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**MULTI-GROUP HELIUM AND HYDROGEN
PRODUCTION CROSS SECTION LIBRARIES FOR
FUSION NEUTRONICS DESIGN**

September 1993

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Multi-group Helium and Hydrogen Production Cross Section
Libraries for Fusion Neutronics Design

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The helium and hydrogen production cross section libraries based on the JENDL-3 data file were compiled for use in neutronics and shielding design calculation of a fusion reactor. These libraries have the same group structures as the transport cross section sets, FUSION-J3 and FUSION-40 which are often used in fusion neutronics design and can be used as the response function libraries for the reaction rate calculation code, APPLE-3. These libraries were processed from the JENDL gas-production cross section file which is one of the JENDL special purpose files.

Some sample calculations using the discrete ordinate code, ANISN with these libraries were performed and the results were compared with the existing results. Consequently it was found that the appropriate results can be obtained with these libraries.

The generated multi-group cross sections for helium and hydrogen production are presented in graphs and tables in appendices.

Keywords: Gas Production, Helium, Hydrogen, Neutron, Cross Section, JENDL-3, Fusion Reactor, First Wall, Blanket, Vacuum Vessel, Metal, Ceramics, Beryllium, Radiation Damage, Neutronics, Shielding

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核融合炉核設計用ヘリウム及び水素生成多群断面積ライブラリー

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(1993年8月18日受理)

核融合炉の核-遮蔽計算において使用されるヘリウム及び水素生成断面積ライブラリーを JENDL-3 データファイルに基づいて作成した。これらのライブラリーは核融合炉核設計において頻繁に使用される輸送計算用断面積セット、FUSION-J3 と FUSION-40 と同じ群構造を有しており、またAPPLE-3 の応答関数として使用できる。本ライブラリーは JENDL 特殊目的ファイルのひとつである JENDL ガス生成断面積ファイルから処理された。

1 次元輸送計算コード ANISN と本ライブラリーを用いたサンプル計算を行ない、計算結果を過去の計算例と比較した。本ライブラリーにより信頼性の高いヘリウム及び水素の生成量の評価が可能となり、今後の核融合炉設計に役立つものと考えられる。

付録には作成された多群ライブラリーをグラフ及び表の形で示した。

Contents

1. Introduction	1
2. Processing of Cross Sections.....	2
2.1 Processing Method	2
2.2 Description of Libraries	2
3. Sample Calculations	7
3.1 Calculational Method	7
3.2 Helium Production in Metals	7
3.3 Helium Production in Blanket Materials	9
4. Conclusions	27
Acknowledgements	27
References	28
Appendix 1 Graphical Presentation of Cross Section Libraries	29
Appendix 2 Numerical Data of Cross Section Libraries	61

目 次

1. はじめに	1
2. 断面積の処理	2
2.1 処理方法	2
2.2 ライブライリー仕様	2
3. サンプル計算	7
3.1 計算方法	7
3.2 金属中のヘリウム生成	7
3.3 ブランケット材料中のヘリウム生成	9
4. 結 論	27
謝 辞	27
参考文献	28
付録 1 断面積ライブラリーのグラフ表示	29
付録 2 断面積ライブラリーの数値データ	61

1. Introduction

Gas (in particular helium and hydrogen) production in fusion reactor materials, such as structural materials, ceramic breeding materials and beryllium, due to neutron irradiation, affects physical and mechanical properties of the materials in terms of helium (hydrogen) embrittlement, void swelling and weldability of the irradiated alloys. Gas concentration in materials, usually expressed in the unit of atomic parts per million, i.e. *appm*, is an important index for material damage study (another important index is displacements per atom, i.e., *dpa*). In neutronics/shielding analysis for in-vessel components (e.g. first wall, blanket and vacuum vessel), therefore, gas production rate must be evaluated to predict lifetime of the components and weldability of the irradiated components.

The JENDL gas-production cross section file was compiled at the Japan Atomic Energy Research Institute (JAERI) as one of the JENDL special purpose files¹⁾. The cross section data used for this file were taken from the JENDL-3 general purpose file²⁾.

Since in the neutronics/shielding design at JAERI neutron flux distribution is calculated with discrete ordinates codes, such as ANISN and DOT3.5 with the multi-group nuclear cross section sets, FUSION-40 and FUSION-J3³⁾, it is necessary to compile gas production cross sections as multi-group response function libraries with the same group structure as the above-mentioned transport cross section sets.

In this report the multi-group helium and hydrogen production cross section libraries compiled in the present work are described and some calculational results which were obtained using these libraries are presented.

2. Processing of Cross Sections

2.1 Processing method

The nuclear data processing code, CRECTJ5⁴⁾ was used to compile the JENDL gas-production file into the multi-group cross section sets. A weighting function of $1/E$ was applied to all the energy groups to calculate the averaged cross sections. These data were written with the ENDF/B-V format and were converted into the format of the response function library which can be applied to the reaction rate calculation with APPLE-3⁵⁾.

2.2 Description of libraries

The following three libraries were compiled ;

- (1) Helium production cross section library (I)
Neutron 125 groups (gamma-ray 40 groups)
Group structure of FUSION-J3 (see Table 2.1)
21 nuclides (see Table 2.3)
- (2) Helium production cross section library (II)
Neutron 42 groups (gamma-ray 21 groups)
Group structure of FUSION-40 (see Table 2.2)
21 nuclides and 5 alloys (see Table 2.3)
- (3) Hydrogen production cross section library
Neutron 42 groups (gamma-ray 21 groups)
Group structure of FUSION-40 (see Table 2.2)
20 nuclides and 3 alloys (see Table 2.3)

The three response function libraries are shown in formats of graphs and tables in Appendix 1 and Appendix 2, respectively.

