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ABSOLUTE MEASUREMENTS OF THE U-238 FISSION CROSS-SECTION AT 4.8 MEV, 8.4 MEV AND 18.8 MEV NEUTRON ENERGIES USING THE TCAPM

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Summary

This paper reviews experimental details and preliminary results of absolute measurements, carried out at the CINR Rossendorf by the TU Dresden/RI Leningrad cooperation. Using the Time-Correlated Associated Particle Method (TCAPM), uncertainties of 1.8% and 2.9% were obtained at 8.4 MeV and 18.8 MeV neutron energies, respectively. Because of progresses in the experimental technique, the properties of the fission deposits became the restrictive factor of the experimental accuracy in these measurements. A first short run with poor statistics at 4.8 MeV resulted in a standard deviation of 2.8% for the U-238(n,f) cross-section.

Introduction

The U-238 fission cross-section possesses increasing importance as a nuclear data standard, especially for fusion technology and reactor dosimetry because of its advantages (reaction threshold, smooth function in the plateau regions). Therefore it was already admitted into the IAEA Standards File /1/. But them faces a lack of experimental data, especially absolut measured ones. Thus, the measurements of the TUD/RIL cooperation (U-235 /2-5/, Pu-239 /4,6/) were continued to get a set of precise absolute spot points for the U-238 fission cross-section, too /21/.

Measuring principle

The measuring principle of the TCAPM is well known /7,2,4,6,8/ and will be recapitulated only in its basic ideas (fig. 1):
Accelerated deuterons are focused on a CD_2- or a Ti-T-target foil producing neutrons by the $D(d,n)^3He$- and $T(d,n)^4He$-reactions, respectively. Associated charged particles (AP), which are emitted within a fixed cone $\Delta\Omega_{AP}$ defined by an aperture A, are registered by an AP detector. The neutrons belonging to the registered AP form a cone $\Delta\Omega_n$, which is defined by the reaction kinematics and has to be intercepted completely by the homogeneous fission foils placed inside an ionization fission chamber. Then, the fission cross-section is given by the formula

$$\sigma_f = N_f / (N_{AP} \cdot n),$$

where N_f is the number of fission events registered in coincidence

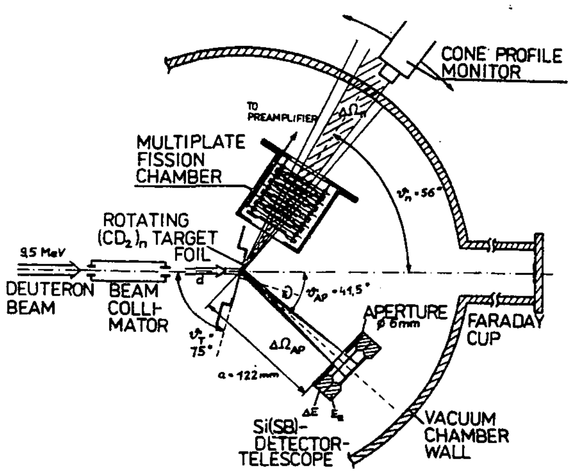

Fig. 1
Experimental set-up of the 8.4 MeV measurement

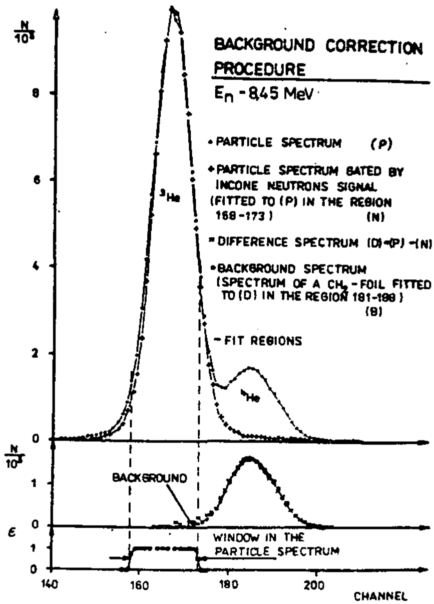

Fig. 2
Background correction procedure at 8.4 MeV

with an AP, N_{AP} the number of counted AP's and n the number of fissionable nuclei per unit area.

AP c o u n t i n g

The AP detection system is based on a telescope of two completely depleted Si-SB-detectors in connection with a fast particle identification circuit /9,2/. This technique allows:

- to suppress rates of scattered deuterons up to $2.5 \cdot 10^5\ s^{-1}$
- to reduce the ^{4}He-background (d(D,n)-reaction) essentially by generating a particle significant spectrum (fig. 2), containing all events inside the former selected window around the ^{3}He-peak in the total energy spectrum.

