RESEARCH OF ACTIVATION CROSS SECTIONS FOR LONG-LIVED RADIONUCLIDES ON ELEMENTS OF CU MO AG EU AND TB

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ABSTRACT: The cross sections for ^{109}Ag(n,2n)^{108m}Ag, ^{151}Eu(n,2n)^{150m}Eu, ^{153}Eu(n.2n)^{152g}Eu and ^{159}Tb(n,2n)^{158}Tb reactions have been measured by the activation method at 14 MeV. The results were compared with existing data (1-4) and calculations of systematic (5,6) and Code HFTT (7) which was based on the compound nucleus evaporation model and the preequilibrium exciton model.

1. INTRODUCTION

The nuclear data requirements for integral calculations for fist wall, blanket , shielding and activating problems of fusion reactor have been listed by E.T.Cheng and dopted by working group 1 of 16th INDC Meeting as high priority data requests for fusion technology. Especially,the products of long-lived radionuclides are important for waste disposal and maintenance of fusion reactors.

Up to now, only few reports for (n,2n) reaction cross section values in this area were found at 14 MeV. In addition, cross sections for ^{109}Ag (n,2n)^{108m}Ag reaction have not been measured before. Investigetions were initiated on the (n,2n) reactions for Ag,Eu and Tb. The cross sections for ^{109}Ag(n,2n)^{108m}Ag, ^{151}Eu(n,2n) ^{150m}Eu, ^{153}Eu(n,2n)^{152g}Eu and ^{159}Tb(n,2n)^{158}Tb reactions have been performed by activation technique at 14 MeV. The calculations of systematic and theoretic also made for Cu, Mo (n,p) reaction and Ag, Eu and Tb (n,2n) reaction.

2. EXPERIMENTAL PROCEDURE

2.1 Irradiation

Irradiations were carried out by neutron source of T(d,n)^{4}He reaction at Intense Neutron Generator of Lanzhou University (INGL) and Cockcroft-Walton at Institute of Atomic Energy Beijing (IAEB). The irradiation geometry on the INGL, the sample groups were placed at 15°, 30°, 50° and 80° angles relative to beam direction and centered at beam stop on the T-Ti target with distances 5 and 10 cm respectively. The irradiation was lasted to 7.36 hours with intensity of neutron flux about $1.1\text{-}3.3\times10^{12}$n/s 4π. One sample group was sent back to IAEB for analysis and three sample groups were counted in Lazhou University. The efficiencies of two Ge(Li) detecters used in both places were calibrated using the same group of gamma-ray standard sources. The irradiation in IAEB, the stacked sample groups with cadmium cover were placed at 0° and 65° angles with effective distances from 12 to 76 mm. The irradiations were lasted to 50 hours at neutron flux densities $(0.7\text{-}2)\times10^{10}$n/s 4π. The energy of deutron beam was taken 300keV.

2.2 Sample

The samples of 20mm diameter were made by natural plates for Ag, Nb or oxide powder for Eu and Tb. The purity of them were better than 99%. The samples in question were sandwiched between two niobium samples with thickness 0.03mm to evaluate the neutron fluence on the samples. The cross sections of ^{93}Nb(n,2n)^{92m}Nb reaction were select as a monitor due to it's high accurate and same shape of excitation functions with reaction investigeted.

In the case of Eu, the sample was wrapped in 0.5mm thickness Cd foils to reduce the activities of ^{152g}Eu from ^{151}Eu(n,r)^{152g}Eu reaction of thermal neutron.

2.3 Measurement of activity

After irradiation, the samples were cooled for 2-6 months, then to analyse each foils with a 136cc Ge(Li) detecter. The distance of sample to surface of the detecter was 15.5 cm to reduce the effect of sum peak. The measurements were lasted to 1-6 days for each samples, and repeated for two or thrr times. The activities of Nb monitor foils were mesured in a week after irradiations.

