IPPE transmission experiments (Fe, ^{238}U)

Ivanova Tatiana

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FUND-JINR-1/E-MULT-TRANS-001

NEUTRON TRANSMISSION THROUGH SAMPLES OF DEPLETED URANIUM, HIGHLY-ENRICHED URANIUM, AND PLUTONIUM FOR DETERMINATION OF RESONANCE SELF-SHIELDING OF TOTAL CROSS SECTIONS AND FISSION CROSS SECTIONS OF U-238, U-235, AND PU-239

Evaluators

Yuri Grigoriev
Yevgeniy Rozhikhin
Olga Pavlova
Institute of Physics and Power Engineering

Internal Reviewers
Mark Nikolaev
Anatoli Tsiboulia

Independent Reviewer

Mark Lee
United States Department of Energy

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MEASUREMENT OF FAST NEUTRON TRANSMISSION THROUGH IRON, NICKEL, AND CHROMIUM SAMPLES OF VARIOUS THICKNESSES

Evaluators

Vladimir Koscheev
Mark Nikolaev
Vladimir Filippov
Institute of Physics and Power Engineering

Internal Reviewers
Yevgeniy Rozhikhin
Anatoli Tsiboulia

Independent Reviewers

Polyakov D. N.
Glushkov E. S.
Glushkov A. E.
Russian Research Center Kurchatov Institute

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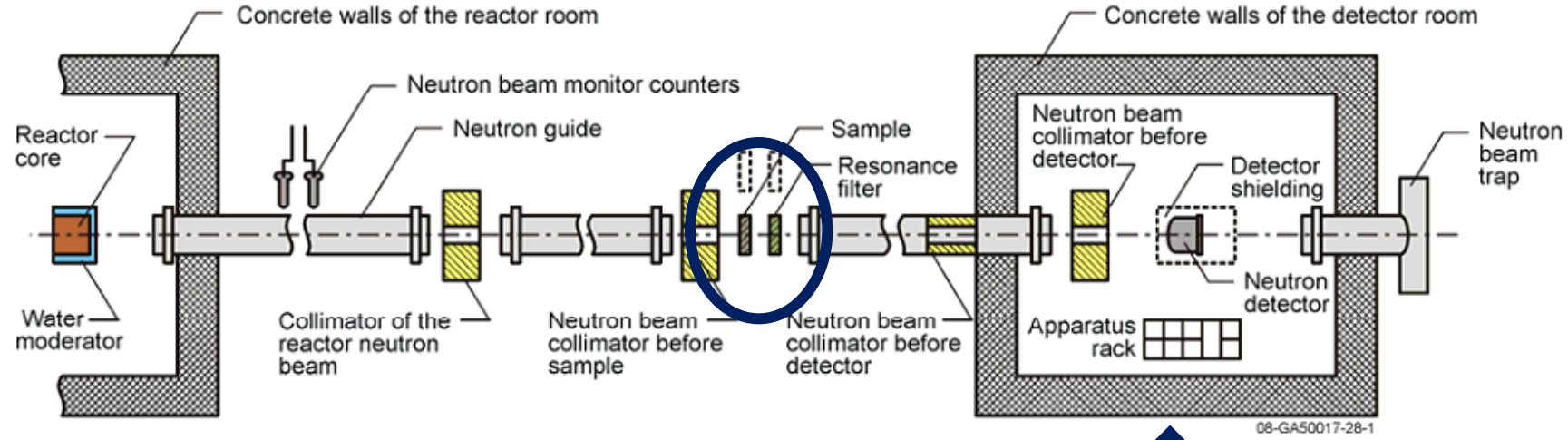
- Several series of neutron transmission experiments were performed from 1969 to 1982 on the Pulse Fast Reactor IBR-30 (designed and operated under IPPE supervision) facility at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia.
- This was accomplished by transmitting a collimated neutron beam with a slowing-down spectrum through samples of depleted uranium, highly enriched uranium, and plutonium of different thicknesses and measuring time-of-flight-dependent shielded total neutron count rates or fission rates for each sample thickness relative to the rate without the sample in the beam line.
- The neutron source was a neutron beam from the IBR-30 pulse reactor passed through a water moderator.
- The explicit product of the experiments was the measurement of the energy-dependent self-shielded total and fission cross sections, as characterized by various self-shielded and unshielded total neutron count rates as well as self-shielded and unshielded fission rates performed using the time-of-flight technique. Self-shielding was varied systematically through the use of samples of different thicknesses.

