Resonance Correlation Study in Transmissions and Self-Indications of ^{235}U, ^{238}U, ^{239}Pu

Yu.V.Grigoriev, V.V.Sinitsa,
Institute of Physics and Power Engineering, Obninsk, Russia

Zh.V.Mezentseva,
Joint Institute for Nuclear Research, Dubna, Russia

H. Faikov-Stanczyk,
University of Lodz, Lodz, Poland

Abstract

The measurements of the transmissions and multiplicity spectra of uranium-235, uranium-238 and plutonium-239 were carried out on the 1006 m and 500 m flight paths of the IBR-30 pulsed neutron booster of the Joint Institute for Nuclear Research (JINR) in Dubna. The He-3 neutron detector (1006 m) and the 16-section scintillation (n, γ)-detector with NaI(Tl) crystals of a total volume of 36 liter (500 m) [1] were used. Metal plates of ^{238}U (0.00137 a/b, 90% ^{235}U and 10% ^{238}U) and ^{239}Pu (0.00114 at/b, 99.9% of ^{239}Pu) served as radiator samples. Filter-samples with two 4.2 mm (0.0188 at/b), 8.4 mm (0.0376 at/b) thickness of 90% ^{235}U and 10% ^{238}U and with two 1 mm (0.0048 at/b), 8 mm (0.0424 at/b) ones ^{238}U and with 2.6 mm (0.0107 at/b) one ^{239}Pu and mixture of these filter-samples were positioned on the 242 m flight path. Resonance correlation coefficients were obtained from transmissions and self-indications in the energy range of 46.5 eV- 46.5 keV. They are more than a unity. Two boron counters SNM-12 monitored the intensity level of the neutron source.

Resonance correlation effects in total transmissions of ^{235}U, ^{238}U, ^{239}Pu

Even a simple analysis of neutron cross-section energetic dependence points to the existence of the influence of various isotope resonances, coincident with the energy, on the reactors integral characteristics (K_{eff}, KV).

We carried out experimental studies of the influence of the resonance structured of cross-section of uranium-235, uranium-238, plutonium-239 on each other at passing the resonance neutrons through the filter samples of these materials and their combination. Total transmissions were obtained from the time-of-flight spectra having been measured on the 1000 m and 500 m flight paths of the IBM-30 reactor with the battery of ten helium counters with and without metallic filter-samples in a neutron beam for [^{235}U(90%)+^{238}U(10%)] 4.2 mm (0.0188 at/b), 8.4 mm (0.0376 at/b) thick; ^{238}U with the thickness of 1 mm (0.0048 at/b), 8 mm (0.0424 at/b); ^{239}Pu with 2.6 mm (0.0107 at/b) in thickness and their mixture:

1) [^{235}U(90%)+^{238}U(10%)] with the thickness of 4.2 mm (0.0188 at/b) + ^{238}U 8 mm (0.0424 at/b) in thickness,

2) ^{239}Pu with the thickness of 2.6 mm (0.0107 at/b +^{238}U 8 mm (0.0424 at/b) in thickness,

3) ^{239}Pu with the thickness of 2.6 mm (0.0107 at/b)+[^{235}U(90%)+^{238}U(10%)] 4.2 mm (0.0188 at/b) in thickness,
4) ^{239}Pu with the thickness of 2.6 mm (0.0107 at/b)+[^{235}U(90%)+^{238}U(10%)] with 8.4 mm (0.037 at/b) in thickness.

In the given experiment were determined the total transmissions in energy groups of BNAB constant system [2] $T_t(n_{U5})$, $T_t(n_{U8})$, $T_t(n_{Pu9})$, $T_t(n_{U5}+n_{U8})$, $T_t(n_{Pu9}+n_{U8})$, $T_t(n_{Pu9}+n_{U5})$ and on this basis were being calculated the resonance correlation coefficients in the total transmissions :

$$K(n_{U5}, n_{U8}) = T_t(n_{U5}+n_{U8}) / [T_t(n_{U5}) * T_t(n_{U8})] \quad (1),$$

$$K(n_{Pu9}, n_{U8}) = T_t(n_{Pu9}+n_{U8}) / [T_t(n_{Pu9}) * T_t(n_{U8})] \quad (2),$$

$$K(n_{Pu9}, n_{U5}) = T_t(n_{Pu9}+n_{U5}) / [T_t(n_{Pu9}) * T_t(n_{U5})] \quad (3),$$

where: n_{U5} - thickness of filter sample uranium-235, n_{U8} - thickness of filter sample uranium-238, n_{Pu} -thickness of filter sample plutonium-239.