2.3 Correction

In general, the corrections for (n,2n) reactions are very small due to it's high threshold. In principle, the same activity was formed by the (n,2n) reaction and (n,r) reaction on an isotope two mass units less then that of investegated nuclide is small and may be neglected. However, in the case of ^{153}Eu(n,2n)^{152g}Eu reaction, there were very high (n,r) cross section for the lower energy neutrons it was necessary to determine the contribution of scattered neutrons. The special experimental arragement was made for measuring the ^{153}Eu(n,2n)^{152g}Eu reaction. The relation of activity as a function of distance square was used to determine the contributionof scattered neutrons in the vicinity of target and sample groups. The results of the measurements are shown in the Fig.1. The least square method was used to get the correction of lower energy neutrons. The corrections were large especialy for heavy mass target assembly and sample groups (4-20%). An

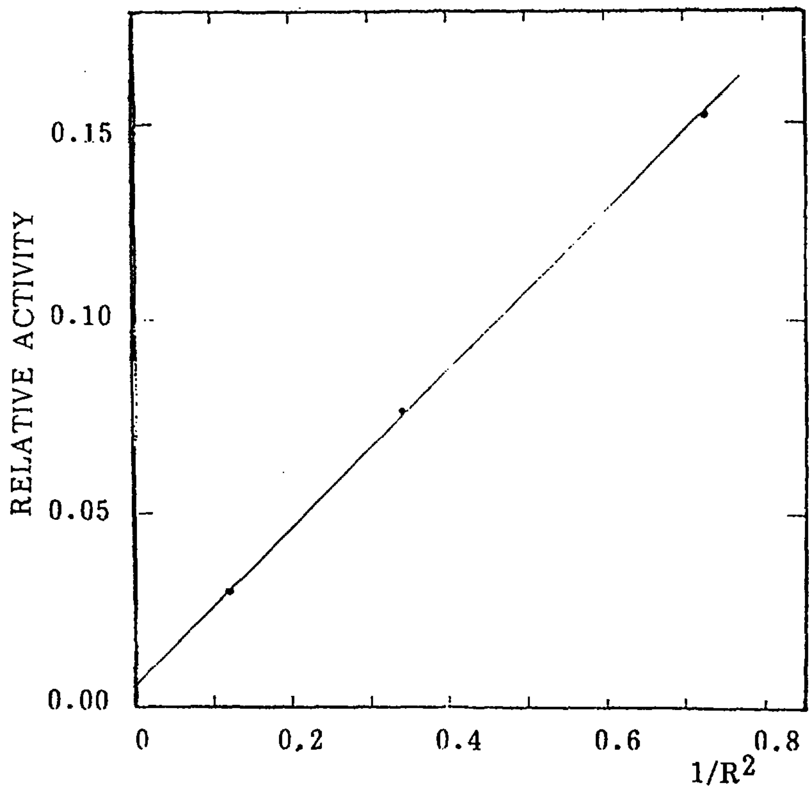

Fig. 1 Dependence 0f the activity on the unproportion of destance squre

another sample group was placed at distance of 2 metres to evaluate the background of the experimental room (about 1% at distance of 3 cm).

Some corrections were also made for the gamma-ray absorption and for scattered neutrons owing to different excitation function shapes for standard reaction and investigated reaction as well as for the effects of the gamma rays with energies close to studied one.

3. THEORETICAL AND SYSTEMATICS CALCULATION

We used the code HFTT (7) for calculating the excitation functions of the (n,2n) reaction on ^{109}Ag, ^{151}Eu, ^{153}Eu, ^{159}Tb and (n,p) reaction on ^{63}Cu, ^{94}Mo. The results are shown in Figs. 2-6. The calculation program used was based on the compound nucleous evaporation model (8) and the preequilibrium exciton model (9). The first and the second emission particles considered in the nuclear reactions were n, p, d, t, ^{3}He, ^{4}He and gamma. The third emission particles considered were n, p and gamma. In preequilibrium theory we chose initial exciton configurations of n_0= 3 (2p, 1h) for neutron induced reactions. The Gelbert-Cameron's formulas were used for calculating the energy level density of nuclei. For computation of inverse cross section of nuclear reaction the optical model was used. The optical paramenters used in the program were recommended by F.Bechetti et al.(10), Lohr (11) and Mefedden (12).