Summary of experiments

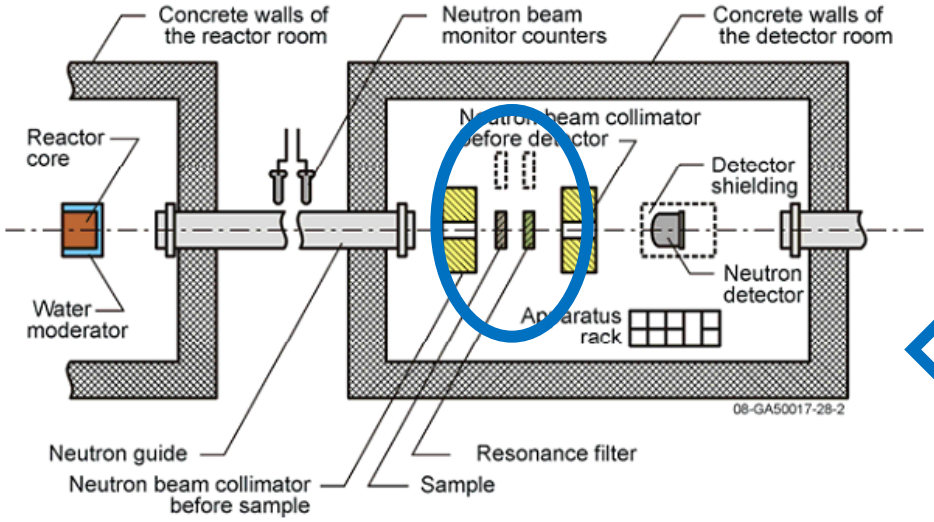
Identification	Transmission	Energy Range	Number of Thicknesses
U-238	Total	0.1 keV – 200 keV	8
U-235	Total	4.64 eV – 21.5 keV	7
	Fission	4.64 eV – 21.5 keV	6
Pu-239	Total	4.64 eV – 21.5 keV	7
	Fission	4.64 eV – 21.5 keV	5

- The transmission functions were measured using the time-of-flight method.
- The neutron source was the reactor core of the IBR-30 reactor at JINR.
- Three lateral sides of the core were surrounded with water moderator with thickness of 4 cm.
- The reactor was in the center of a room with dimensions 10×10×7 m at the distance of 2 m from the floor.
- Thickness of the concrete walls of the room was 2 m.
- The facility was operated
  - in the pulse reactor mode for the measurements of the total transmission functions and
  - in the booster mode for the measurements of the fission self-indication functions.

Experimental Setups for Transmission Functions Measurements



Experimental Setup for Measurements of Total Transmissions



Experimental Setup for Measurements of Fission Self-indications

Benchmark Data

Transmission functions

$$T_t(t) = \int_{\Delta E} \varphi(E)\exp[-\sigma_t(E)t]dE \Big/ \int_{\Delta E} \varphi(E)dE$$ for the total cross section

$$T_f(t) = \int_{\Delta E} \varphi(E)\sigma_f(E)\exp[-\sigma_t(E)t]dE \Big/ \int_{\Delta E} \varphi(E)\sigma_f(E)dE$$ for the fission cross section

- unfolding of the background spectra,
- subtracting of the background spectra from the experimental time-of-flight spectra,
- normalizing of the time-of-flight spectra to the score of monitor counters,
- collapsing of the spectra into broad groups,
- dividing of the spectra with the sample in the beam line to the spectra without the sample in the beam line for the final determination of the total or fission self-indication functions.

