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Data requirements for neutron activation Part I: Cross sections

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Abstract

Existing neutron cross section libraries such as EAF-2003 contain a large number of reactions. Of these only a small proportion are significant in the production of the nuclides that dominate activation quantities such as activity or γ-dose rate at various decay times. These reactions were identified in a recent extensive set of calculations on all the elements and reported in the 'Activation Handbook'. These 1340 reactions are considered here and the set of reactions with no differential or integral data are listed and prioritised. A set of 339 reactions with very limited possibility of measurement are given; these require further study by theoretical calculations. A set of 100 reactions with either discrepant or no data, that might be measurable are listed and are recommended to be the subject of future experimental work.

Keywords: Neutron; Cross section; Activation; Neutron spectrum; Importance diagram; Dominant nuclide; Evaluation

1. Introduction

Calculations of neutron-induced activation are very important for fusion technology studies. A wide range of materials need to be considered, and as the effect of impurities can be significant it is actually necessary to assemble libraries of neutron-induced cross sections for target nuclides of all the elements. In Europe, such work has focussed on the European Activation System (EASY) which includes nuclear data in the European Activation File (EAF) and uses the FISPACT inventory code for the calculations. The most recent version (EASY-2005) [1] contains data up to 60 MeV, while previous versions extend only to 20 MeV. As yet there is limited experience with the use of EASY-2005 and in this paper results from EASY-2003 [2] are used.

A recent review of measurements of neutron activation cross sections has been produced as part of the NEA Working Party on evaluation cooperation [3]. This contains information on the type of data that can be measured and lists recent results.

2. Results

A very extensive set of calculations of the activity of all the elements in various neutron spectra are reported

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Table 1
Irradiation conditions used for the calculations reported in reference [4]

Spectrum	Flux ($n\,cm^{-2}\,s^{-1}$)	Irradiation time (year)	Reference
PPCS Model B First wall	1.04×10^{15}	5	[6]
PPCS Model C Blanket	7.71×10^{14}	5	[7]
PPCS Model A Shield	2.53×10^{11}	25	[8]
JET Inboard vacuum vessel wall	3.46×10^{6}	1	[9]

in the recent 'Activation Handbook' [4]. The irradiation conditions used for the calculations are summarized in Table 1. In addition to these calculations in three D–T and one D–D spectra, a set of mono-energetic spectra were used to produce 'importance diagrams' [5]. For each element, a set of 42 irradiations were carried out, with an irradiation time of 5 years and a flux of $1 \times 10^{15}\,n\,cm^{-2}\,s^{-1}$, using spectra which contain neutrons only in a single group (the VITAMIN-J 175-group energy structure was used). The FISPACT output files were read by a subsidiary code which extracts the dominant nuclides at a series of decay times and enabled the construction of a contour plot of the contributions. An example of an importance diagram is given in Fig. 1, where the activity importance diagram for pure copper is shown. The diagram consists of a series of regions labelled by a nuclide name. In each region, the nuclide contributes more than 50% of the activity. Thus, for decay times between about 2×10^5 and 6×10^8 s and for neutron energies less than about 0.5 MeV, Zn-65 contributes more than 50% of the activity.

For each one of the 'primary nuclides' shown in the figure, a table of pathway information at four energies (0.26 eV, 148 eV, 37.6 KeV and 14.7 MeV) is given in reference [4], showing the pathways responsible for the production of the nuclide. As an example for the production of Zn-65 at an incident energy of 14.7 MeV, there are two dominant pathways:

Cu-65(n,γ)Cu-66(β^-)Zn-66(n,2n)Zn-65 (52.1%)
Cu-65(n,2n)Cu-64(β^-)Zn-64(n,γ)Zn-65 (47.5%)

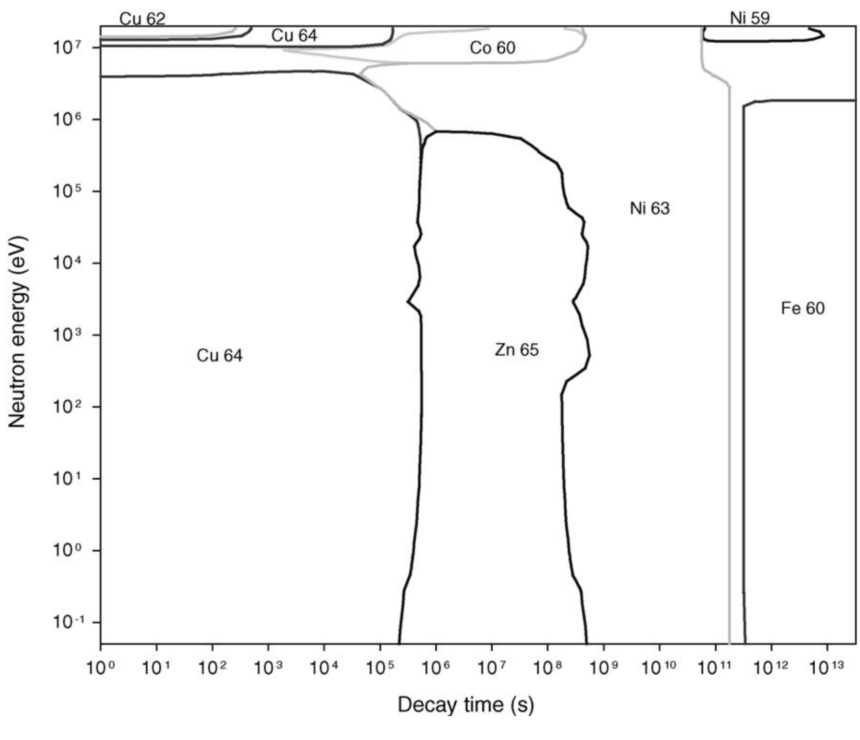

Fig. 1. Activity importance diagram for pure copper.