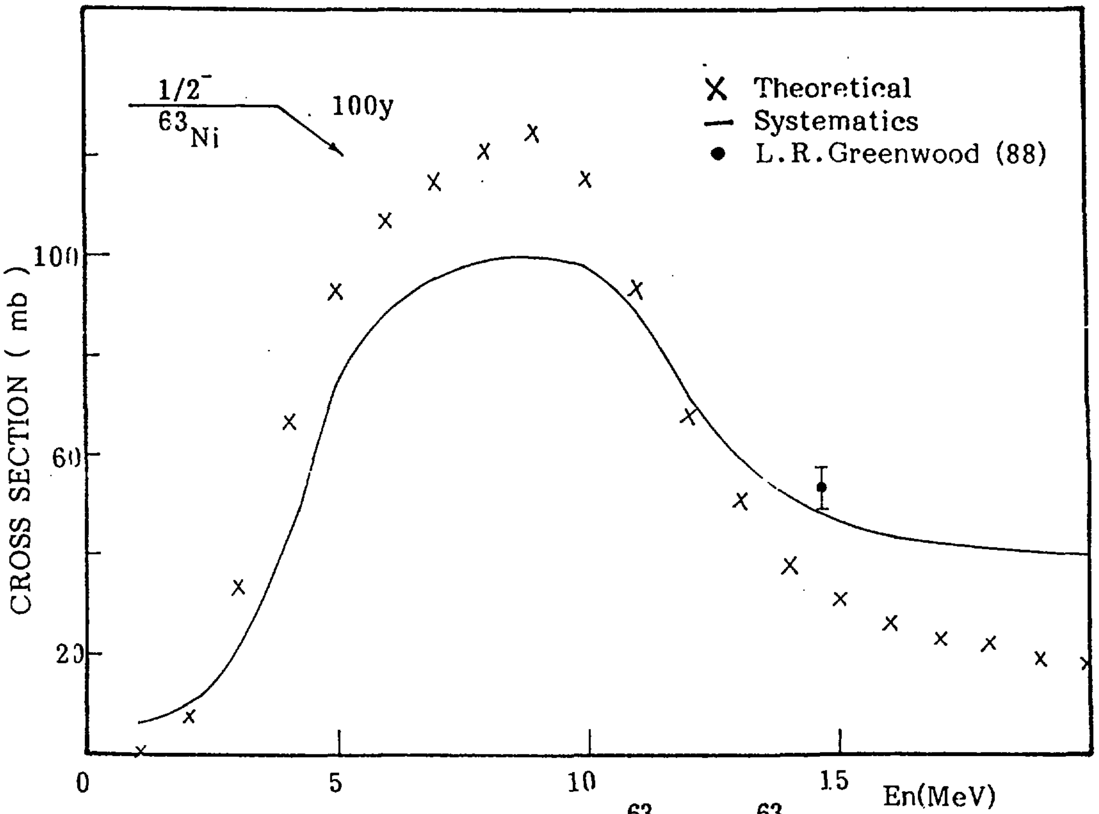

Fig. 2 Excitation function of ^{63}Cu(n,p)^{63}Ni reaction

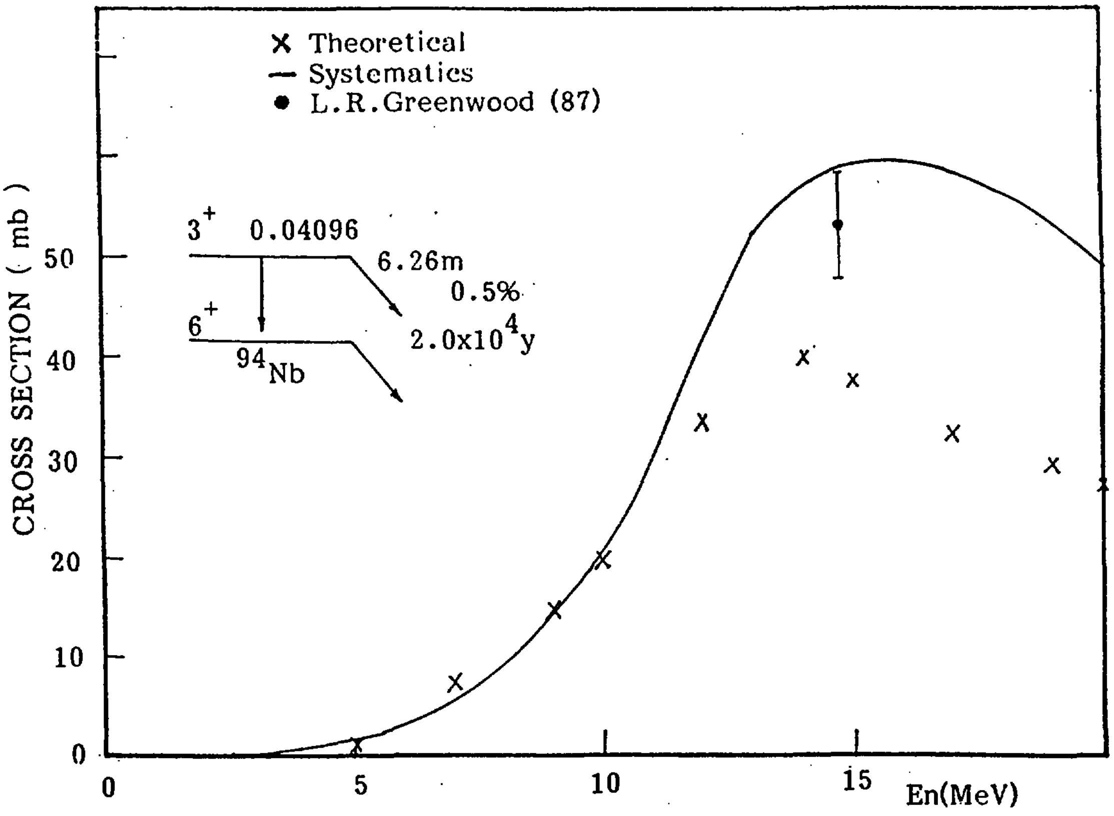

Fig. 3 Excitation function of ^{94}Mo(n,p)^{94}Nb reaction

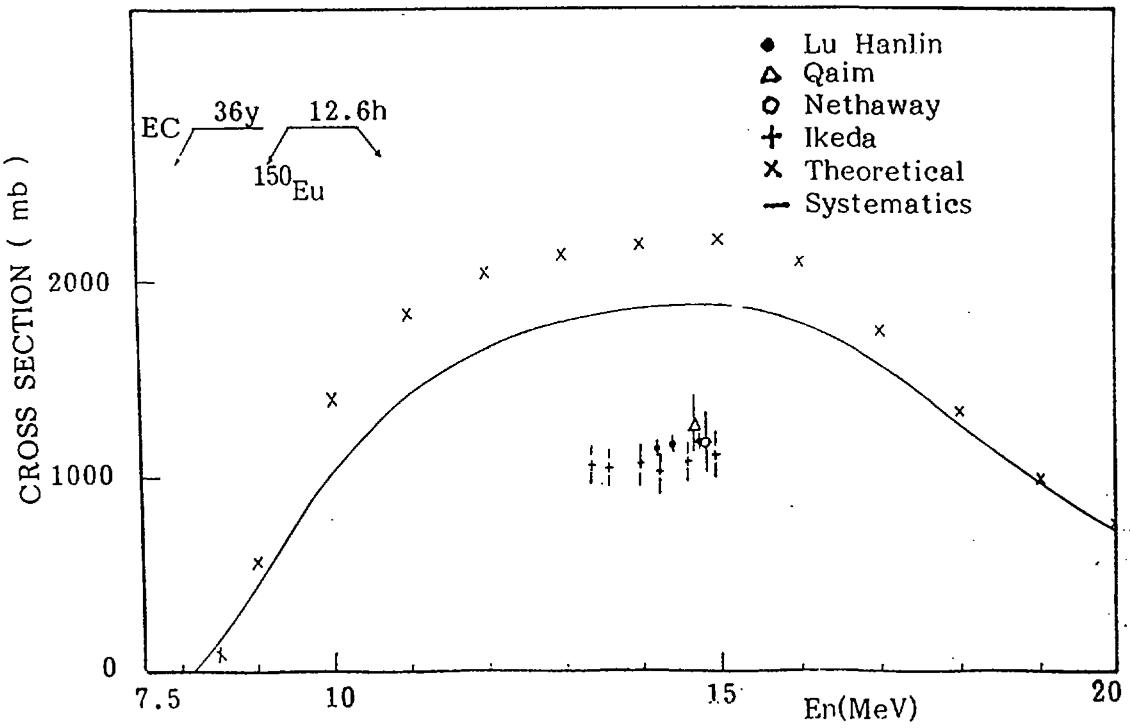

Fig. 4 Excitation function of $^{151}Eu(n,2n)^{150}Eu$ reaction