$$T_x(n, \Delta E) = (N_{\text{sample-in}} - F_{\text{sample-in}}) \times M / (N_{\text{sample-out}} - F_{\text{sample-out}})$$

- Modification of the spectra from the experimen $\varphi(E) \sim 1/E^{0.9}$ $\varphi(E) \sim 1/E$
- Removal (substituting by void) of all impurities and isotopes in samples
- Modification of the weighting function of the fission chamber

Benchmark Data

Estimated Benchmark-Model Uncertainties

Identification	Transmission	Sample No.							
		1	2	3	4	5	6	7	8
U-238	Total	1%	1%	2%	2%	3%	10%	10%	10%
U-235	Total	1%	2%	-	4%	6%	8%	9%	15%
	Fission	2%	-	4%	6%	8%	10%	20%	-
Pu-239	Total	2%	3%	4%	6%	8%	10%	20%	-
	Fission	4%	5%	12%	20%	60%	-	-	-

Comparison of Calculation and Benchmark-Model Values (C/E-1) of Total Transmission Functions of ^{238}U (%).

Group	Energy	Sample Thickness, 10^{-2} atoms/barn							
		0.477	0.954	1.907	3.814	7.629	15.26	30.52	61.03
8	200-100 keV	-1	1	-1	-3	-7	-13	-22	
9	100-46.5 keV	1	1	-2	-1	-4	-10	-30	-37
10	46.5-21.5 keV	1	2	-3	-1	-3	-16	-24	-48
11	21.5-10 keV	1	-1	-4	-1	-5	-14	-24	-14
12	10-4.65 keV	1	1	-2	-1	-3	-16	-22	-8
13	4.65-2.15 keV	0	2	-4	2	0	-7	-29	-26
14	2.15-1.0 keV	2	6	0	3	3	-3	-15	19
15	1.0-0.465 keV	2	3	4	4	0	-2	-16	-
16	465-215 eV	-1	2	3	4	7	-5	-17	-
17	215-100 eV	-1	1	4	-1	-6	-	-	-

28 gr ABBN-93 Library

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11	21.5-10 keV	1	-1	-3	0	-3	-8	-9	6
12	10-4.65 keV	2	2	-1	1	2	-8	-9	5
13	4.65-2.15 keV	0	2	-5	2	-1	-6	-17	-1
14	2.15-1.0 keV	2	6	-1	1	1	-3	-4	4
15	1.0-0.465 keV	2	2	3	1	-6	-10	-24	-
16	465-215 eV	-1	1	0	-3	-10	-33	-60	-
17	215-100 eV	-1	1	2	-5	-12	-	-	-

