ACTIVATION CROSS SECTIONS RELATED TO NUCLEAR HEATING OF HIGH T_c SUPERCONDUCTORS*

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ABSTRACT

Activation cross-sections have been measured for some isotopes of the elements in $Tl_2Ca_1Ba_2Cu_2O_8$ high T_c superconducting oxide. In addition, cross sections for producing long-lived isotopes in Cu and Ag were also determined. Results for the following reactions are given at E_n=14.5 MeV: $^{63}Cu(n,\alpha)^{60g}Co$, $^{90}Zr(n,2n)^{89}Zr$, $^{107}Ag(n,2n)^{106m}Ag$, $^{109}Ag(n,2n)^{108m}Ag$, $^{134}Ba(n,2n)^{133g}Ba$, $^{134}Ba(n,p)^{134g}Cs$, $^{136}Ba(n,p)^{136}Cs$, $^{137}Ba(n,p)^{137}Cs$ and $^{203}Tl(n,2n)^{202}Tl$. Results are compared to the corresponding data published in the literature and given by systematics.

1. INTRODUCTION

During the last decades, interest in the determination of fast neutron cross-sections has been increased because of their use in the designs of fast breeder, fusion, and fusion-fission hybride reactors as well as in radiation damage experiments and cancer therapy. Recent studies on fusion reactors show that the energy will probably be

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Table 1. Data related to the irradiation and measurement

Radio nuclide	Energies of the measured γ-rays[6][keV]	Half-life [5]	γ-emission probabilities [6]	Sample [mm^3]	Cooling time [day]
^{60g}Co	1173.2	5.2719 y	0.999	Cu 12x13x0.7	33
	1332.5		1.0		
^{106m}Ag	717.3	8.51 d	0.291	Ag 12x13x0.2	22
	1527.7		0.164		
^{108m}Ag	433.9	127.7 y	0.907	Ag 12x13x0.2	274
^{133g}Ba	302.9	10.6612 y	0.186	Tl-ceramic	
	356.0		0.623	ϕ 15.3x2.3	40
	276.4		0.0729		
^{134g}Cs	795.8	2.062 y	0.854	ϕ 15.3x2.3	40
^{136}Cs	1235.3	13.002 d	0.198	ϕ 15.3x2.3	40
	818.5		0.997		
^{137}Cs	661.6	30.174 y	0.851	ϕ 15.3x2.3	40
^{202}Tl	439.6	12.232 d	0.914	ϕ 15.3x2.3	40
^{89}Zr	909.2	78.43 h	0.99	Zr 12x13x0.5	22

produced by the D-T-Li fuel cycle. Therefore, the measurements of the activation cross sections with $E_n \leq 15$ MeV for long-lived radionuclides are of primary importance for radioactive waste estimates and nuclear heating of the superconductors[1]. Recently, the nuclear data requirements for fusion energy development summarized in a number of papers[2] indicate that the measurements of activation cross-sections for $^{137}Ba(n,p)$ and $^{109}Ag(n,2n)$ reactions have high priority for dosimetry, too. The aim of this work is to complete the activation cross-sections for long-lived products with high precision.

2. EXPERIMENTAL PROCEDURE

Rectangular and disc shaped high-purity metallic samples of natural Cu, Zr, Nb and Ag as well as $Tl_2Ca_1Ba_2Cu_2O_8$ ceramic were irradiated at the KORONA generator of the GKSS, Geesthacht[3]. The use of high T_c superconducting ceramic sample rendered it possible to measure simultaneously both the cross-sections and the irradiation effects of fast neutrons. The dimensions of the samples are given in Table 1. The total neutron yields were $(1.03\text{-}1.21)10^{14}$ n/cm^2 in approximately 2 hs irradiation time, depending on the positions of the samples. The samples were sandwiched between two Nb fluence monitor foils. The cross sections were measured relative to the $^{93}Nb(n,2n)^{92m}Nb$ reaction for which a value of (460 ± 5)mb was accepted[4] at 14.7 MeV. The neutron energy scale for the thick and extended stack of samples has been determined by measuring the ratio of the ^{89}Zr to ^{92m}Nb specific activities induced in Zr and Nb foils placed back-to-back in different positions inside the sample. The cross-section values obtained for the $^{90}Zr(n,2n)^{89}Zr$ reaction were found to be between 713 and 732 mb for the seven Nb-Zr pairs in the sample stack. On the basis of the cross-section-energy curve, shown in Fig.1., the corresponding energy range is (14.42-14.47) MeV. The average energy (14.44 MeV) is consistent with the (14.5 ± 0.3)MeV value measured in Geesthacht.