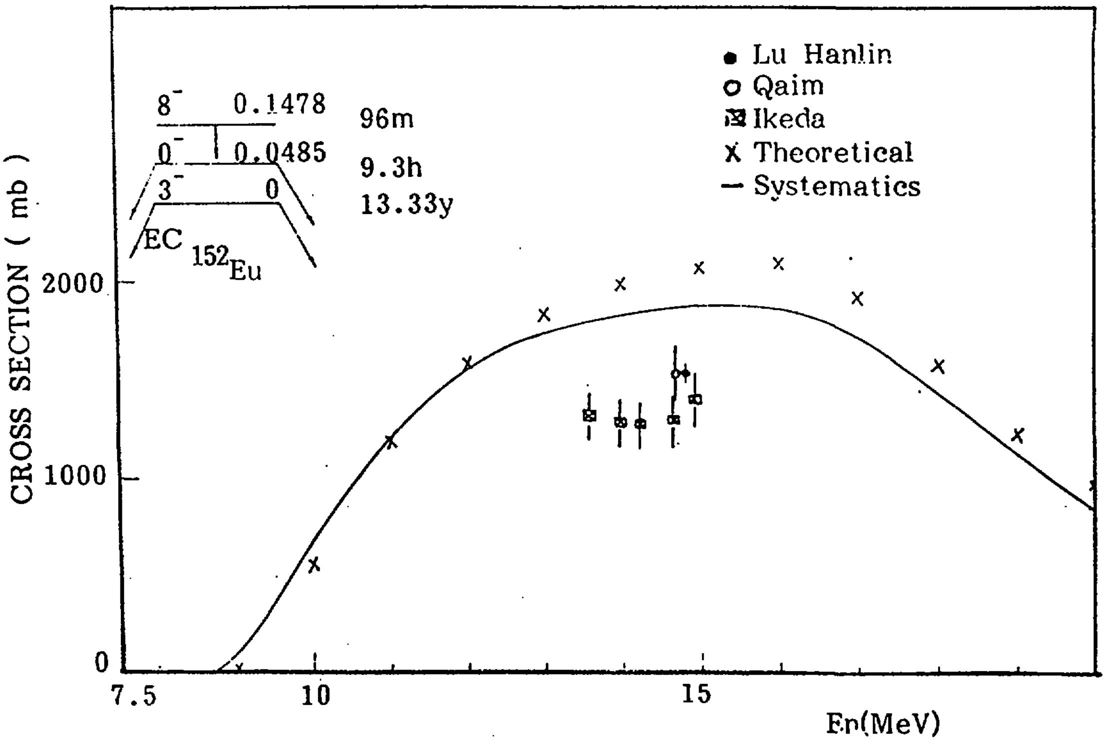

Fig. 5 Excitation function of $^{153}Eu(n,2n)^{152}Eu$ reaction

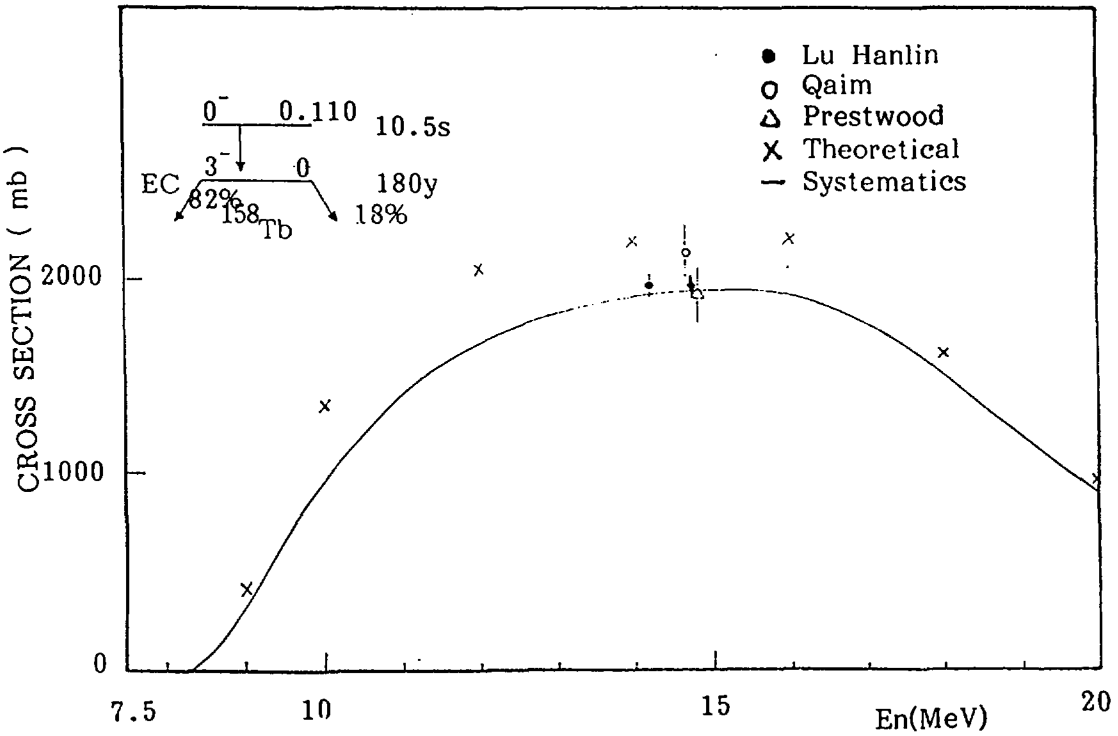

Fig. 6 Excitation function of ^{159}Tb(n,2n)^{158}Tb reaction

The calculations of (n,p) and (n,2n) excitation functions using the systematics model were made by Zhao Zhixiang (5) and Zhang Jin (6). The code was based on the constant temperature evaporation model in which preequilibrium emission was considered.

4. RESULTS AND UNCERTAINTIES

The measured results of the cross sections are given in Table 1 and some of them are ploted in Figs. 2-6 with existing data and calculated curves. The error correlations for the measurements of ^{109}Ag, ^{151}Eu, ^{153}Eu, ^{159}Tb and ^{93}Nb are shown in the Table 2. The principal sources of uncertainties are listed in Table 3. For ^{109}Ag(n,2n)^{108m}Ag reaction the experiments showed that the activity of ^{108m}Ag was very few produced by ^{107}Ag(n,r)^{108m}Ag reaction.