The remaining background components have to be considered by the analysis of recorded spectra.

4.8 MeV and 8.4 MeV

The portion of the remaining ^{4}He-background not separated is caused by the tail of the ^{4}He-peak and amounts to 0.5...0.6 %. To determine this background underlying the ^{3}He-peak the particle significant spectrum is collected during the whole measurement. In intervals background spectra are collected using CH_2-foils of comparable thickness and besides particle spectra gated by correlated (incone) neutron signals. The background normalization procedure by spectra fitting is illustrated by fig. 2. This procedure is based only on experimental spectra, not on mathematical descriptions of peak shapes.
Unfortunately, this method requires a sufficient large ^{4}He-peak for background spectra fitting. Therefore, the energy window in the total energy spectrum of the detector telescope must be chosen wide enough to admit a sufficient part of ^{4}He events in the particle spectrum. This, of course, will enlarge the ^{4}He amount within the AP window, too. In order to reduce the ^{4}He background as much as possible, a new and independent method of background determination was tested in the 4.8 MeV measurement. In the total energy spectrum the events of a separated ^{4}He peak were counted as a monitor rate during both measurement and background control runs, using CD_2- and CH_2-foils, respectively. The background particle spectra are normalized to the effect particle spectra by means of the ratio of these monitor rates,

and in the normalized background spectra the interesting background amount inside the particle window is determined. The results by using this independent method confirm to these by spectra fitting within the error limits of 0.2 %. But for a general application of this method some experimental modifications are necessary to improve the separation of the ^{4}He peak used so that small electronic drifts will not influence the result.

18.8 MeV

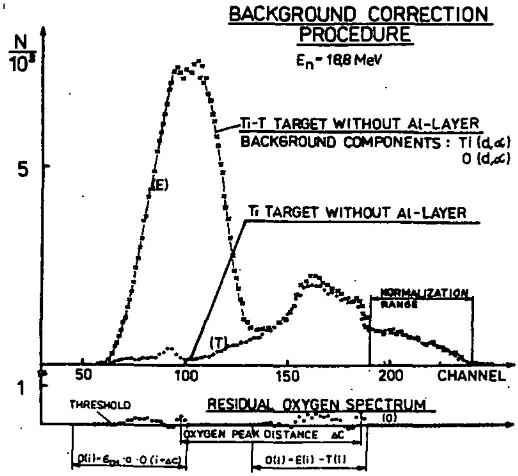

Fig. 3
Background correction procedure at 18.8 MeV

Normalization of the Ti(d,α) and ^{16}O(d,α) background components was carried out by fitting the spectra of non-tritiated foils of nearly the same thickness to these registred during the runs considering different ^{16}O-depht-profiles (/2,10,11/ see also fig. 3). Employing selfsupporting Ti-T-targets without Al-layer (in contrary to /2,10,11/), the error contribution of background correction in the AP channel was reduced from 1.35 % to 0.60 % because of the absence of the Al(d,α)-component. Using a rotating target holder system at beam-currents up to 600 nA, no T-escape from these targets was detectable.

N e u t r o n   c o n e

The principle of the TCAPM presupposes the complete interception

of the neutron cone by all fission foils. This basic condition was controlled during the whole run by scanning the horizontal neutron cone profile outside the 40 cm in diameter vaccuum chamber with a scintillation detector /12/. Far from the cone maximum this measurement gives no significant information because of the raising amount of events, caused by scattering on fission chamber material and vaccuum chamber wall. Therefore in the 18.8 MeV measurement separate measurements of the proton cone /13/ inside the vaccuum chamber were carried out (protons from the d(^{3}He,p)-reaction; ^{3}He originating in the T-decay). They have shown an exponential slope of the cone edges so that the experimental neutron cone tails can be explained by these neutron scattering processes /14/.
This allowed to open the neutron cone wider in the 8.4 MeV and 4.8 MeV measurements in contrary to former measurements by use of larger AP apertures to reach better statistics. The counting losses caused by neutrons outside the cone were found to be smaller by calculations based on the measured cone profile than 0.02 % in these two measurements.