Table 2.1 Neutron 125 and Gamma-Ray 40 Energy Group
Structure of FUSION-J3

Neutron 125 groups			Neutron 125 groups		
	ENERGY (EV)			ENERGY (EV)	
1	1. 6 5 E + 0 7	1. 6 2 E + 0 7	41	6. 0 7 E + 0 6	5. 7 0 E + 0 6
2	1. 6 2 E + 0 7	1. 6 0 E + 0 7	42	5. 7 0 E + 0 6	5. 3 5 E + 0 6
3	1. 6 0 E + 0 7	1. 5 7 E + 0 7	43	5. 3 5 E + 0 6	5. 0 3 E + 0 6
4	1. 5 7 E + 0 7	1. 5 5 E + 0 7	44	5. 0 3 E + 0 6	4. 7 2 E + 0 6
5	1. 5 5 E + 0 7	1. 5 3 E + 0 7	45	4. 7 2 E + 0 6	4. 4 4 E + 0 6
6	1. 5 3 E + 0 7	1. 5 0 E + 0 7	46	4. 4 4 E + 0 6	4. 1 7 E + 0 6
7	1. 5 0 E + 0 7	1. 4 9 E + 0 7	47	4. 1 7 E + 0 6	3. 9 2 E + 0 6
8	1. 4 8 E + 0 7	1. 4 6 E + 0 7	48	3. 9 2 E + 0 6	3. 6 8 E + 0 6
9	1. 4 6 E + 0 7	1. 4 3 E + 0 7	49	3. 6 8 E + 0 6	3. 4 6 E + 0 6
10	1. 4 3 E + 0 7	1. 4 1 E + 0 7	50	3. 4 6 E + 0 6	3. 2 5 E + 0 6
11	1. 4 1 E + 0 7	1. 3 9 E + 0 7	51	3. 2 5 E + 0 6	3. 0 5 E + 0 6
12	1. 3 9 E + 0 7	1. 3 7 E + 0 7	52	3. 0 5 E + 0 6	2. 8 7 E + 0 6
13	1. 3 7 E + 0 7	1. 3 5 E + 0 7	53	2. 8 7 E + 0 6	2. 6 9 E + 0 6
14	1. 3 5 E + 0 7	1. 3 3 E + 0 7	54	2. 6 9 E + 0 6	2. 5 3 E + 0 6
15	1. 3 3 E + 0 7	1. 3 0 E + 0 7	55	2. 5 3 E + 0 6	2. 3 8 E + 0 6
16	1. 3 0 E + 0 7	1. 2 8 E + 0 7	56	2. 3 8 E + 0 6	2. 2 3 E + 0 6
17	1. 2 8 E + 0 7	1. 2 6 E + 0 7	57	2. 2 3 E + 0 6	2. 1 0 E + 0 6
18	1. 2 6 E + 0 7	1. 2 5 E + 0 7	58	2. 1 0 E + 0 6	1. 9 7 E + 0 6
19	1. 2 5 E + 0 7	1. 2 3 E + 0 7	59	1. 9 7 E + 0 6	1. 8 5 E + 0 6
20	1. 2 3 E + 0 7	1. 2 1 E + 0 7	60	1. 8 5 E + 0 6	1. 7 4 E + 0 6
21	1. 2 1 E + 0 7	1. 1 9 E + 0 7	61	1. 7 4 E + 0 6	1. 5 3 E + 0 6
22	1. 8 9 E + 0 7	1. 1 7 E + 0 7	62	1. 5 3 E + 0 6	1. 3 5 E + 0 6
23	1. 1 7 E + 0 7	1. 1 5 E + 0 7	63	1. 3 5 E + 0 6	1. 1 9 E + 0 6
24	1. 1 5 E + 0 7	1. 1 3 E + 0 7	64	1. 1 9 E + 0 6	1. 0 5 E + 0 6
25	1. 1 3 E + 0 7	1. 1 2 E + 0 7	65	1. 0 5 E + 0 6	9. 3 0 E + 0 5
26	1. 1 2 E + 0 7	1. 1 0 E + 0 7	66	9. 3 0 E + 0 5	8. 2 1 E + 0 5
27	1. 1 0 E + 0 7	1. 0 8 E + 0 7	67	8. 2 1 E + 0 5	7. 2 4 E + 0 5
28	1. 0 8 E + 0 7	1. 0 7 E + 0 7	68	7. 2 4 E + 0 5	6. 3 9 E + 0 5
29	1. 0 7 E + 0 7	1. 0 5 E + 0 7	69	6. 3 9 E + 0 5	5. 6 4 E + 0 5
30	1. 0 5 E + 0 7	1. 0 3 E + 0 7	70	5. 6 4 E + 0 5	4. 9 3 E + 0 5
31	1. 0 3 E + 0 7	1. 0 2 E + 0 7	71	4. 9 8 E + 0 5	4. 3 9 E + 0 5
32	1. 0 2 E + 0 7	1. 0 0 E + 0 7	72	4. 3 9 E + 0 5	3. 8 8 E + 0 5
33	1. 0 0 E + 0 7	9. 3 9 E + 0 6	73	3. 8 8 E + 0 5	3. 4 2 E + 0 5
34	9. 3 4 E + 0 6	8. 8 3 E + 0 6	74	3. 4 2 E + 0 5	3. 0 2 E + 0 5
35	8. 8 3 E + 0 6	8. 2 9 E + 0 6	75	3. 0 2 E + 0 5	2. 6 7 E + 0 5
36	8. 2 9 E + 0 6	7. 7 9 E + 0 6	76	2. 6 7 E + 0 5	2. 3 5 E + 0 5
37	7. 7 9 E + 0 6	7. 3 2 E + 0 6	77	2. 3 5 E + 0 5	2. 0 8 E + 0 5
38	7. 3 2 E + 0 6	6. 8 7 E + 0 6	78	2. 0 8 E + 0 5	1. 8 3 E + 0 5
39	6. 8 7 E + 0 6	6. 4 6 E + 0 6	79	1. 8 3 E + 0 5	1. 6 2 E + 0 5
40	6. 4 6 E + 0 6	6. 0 7 E + 0 6	80	1. 6 2 E + 0 5	1. 4 3 E + 0 5

(continued)

Table 2.1 (continued)

