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MEASUREMENT AND NORMALIZATION OF THE ^{239}Pu FISSION CROSS-SECTION IN THE LOW RESONANCE REGION

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INTRODUCTION

Very large discrepancies exist for ^{239}Pu between the available fission integrals $\int \sigma_f (E) dE$ and resonance integrals $\int \sigma_f (E) \frac{dE}{E}$. Differential data retrieved from the CCDN-files were integrated by CCDN in a few selected energy regions, showing differences up to a factor of 2 for the fission integrals. The need for highly reliable values is evident. These fission integrals are often used to normalize fission cross-section curves that do not go down to thermal energy. In order to improve this situation, the ^{239}Pu fission cross-section was measured from 0.010 eV up to about 40 eV, allowing a direct normalization at the thermal value σ_f^o = 741.6 barn, recommended by the IAEA (1). This measurement is briefly reported here, and a comparison is made between the results of the present work and the other integrals available. The results should be considered as preliminary, since some final checks have still to be performed.

MEASUREMENTS

a) Apparatus

The measurements were performed at a short (8 m) flight-path of the CBNM Linac by a joint CBNM-SCK/CEN group. The experimental set-up has already been described (2) (3). In the centre of the cylindrical detection chamber a back-to-back layer of ^{10}B and ^{239}Pu was mounted, viewed on each side by a large Au-Si surface barrier detector placed outside the neutron beam.
The detector signals are amplified by charge-sensitive preamplifiers and DD2-amplifiers and sent into fast timing single channel analysers. The signals originating from the ^{10}B(n,α)- and the

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^{239}Pu(n, fission)-reactions are fed into the two halves of a 4096-channel time-of-flight analyser with "accordeon" system, so that both spectra are recorded simultaneously from the same location in the neutron beam. These data are transferred from the analyser memory, via a read-out unit, to a magnetic tape for storage.
The data handling is performed afterwards with an IBM 1800 computer.

b) Measurements

Two series of measurements of σ_f were performed. Table I gives pertinent data concerning neutron energy regions, linac parameters and neutron filters used. Series I (low resolution) included the thermal energy region and series II (higher resolution) extended the measurements up to about 40 eV.
Each series consisted of several measuring runs alternated with background runs so as to detect eventual changes in background during the measurement. In the measuring runs the ^{10}B(n,α)^{7}Li counts (TSCA set to register only the α-particles) and the ^{239}Pu fission events (TSCA set to eliminate the natural α-particles and their pile-up pulses) were simultaneously recorded.
For each background run the appropriate additional filters were put into the beam and again fission and ^{10}B(n,α)-counts were registered.

The ^{10}B-deposit is an elemental boron layer prepared by evaporation in vacuum. Its thickness is 103 μg/cm^2, its isotopic enrichment 92% and its diameter 80 mm. The ^{239}Pu-layer was prepared by the electrospraying of plutonium-acetate on a thin aluminium plate. The thickness of the layer is 120 μg/cm^2 over a diameter of 60 mm. The isotopic composition is 99.956 $\pm$ 0.010 atom % ^{239}Pu; 0.044 $\pm$ 0.010 % ^{240}Pu, < 0.005% ^{238}Pu and < 0.005% ^{241}Pu.

c) Treatment of the data and results

To normalize the background runs to the same neutron fluence of the measuring runs a Pd-filter was used throughout series I and a Cd-filter in series II. Background produced by spontaneous fission of ^{240}Pu has been checked with the Linac off and was found to be completely negligible in comparison with the induced fission rate in ^{239}Pu. The determination of the background shape, the corrections and the calculations are similar as for ^{235}U (4). The relative σ_f-curve is obtained with respect to a 1/v-behaviour of the ^{10}B(n,α)-cross-section. The σ_f-curves are normalized to the thermal value σ_f^o = 741.6 $\pm$ 3.1 barn recommended by the IAEA (1). Figures 1a and 1b show the normalized fission cross-sections from 0.010 eV to 25 eV. The quality of the present low-energy fission cross-section curve obtained at the Linac is illustrated by the value of the Westcott g-factor calculated* from it:

$$g = 1.057 \pm 0.002 \text{ (preliminary value).}$$

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* Program written by L. Schotsmans and W. Becker

This value is in excellent agreement with the IAEA recommended value g = 1.0548 ± 0.0030 (1).

From the σ_f-curves of this measurement a few fission integrals $\int_{E_1}^{E_2} \sigma_f (E) dE$ and resonance integrals $\int_{E_1}^{E_2} \sigma_f (E) \frac{dE}{E}$ were calculated (Tables II and III).
Some of these fission integrals may be very useful for further normalization of ^{239}Pu fission cross-sections. We propose e.g. the fission integral from 9.0 to 12.6 eV from this experiment with a value of 498 ± 5 barn.eV.

DISCUSSION

A comparison between the present fission integrals and previous results obtained with other normalization procedures and/or with other detection techniques are summarized in Table II. The integrals of Blons (5), Bollinger (6), Ryabov (7) and Ignatiev (8) were obtained by integration of differential data retrieved from the CCDN files.

