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APPLICATION OF INTRANUCLEAR CASCASE EVAPORATION MODEL FOR EVALUATION OF HELIUM AND TRANSMUTATION PRODUCT CROSS-SECTION

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Abstract: For simulating neutron damage in materials needed for the design of fusion reactors, the application of high energy spallation neutrons are considered to be very promising. Feasibility study of such spallation neutron source for simulation of fusion reactor first wall is constrained by the lack of cross-section data for quantities like helium production, transmutation nuclide production etc. In this paper we discus the application of Intranuclear Cascade evaporation model for predicting neutron and proton induced helium and transmutation product cross-section and examine the effect of the variation of level density parameter on helium production cross-section. The elements used for this study are Fe, Cr, Mn and Ni for neutron and proton energy varying from 50 MeV to 600 MeV. Results indicate that helium production cross-section increases by a factor of three when neutron or proton energy increases from 50 to 600 MeV.

(SPALLATION, HELIUM, TRANSMUTATION, NEUTRON, PROTON, HIGH ENERGY)

Introduction

Spallation neutrons produced by high energy proton bombardment on a heavy metal target are considered to be an important tool for the simulation of the radiation environment of the first wall of Tokamak fusion reactors. The energy spectra of these spallation neutrons range from a few electron volts to several hundred million electron volts depending upon the energy of incident protons. Evaluation of such spallation neutron source for simulation studies is constrained by lack of cross-section data for quantities such as helium and transmutation nuclide production in the high energy region. Earlier estimates of helium and transmutation nuclide production have been based on constant cross-section approximation [1] in the high energy region of neutron and proton spectra or arbitrary extrapolation of low energy cross-section [2]. However experimental results show [2] eventhough the high energy tail of neutron or proton spectra forms only a very small fraction of total spectra, its contribution to helium production is substantial. Similar results are expected for transmutation product. This implies that there is a need for accurate estimate of cross-section information for helium and transmutation nuclide production cross-section.

This paper deals with the evaluation of neutron and proton induced helium production and transmutation product cross-section for Fe, Cr & Ni from 50 MeV to 600 MeV. These cross-sections have been evaluated based on intranuclear cascade evaporation model (INCE). Effect of variation of level density on these cross-sections have also been examined. We present in this paper some representative result due to lack of space.

Description of the INCE Model

The INCE model describes nonelastic nucleon-nucleus collisions at high energies by a two step model.

The first step, which is also called cascade stage, is described in terms of the Serber Model [3]. It is assumed that at high energies the particle-nucleus collision can be represented by a series of particle-particle binary collisions constrained by the Pauli-exclusion principle. Using free particle-particle total and differential cross-sections, the trajectory of each particle inside the nucleus is followed until they escape the nucleus or their energy falls below a certain cut off below which assumption of binary collision is not valid. At high energies particle neutron collision becomes productive resulting in the production of pions and muons. A cascade of interactions develop within the nucleus. At this stage emissions of neutrons, protons, pions and muons are taken into account.

In the second step the residual nucleus after the cascade stage which still has considerable excess energy left, deexcites by the emission of particles as described by the statistical evaporation model [4,5]. The emission probability in this phase of reaction is governed by level density parameter a, given by Lecouteur et al. [6] as

$$a = \frac{A}{B_o}\,[1+ y(A-2z)^2/A^2],$$

where A = mass No. of the nucleus,
z = charge No. of the nucleus,
y = 1.5,
B_o = a free parameter.

In this expression of "a", B_o is a free parameter which governs the magnitude of a and hence decides the emission probability. In the remaining part of paper we shall refer B_o itself as level density parameter.

The magnitude of B_o has been quoted by different workers [7,8] to be in the range of 8 to 20 MeV. In our evaluation of He production cross-section for Fe and Ni we have adopted a value of B_o = 20 MeV. This choice of B_o has been dictated mainly by the requirement of consistency of the cross-section for helium production as evaluated by Reiter [9] below 40 MeV and those by the INCE model.

We have also calculated helium production cross-section at B_o = 14 MeV in order to see the difference in magnitudes of the helium production cross-section for the two valuues of B_o.

Methodology

In order to evaluate helium and other transmutation product cross-sections a total of 10,000 collision histories have been traced with 10 evaporations calculation per collision. For helium and major transmutation product this gives a fairly good statics. Inelastic cross-section is calculated using geometrical cross-section and real and pseudo collision ratios. Helium and transmutation product cross-sections are evaluated using corresponding yield and inelastic cross-sections.

For all the calculations of He production a value of B_o = 20 MeV has been used in order to get a consistency with extrapolated values of Reiter et al [7].

Results and Discussion

Fig. 1 gives neutron induced He production cross-section for Fe and Cr. Fig. 2 shows similar values for proton induced reaction. From figs. 1 and 2 it is evident that helium production cross-section increases by a factor of three if the neutron energy increases from 50 to 600 MeV. Obviously earlier estimates [1] of He production based on constant cross-section approximation will considerably underestimate the helium production cross-section. Fig.3 examines the effect of the level density parameter B_o on the helium production cross-section for Fe. The change in B_o from 14 MeV to 20 MeV changes the helium production by less than 10%. Table 1 and Table 2 give representative values of neutron induced transmutation product cross-section for Ni and Fe. It is to be noted that the values of helium and transmutation product cross-section calculated using INCE model are not so accurate between 50 and 100 MeV and there is a need to update these values using more acurate statistical preequilibrium model. However the approach of statistical preequilibrium model is constrained by lack of accurate nuclear model parameters in this energy region.

From Table 1 and Table 2 it is clear that a large number of "new" transmutation product are produced which will not be produced in the radiation environment of fusion reactor. Analysis and relative importance of these new transmutation product will critically depend on the value of their production cross-section. This clearly underlines the need for present work.

