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Determination of the ratios of the average plutonium-239 and neptunium-237 fission cross-sections to the average uranium-235 fission cross-section in the assembly QUINTA neutron field

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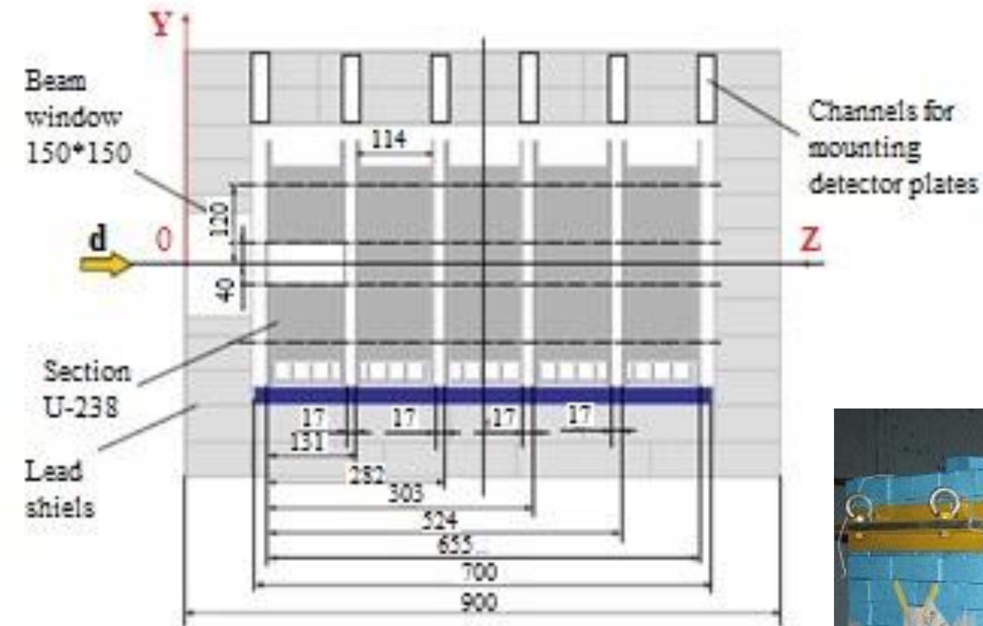
Accumulation and burning of plutonium, neptunium and other isotopes occur on the installation. It has an effect on the balance of neutrons. These causes make for interest to carry out such measurements.

Experiments objectives:

- determination of the ratio of the average ^{239}Pu fission cross-section to the average ^{235}U fission cross-section in the assembly QUINTA neutron field
- determination of the ratio of the average ^{237}Np fission cross-section to the average ^{235}U fission cross-section in the assembly QUINTA neutron field

Target assembly description



Experimental details_1

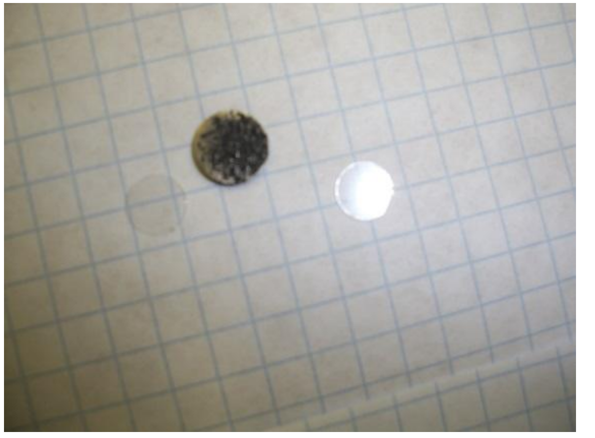
- The method of the SSNTD was chosen for the determination of the ratios of the average ^{239}Pu and ^{237}Np fission cross-sections to the average ^{235}U fission cross-section.

This technique was developed by I. Zhuk and A. Malikhin. It was applied for fission reactions rates measurements in reactor systems

- RUN December 2013
- QUINTA was irradiated
  - by deuterons (2 GeV/A and 4 GeV/A)
  - and carbon ions (2 GeV/A and 4 GeV/A)

Experimental details_2

SSNTD-sensors consist of two parts: of the target-foil that interacts with incident particles via nuclear fission (irradiator) and of the material in which fission fragments leave tracks (track detector). The detectors material was artificial mica.



