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FISSION CROSS SECTION OF ^{181}Ta FOR PROTONS IN THE ENERGY RANGE 200–1000 MeV

V. I. Yurevich [a,1], *V. A. Nikolaev* [b], *R. M. Yakovlev* [b], *I. B. Vorobiev* [b]

[a] Joint Institute for Nuclear Research, Dubna
[b] V. G. Khlopin Radium Institute, St. Petersburg, Russia

The experimental estimation of fission cross section of ^{181}Ta for protons in the energy range 200–1000 MeV was carried out by method of solid-state nuclear track detectors based on 6-μm lavsan film. A comparison of the obtained data with the available experimental results is performed.

Выполнена экспериментальная оценка сечения деления ^{181}Ta протонами в области энергий 200–1000 МэВ методом твердотельных трековых детекторов ядер на основе 6-мкм лавсановой пленки. Проводится сравнение полученных данных с имеющимися экспериментальными результатами.

INTRODUCTION

An energy dependence of fission cross sections for protons is poorly known for nuclei lighter than lead. Therefore, any new experimental results on fission of nuclei in a range of mass numbers $A < 200$ are important for understanding of the fission process. For ^{181}Ta the fission cross section σ_f was measured at energy of protons from 155 up to 1000 MeV [1–4].

On a basis of available experimental data on fission of various nuclei, Fukahori and Pearlstein obtained the analytical expression with three parameters for description of energy dependence of fission cross sections in intermediate-energy range [5]. Recently, the most full systematization of experimental data on fission cross sections has been made, and a slightly different formula with four parameters offered [6]. Using this formula with evaluated parameters, one can predict a value of σ_f for ^{181}Ta at any energy of protons.

In this paper we discuss the results of our measurements of the fission cross section of ^{181}Ta. The experiment was performed on a beam of protons of the Dubna Synchrophasotron in the energy range 200–1000 MeV. The experimental method was described in [7].

1. DATA PROCESSING

A probability of formation of registered fragments and residues in reactions of fragmentation and spallation of heavy nuclei, such as tantalum and lead, begins to grow rapidly with increasing proton energy in a range $E > 1.0$ GeV. At lower energies a dominating process is a reaction of fission, and the first two processes give only insignificant contribution to the

[1] E-mail: yurevich@sunhe.jinr.ru

number of the registered tracks. Also, from the experimental results it follows that in the energy range 200–1000 MeV the reactions of fragmentation and spallation give lower number of counts in SSNTDs for tantalum than for lighter nuclei, for example, for cadmium target.

In our measurements the assemblies target–SSNTD–target (T–D–T) were used. Thus, the registered number of counts in SSNTD is a sum of contributions from the first and second targets surrounding the SSNTD:

$$N = N_F + N_B,$$

where N_F is the number of the registered tracks from nuclear fragments leaving the target in forward direction (a direction of proton beam), and N_B is a contribution from nuclear fragments emitted in back hemisphere. A registration of fission fragments is possible only in a limited angular interval. Therefore, the measured number of fission fragments is only a part of their total number N_{tot} emitted in a total solid angle. At $E > 200$ MeV the angular distribution of fission fragments becomes close to isotropic in a center-of-mass system, which in a laboratory system corresponds to the distribution extended forward because fissile nuclei have a momentum after $p{-}A$ interactions [8]. In the case of thin target, whose thickness is much less than average path length of fission fragments in the target, the critical angle of registration of fission fragments by 6-μm lavsan SSNTD is 29°, which is equivalent to registration in the angular intervals 0–61° and 119–180° by the assembly T–D–T [7]. It was shown that the total number of fission events (or fission cross section) is proportional to the number of the registered fission fragments in the specified angular intervals [7]. In our case of thick fissile targets, the value of the effective critical angle increases and the effective width of the angular intervals becomes narrower in comparison with thin targets due to worse registration characteristics of fission fragments leaving the target surfaces.

For estimation of the fission cross section of ^{181}Ta for protons in the energy range 200–1000 MeV the following assumptions were used:

1. Fission fragments leaving tantalum and lead targets have the same registration properties.

2. Kinematic characteristics of fission fragments are such that a magnitude of ratio N/N_{tot} is energy-independent in the studied energy interval.

3. The contribution to the total number of counts from the nuclear fragments arising in other processes is small in this energy range and can be taken into account by a small correction.

4. The value of this correction can be estimated from results obtained for lighter targets (we used cadmium) where the process of fission can be neglected in comparison with the contribution from reactions of fragmentation and spallation.

