design

(I.P.Matveenko, Institute of Physics and Power Engineering, Obninsk, ISTC # 2884)

It is planned to assemble critical configurations at BFS facility simulating core compositions of fast LBR and MSR types of reactors. The following measurements will be carried out with these assemblies:

$\langle\sigma_f\rangle$	$\langle\sigma_c\rangle$	***CRC***	$\Delta\langle\sigma_c\rangle/\Delta T$
^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{243}Am, ^{244}Cm, ^{245}Cm.	^{237}Np, ^{240}Pu	^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am	^{237}Np, ^{241}Am

Fission $\langle\sigma_f\rangle$ and capture $\langle\sigma_c\rangle$ cross-sections averaged over the neutron spectrum as well as reactivity coefficients (*CRC*) and Doppler-effect ($\Delta\langle\sigma_c\rangle/\Delta T$) will be measured using fission chambers, solid state detectors, and oscillating cold and hot samples.

Analysis of the experiments (together with the irradiation experiments at BN-350 reactor performed earlier) will allow updating of MA neutron data for real reactor spectra as well as neutron parameters of the benchmark cores.

Evaluation of MA nuclear data.

For the evaluation of the obtained experimental data the group of leading experts in the field will be created:

1. Nikolaev M.N. - IPPE, Obninsk, *head of the group*
2. Tsybulya A.M. - IPPE, Obninsk
3. Manokhin V.N. - IPPE, Obninsk
4. Ignatyuk A.V. - IPPE, Obninsk
5. Abagyan L.P. - RRC "Kurchatov Institute", Moscow
6. Yudkevich M.S. - RRC "Kurchatov Institute", Moscow
7. Anufriev V.A. - RIAR, Dimitrovgrad
8. Gorelov V.P. - VNIIEF, Sarov
9. Maslov V.M. - INF, Minsk.

The members of this group created the Russian neutron data libraries (BNAB, BROND, TENDL) as well as participate in the development of the international nuclear data libraries.

Using the obtained experimental data and their cross-checks the working group will prepare the revised file of the evaluated MA nuclear data compatible with the most known nuclear data libraries (ENDF/B, JENDL etc.).

The cumulative list of planned measurements in all five subprograms is presented in Table 3.

Table 3. **List of MA isotopes planned to be measured**

	Isotope	Measuring characteristics	Energy range	Team leader
1	^{237}Np	$\sigma_c(E)$, RIC	0.5 to 2000 eV	Muradyan
		$\sigma_f(E)$	0.04 to 12 MeV	Ivanin
		$<\sigma_f>$ *) $<\sigma_c>$ $\Delta<\sigma_c>/\Delta T$ $<\sigma_{in}>$ CRC	Fis.thres. to 5 MeV 0.05 to 100 keV 0.05 to 100 keV 0.8 to 5 MeV	Matveyenko
2	^{238}U	$\Delta<\sigma_c>/\Delta T$	0.05 to 100 keV	Matveyenko
		$<\sigma_f>,<\sigma_c>$	0.1 to 100 keV	Toporov
3	^{238}Pu	$\sigma_c(E)$ RIA	0.5 to 30 eV 0.5 to 300 eV	Muradyan
		$<\sigma_f>$ $<\sigma_c>$	0.1 to 5000 keV 0.05 to 100 keV	Matveyenko
		$\sigma_f(E)$	0.04 to 12 MeV	Ivanin
4	^{239}Pu	$<\sigma_f>$ $<\sigma_c>$ CRC	0.1 to 500 keV**) 1 to 5000 keV***) 0.05 to 100 keV	Matveyenko
5	^{240}Pu	$<\sigma_f>$ $<\sigma_c>$ CRC	Fis.thres. – 5 MeV 0.05 to 100 keV	Matveyenko
		$<\sigma_f>$, $<\sigma_c>$	0.1-100 keV	Toporov
6	^{241}Pu	$\alpha(E)$ RIF, RIC $\sigma_f(E)$	0.5 to 200 eV 0.5 to 300 eV 0.5 to 2000 eV	Muradyan
		$<\sigma_f>$	0.1 to 500 keV**) 1 to 5000 keV***)	Matveyenko
7	^{242}Pu	$<\sigma_f>$, $<\sigma_c>$	0.1-100 keV	Toporov
8	^{244}Pu			
9	^{241}Am	RP RIF, RIA $\sigma_f(E)$	0.5 to 5 eV 0.5 to 300 eV 0.5 to 2000 eV	Muradyan
		$\sigma_f(E)$	5 to 30 MeV 1 eV to 50 keV (Pb-cube)	Fursov
		$<\sigma_f>$ $\Delta<\sigma_c>/\Delta T$ $<\sigma_c>$ CRC	Fis.thres. – 5 MeV 0.05 to 100 keV 0.05 to 100 keV	Matveyenko
		$\sigma_f(E)$	0.04 to 12 MeV	Ivanin