Neutron 125 groups			Gamma ray 40 groups		
	ENERGY (EV)			ENERGY (EV)	
81	1. 4 3 E + 0 5	1. 2 6 E + 0 5	1	1. 4 0 E + 0 7	1. 2 0 E + 0 7
82	1. 2 6 E + 0 5	1. 1 1 E + 0 5	2	1. 2 0 E + 0 7	1. 0 0 E + 0 7
83	1. 1 1 E + 0 5	9. 8 0 E + 0 4	3	1. 0 0 E + 0 7	9. 0 0 E + 0 6
84	9. 8 0 E + 0 4	8. 6 5 E + 0 4	4	9. 0 0 E + 0 6	8. 0 0 E + 0 6
85	8. 6 5 E + 0 4	7. 6 4 E + 0 4	5	8. 0 0 E + 0 6	7. 5 0 E + 0 6
86	7. 6 4 E + 0 4	6. 7 4 E + 0 4	6	7. 5 0 E + 0 6	7. 0 0 E + 0 6
87	6. 7 4 E + 0 4	5. 9 5 E + 0 4	7	7. 0 0 E + 0 6	6. 5 0 E + 0 6
88	5. 9 5 E + 0 4	5. 2 5 E + 0 4	8	6. 5 0 E + 0 6	6. 0 0 E + 0 6
89	5. 2 5 E + 0 4	4. 6 3 E + 0 4	9	6. 0 0 E + 0 6	5. 5 0 E + 0 6
90	4. 6 3 E + 0 4	4. 0 9 E + 0 4	10	5. 5 0 E + 0 5	5. 0 0 E + 0 6
91	4. 0 9 E + 0 4	3. 6 1 E + 0 4	11	5. 0 0 E + 0 6	4. 5 0 E + 0 6
92	3. 6 1 E + 0 4	3. 1 8 E + 0 4	12	4. 5 0 E + 0 6	4. 0 0 E + 0 6
93	3. 1 8 E + 0 4	2. 8 1 E + 0 4	13	4. 0 0 E + 0 6	3. 5 0 E + 0 6
94	2. 8 1 E + 0 4	2. 4 8 E + 0 4	14	3. 5 0 E + 0 6	3. 0 0 E + 0 6
95	2. 4 8 E + 0 4	2. 1 9 E + 0 4	15	3. 0 0 E + 0 6	2. 5 0 E + 0 6
96	2. 1 9 E + 0 4	1. 9 3 E + 0 4	16	2. 5 0 E + 0 6	2. 2 5 E + 0 6
97	1. 9 3 E + 0 4	1. 5 0 E + 0 4	17	2. 2 5 E + 0 6	2. 0 0 E + 0 6
98	1. 5 0 E + 0 4	1. 1 7 E + 0 4	18	2. 0 0 E + 0 6	1. 7 5 E + 0 6
99	1. 1 7 E + 0 4	9. 1 2 E + 0 3	19	1. 7 5 E + 0 6	1. 5 0 E + 0 5
100	9. 1 2 E + 0 3	7. 1 0 E + 0 3	20	1. 5 0 E + 0 6	1. 3 8 E + 0 5
101	7. 1 0 E + 0 3	5. 5 3 E + 0 3	21	1. 3 8 E + 0 6	1. 2 5 E + 0 5
102	5. 5 3 E + 0 3	4. 3 1 E + 0 3	22	1. 2 5 E + 0 6	1. 1 3 E + 0 5
103	4. 3 1 E + 0 3	3. 3 6 E + 0 3	23	1. 1 3 E + 0 6	1. 0 0 E + 0 5
104	3. 3 6 E + 0 3	2. 6 1 E + 0 3	24	1. 0 0 E + 0 6	9. 0 0 E + 0 5
105	2. 6 1 E + 0 3	2. 0 4 E + 0 3	25	9. 0 0 E + 0 5	8. 0 0 E + 0 5
106	2. 0 4 E + 0 3	1. 5 9 E + 0 3	26	8. 0 0 E + 0 5	7. 0 0 E + 0 5
107	1. 5 9 E + 0 3	1. 2 3 E + 0 3	27	7. 0 0 E + 0 5	6. 0 0 E + 0 5
108	1. 2 3 E + 0 3	9. 6 1 E + 0 2	28	6. 0 0 E + 0 5	5. 2 0 E + 0 5
109	9. 6 1 E + 0 2	5. 8 3 E + 0 2	29	5. 2 0 E + 0 5	5. 0 0 E + 0 5
110	5. 8 3 E + 0 2	3. 5 4 E + 0 2	30	5. 0 0 E + 0 5	4. 0 0 E + 0 5
111	3. 5 4 E + 0 2	2. 1 5 E + 0 2	31	4. 0 0 E + 0 5	3. 0 0 E + 0 5
112	2. 1 5 E + 0 2	1. 3 0 E + 0 2	32	3. 0 0 E + 0 5	2. 0 0 E + 0 5
113	1. 3 0 E + 0 2	7. 8 9 E + 0 1	33	2. 0 0 E + 0 5	1. 5 0 E + 0 5
114	7. 8 9 E + 0 1	4. 7 9 E + 0 1	34	1. 5 0 E + 0 5	1. 0 0 E + 0 5
115	4. 7 9 E + 0 1	2. 9 0 E + 0 1	35	1. 0 0 E + 0 5	8. 0 0 E + 0 4
116	2. 9 0 E + 0 1	1. 7 6 E + 0 1	36	8. 0 0 E + 0 4	6. 0 0 E + 0 4
117	1. 7 6 E + 0 1	1. 0 7 E + 0 1	37	6. 0 0 E + 0 4	4. 5 0 E + 0 4
118	1. 0 7 E + 0 1	6. 4 8 E + 0 0	38	4. 5 0 E + 0 4	3. 0 0 E + 0 4
119	6. 4 8 E + 0 0	3. 9 3 E + 0 0	39	3. 0 0 E + 0 4	2. 0 0 E + 0 4
120	3. 9 3 E + 0 0	2. 3 8 E + 0 0	40	2. 0 0 E + 0 4	1. 0 0 E + 0 4
121	2. 3 8 E + 0 0	1. 4 5 E + 0 0			
122	1. 4 5 E + 0 0	8. 7 6 E - 0 1			
123	8. 7 6 E - 0 1	5. 3 2 E - 0 1			
124	5. 3 2 E - 0 1	3. 2 2 E - 0 1			
125	3. 2 2 E - 0 1	1. 0 0 E - 0 5			