MCNP + ENDF/B-VI.8

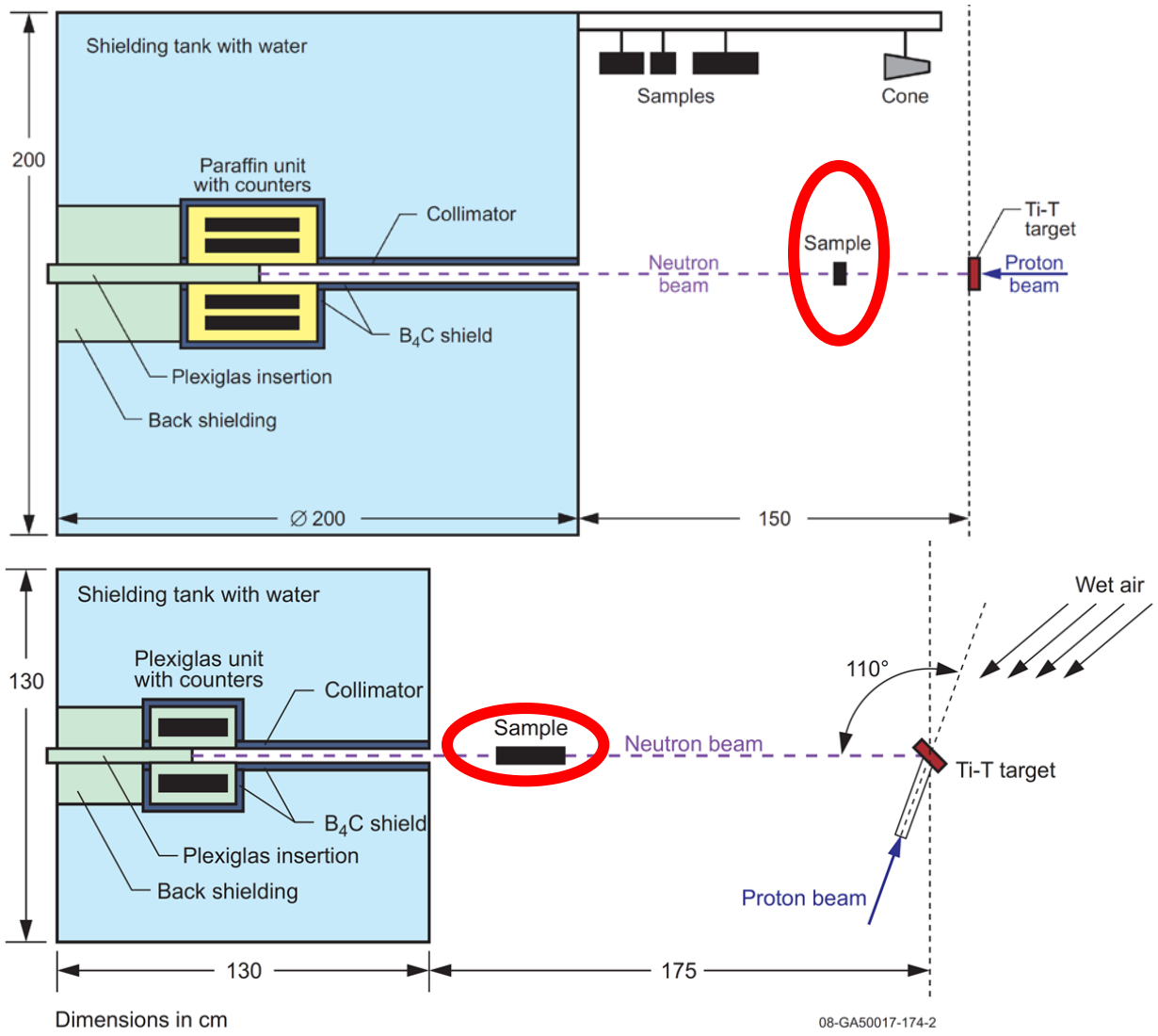
Measurement of Fast Neutron Transmission through Fe, Ni and Cr Samples of Various Thicknesses

- In the 60s and 70s, experimental studies were performed at IPPE (Obninsk, Russia) on the characteristics of resonance structure of total cross sections of structural and technological materials.
- The neutron transmission **T(t)** is the fraction of the incident neutron beam that goes through the sample without any interaction

$$\mathrm{T(t)} = \int_{E_{\min}}^{E_{\max}} R(E)\exp[-\sigma_t(E)ct]\mathrm{dE}$$

- The titanium-tritium target of the electrostatic proton generator was used as a neutron source.

Diagram of the Experiment at the FP-1 and FP-2 Facilities



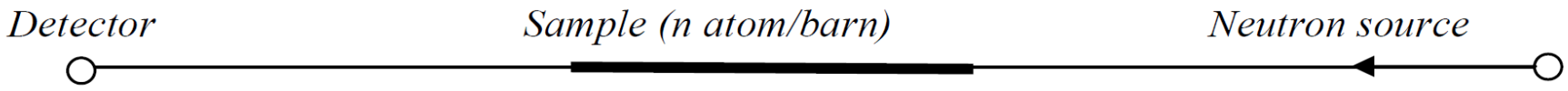
The Main Characteristics of Facilities for Measurement of Neutron Transmission