We are placed sensors on backplate of left side on lead blanket of QUINTA.

Experimental technique_1

- The procedure of the determination of the ratios of the average fissionable nuclides cross-sections to the average ^{235}U fission cross-sections $\frac{\overline{\sigma}^i_f}{\overline{\sigma}^{25}_f}$ is based on correlation between

the track density on a track detector N_i, which irradiated in contact with target, and energy neutron flux density of investigated neutron field φ_E:

- $$N^i = A^i_k \; \mu^i \; \varepsilon^i \; t \; d^i \; \rho^i \; \int_0^\infty \; \sigma^i_k(E)\varphi(E) \, dE \qquad (1)$$

where A^i_k-number of charged particles produced in k -reaction of i -nuclide; μ_i -the fraction of charged particles reaching the detector; ε_i -detection efficiency of the charged particle track detectors; t -duration of sensors the exposure, sec; d_i -the radiator thickness, cm; ρ_i-nuclear density of i -nuclide in the radiator, nuclei/cm^3; σ^i_k -microscopic cross-section of k -reaction on i -nuclide.

Experimental technique_2

$$N^i = A_k^i \; \mu^i \; \varepsilon^i \; t \; d^i \; \rho^i \; \int_0^\infty \sigma_k^i(E)\varphi(E) \, dE \qquad (1)$$

The average cross-section of k -reaction on i -nuclide is equal to

$$\overline{\sigma}_k^i = \frac{\int\limits_0^\infty \sigma_k^i(E)\varphi(E) \, dE}{\int\limits_0^\infty \varphi(E) \, dE}$$

Then the ratio of average cross sections is the ratio of reaction rates of these nuclides – spectral indices

$$\frac{\overline{\sigma}_f^i}{\overline{\sigma}_f^{25}} = \frac{\int\limits_0^\infty \sigma_f^i(E)\varphi(E) \, dE}{\int\limits_0^\infty \sigma_f^{25}(E)\varphi(E) \, dE} \qquad (2)$$

The spectral indices are experimental values which are most accurate and easy-to-use for comparison with the simulation results. Because they don’t contain the error which is associated with the uncertainty of the fluence of the primary particles.

Experimental technique_3

- Absolute and relative methods are used for the determination of the ratios of the average cross-sections. Equations (1) and (2) are used for absolute methods. But absolute methods has a additional uncertainties from determination of ε, ρ, d uncertainties.
- In relative methods ε, ρ, d are determined from calibration measurements in standard neutron field.
- So equation for the ratio of average fissionable nuclides cross-sections is $$\frac{\overline{\sigma}_f^i}{\overline{\sigma}_f^{25}} = \frac{Nm^i}{Nm^{25}} \frac{Ns^i}{Ns^{25}} \frac{(\sigma_f^i)_s}{(\sigma_f^{25})_s}$$
- where *m* and *s* are the results from investigated and standard neutron fields.
- We denoted $a = \frac{Ns^i}{Ns^{25}}$ and $b = \frac{Nm^i}{Nm^{25}}$
- Then we obtain following ratio: $$\frac{\overline{\sigma}_f^i}{\overline{\sigma}_f^{25}} = \frac{b}{a} \frac{(\sigma_f^i)_s}{(\sigma_f^{25})_s}$$

Experimental technique_4

- For calculation the ratio of the average ^{238}U fission cross-section to the average ^{235}U fission cross-section formula is used:

$$\frac{\overline{\sigma}_f^{238U}}{\overline{\sigma}_f^{235U}} = \frac{\frac{b}{a} - 1}{\frac{\chi_{U\text{ест}}^{238U}}{\chi_{U\text{ест}}^{235U}} - \frac{b}{a}\frac{\chi_{U6.5}^{238U}}{\chi_{U6.5}^{235U}}}$$