Table 2.2 Neutron 42 and Gamma-Ray 21 Energy Group
Structure of FUSION-40

42-Group Neutron Energy Group Structure

Group	Energy Limits	Mid-Point Energy
1	15.000 - 13.720 MeV	14.360 MeV
2	13.720 - 12.549	13.135
3	12.549 - 11.478	12.014
4	11.478 - 10.500	10.989
5	10.500 - 9.314	9.907
6	9.314 - 8.261	8.788
7	8.261 - 7.328	7.795
8	7.328 - 6.500	6.914
9	6.500 - 5.757	6.129
10	5.757 - 5.099	5.428
11	5.099 - 4.516	4.808
12	4.516 - 4.000	4.258
13	4.000 - 3.162	3.581
14	3.162 - 2.500	2.831
15	2.500 - 1.871	2.186
16	1.871 - 1.400	1.636
17	1.400 - 1.058	1.229
18	1.058 - 0.800	0.929
19	0.800 - 0.566	0.683
20	0.566 - 0.400	0.483
21	0.400 - 0.283	0.342
22	0.283 - 0.200	0.242
23	0.200 - 0.141	0.171
24	0.141 - 0.100	0.121
25	100.0 - 46.5 keV	73.25 keV
26	46.5 - 21.5	34.0
27	21.5 - 10.0	15.75
28	10.0 - 4.65	7.325
29	4.65 - 2.15	3.40
30	2.15 - 1.00	1.575
31	1.00 - 0.465	0.733
32	0.465 - 0.215	0.340
33	0.215 - 0.100	0.158
34	100.0 - 46.5 keV	73.25 keV
35	46.5 - 21.5	34.0
36	21.5 - 10.0	15.75
37	10.0 - 4.65	7.325
38	4.65 - 2.15	3.40
39	2.15 - 1.00	1.58
40	1.00 - 0.465	0.733
41	0.465 - 0.215	0.340
42	0.215 - 0.100	0.158

21-Group Gamma-Ray Energy Group Structure

Group	Energy Limits (MeV)	Mid-Point Energy (MeV)
1	14.0 - 12.0	13.0
2	12.0 - 10.0	11.0
3	10.0 - 8.0	9.0
4	8.0 - 7.5	7.75
5	7.5 - 7.0	7.25
6	7.0 - 6.5	6.75
7	6.5 - 6.0	6.25
8	6.0 - 5.5	5.75
9	5.5 - 5.0	5.25
10	5.0 - 4.5	4.75
11	4.5 - 4.0	4.25
12	4.0 - 3.5	3.75
13	3.5 - 3.0	3.25
14	3.0 - 2.5	2.75
15	2.5 - 2.0	2.25
16	2.0 - 1.5	1.75
17	1.5 - 1.0	1.25
18	1.0 - 0.4	0.7
19	0.4 - 0.2	0.3
20	0.2 - 0.1	0.15
21	0.1 - 0.01	0.055

Table 2.3 Nuclides and Alloys Contained in the Helium and
Hydrogen Production Libraries

Nuclides or Alloys	Helium Production 125 Groups	Helium Production 42 Groups	Hydrogen Production 42 Groups
Li-6	O	O	O
Li-7	O	O	X
Be-9	O	O	O
B-10	O	O	O
B-11	O	O	O
C-12	O	O	O
N	O	O	O
F-19	O	O	O
Al-27	O	O	O
Si	O	O	O
Ti	O	O	O
V-51	O	O	O
Cr	O	O	O
Mn-55	O	O	O
Fe	O	O	O
Co-59	O	O	O
Ni	O	O	O
Cu	O	O	O
Zr	O	O	O
Nb-93	O	O	O
Mo	O	O	O
316SS	X	O	O
HT-9	X	O	O
V-5Cr-5Ti	X	O	O
INCONEL625	X	O	X
Ti-6Al-4V	X	O	X

O : Contained in the library

X : Not contained in the library

3. Sample calculations.

3.1 Calculational method.

The ANISN⁶⁾ neutron transport code with the FUSION-40³⁾ and FUSION-J3³⁾ libraries of multigroup constants are used in this study. Neutron transport calculations were carried out in one-dimensional cylinder geometry. The P5S8 approximation was used.

The simplified geometrical model of an experimental thermonuclear reactor build-up is shown in Fig. 3.1. A uniform volume source of 14-MeV monoenergetic neutrons in the first energy group (15.00-13.72 MeV) was assumed to exist at zone 1. The scrape-off layer is assumed to be a 15-cm-thick void zone 2. A neutron wall load of 1 MW/m² was assumed to exist on the first wall of employed calculational model. The first wall/blanket/shield/ vacuum vessel/magnets composition is assumed to be a 200-cm-thick homogeneous mixture of water and stainless steel or blanket materials so that the results obtained could provide useful design-independent information on the helium production in metals of a fusion reactor.

The atomic densities and fractions of shield and blanket components in the four homogeneous compositions employed for neutron transport calculations are shown in Table 3.1. The chemical contents of the five alloys used for helium production calculations are shown in Table 3.2.

3.2 Helium production in metals.

Four homogeneous compositions (zone 3 in Fig. 3.1) were used for neutron transport calculations, namely steel-rich (80% steel/20% water) shield, water-rich (80% water/20% steel) shield, Li₂O/Be blanket composition (15% SS, 10% H₂O, 15% Li₂O, 60% Be) and liquid lithium blanket composition (21.4% V, 20.3% Be, 58.3% Li), so that the results obtained could be extrapolated, if necessary, on any mixture of steel and water. The lithium is enriched with the 50% of ⁶Li isotope in both employed blanket compositions.

The results of transport calculations of neutron/gamma ray fluxes for the the steel-rich, water-rich, the Li₂O/Be blanket and the liquid lithium blanket compositions versus the distance from the plasma axis are shown in Figs. 3.2-3.5, respectively. The results of helium production calculations for above-mentioned compositions are shown in Figs. 3.6-3.8, Figs. 3.9-3.11, Figs. 3.12-3.14 and Figs. 3.15- 3.17, respectively.

