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NEUTRON ACTIVATION CROSS SECTION MEASUREMENTS AT BRATISLAVA

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Final report

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I. Introduction

Activation technique has been used to measure the cross sections for neutron-induced reactions of Ti, Cr and Ni isotopes with emphasis on the (n,p) and (n,np) *. Though many such data have bee been measured in the past it is generally difficult to determine which values are to be preffered as those data often exhibit mutual disagreement substantially exceeding the quoted uncertaintes. This is probably the reason why the new data are still requested in WRENDA 83/84. Moreover, Ti, Cr and Ni are a potential component of fusion reactor construction material and precise and reliable activation data are obviously needed in accordance with the Coordinate Research Programme objectives.

The measurements of the reported data were undertaken in a belief that the efficient way to improve the existing situation in activation data for Ti, Cr and Ni is their careful remeasurement using modern experimental procedures, data processing techniques and error-handlings methods.

In sect. II. the novel experimental approaches are briefly described together with error-handling method. In sect. III the data measured within CRP are presented without any further comment and analysis as very many input informations are needed. They can be found in the quoted literature. The same refer to the relevant experimental details.

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* The (n,np) symbol stands for the sum of the (n,n'p), (n,pn) and (n,d) contributions.

II. Experimental procedures and uncertainties

1. Coincidence summing corrections (CSC). In the fast neutron activation the most precise and reliable method for measurement of the activity of the reaction products is the Ge Li /HPGE γ- ray spectroscopy of the irradiated samples. Due to relatively low detection efficiency of these detectors and - generally - low activity of the samples the close geometry has to be used for their γ- counting. However at close geometry the coincidence summing /due to cascading γ-transitions/ becomes an important source of systematic errors up to several tens of percents . To corect for these effects one has to know the absolute photo- and total-detection efficiences for a specific geometry used.

We have developed the method of Ge detector calibration at close geometry. The advantage of the method is in use of a standard set, and therefore easily available of absolutely calibrated γ-sources for detector calibration at for geometry where CSC are negligible. These data are transformed to close geometry by measuring the transformation curve using a set of uncalibrated single-line sources which can easily be prepared using standard radiactive solutions.

Using this method we have succeeded to measure the photo-efficiency of our detector at close geometry with the uncertainty $\lesssim$1,5 % in the interval 60 - 2000 keV. The overall uncertainty for the total efficiency was $\lesssim$5 % which is sufficient to keeps the CSC's uncertainty below $\sim$ 1 %.

The method is described in ref. [1].

2. Interference of (n,p) and (n,np) processes. For the relatively light nuclei (like Ti, Cr and Ni) the contribution to the activity of the (A,Z-1) reaction product from (A+1, Z) target - (n,np) channel - might be comparable with that from (A, Z)

target - (n,p) channel. In order to distinquish between these two channels the highly euriched samples are required. However such targets are not readily available and the price might be prohibitive especially if a given element consists from many stable isotopes. In some cases even the high enrichment can not guarantee that the contribution from n,np channel will be negligible (i.e. if $\sigma_{n,np}(A+1,Z) \gg \sigma_{n,p}(A,Z)$).

In our measurements we have used several isotopic mixtures in order to distinquish between these two channels. Than the experimentaly measured quantity X_i for a given mixture i is given as

$$X_i = \sigma_{n,p}(A,Z)\eta_i(A,Z) + \sigma_{n,np}(A+1,Z)\eta_i(A+1,Z) \quad (1)$$

To solve this system of linear equations $(i \geq 3)$ one has to use statistical method as bothhX's and η's have their uncertainties. Such methods are readily available.

The advantage of this method is that the high enrichment is no more imperative, error assignement of the extracted quantities is consistent and well defined. Moreover the well established statistical tests might help to discover inconsistences in measured quantities. Next, this method can be extended to include three nucleon emission from (A+2, Z) target.

3. Uncertainties. To avoid an ad hoc assignement of uncertainties of the measured cross sections and to include in final uncertainties also known systematic errors in a consistent way the covariance matrix method developed in refs. [2,3] were adopted. Thus all our experimental results represent total uncertainties.