Characteristics	FP-1	FP-2
Van de Graaff accelerator[a]	EG-5	EG-2.5
Nuclear Reaction – Neutron Source	T(p,n)	T(p,n)
Maximal Energy of Protons	4.5 MeV	2.5 MeV
Angle of Neutron Emission[b]	0°	≤110°
Neutron Energy Range	0.3–3.0 MeV	10–500 keV
Width of Resolution Function	150–370 keV (2.6 mg/cm^2 target)	12–100 keV (0.7 mg/cm^2 targets at 45°)
Angle of Neutron Beam Registration[c]	0.6°	0.3°
Diameter of Collimator Hole	45 mm	35 mm
Minimal Value of Transmission	0.001–0.01	0.01–0.03
Background Fraction of the Counting Rate in the Open Beam	0.0005–0.001	0.003–0.01
Number of Thickness Values Measured	10–25	8–20

The Main Characteristics of Samples

Chromium, D=50 mm (metal samples 1–5) and 45.2 mm (powder samples 6–8)								
Sample No.	1	2	3	4	5	6	7	8
Weight, g	59.5	105.0	222.4	279.0	687.8	896.4	1864.9	2179.9
Thickness, nuclei/barn	0.0431	0.0760	0.161	0.202	0.498	0.649	1.344	1.571
Armco iron, D=50 mm								
Sample No.	1	2	3	4	5	6	7	
Weight, g	62.8	125.6	252.3	494.1	992.1	1973.3	3968.5	
Thickness, nuclei/barn	0.0345	0.0690	0.1386	0.2714	0.545	1.084	2.180	
Nickel, D=50 mm								
Sample No.	1	2	3	4	5	6	7	
Weight, g	70.0	140.7	278.6	525.3	1050.6	2229	4317.6	
Thickness, nuclei/barn	0.0365	0.0734	0.1453	0.274	0.541	1.164	2.252	

Benchmark Model Characterization

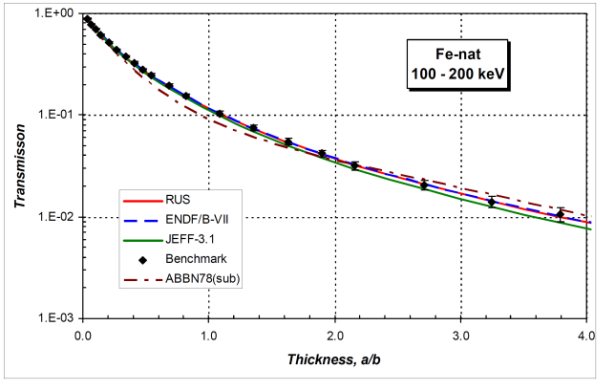


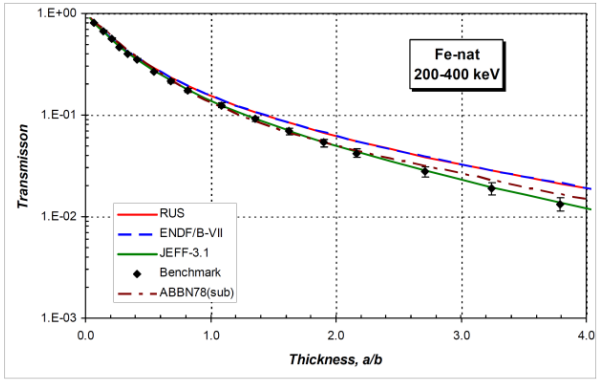
Benchmark Model Geometry

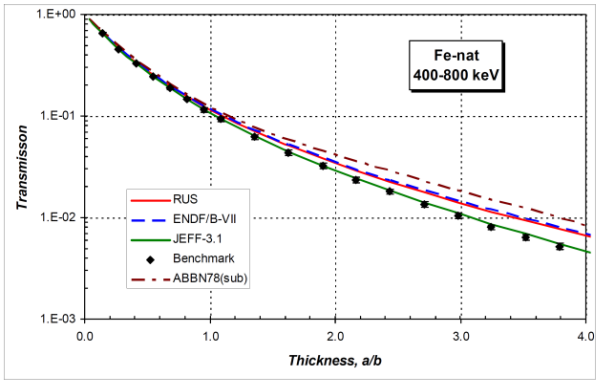
Group-wise benchmarks were created for the energy groups