Only limited information we have at present on the radiation limit of helium production, subject to rewelding. It is believed that the total helium production in the construction stainless steel components to be rewelded must be limited by 0.1⁷⁾ to 18) He appm.

The concentrations of helium produced in metals in the first wall of a fusion reactor are very high, relative to helium production in the shield, the vacuum vessel and the superconducting magnets, particularly so in the case of nickel, iron and chromium contents. This is both due to the hard neutron spectra at the first wall, as shown in Figs. 3.18-3.21, and the high neutron fluxes at the first wall, relative to other components of a fusion reactor, as shown in Figs. 3.2-3.5.

The highest and smallest helium production rates at the first wall containing metals were observed for aluminum and zirconium, respectively, namely 332 He appm/1 MW·a/m² and 21.7 He appm/1 MW·a/m², respectively. The highest and smallest helium production rates at the first wall containing alloys were observed for the PCA and the V-5Cr-5Ti alloy, respectively, namely 139 He appm/1 MW·a/m² and 46.6 He appm/1 MW·a/m², respectively.

The helium production rates at the first wall of a fusion reactor after 1 MW·a/m² operation time and at some representative cuts behind the first wall for all considered in this study alloys and metals are summarized in Tables 3.3-3.5. The result of helium production calculations at the stainless steel first wall of a fusion reactor published in Ref. 9 is shown in Tables 3.3 and 3.5 for comparison. The difference between the result of Ref. 9 and that obtained in this study is less than 7%. According to Table 3.4 the difference between the calculational results with FUSION-40 and FUSION-J3 nuclear data libraries are negligible at the first wall and less than 10% at the vacuum vessel zone.

The helium production rate linearly increases with the operation time. This behavior is shown in Fig. 3.22 for some alloys. After 3 MW·a/m² operation time, the helium production at the first wall containing V-5Cr-5Ti vanadium alloy is less by about three times than that of the first wall containing PCA.

The helium production rate in any alloy containing considered in this study elements can be easily obtained by combining results obtained for single elements. For instance, the helium production rate at the first wall containing a binary alloy can be obtained as follows:

$$F = F_A \cdot X + F_B \cdot Y \quad (3.1)$$

, where

F_A and F_B are the helium production rates of elements "A" and "B", respectively;

X and Y are the fractions of elements "A" and "B" in a binary alloy, respectively;

Let suppose the steel-rich (80% steel/20% water) blanket/shield is placed behind the first wall. Therefore, the helium production rate in the first wall having a binary Fe-16Cr alloy is calculated by the Eq. (3.1) as follows:

$$F = F_A \cdot X + F_B \cdot Y = 116 \cdot 0.84 + 95.1 \cdot 0.16 = 113 \text{ appm/1 MW}\cdot\text{a/m}^2$$

, where

116 and 95.1 are the helium production rates measured in appm/1 MW·a/m² and given in Table 3.3 for the iron and chromium, respectively;

0.84 and 0.16 are the iron and chromium fraction in the binary Fe-16Cr alloy, respectively.

3.3 Helium production in blanket materials.

The gas production in blanket materials, such as a neutron multiplier, lithium-bearing materials etc., has been investigated in some studies. For instance, the He production has been investigated for Li₂O¹⁰), a perspective candidate material for a fusion reactor blanket, and Be¹¹), the best neutron multiplier.

The direct helium production in Be via (n,α) reaction is calculated in this study for the outboard ITER buildup with the ceramic blanket with beryllium multiplier¹²) proposed by Japan for ITER design. However, as shown in Ref. 11, the helium production by (n,2n) reaction is by about ten times larger than the helium production by (n,α) reaction. The calculational results are shown in Fig. 3.23. The maximum helium production rate at the first (behind the first wall) beryllium layer reaches 188 He appm/1 MW·a/m² (see Fig. 3.23, R=231.55 cm). The calculation of maximum helium production rate with the FUSION-J3 nuclear data library gives the helium production rate of 185 He appm/1 MW·a/m².

The helium production in Li₂O reaches its maximum at the first (behind the first wall) Li₂O layer. The helium production rate at this layer in ⁶Li and ⁷Li reaches $2.18 \cdot 10^5$ He appm/1 MW·a/m² and 824 He appm/1 MW·a/m², respectively.

Table 3.1 The atomic densities⁺ and fractions of materials of the two shield and the two blanket compositions.

Composition Component	Homogeneous shields (Zone 3 in Fig. 3.1)		Homogeneous blankets (Zone 3 in Fig. 3.1)	
	80% SS 20% H ₂ O	20% SS 80% H ₂ O	15% SS 10% H ₂ O 15% Li ₂ O 60% Be	21.4% V 20.3% Be 58.3% Li
H	1.338-2*	5.352-2	6.690-3	-
O	6.680-3	2.672-2	6.700-3	-
Cr	1.264-2	3.160-3	2.370-3	-
Fe	4.728-2	1.182-2	8.865-3	-
Ni	7.880-3	1.970-3	1.478-3	-
Mo	1.008-3	2.520-4	1.890-4	-
⁶ Li	-	-	3.360-3	1.353-2
⁷ Li	-	-	3.360-3	1.353-2
Be	-	-	7.496-2	2.579-2
V	-	-	-	1.759-2

+ 10²⁴ 1/cm³

* Read as 1.338 x 10⁻²

Table 3.2 The chemical contents (weight percent) of PCA, HT-9, V-5Cr-5Ti, INCONEL 625 and Ti-6Al-4V alloys used for helium production calculations.

Element \ Alloy	PCA*	HT-9**	V-5Cr-5Ti	INCONEL 625	Ti-6Al-4V
Cr	14	11	4.6	22	-
Fe	68	87.15	-	4	-
Ni	16	0.5	-	61	-
Mo	2	0.85	-	9	-
Ti	-	-	5.1	-	90
W	-	0.5	-	-	-
V	-	-	90.3	-	4
Nb	-	-	-	4	-
Al	-	-	-	-	6

* 316 stainless steel

** Ferritic steel containing 11% Cr

Table 3.3 Helium production in metals and alloys of steel/water compositions of a fusion reactor after 1 MW · a/m² operation.

