ISSN 0029 - 3865

CBPF-NF-042/89

PROBABILITY OF TERNARY FISSION OF ^{93}Nb AND ^{nat}Ag NUCLEI INDUCED BY 0.8-1.8 GeV PHOTONS

by

D.A. de LIMA[1]*, W.C.C. MILOMEM[2] and O.A.P. TAVARES

Centro Brasileiro de Pesquisas Físicas - CBPF/CNPq
Rua Dr. Xavier Sigaud, 150
22290 - Rio de Janeiro, RJ - Brasil

[1]Istituto Nazionale di Fisica Nucleare-INFN
Laboratori Nazionali di Frascati-LNF, Via E. Fermi 40
00044 Frascati (Roma), Italia

[2]Departamento de Física, Universidade Federal do Mato Grosso,
Av, Fernando Correa da Costa s/n
78000 - Cuiabá, MT - Brasil

*On leave of absence from the Departamento de Física,
Universidade Federal da Paraíba,
58000 - João Pessoa, PB - Brasil

Abstract. - The yields of ternary fission of ^{93}Nb and ^{nat}Ag nuclei induced by bremsstrahlung photons of 0.8, 1.0, 1.4 and 1.8 GeV end-point energies have been measured by using the 2π-forward geometry with thick target metal foils in contact with makrofol polycarbonate sheets as fission-track detectors. Absolute mean cross sections per photon in the range 0.8-1.8 GeV have been obtained as 0.3±0.3 μb and 0.5±0.4 μb, respectively, for ^{93}Nb and ^{nat}Ag nuclei. These correspond to a probability of ternary fission of $\sim 10^{-5}$ for both nuclei. Results are discussed and compared with previous ternary fission data obtained by us for nuclei of $A \lesssim 90$.

Key-words: Ternary fission; Nb, Ag natural targets; 0.8-1.8 GeV bremsstrahlung; Makrofol detector; Photofission.

In a previous paper [1] we reported results on cross section and nuclear fissility of ternary fission of some light- and intermediate-mass nuclei induced by photons of 0.8-1.8 GeV as incident particles. The process, i.e., the break-up of the nucleus into three fragments of comparable masses, has shown to be a rare nuclear decay mode since a probability of ternary fission of $\sim 10^{-4}$ has been obtained for Al, Ti, Co, and Zr nuclei. Data have indicated, however, that the ratio of ternary to binary fission cross sections (σ_T/σ_B) varies from $\sim 10^{-3}$ to $\sim 10^{-1}$ as one goes from Al to Zr. Besides, a comparative study on a number of σ_T/σ_B-values taken from the literature for different combinations of target nuclei and incident particles and energies as well [1] has shown that σ_T/σ_B seems to increase towards the intermediate-mass region of target nuclei ($100 \lesssim A \lesssim 200$). In the present work we contribute to new data by reporting the results we have obtained for ternary fission of Nb and Ag target nuclei induced by 0.8-1.8 GeV photons. These new data have shown to be consistent with the trend exhibited by the σ_T/σ_B-ratio as mentioned previously.

The experiment consisted of stacking thick metal foils of niobium and silver target elements placed in contact with sheets of 100-μm thick makrofol polycarbonate track detectors (2π-forward geometry). These were exposed perpendicularly to high-intensity bremsstrahlung beams of 0.8, 1.0, 1.4, and 1.8 GeV maximum energies at the Bonn 2.5-GeV Elektronen Synchrotron [2] (typical doses were $\sim 3\times10^{13}$ equivalent quanta/cm^2). Track etching proceeded by the usual way (6.25 N NaOH etching solution at 70°C during 1h), and the scanning of the detector surfaces and the measurements of the geometrical quantities of etched tracks were carried out by using an Olympus CBB213 microscope fitted out with calibrated eye-pieces inside occulars of 10X and a dry objetive of 40X magnification. Under these conditions, and apart from a large number of single etched tracks observed, a number of double divergent tracks from a point inside the target materials has been also observed. These double tracks may be related to the occurrence of ternary fission and, therefore, based on the fission mechanism and track registration properties of the detector used, the methods to ascertain and to discriminate ternary fission events against other types of events have been established, thus making it possible to evaluate the ternary fission yields.