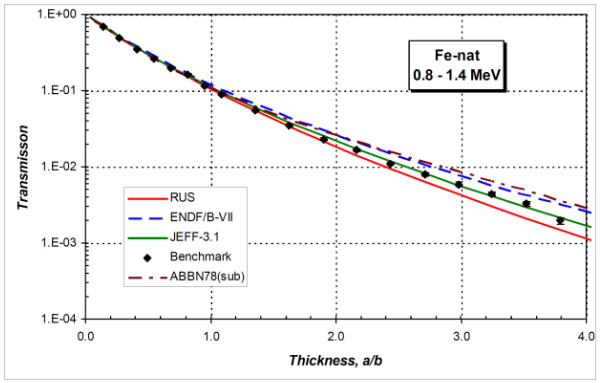
-	9th group	46.5–100 keV	(for Ni)
-	8th group	100–200 keV	(for Fe and Ni)
-	7th group	200–400 keV	(for Fe and Ni)
-	6th group	400–800 keV	(for Cr, Fe, and Ni)
-	5th group	800–1400 keV	(for Cr, Fe, and Ni)
-	4th group	1400–2500 keV	(for Cr, Fe, and Ni)
-	3th group	2500–4000 keV	(for Fe and Ni).

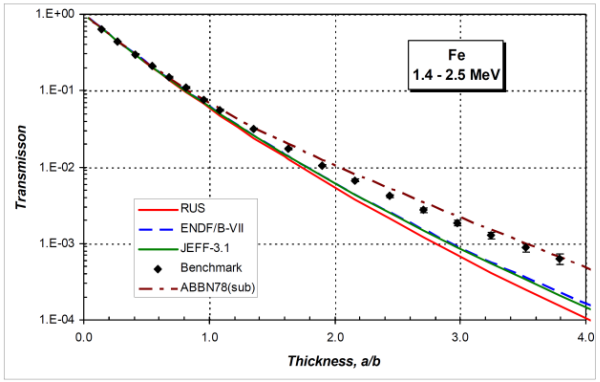
Comparison of Calculation and Benchmark-Model Values for ^{nat}Fe

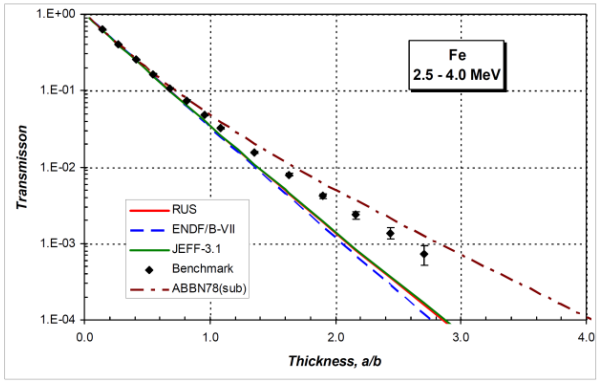












Remarks

- Russian FUND data in the ICSBEP Handbook includes also
  - **CROSS SECTION RATIOS MEASURED IN THE CORE CENTER OF THE BR-1 FAST SPECTRUM ASSEMBLY (*IPPE*)**
- Other data of interest:
  - **SELF-SHIELDED FISSION RATES FOR 235U (*LLNL*)**
  - **NIST SPHERE EXPERIMENTS FOR ^{235}U, ^{239}Pu, ^{238}U, AND ^{237}Np FISSION RATES** (*NIST*)
  - **^{235}U, ^{239}Pu, ^{238}U, AND ^{237}Np FISSION RATES FOR CADMIUM COVERED FISSION CHAMBERS (*NIST*)**