Metal/ Alloy	Helium production, appm	First wall	Behind blanket (Δ#=50 cm)	Behind shield (Δ=70 cm)	Behind vacuum vessel (Δ=100 cm)
²⁷ Al	322*	1.39-1	8.33-3	1.23-4	
	332**	1.14	1.48-1	7.01-3	
Ni	273	1.91-1	1.19-2	1.80-4	
	266	1.27	1.71-1	8.46-3	
Fe	116	4.81-2	2.86-3	4.18-5	
	119	3.89-1	5.03-2	2.37-3	
Ti	100	3.97-2	2.34-3	3.39-5	
	103	3.08-1	3.93-2	1.82-3	
Cr	95.1	3.66-2	2.15-3	3.10-5	
	97.3	2.81-1	3.57-2	1.65-3	
⁵⁵ Mn	77.1	3.01-2	1.77-3	2.57-5	
	79.0	2.35-1	2.99-2	1.39-3	
⁵¹ V	41.3	1.55-2	9.02-4	1.29-5	
	42.2	1.16-1	1.45-2	6.62-4	
Mo	34.1	1.41-2	8.34-4	1.21-5	
	34.7	1.07-1	1.37-2	6.38-4	
Zr	21.7	7.73-3	4.47-4	6.33-6	
	22.1	5.68-2	7.04-3	3.18-4	
PCA	138(148+)	6.90-2	4.18-3	6.22-5	
	139	5.12-1	6.72-2	3.22-3	
HT-9	114	4.68-2	2.78-3	4.06-5	
	117	3.77-1	4.68-2	2.29-3	
V-5Cr-5Ti	46.6	1.76-2	1.03-3	1.48-5	
	47.6	1.33-1	1.67-2	7.67-4	
INCONEL 625	196	1.27-1	7.88-3	1.19-4	
	193	8.58-1	1.15-1	5.65-3	
Ti-6Al-4V	111	4.47-2	2.64-3	3.84-5	
	114	3.50-1	4.48-2	2.09-3	

Distance from the first wall (see Fig. 3.1)

* For 80% steel/20% water composition in zone 3 (see Fig. 3.1)

** For 80% water/20% steel composition in zone 3 (see Fig. 3.1)

+ Ref. 9, page 71.

Table 3.4 Helium production in some metals of steel-rich (80 %SS and 20%water) composition of a fusion reactor after 1 MW · a/m² operation.

Metal/ Alloy	Helium production, appm	First wall	Behind blanket (Δ#=50 cm)	Behind shield (Δ=70 cm)	Behind vacuum vessel (Δ=100 cm)
Ni	273*	1.91-1	1.19-2	1.80-4	
	274&	1.86-1	1.14-2	1.68-4	
Fe	116	4.81-2	2.86-3	4.18-5	
	116	4.52-2	2.64-3	3.83-5	
Cr	95.1	3.66-2	2.15-3	3.10-5	
	93.7	3.36-2	1.93-3	2.84-5	

* - FUSION-40
& - FUSION-J3

Table 3.5 Helium production in metals and alloys of blanket compositions
of a fusion reactor after $1 \text{ MW} \cdot \text{a/m}^2$ operation.

Metal/ Alloy	Helium production, appm	First wall	Behind blanket ($\Delta^{\#}=50 \text{ cm}$)	Behind shield ($\Delta=70 \text{ cm}$)	Behind vacuum vessel ($\Delta=100 \text{ cm}$)
27Al	361*	8.08-1	7.85-2	2.25-3	
	364**	4.20	8.24-1	7.00-2	
Ni	324	1.25	1.32-1	4.17-3	
	322	6.00	1.28	1.19-1	
Fe	128	2.68-1	2.60-2	7.46-4	
	130	1.40	2.71-1	2.29-2	
Ti	109	2.01-1	1.90-2	5.32-4	
	111	1.09	2.07-1	1.71-2	
Cr	102	1.79-1	1.68-2	4.65-4	
	105	9.86-1	1.87-1	1.53-2	
55Mn	83.7	1.53-1	1.45-2	4.07-4	
	85.3	8.28-1	1.58-1	1.31-2	
51V	44.0	7.06-2	6.48-3	1.75-4	
	45.1	4.02-1	7.49-2	6.01-3	
Mo	37.0	7.29-2	7.06-3	2.04-4	
	37.6	3.83-1	7.38-2	6.21-3	
Zr	22.8	3.29-2	2.99-3	7.97-5	
	23.5	1.90-1	3.48-2	2.75-3	
PCA	155(148+)	4.11-1	4.14-2	1.25-3	
	157	2.07	4.18-1	3.70-2	
HT-9	126	2.58-1	2.50-2	7.15-4	
	127	1.35	2.62-1	2.20-2	
V-5Cr-5Ti	49.8	8.24-2	7.61-3	2.07-4	
	51.0	4.64-1	8.69-2	7.02-3	
INCONEL 625	230	8.14-1	8.53-2	2.68-3	
	229	3.96	8.33-1	7.71-2	
Ti-6Al-4V	121	2.32-1	2.21-2	6.21-4	
	123	1.25	2.38-1	1.98-2	

Distance from the first wall (see Fig. 3.1)

* For Li₂O/Be blanket composition in zone 3 (see Fig. 3.1)

** For liquid lithium blanket composition in zone 3 (see Fig. 3.1)

+ Ref. 9, page 71.