The results of the present work are in very good agreement with those of Gwin (9) (maximum deviation 2%), which were also directly normalized to σ_f^o = 741.6 barn.
The differences with the results of Blons are maximum 3% and with those of Bollinger 4%.
The values of Ryabov and Ignatiev (σ_f deduced from σ_t and η) are systematically lower than all the other data.

In Table III the resonance integrals of this work are compared with those of Gwin et al.. Here also the agreement is within 2%.

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TABLE I: Experimental conditions

ENERGY REGION	LINAC PARAMETERS	NEUTRON FILTERS	
		Common filter	Background filters
I 0.0065 - 42 eV useful region: 0.01 - 10 eV	2 μs, 100 Hz E_{el} = 45 MeV, i_{av} = 80 μA P = 3.60 kW	Pd also run with Cd	Rh, Ta, W
II 0.14 - 48 eV useful region: 1 - 40 eV	50 ns, 400 Hz E_{el} = 60 MeV, i_{av} = 50 μA P = 3 kW	Cd	Rh, Ta, W

TABLE II: ^{239}Pu fission integrals $\int_{E_1}^{E_2} \sigma_f(E)\, dE$ (barn. eV)

ENERGY INTERVAL (eV)	PRESENT WORK (preliminary)	GWIN (9)		BLONS (5)	BOLLINGER (6)	RYABOV (7)	IGNATIEV (8)
6.0 - 9.0	179.1	181.0		181.6	173.0	107.0	159.0
9.0 - 12.6	498.1	496	498	509.6	516.9	348.3	412.9
12.6 - 20.0	537.1	547	546	554.8	538.4	479.5	443.2
20.0 - 24.7	221.0	225	221	222.0	221.4	191.8	177.4

TABLE III: ^{239}Pu resonance integrals $\int_{E_1}^{E_2} \sigma_f(E) \frac{dE}{E}$ (barn)

ENERGY INTERVAL (eV)	PRESENT WORK (preliminary)	GWIN et al. (9)	
6.0 - 9.0	23.1	23.3	
9.0 - 12.6	44.6	44.4	44.8
12.6 - 20.0	34.7	35.3	35.3
20.0 - 24.7	9.9	10.1	9.9