The result of these assumptions is a proportionality of fission cross section value σ_f to the measured number of counts N after a deduction of the correction on contribution from other background processes ΔN. The value of the correction was accepted equal to half of the number of counts of the assembly Cd–D–Cd with the same value of error $\Delta N = 0.5N^{\text{Cd}} \pm 0.5N^{\text{Cd}}$.

The value of the fission cross section of ^{181}Ta was determined with the help of the following relation:

$$\sigma_f^{\text{Ta}}(E) = N^{*\text{Ta}}(E)\frac{\sigma_f^{\text{Pb}}\,(1000\text{ MeV})}{N^{*\text{Pb}}\,(1000\text{ MeV})},$$

where

$$N^{*\text{Ta}} = N^{\text{Ta}} - \frac{1}{2}N^{\text{Cd}} \quad \text{and} \quad N^{*\text{Pb}} = N^{\text{Pb}} - \frac{1}{2}N^{\text{Cd}}.$$

The fission cross section for a natural mix of lead isotopes at a proton energy of 1000 MeV was used for normalization of the results of our measurements. The fission cross section for $^{\rm nat}$Pb in the energy range from hundreds of MeV to several GeV was investigated in $[1, 4, 9, 10]$, and these experimental results are in good agreement. The evaluation [6] gives the value $\sigma_f^{\rm Pb} = 133.8$ mb at $E = 1000$ MeV, which coincides with an average value found on the experimental data in the interval 600–3000 MeV. The error of this magnitude, apparently, does not exceed 10%.

For the assembly Pb–D–Pb and flux of 1-GeV protons of 10^{10}, 15750 ± 2360 counts have been obtained in SSNTD, which corresponds to $N^{*\rm Pb} = 15515 \pm 2327$.

A list of main errors for the value $N^{\rm Ta}$ is shown in Table 1.

Table 1. **Experimental errors for the value $N^{\rm Ta}$**

Error	Value, %
Statistical	3–5
Determination of number of counts N	12
Determination of proton flux	20

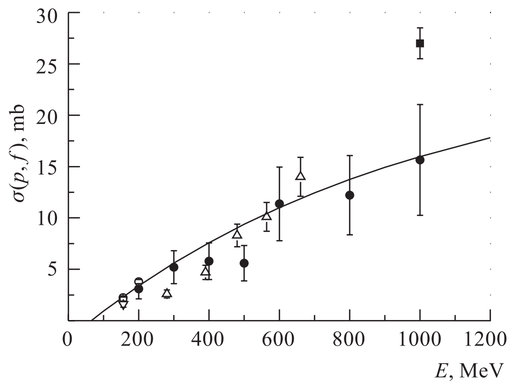
The values $N^{\rm Ta}$, $\Delta N = 0.5N^{\rm Cd}$ and $\sigma_f^{\rm Ta}$ obtained by the formula are given for seven energies of protons in Table 2.

Table 2. **Experimental results and fission cross section of $^{181}{\rm Ta}(p, f)$**

E, MeV	$N^{\rm Ta}$	ΔN	$\sigma_f^{\rm Ta}$, mb
200	381 ± 90	22 ± 22	3.09 ± 0.98
300	633 ± 150	30 ± 30	5.20 ± 1.60
400	707 ± 168	35 ± 35	5.79 ± 1.78
500	701 ± 166	52 ± 52	5.59 ± 1.72
600	1401 ± 330	82 ± 82	11.37 ± 3.59
800	1517 ± 360	101 ± 101	12.21 ± 3.86
1000	2050 ± 480	235 ± 235	15.65 ± 5.40

2. DISCUSSION OF RESULTS

For comparison of our results with other data on fission cross section of $^{181}{\rm Ta}(p, f)$, a set of available experimental results and the evaluation [6] are shown in figure. The fission cross section monotonically rises with increase in proton energy up to 1 GeV. There are no any experimental data at higher energies. Our results are in close agreement with the prediction [6] in all the energy range studied. Also, good agreement with the results [1] and [3] below 1 GeV is observed. However, there is a large discrepancy between our result and data [4] at 1 GeV, where we have obtained the value $\sigma_f^{\rm Ta} = 15.65 \pm 5.40$ mb and the authors of [4] gave the magnitude 27.0 ± 1.5 mb. This discrepancy much exceeds the experimental errors.



Fission cross section of ^{181}Ta for protons: ● — present work; △ — [1]; □, ▽ — [2]; ○ — [3]; ■ — [4]; curve — [6]

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