Table 1 shows the resonance correlation coefficients in total transmissions for ^{235}U, ^{238}U, ^{239}Pu filter samples. The correlation coefficients (1-3) must be more than a unit if energy coincidence of neutron resonances of the given isotopes happens. One can clearly see it in Table 1.

If the magnitude of these values coincide with a unit then resonance structure of various isotope cross-sections do not influence each other, i. e. there is no resonance self-shielding of one isotope at the expense of resonances of another isotope.

Table 1

The resonance correlation coefficients in the total transmissions for ^{235}U, ^{238}U, ^{239}Pu filter samples.

N_{lim}	E_{lim} (KeV)	$K(n_{U5}, n_{U8})$	$K(n_{Pu9}, n_{U8})$	$K(n_{Pu9}, n_{U5})$	$K(n_{Pu9}, n_{U5})$	ΔK
10	46.5-21.5	1.008	1.004	1.047	1.063	0.030
11	21.5-10.0	1.027	1.027	1.000	1.025	0.030
12	10 – 4.65	1.006	1.022	1.018	1.049	0.025
13	4.65-2.15	1.024	1.006	1.007	1.061	0.020
14	2.15-1.00	1.009	1.018	0.996	1.041	0.018
15	1.0-0.465	1.013	1.022	1.027	1.051	0.016
16	0.465-0.215	1.003	0.993	1.002	1.035	0.015
17	0.215-0.100	1.041	1.014	1.002	1.023	0.013
18	0.10-0.0465	1.004	1.005	1.026	1.059	0.012
19	46.5-0.0465	1.015	1.017	1.014	1.045	0.008

It is a pity but in most narrow energetic groups experimental errors are compared with the resonance correlation effect for different isotope couples, and in a wide range of energies 46.5-0.0465 keV one may observe the effect with confidence. One can also observe an increase of correlation coefficients with the growth in filter sample thickness.

Resonance correlation effects in the self-indication functions and in ^{235}U, ^{239}Pu filter neutron cross-sections

Besides the measurements of correlation effects in total transmissions on the ^{235}U, ^{238}U, ^{239}Pu thick sample filters there were also being measured with different detectors self-indication functions on the ^{238}U thick filter sample. Table 2 presents measurement results, got on the 502 m and 1006 m flight paths of the IBR-30 reactor. As a filter sample one used the ^{238}U metallic disk of 195 mm in diameter and 1 mm in thickness, set in turn on a neutron beam at the 242 m distance from the IBR-30 reactor. Total transmissions T_t(U1mm) for ^{238}U were being measured with the neutron ring-detector with a polyethylene radiator sample on the 1006 m flight path. Self-indication function in $T_{t\gamma}$ (U1mm) for ^{238}U and that of $T_{t\gamma f}$ (U1 mm) for ^{239}Pu were being measured with the 16-section γ-ray detector on the 502 m flight path. As radiator sample set inside the (n, γ)-detector with NaI(Tl) crystals were used ^{238}U metallic disks 0.25 mm in thickness and those of ^{239}Pu ones 0.1 mm thick.

To get self-indication functions in ^{238}U radiation capture there was the summation time-of-flight spectra from the 1st to the 6th multiplicity of γ-ray and for ^{239}Pu – from the 1st to the 12th multiplicity, i.e. radiation capture and division were taken into account simultaneously. Fig. 1 shows the typical time-of-flight spectra of various multiplicities for ^{235}U, ^{238}U, ^{239}Pu. This Figure demonstrates well the resonance correlation of the given isotopes within the resolved energy region.