Experimental technique_5

- For calculation the ratio of the average ^{237}Np and ^{232}Th fission cross-section to the average ^{235}U fission cross-section formula is used:

$$\frac{\bar{\sigma}_f^{i}}{\bar{\sigma}_f^{235U}} = \frac{b}{a}\,\frac{(\sigma_f^{i})_{14}}{(\sigma_f^{235U})_{14}}\,\frac{\left(1+\frac{\chi_{U6.5}^{238U}}{\chi_{U6.5}^{235U}}\,\frac{\bar{\sigma}_f^{238U}}{\bar{\sigma}_f^{235U}}\right)_u}{\left(1+\frac{\chi_{U6.5}^{238U}}{\chi_{U6.5}^{235U}}\,\frac{\bar{\sigma}_f^{238U}}{\bar{\sigma}_f^{235U}}\right)_{14}}$$

Experimental technique_6

- For calculation the ratio of the average ^{239}Pu fission cross-section to the average ^{235}U fission cross-section formula is used:

$$\frac{\overline{\sigma}_{f}^{239Pu}}{\overline{\sigma}_{f}^{235U}} = \frac{b}{a}\frac{\overline{\sigma}_{f0}^{239Pu}}{\overline{\sigma}_{f0}^{235U}}\frac{g_{f0}^{239Pu}}{g_{f0}^{235U}}\left(1+\frac{\chi_{U6.5}^{238U}}{\chi_{U6.5}^{235U}}\left(\frac{\overline{\sigma}_{f}^{238U}}{\overline{\sigma}_{f}^{235U}}\right)_{u}\right)$$

Results_1

- This part includes measured results of the ratios of the average ^{239}Pu, ^{237}Np, ^{232}Th and ^{238}U fission cross-sections to the average ^{235}U fission cross-section.
- Moreover, comparison of the experimental data with results of calculations are presented.

- The calculations were done by Petar Zhivkov.

- The calculations performed with the computer code MCNPX 2.7e with energy neutron data library ENDF70, JANIS 4.0 database, models ISABEL, INCL4/ABLA, CEM2K.

Results_2

	Deuterons 2 GeV/A	Deuterons 4 GeV/A	Carbon ions 2 GeV/A	Carbon ions 4 GeV/A
$^{239}Pu/^{235}U$	0,041±0,010	0,040±0,010	0,041±0,010	0,042±0,010
$^{237}Np/^{235}U$	1,17±0,14	1,17±0,14	1,16±0,14	1,07±0,13
$^{238}U/^{235}U$	0,35±0,04	0,35±0,04	0,34±0,04	0,35±0,04
$^{232}Th/^{235}U$	0,0119±0,0014	0,0116±0,0014	0,0126±0,0015	0,0117±0,0014

Measurement uncertainty is estimated by the international standard ISO / IEC 17025: 1999

Results_3

	Deuterons 2 GeV/A		Deuterons 4 GeV/A		Carbon ions 2 GeV/A		Carbon ions 4 GeV/A	
	Exp	Calc	Exp	Calc	Exp	Calc	Exp	Calc
$^{239}Pu/^{235}U$	0,041 ±0,010	0,040	0,040 ±0,010	0,048	0,041 ±0,010	0,051	0,042 ±0,010	0,055
$^{237}Np/^{235}U$	1,17 ±0,14	1,17	1,17 ±0,14	1,17	1,16 ±0,14	1,17	1,07 ±0,13	1,18
$^{238}U/^{235}U$	0,35 ±0,04	0,38	0,35 ±0,04	0,38	0,34 ±0,04	0,39	0,35 ±0,04	0,41
$^{232}Th/^{235}U$	0,0119 ±0,0014	0,0123	0,0116 ±0,0014	0,0123	0,0126 ±0,0015	0,0133	0,0117 ±0,0014	0,0143

Conclusions

- We obtain the ratios of the average plutonium-239, neptunium-237, thorium-232, uranium-238 fission cross-sections to the average uranium-235 fission cross-section in the assembly QUINTA neutron field. Assembly was irradiated by deuterons and carbon ions with energies 2 GeV/A and 4 GeV/A.

- The ratio of average fissionable nuclides cross-sections does not depend on type of incident particles and their energies.

- The experimental data and calculation are in good agreement.

Thank you!