The reaction yield, i.e., the cross section per equivalent quantum σ_Q at maximum bremsstrahlung energy E_0, is given by

$$\sigma_Q = \frac{N_e}{Q\,N_a} \quad , \tag{1}$$

where N_e is the number of true ternary fission events identified per unit area, Q is the number of equivalent photons incident on the target-detector stacks per unit area, and N_a is the "effective" number of target nuclei of the thick sample per unit area, i.e., the number of target nuclei which contribute effectively to the observed number of ternary fission events. Thus, N_a defines an "effective thickness", x_{ef}. Since the results reported here are part of an experimental systematic investigation we are doing on photon-induced ternary fission of complex nuclei, we left to previous papers [1,3] the detailed description of the criteria of identification and recognization of true ternary fission events as well as the method of evaluation of x_{ef}. In Table I we list the main data from which the ternary fission yield (last column) have been obtained (only statistical errors are indicated).

In order to determine the cross section "per photon" $\sigma(k)$ at photon energy k we used the 1/k approximation for bremsstrahlung spectra, and, by assuming $\sigma(k)$ constant within a small energy range, one obtains

$$\sigma = \frac{d\sigma_Q}{d(\ln E_0)} \quad , \tag{2}$$

i.e., the slope of the curve σ_Q *versus* $\ln E_0$. Fig. 1 reports the measured ternary fission yields as a function of $\ln E_0$ where the linear dependence is the most appropriate one to fit the data (the point enclosed by parentheses shows to be far from the expected increasing trend of σ_Q and, thus, it was not considered in the least-squares analysis). Therefore, the absolute mean ternary fission cross sections per photon in the range 0.8-1.8 GeV have been obtained as 0.3±0.3 μb and 0.5±0.4 μb, respectively, for ^{93}Nb and ^{nat}Ag nuclei.

Finally, we evaluated the probability of ternary fission (nuclear fissility of the ternary fission mode) by calculating the ratio $f = \bar{\sigma}/\bar{\sigma}_t$ of mean ternary fission cross section ($\bar{\sigma}$) to mean total nuclear photoabsorption cross section ($\bar{\sigma}_t$). As explained in [1], for photons of energy in the range 0.8-1.8 GeV $\bar{\sigma}_t \approx 180$ A μb, where A denotes the mass number. Table II reports mean values of fissility so obtained (last column).

Also in this table are shown the mean values of nuclear fissility of the binary fission mode from our previous work (fifth column) to allow a direct comparison. In spite of the large experimental errors quoted, which are due mainly to poor statistics, results show that ternary fission of the target nuclei considered here is a very rare nuclear de-exciting mode following the absorption of intermediate-energy photons by the nucleus (the probability of ternary fission mode amounts to $\sim 10^{-5}$ only).

A comparative study of the data of the present work with those obtained in [1] is presented in Fig. 2 where we chose to represent the ratio of ternary to binary fission cross sections, σ_T/σ_B, as a function of parameter Z^2/A. The result by Khan and Khan [6] of 7-GeV proton-induced fission on Ag nucleus is also quoted to a comparison (open circle). As can be seen, σ_T/σ_B varies by almost three orders of magnitude in the range 6-22 covered by Z^2/A-values. Within the large uncertainties referred, results indicate the existence of a maximum for the ratio σ_T/σ_B of the order of $\sim 10^{-1}$ in the vicinity of $Z^2/A \approx 18$. The trend depicted in Fig. 2 shows that σ_T/σ_B should decrease for $Z^2/A \gtrsim 18$. This was demonstrated experimentally by Khan and Khan [6] for 7-GeV proton-induced fission reactions on nuclei ranging from Ag to U. The data of the present work point towards a similar behavior if intermediate-energy photons be used as incident particles. New experimental results in this line are called for to confirm (or not) such a prediction.