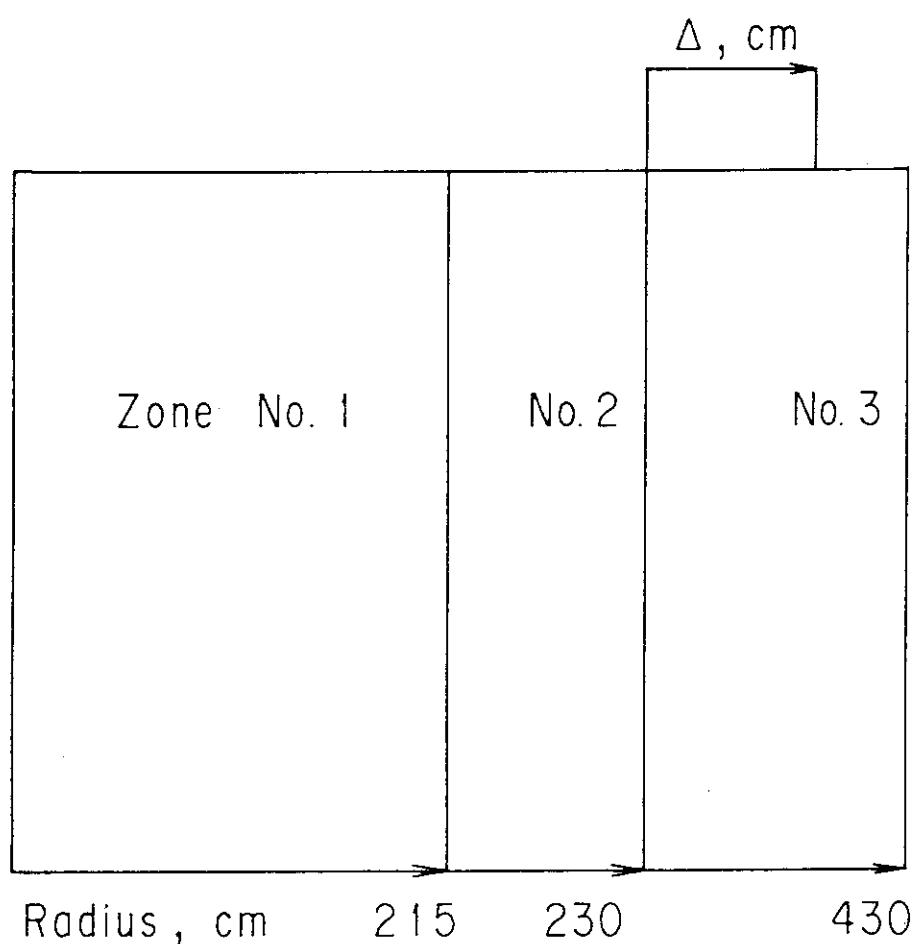


Fig.3.1 Simplified geometrical calculational model of an experimental thermonuclear reactor. 1-Plasma (isotropic 14.1-MeV neutron source); 2-Scrape-off layer(void); 3-Homogeneous composition as shown in Table 3.1.

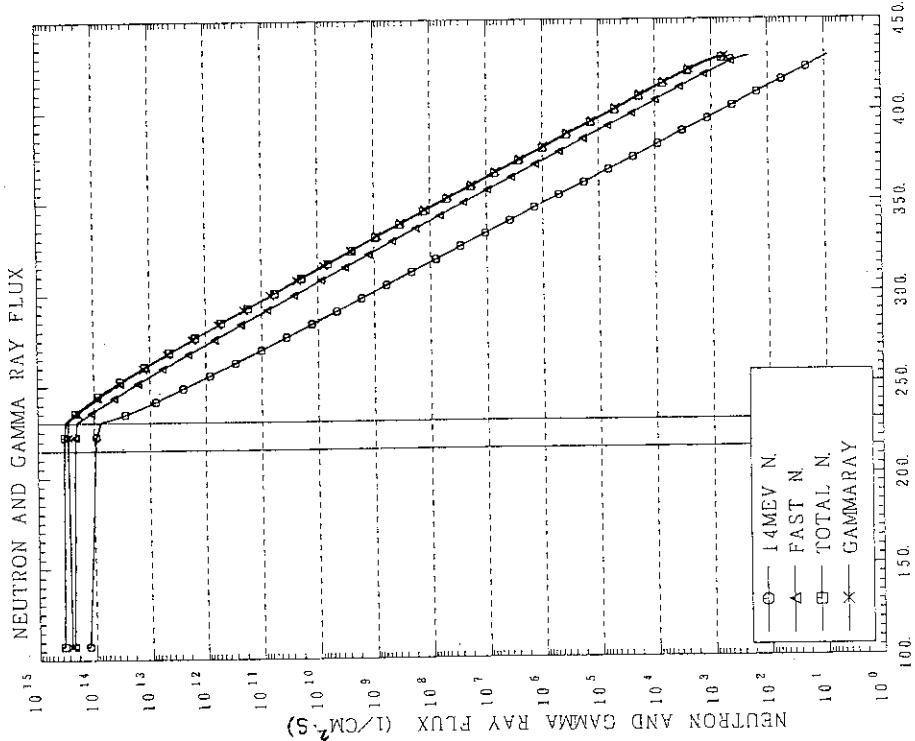


Fig.3.2 Neutron and gamma ray fluxes in the steel-rich (80% steel/20% water shield) composition versus the distance from the plasma axis.