Table 2. Cross section results at E_n=14.5 MeV

Nuclear reactions	Cross-section (mb) measured in Geesthacht	Cross-section (mb) measured in Debrecen	Recommended cross section (mb) Qaim[7]	Recommended cross section (mb) Bychkov et al.[8]
$^{63}Cu(n,\alpha)^{60g}Co$	51 ± 2	45.5 ± 2	40 ± 1	(35 ± 8)
$^{107}Ag(n,2n)^{106m}Ag$	570 ± 17	552 ± 20	600 ± 80	400
$^{109}Ag(n,2n)^{108m}Ag$	220 ± 12	263 ± 20	-	27
$^{134}Ba(n,2n)^{133g}Ba$		655^{+60}_{-20}	[1550]	[1640]
$^{134}Ba(n,p)^{134g}Cs$		4.9^{+2}_{-1}	[8]	[7.7]
$^{136}Ba(n,p)^{136}Cs$		6.3^{+2}_{-1}	8 ± 3	8 ± 3
$^{137}Ba(n,p)^{137}Cs$		5.3 ± 0.7	[4.5]	[2.9]
$^{203}Tl(n,2n)^{202}Tl$		1902^{+8}_{-15}	1950 ± 200	(2065 ± 150)
$^{90}Zr(n,2n)^{89}Zr$		723 ± 15	768 ± 78	(768 ± 30)

[ ] from systematics. ( ) from excitation functions.