III. Experimental results

The final results for the neutron activation cross sections for Ti, Cr and Ni isotopes are given subsequently in tables [1, 2] and 3. The corresponding experimental details, comparisons with other data and their analyses are given in refs. [4, 5] for Ti, in refs [6] for Cr and in refs. [7, 8] for Ni isotopes.

Literature

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Table 1. Activation cross sections for Ti isotopes at 14.8 MeV

Reaction	σ (mbarn)	Uncertainties (mbarn)	Correlation matrix (%)	
$^{46}Ti(n,p)^{46m}Sc$	55.0	2.2	100	
$^{47}Ti(n,np)^{46m}Sc$	6.92	0.33	-45	100
$^{46}Ti(n,p)^{46g}Sc$	211.7	8.3	100	
$^{47}Ti(n,np)^{46g}Sc$	55.9	2.3	-14	100
$^{46}Ti(n,p)^{46m+g}Sc$	266.7	8.6		
$^{47}Ti(n,np)^{46m+g}Sc$	62.8	2.4		
$^{47}Ti(n,p)^{47}Sc$	169.5	6.9	100	
$^{48}Ti(n,np)^{47}Sc$	11.52	0.51	-51	100
$^{48}Ti(n,p)^{48}Sc$	71.7	2.6	100	
$^{49}Ti(n,np)^{48}Sc$	6.9	0.7	-23	100
$^{50}Ti(n,p)^{50}Sc$	15.40	0.63		
$^{50}Ti(n,\alpha)^{47}Ca$	9.0	0.8		

Table 2. Neutron activation cross-sections for Cr isotopes at 14.3 MeV

Reaction	σ (mbarn)	Uncertainty (mbarn)	Correlation matrix (%)	
$^{50}Cr(n,2n)^{49}Cr$	21.2	1.2	-	
$^{52}Cr(n,2n)^{51}Cr$	375	23	-	
$^{52}Cr(n,p)^{52}V$	73.4	3.2	100	
$^{53}Cr(n,np)^{52}V$	7.6	0.6	-14	100
$^{53}Cr(n,p)^{53}V$	37.0	1.6	100	
$^{54}Cr(n,np)^{53}V$	1.6	0.2	-25	100
$^{54}Cr(n,p)^{54}V$	15.3	0.7	-	
$^{54}Cr(n,\alpha)^{51}Ti$	11.0	0.5	-	

Table 3. Neutron activation cross sections for Ni isotopes at 14.3 MeV.

Reaction	σ (mbarn)	Uncertainty (mbarn)	Correlation matrix (%)	
$^{58}Ni(n, 2n)^{57}Ni$ ^{57}Co	32.6	2.8	100	
$^{58}Ni(n,np)^{57}Co$	467	23.3	-23	100
$^{58}Ni(n,p)^{58m}Co$	134.2 a/	6.2	100	
$^{58}Ni(n,p)^{58g}Co$	120.4 a/	6.9	-29	100
$^{58}Ni(n,p)^{58m+g}Co$	254.6	7.1		
$^{60}Ni(n,p)^{60m}Co$	50.1	4.2	100	
$^{61}Ni(n,np)^{60m}Co$	25.3	0.9	-49	100
$^{61}Ni(n,p)^{61}Co$	66.6	3.1		
$^{62}Ni(n,p)^{62m}Co$	11.7 b/	0.8	100	
$^{62}Ni(n,p)^{62g}Co$	17.3 b/	1.2	-66	100
$^{62}Ni(n,p)^{62m+g}Co$	29.0	0.9		
$^{64}Ni(n,np)^{63}Co$	0.36	0.04		
$^{64}Ni(n,\alpha)^{61}Fe$	4.23	0.15		

a/ Analysis of the 810.8 keV γ-line decay curve

b/ Analysis of the 1129.1 keV, 1163.5 keV and 1173.0 keV γ-line decay curves.