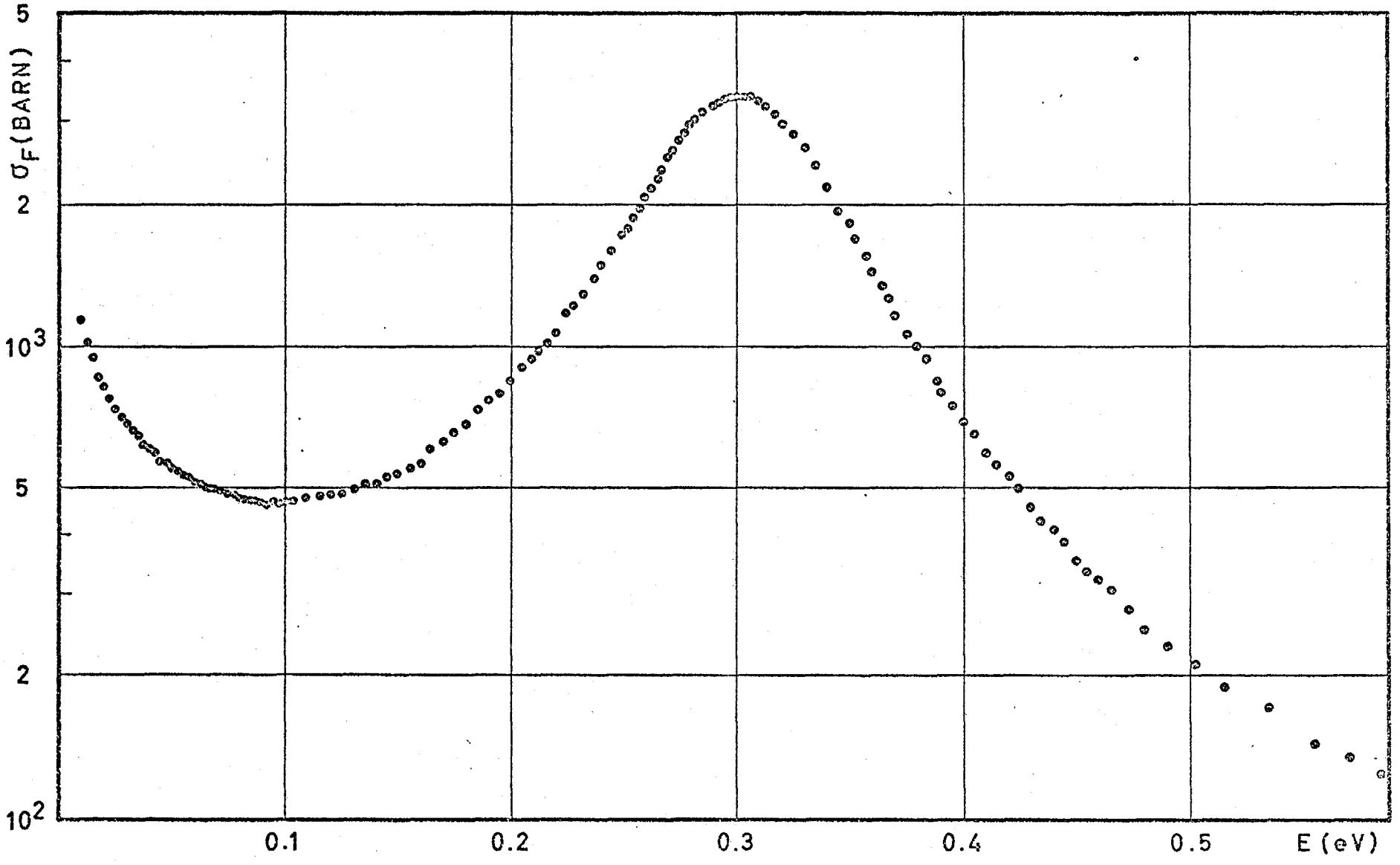

Fig. 1a Fission cross-section for ^{239}Pu from 0.01 to 0.6 eV as measured at the LINAC.

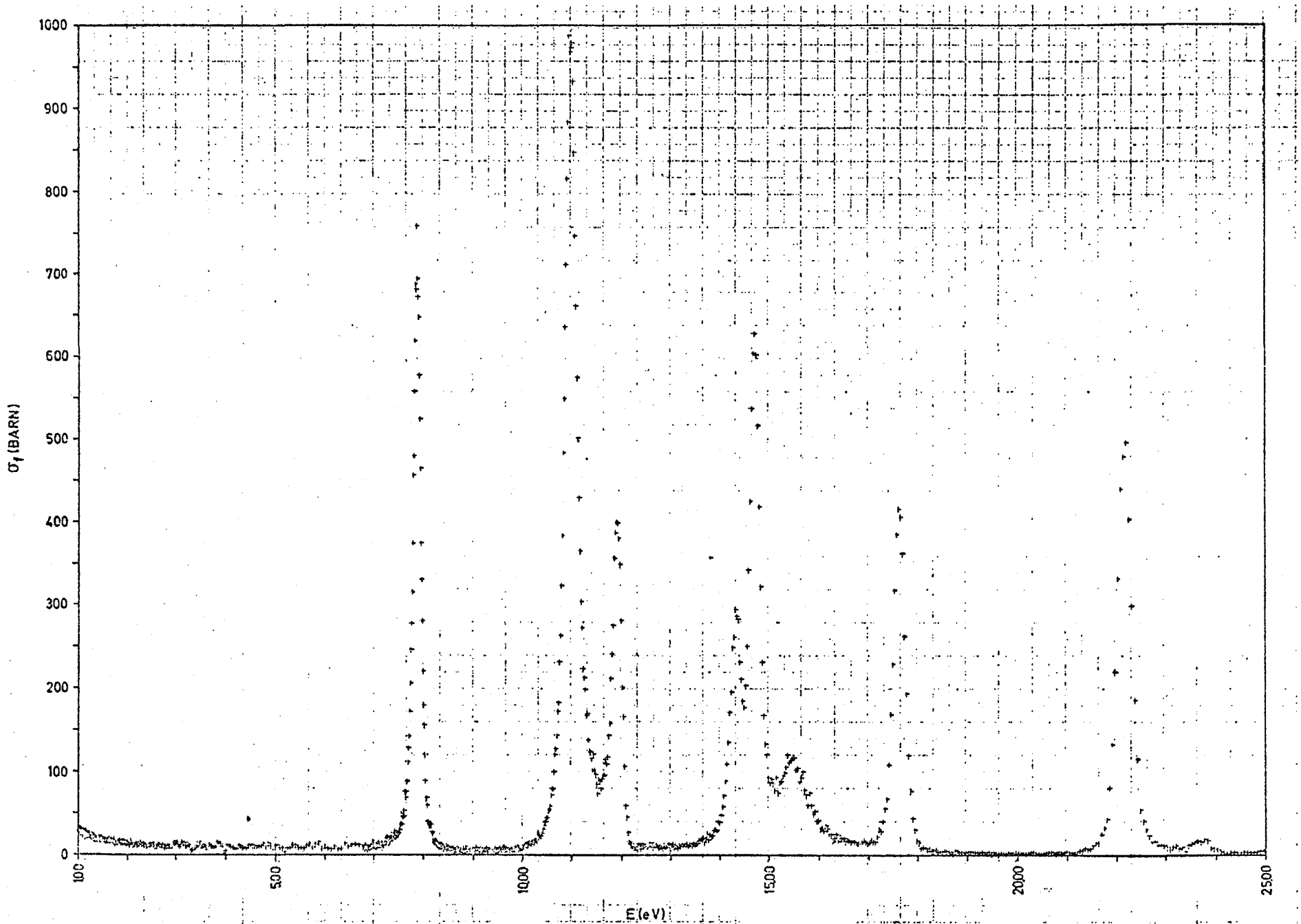

Figure 1b. ^{239}Pu fission cross-section from 1 to 25 eV