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The authors are indebted to Dr. D. HUSMANN for the opportunity given and his interest of exposing the samples at the Elektronen Synchrotron of the Universität Bonn. Thanks are due also to the technical machine staff for the assistance given during the irradiations. The partial support by the Brazilian Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) is also gratefully acknowledged.

FIGURE CAPTIONS

Fig. 1 - Ternary fission yields, expressed as cross section per equivalent quantum (σ_Q), are plotted against maximum bremsstrahlung energy E_0 (log scale). Points represent the results obtained in the present experiment for Nb and Ag. The straight lines are least-squares fits to the points.

Fig. 2 - Ratio of ternary to binary fission cross sections, σ_T/σ_B, plotted as a function of Z^2/A of the system target nucleus plus incident particle. Data are as follows: ■ , 0.8-1.8GeV photons + ^{27}Al and ^{nat}Ti (2π-forward geometry with CR-39 detector) and + ^{59}Co and ^{nat}Zr (2π-forward geometry with makrofol detector), ref. [1]; O , 7-GeV proton + ^{108}Ag (Daicel sandwich detector), ref. [6]; ● , 0.8-1.8 GeV photons + ^{93}Nb and ^{nat}Ag (2π-forward geometry with makrofol detector), this work. The curve is an eye-fit to the experimental points.

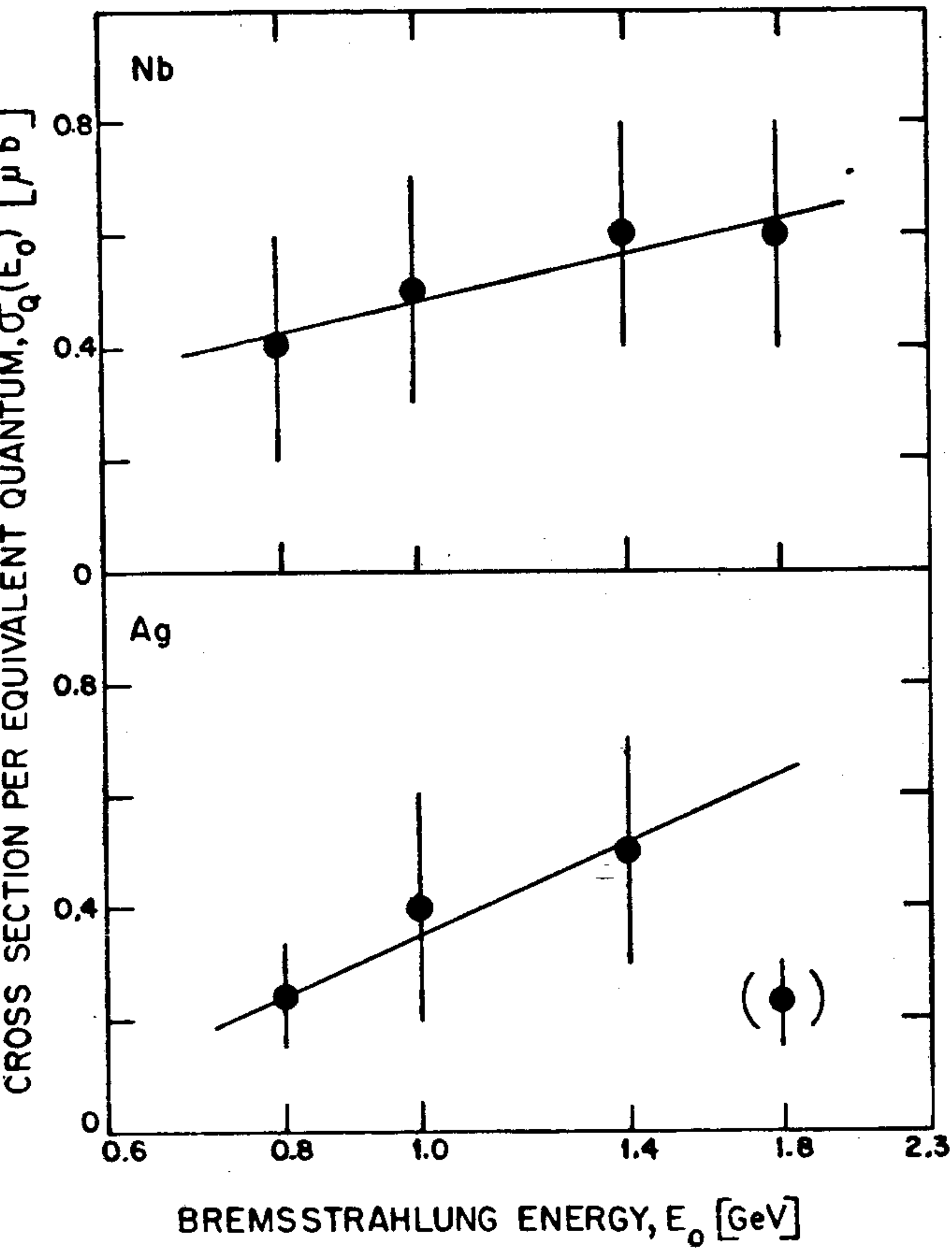
Nb
Ag
0.8
0.4
0
0.8
0,4
0
0.6
0.8
1.0
1.4
1.8
2.3
CROSS SECTION PER EQUIVALENT QUANTUM, $\sigma_q(E_o)$ [μb]
BREMSSTRAHLUNG ENERGY, E_o [GeV]