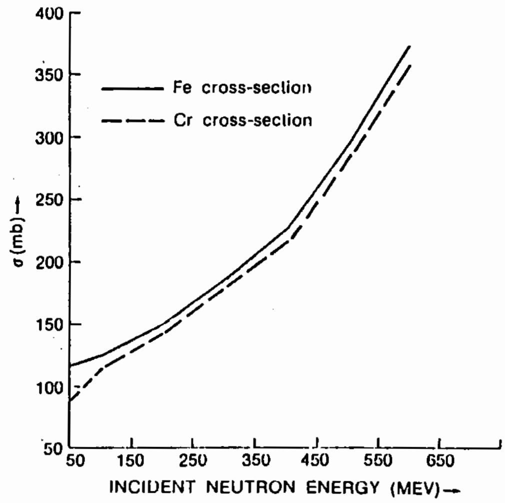

Fig.1

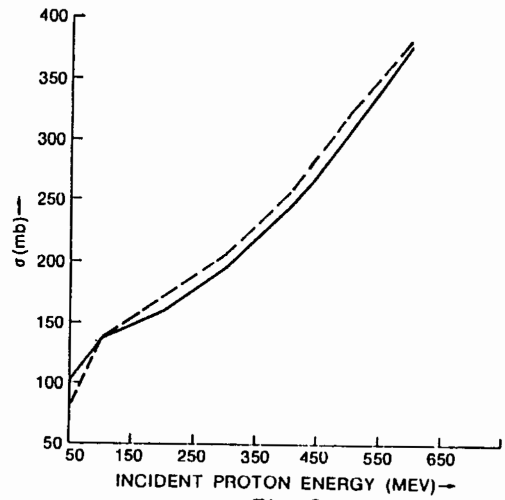

Fig.2

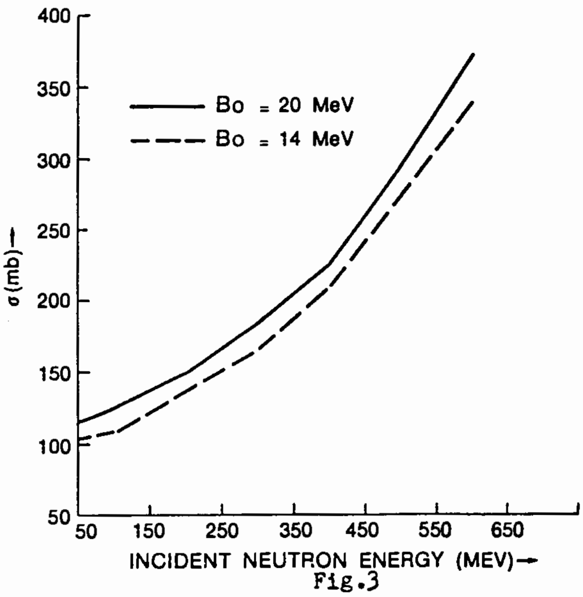

Fig.3

TABLE I

Transmuration Product Cross-Section

REACTION (n + 56 Fe)

Element	CROSS SECTION IN MB AT VARIOUS ENERGIES (Mev)						
	600	500	400	300	200	100	50
C	0.15						
N	0.34	.096					
O	0.34	.082					
F	0.53	.178					
Ne	0.88	.205					
Na	0.65	.246					
Mg	3.2	1.41	.42				
Al	4.4	1.9	0.5				
Si	16.0	8.5	3.7	0.9			
P	15.6	9.0	3.9	1.0			
S	25.5	17.7	9.6	4.12	0.8		
Cl	24.2	16.0	9.4	4.02	0.9		
A	34.3	26.4	18.3	11.2	4.7	.09	
K	33.1	26.5	19.5	13.1	6.4	.21	
Ca	52.4	48.1	39.2	31.8	23.3	3.74	
Sc	43.8	41.2	36.3	32.9	28.6	8.67	.21
Ti	64.6	66.3	64.1	61.8	59.9	41.4	8.31
V	72.8	76.0	77.1	82.1	81.6	78.7	37.6
Cr	92.8	99.3	102.1	113.1	117.2	160.7	120.1
Mn	117.9	134.4	148.2	165.6	179.7	235.5	391.7
Fe	61.5	63.3	65.4	71.4	79.7	116.7	219.6

TABLE 2

Transmutation Product Cross-Section

REACTION (n+ 58 Ni)

Element	CROSS-SECTION IN MB AT VARIOUS ENERGIES (MEV)						
	600	500	400	300	200	100	50
C	.083						
N	.125						
O	.25						
F	.21						
Ne	.53						
Na	.46						
Mg	2.52	1.32					
Al	2.72	1.1					
Si	11.36	5.33	1.7	.389			
P	10.45	5.08	1.69	.40			
S	19.45	11.5	6.02	2.05	.24		
Cl	17.85	10.98	6.50	1.65	.33		
A	29.66	20.9	13.48	6.62	1.89		
K	27.74	21.1	13.46	7.06	2.2		
Ca	47.37	37.9	28.02	19.24	11.05	.51	
Sc	33.86	28.98	22.99	18.24	11.9	1.17	
Ti	56.3	53.4	45.15	40.9	33.97	9.98	
V	63.1	62.9	57.95	55.0	51.5	27.5	2.13
Cr	72.1	76.1	77.4	79.7	80.16	78.7	27.40
Mn	78.7	84.7	88.9	91.8	101.77	133.5	85.79
Fe	88.75	93.0	102.3	113.1	131.53	177.8	237.2
Co	106.2	124.0	127.5	141.0	155.4	206.8	351.4
Ni	39.8	33.9	39.1	41.6	47.91	61.99	121.0

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