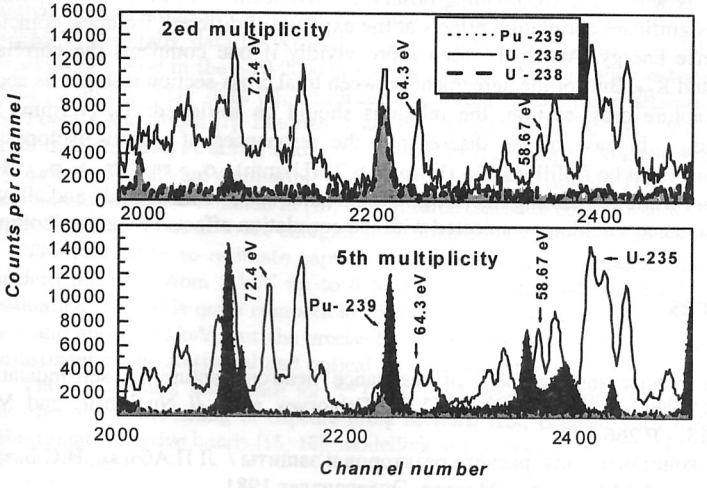

Figure 1. Time-of-flight spectra of the 2ed and 5th multiplicity gamma-ray coincidence for ^{235}U, ^{238}U, ^{239}Pu.

Table 2 presents the transmissions and cross-sections of ^{238}U and ^{239}Pu. The observed cross-sections were obtained by taking the logarithm of transmissions and division by the ^{238}U sample thickness of 0.0048 at/b(1 mm). The errors within the transmissions are 0.5-2%, and the ones within the cross-sections – 5-10%.

Table 2

The transmissions, observed total cross-sections and coefficients of the correlation $K_{t\gamma}= \sigma_{t\gamma}$ (U1 mm)/ σ_t (U1 mm), $K_{t\gamma f} = \sigma_{t\gamma f}$ (U1 mm)/ σ_t (U1mm).

N_{lim}	E_{lim}(keV)	T_t (U1 mm)	$T_{t\gamma}$ (U1 mm)	$T_{t\gamma f}$ (U1 mm)	σ_t	$\sigma_{t\gamma}$	$\sigma_{t\gamma f}$	$K_{t\gamma}$	$K_{t\gamma f}$
9	100 -46.5	0.945	0.941	0.927	11.8	13	15.9	1.08	1.34
10	46.5-21.5	0.940	0.916	0.920	12.9	18	17.4	1.42	1.35
11	21.5-10.0	0.932	0.908	0.913	14.7	20	19.0	1.37	1.29
12	10 – 4.65	0.930	0.922	0.909	15.2	17	20.0	1.12	1.32
13	4.65-2.15	0.913	0.772	0.884	19.0	54	25.8	2.84	1.36
14	2.15-1.00	0.908	0.636	0.897	20.2	95	22.7	4.69	1.13
15	1.0-0.465	0.935	0.530	0.888	14.1	133	24.9	9.45	1.77

The comparison of total transmissions with self-indication functions, measured with the help of the γ-ray detector with the ^{238}U $T_{t\gamma}$ (U1 mm) or ^{239}Pu $T_{t\gamma f}$ (U1 mm) samples inside the detector, as well as with the corresponding observed cross-sections σ_t , $\sigma_{t\gamma}$, $\sigma_{t\gamma f}$ points to the existence of significant correlation effects at the expense of different isotopes, coinciding with the resonance energy. At can be seen more vividly if one compares the correlation coefficients $K_{t\gamma}$ and $K_{t\gamma f}$. But for the agreement between total cross-section resonances and the ^{238}U radiation capture cross-section, the relations should be fulfielled: $T_{t\gamma}$ (U1mm) > T_t (U1mm), $\sigma_t > \sigma_{tc}$. In case of the discrepancy the resonances of various isotopes, the following relations must be fulfilled: $T_{t\gamma f}$ (U1mm) > T_t (U1mm), $\sigma_t > \sigma_{t\gamma f}$, $\sigma_{t\gamma f} = \sigma_{м.р.}$. From this is follows that while calculating nuclear power installations one must study and allow for the effects of resonance shielding, connected with the correlation effects of various isotopes.

References

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