Fig. 1

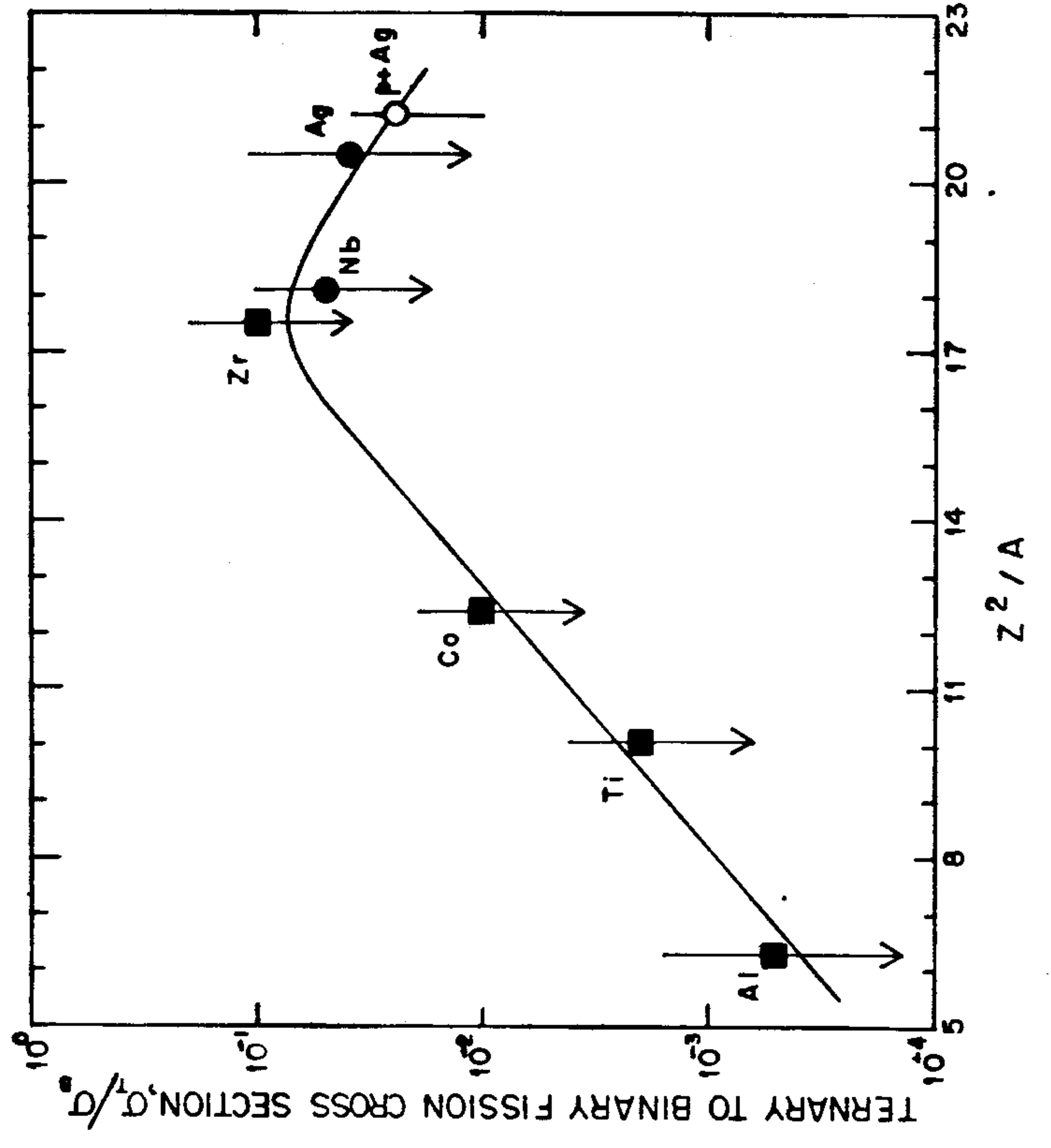
TERNARY TO BINARY FISSION CROSS SECTION, σ_T/σ_B
Z^2/A
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
5
8
11
14
17
20
23
Al
Ti
Co
Zr
Nb
Ag
p+Ag