10	^{242m}Am	RP RIF, RIA $\sigma_f(E)$	0.5 to 5 eV 0.5 to 300 eV 0.5 to 2000 eV	Muradyan
		$\sigma_f(E)$	5 to 30 MeV 1 eV to 50 keV	Fursov
		$\sigma_f(E)$	0.04 to 12 MeV	Ivanin
11	*^{243}Am*	$\sigma_\gamma(E)$ RIF, RIA $\sigma_f(E)$	0.5 to 10 eV 0.5 to 300 eV 0.5 to 2000 eV	Muradyan
		$\sigma_f(E)$	5 to 30 MeV 1 eV to 50 keV	Fursov
		$\sigma_f(E)$	0.04-12 MeV	Ivanin
		$<\sigma_f>$	Fis.thres. – 5 MeV	Matveyenko
12	^{242}Cm	$<\sigma_f>$, $<\sigma_c>$	0.1-100 keV	Toporov
13	^{243}Cm	$\sigma_f(E)$	5 to 30 MeV 1 eV to 50 keV (Pb-cube)	Fursov
		$\sigma_\gamma(E)$, RP, RIF, RIA	0.5 to 10	Muradyan
14	^{244}Cm	$<\sigma_f>$, $<\sigma_c>$	0.1-100 keV	Toporov
		$\sigma_f(E)$	5 to 30 MeV 1 eV to 50 keV (Pb-cube)	Fursov
		$\sigma_f(E)$, $\sigma_\gamma(E)$, $\alpha(E)$ RIF, RIC	0.5 to 200 eV	Muradyan
		$<\sigma_f>$ $<\sigma_c>$	Fis.thres. to 5 MeV 0.05 to 100 keV	Matveyenko
15	^{245}Cm	$<\sigma_f>$, $<\sigma_c>$	0.1 to 100 keV	Toporov
		$\sigma_f(E)$	5 to 30 MeV 1 eV to 50 keV (Pb-cube)	Fursov
		$<\sigma_f>$ $<\sigma_c>$	0.1 to 500 keV$^{**)}$ 1 to 5000 keV$^{***)}$ 0.05 to 100 keV	Matveyenko
		RP, $\sigma_a(E)$, $\alpha(E)$ **RIF, RIA** $\sigma_f(E)$	0.5 to 20 eV 0.5 to 300 eV 0.5 to 2000 eV	Muradyan
16	^{246}Cm	$<\sigma_f>$, $<\sigma_c>$	0.1-100 keV	Toporov
		$\sigma_f(E)$	5 to 30 MeV 1 eV to 50 keV (Pb-cube)	Fursov
		RP, $\sigma_c(E)$, RIC	0.5 to 50 eV	Muradyan

17	^{247}Cm	$\sigma_f(E)$	5 to 30 MeV 1 eV to 50 keV (Pb-cube)	Fursov
		$\sigma_a(E)$ RIF, RIA $\sigma_f(E)$	0.5 to 100 eV 0.5 to 300 eV 0.5 to 2000 eV	Muradyan
18	^{248}Cm	$<\sigma_f>$, $<\sigma_c>$	0.1-100 keV	Toporov
		$\sigma_f(E)$	5 to 30 MeV 1 eV to 50 keV (Pb-cube)	Fursov
19	^{249}Bk	$<\sigma_f>$, $<\sigma_c>$	0.1-100 keV	Toporov
20	^{250}Cf			
21	^{251}Cf	$<\sigma_f>$, $<\sigma_c>$	0.1-100 keV	Toporov
		RP, RIF, RIA	0.5 to 5.	Muradyan
22	^{252}Cf	$<\sigma_f>$, $<\sigma_c>$	0.1-100 keV	Toporov

*) - $<\sigma>$ is the spectrum averaged cross-section.
**) - MSR neutron spectrum.
***) - LBC neutron spectrum.
+) - *CRC* is the central reactivity coefficient.

Conclusion

We have now all the necessary to begin and complete the programme:

- all the set of MA certified isotopes;
- accelerator LU-50 (VNIIEF), MMF linac (INR), tandem generator (IPPE);
- high flax research reactors SM-3 and BOR-60 (RIAR);
- unique research facility BFS (IPPE);
- different types of spectrometers (ToF, LSD, etc.)
- high class radiochemistry;
- qualified personnel;
- world known team for the measured data evaluation.

It seems to me at present only in Russia the presented programme can be performed within three years for moderate price, but due to the common interest to these data it is reasonable to transform it into the international one.

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