F i s s i o n   c h a m b e r

The necessary increase of fissionable material in the fission chamber results in an increasing number of fission foils. To realize a compact chamber design the facility of decreasing the foil-electrode-distance was investigated. Using an Am-Be-n-source fission chamber spectra with foil-electrode-distances of 2 mm and the former used 3 mm were registered.
Figure 4 shows that the decrease reduces the visible plateau region to a third, which would enlarge the error contribution by spectrum extrapolation to zero, essentially.
Thus, for the foil-electrode-distance of 3 mm given optimum number of foils is nine. In case of a further extension the necessary cone-contraction (because of the raised distance of the last foil from the neutron source target) decreases the amount of fissionable material inside the cone more than the additional foil enlarges it.

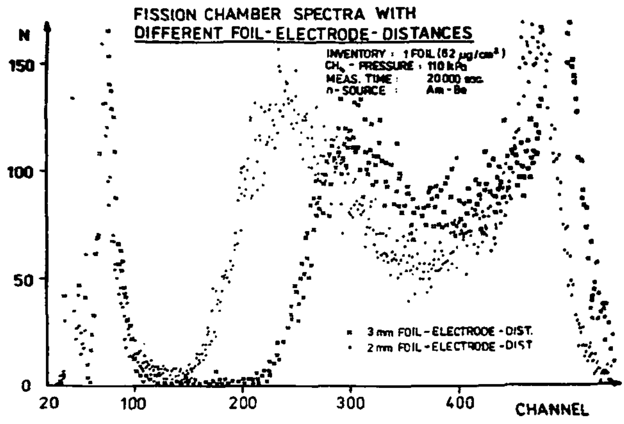

Fig. 4
Fission chamber spectra with different foil-electrode-distance

Our well optimized fission chamber allows to set the threshold in fission chamber spectra at very low energies. Therefore, at the neutron energies of 18.8 MeV a correlated background not negligible was determined explained by the $^{12}C(n,n')3\alpha$-reaction at the chamber gas CH_4 /6,22/. Now, at the neutron energy of 8.4 MeV a correlated background was detected, too. Because of the higher reaction threshold of the $^{12}C(n,n')3\alpha$-reaction it is sure to originate in other reactions at chamber construction materials. In general this correlated background is not ruled out at neutron energies above 8 MeV in dependence on the threshold position. But the amount of correlated background correction is rather small (5.92 % and 0.15 % in the 18.8 MeV and the 8.4 MeV measurements, respectively) compared to the correction values in table 2, which include all events below the threshold introduced with the analysis.

F i s s i o n f o i l s

The fission foils used were prepared at the KRI Leningrad by HF-sputtering (foil II) and by separation from a metal-organic compound (all other foils). The active layers are situated on 0.17 mm thick Ni-Cr-backings contained in brass frames 40 mm in diameter.

Table 1

Properties of the fission foils used

Foil No.	Ø (mm)	manufactured (year)	n ($\frac{\mu g}{cm^2}$)	Δn/n (%)	Inhomogeneity round points to centr. point (%)	Inhomogeneity stand. dev. at round points (%)	Mounting position 4.8 / 8.4 MeV (1986) (F = foreward, B = backward)	Mounting position 18.8 MeV (1985)
II	21	1979	288.6	1.0	+0.16	0.51	4/B	4/B
1	21	1985	427.7	1.0	-0.97	1.79	1/F	3/F
2	21	1985	521.0	1.0	-1.94	2.94	-	1/F
4	21	1985	331.6	1.0	-2.91	1.14	-	2/B
7	21	1985	340.5	1.0	-1.50	0.59	2/B	5/F
1	24	1986	348.2	1.28	-0.38	1.35	6/B	not avail.
3	24	1986	418.9	1.29	-1.31	1.09	3/F	not avail.
4	24	1986	375.6	1.28	+0.11	1.30	9/F	not avail.
5	24	1986	409.6	0.88	-1.27	1.34	5/F	not avail.
6	24	1986	430.7	1.32	+0.35	0.83	7/F	not avail.
8	24	1986	332.4	1.28	+0.20	0.46	8/B	not avail.