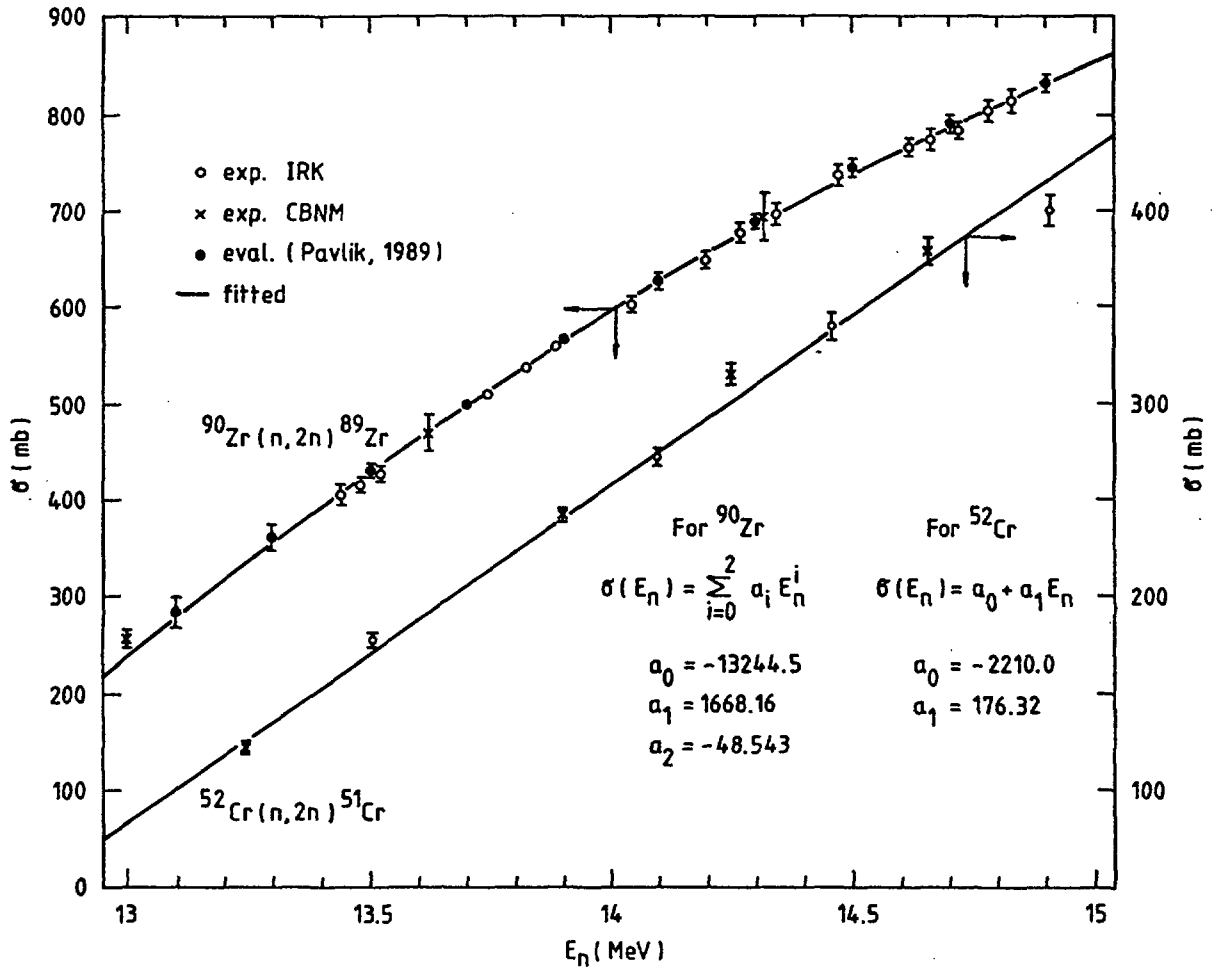

Fig.1. Cross-section curves of $^{90}Zr(n,2n)^{89}Zr$ and $^{52}Cr(n,2n)^{51}Cr$ reactions for the determination of incident neutron energy

The activities of the Ag and Cu samples and the corresponding Zr-Nb monitor foils were measured by calibrated Ge(Li) gamma-ray detectors both in Debrecen and Geesthacht. The activities of the radionuclides produced in the ceramic sample have been measured in Debrecen. Efficiency corrections for different dimensions of the samples were applied. Decay data accepted for the determination of the cross-sections[5,6] are given in Table 1.

3. RESULTS AND DISCUSSION

The cross-sections obtained in the present measurements at 14.5 MeV neutron energy are summarized in Table 2.

Uncertainties combined in quadrature have been estimated at 1σ. As it can be seen in Table 2., cross-sec-

tion data measured in Debrecen and Geesthacht are in agreement within 10 %. Considering the long half-lives and complex decay schemes of the ^{60g}Co, ^{106m}Ag and ^{108m}Ag isotopes, the agreement is satisfactory. The cross-sections for the $^{109}Ag(n,2n)^{108m}Ag$, $^{134}Ba(n,p)^{134g}Cs$, $^{134}Ba(n,2n)^{133g}Ba$ and $^{137}Ba(n,p)^{137}Cs$ reactions were measured the first time in this experiment. Data predicted from systematic trends[7,8] and the measured values differ significantly from each other for these reactions. Therefore, it is needed to improve the systematics by the analysis of the recent more precise data. For Ba the data are in contradiction with the systematic trend observed in the isotopic dependence of (n,p) cross-sections. In general, the results agree better with those recommended by Qaim[7] than by Bychkov et al.[8]. Further precise measurements are needed to complete the data for reaction producing long-lived isotopes and to check the reliability of different systematics[9].

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