The Table 4 shows the present knowledge of cross sections for long-lived radionuclides with experimental data and semi-systimatical data, which are given through systimatical calculations and experimental data of short-lived. Semi-systimatical data agreed with experimental data except the reaction of ^{109}Ag(n,2n)^{108m}Ag. Our data are very coincident with D.R.Nethaway and S.M.Qaim for ^{151}Eu(n ,2n)^{150m}Eu and ^{153}Eu(n,2n)^{152g}Eu reactions. Consistent results are given by S.M.Qaim, R.J.Prestwood and us, if the same value of half-lift for the residual nucleus was used for them.

TABLE 1. CROSS SECTIONS AND DECAY DATA

Neutron energy (MeV)	^{93}Nb(n,2n)^{92m}Nb	^{109}Ag(n,2n)^{108m}Ag	^{151}Eu(n,2n)^{150m}Eu (mb)	^{153}Eu(n,2n)^{152g}Eu	^{159}Tb(n,2n)^{158}Tb
14.19±0.23	457.5±4.5	224±6	1190±27		1980±56
14.28±0.24	458.0±4.5	215±11			
14.41±0.16	458.7±4.5		1215±36		
14.44±0.26	458.8±4.5	223±10			
14.77±0.48	458.6±5.6	230±7	1219±28	1544±42	1968±56
14.83±0.34	458.6±5.6	233±7			
$T_{\frac{1}{2}}$	10.15d	127y	35.8y	13.33y	180y
E_r (keV)	934.5	433.9	333.9	344.3	944.2
I_r (%)	99.0	90.5	94.0	26.58	43

TABLE 2. CORRELATION MATRIX (14.77 MeV)

Reaction	Error					
^{109}Ag(n,2n)^{108m}Ag	3.1%	1.000				
^{151}Eu(n,2n)^{150m}Eu	2.4%	0.551	1.000			
^{153}Eu(n,2n)^{152g}Eu	2.7%	0.377	0.480	1.000		
^{159}Tb(n,2n)^{158g}Tb	2.9%	0.599	0.435	0.370	1.000	
^{93}Nb(n,2n)^{92m}Nb	1.2%	0.436	0.639	0.756	0.492	1.000

TABLE 3. THE PRINCIPAL SOURCES OF UNCERTAINTY

Source of error	Uncertainty (%)			
	^{108m}Ag	^{150m}Eu	^{152g}Eu	^{158g}Tb
reference cross section	1.2	1.2	1.2	1.2
detector efficiency	1.5	1.5	1.5	1.5
counting statistics	1.1-2.4	0.9-2.7	0.9	0.8
gamma absorption	0.4	0.9	0.9	0.6
neutron scattering	0.5	0.5	1.3	1.8
gamma mixture		0.1	0.1	
sample mass including purity	0.1	0.35	0.35	0.5
sum peak	0--4			
Total	2.3--5.1	2.4--3.5	2.7	2.9

* Uncertainties in decay schemas are not included

Table 4. Existing data for experiment and systematic (14MeV)

Nuclear reaction	Present work (mb)		Reference (mb)			
	exp.	semi-syst.	exp.	ref.	semi-syst.	
^{63}Cu(n,p)^{63}Ni		50	54±4	88 (13)		
^{94}Mo(n,p)^{94}Nb		58	53.1±5.3	87 (14)		
^{109}Ag(n,2n)^{108m}Ag	230±7	585	263±20	89 (4)	665±73	89 (4)
^{151}Eu(n,2n)^{150m}Eu	1219±28	1400	1180±150	72 (1)	1325±34	89 (4)
			1270±149	74 (2)		
			1080±100	89 (4)		
^{153}Eu(n,2n)^{152g}Eu	1544±42	1429	1542±138	74 (2)	1442±60	89 (4)
			1300±130	89 (4)		
^{159}Tb(n,2n)^{158}Tb	1968±56	1940	*2161±140	74 (2)	1930±49	89 (4)
			1930±135	84 (3)		

* correction to value of half-life 180y

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