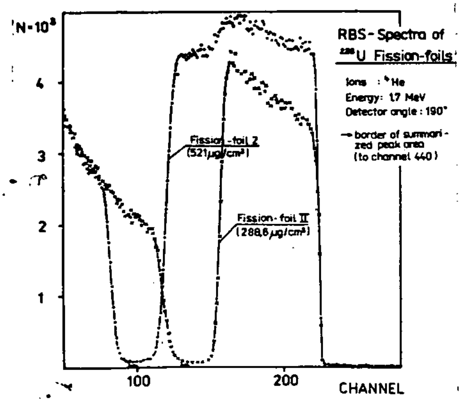

Fig. 5

Typical RBS-spectra of U-238 fission foils

The number of fissionable nuclei per unit area was determined at the KRI by $\frac{2}{3}\pi$-α-counting, using $T_{1/2}$ (U-238) = $4.468 \cdot 10^9$ y

± 0.11 % /15/.
Nonuniformity of the layers was determined at then van-de-Graaff-accelerator of the CINR Rossendorf by Rutherford backscattering measurements with 1.7 MeV ^{4}He-ions /16/. Figure 5 shows typical RBS-spectra of two fission foils prepared by two different technologies. The brutto area of the effect peak (at right) was used as a measure of Uranium contents in the foils. Nine measuring points 3 mm in diameter were located in the centre of the foil and on a circle (Ø 12 mm) around the centre in steps of 45°. Based on these results nine fission foils were selected from the available 16 ones (for the 18.8 MeV measurement 5 foils) and their true mounting positions in the fission chamber were optimized, so that the inhomogeneities of the round measuring points will compensate each other at a maximum /6/.
The whole inhomogeneity of the complete set of foils was calculated by quadratic addition of the standard deviation of the points outside the centre (0.06 %) and the averaged difference relative to the central point (0.54 %, values for the 1986 9 plate chamber).

Results

Correction values, error contributions and the preliminary results of the measurements presented are given in table 2. Figure 6 presents our results compared to the ENDF/B-V data file /1/.
Small correction values demonstrate the advantages of the TCAPM. In all measurements (except at 4.8 MeV because of the poor statistics) the summarized error contribution from neutron flux determination and counting statistics is smaller than that of foil parameters.
All corrections based on experimental results are derived from spectra recorded during the whole measurement time using a CAMAC-instrumentation system /17/. Correction of the correlated background was realized by setting a threshold in the fission chamber spectrum with the analysis /6/.
Neutron scattering correction is calculated with a Monte-Carlo-Program /18/.

Table 2

Corrections (a) and error contributions (b) of the measurements presented

Neutron energy (MeV)	4.8		8.4		18.8	
	a (%)	b (%)	a (%)	b (%)	a (%)	b (%)
Counting of coincidences						
- Statistics of effect	-	2.22	-	0.87	-	1.81
- Random coincidences	0.48	0.17	1.19	0.11	1.07	0.21
Fission chamber efficiency						
- Pulses below correlated background threshold	1.02	0.07	0.56	0.04	6.34	0.06
- Extrapolation to zero	0.87	0.27	1.24	0.14	1.20	0.20
- Fragment absorption	3.07	0.90	2.74	0.81	2.91	0.90
AP counting						
- Background	3.30	0.60	0.94	0.29	5.65	0.60
Neutron cone						
- Neutron scattering and effective foil thickness due to the cone aperture	1.07	0.40	1.16	0.40	0.54	0.40
- Cone neutrons outside the angular extend of the fission foils	-	0.02	-	0.01	-	0.36
Fissile layer						
- Areal density	-	1.15	-	1.15	-	1.00
- Inhomogeneity	-	0.54	-	0.54	-	1.59
Result (10^{-24} cm^2)	0.551		1.022		1.351	
Standard deviation (%)	2.82		1.82		2.89	

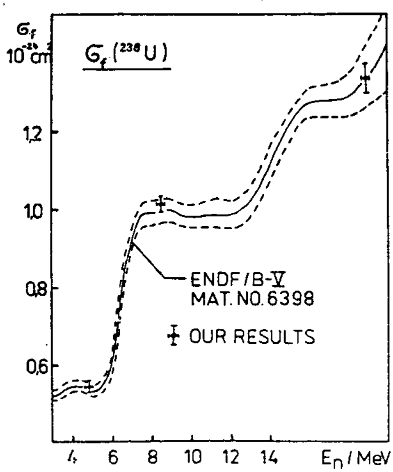

Fig. 6

Results compared with the ENDF/B-V data file

Based on a value of 7.5 mg/cm^2 for the averaged fragment range in U_3O_8 /19/ a value of $(5.5 {}^{+2.0}_{-1.0})$ mg/cm^2 related to the Uranium content (data from the foil manufacturer about microscopic inhomogeneity and about admixtures of other elements considered) was assumed to calculate the fission counting loss caused by absorption /20/. Experimental investigations of the individual absorption parameters of all foils used are planned, and a further decrease of the fragment range may be expected by reason of surface effects, as measurements at Pu-239 foils have shown /21/.

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