Fig. 2

Table I. - Relevant data regarding the determination of the ternary fission yields.

Target nucleus	Effective thickness of the target sample x_{ef} (μm)	Effective number of target nuclei N_a (10^{18} cm^{-2})	Bremsstrahlung maximum energy E_0 (GeV)	Number of equivalent photons Q (10^{12} cm^{-2})	Area of scanning (cm^2)	Number of ternary fission events, N_e	Ternary fission yield, σ_Q(μb)
^{93}Nb	0.058±0.007	0.32±0.04	0.8	28.4	2.0±0.2	7±3	0.4±0.2
			1.0	29.6	1.8±0.2	8±3	0.5±0.2
			1.4	30.0	1.8±0.2	10±3	0.6±0.2
			1.8	30.0	2.2±0.2	13±4	0.6±0.2
$^{107.8}$Ag*	0.093±0.009	0.55±0.05	0.8	28.4	1.6±0.2	6±2	0.24±0.09
			1.0	29.6	1.0±0.1	7±3	0.4±0.2
			1.4	30.0	1.2±0.1	9±3	0.5±0.2
			1.8	30.0	1.6±0.2	6±2	0.23±0.08

*Mean mass number taking into account the isotopic abundances of the naturally occurring isotopes.

Table II. - Mean values of binary and ternary fission cross sections and fissilities of Nb and Ag by photons in the energy-range 0.8-1.8 GeV.

Nucleus	Mean cross section per photon, $\overline{\sigma}$ (μb)			Mean nuclear fissility, $\overline{f}$	
	binary fission(a)	ternary fission	ratio (ternary/binary)	binary fission(a)	ternary fission
^{93}Nb	6±4	0.3±0.3	$\sim 5\times10^{-2}$	$(4\pm2)\times10^{-4}$	$(2\pm2)\times10^{-5}$
$^{107.8}Ag$	12±4	0.5±0.4	$\sim 4\times10^{-2}$	$(6\pm2)\times10^{-4}$	$(3\pm2)\times10^{-5}$

(a) Data taken from Refs. [2,4,5].

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