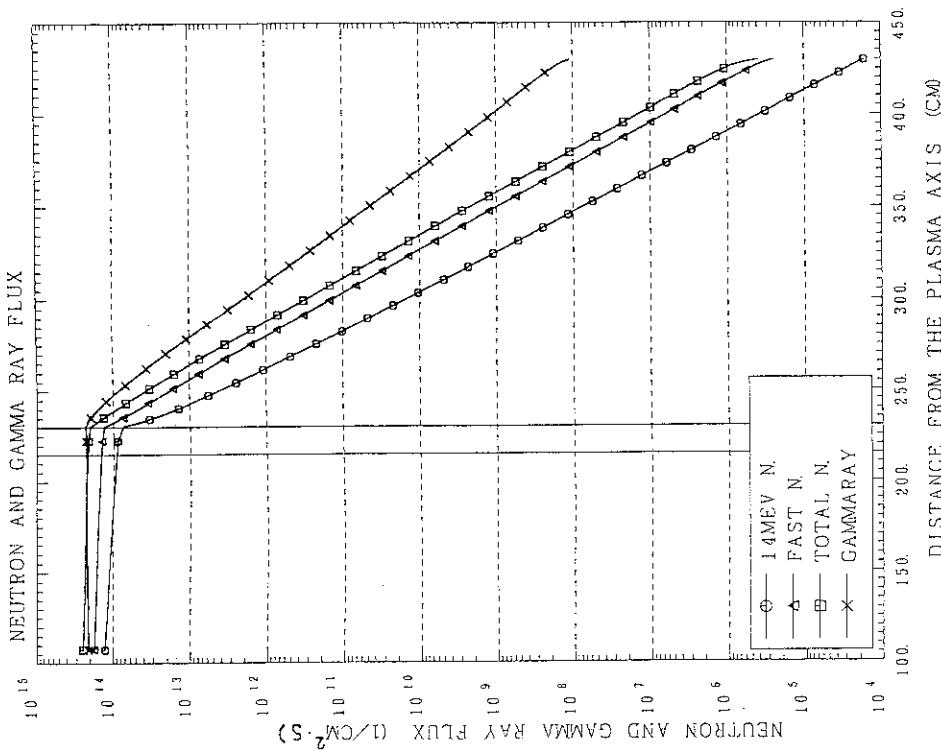


Fig.3.3 Neutron and gamma ray fluxes in the water-rich (80% water/20% steel shield) composition versus the distance from the plasma axis.

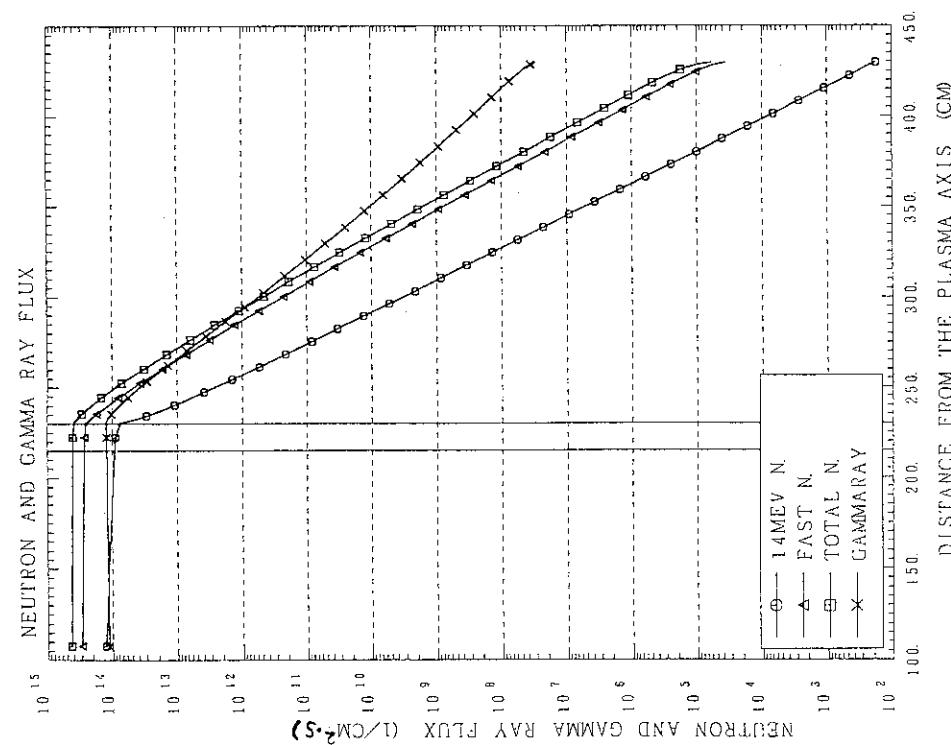


Fig.3.4 Neutron and gamma ray fluxes in the $\text{Li}_2\text{O}/\text{Be}$ blanket (15%SS, 10% water, 15% Li_2O and 60% Be) composition versus the distance from the plasma axis.

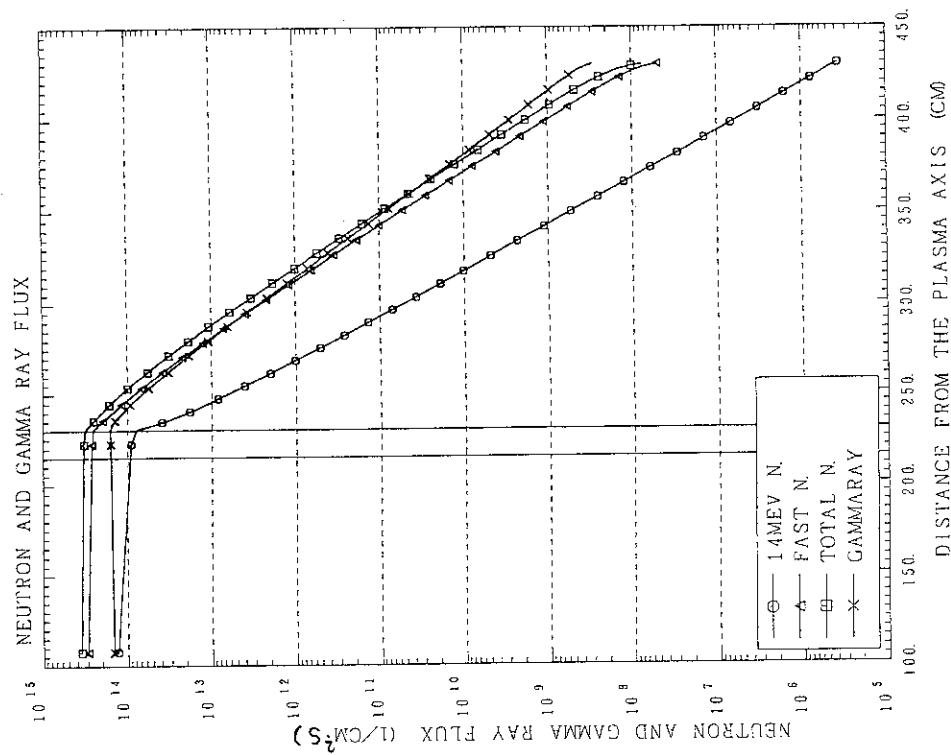


Fig.3.5 Neutron and gamma ray fluxes in the liquid lithium blanket (21.4% V, 20.3% Be and 58.3% Li) composition versus the distance from the plasma axis.

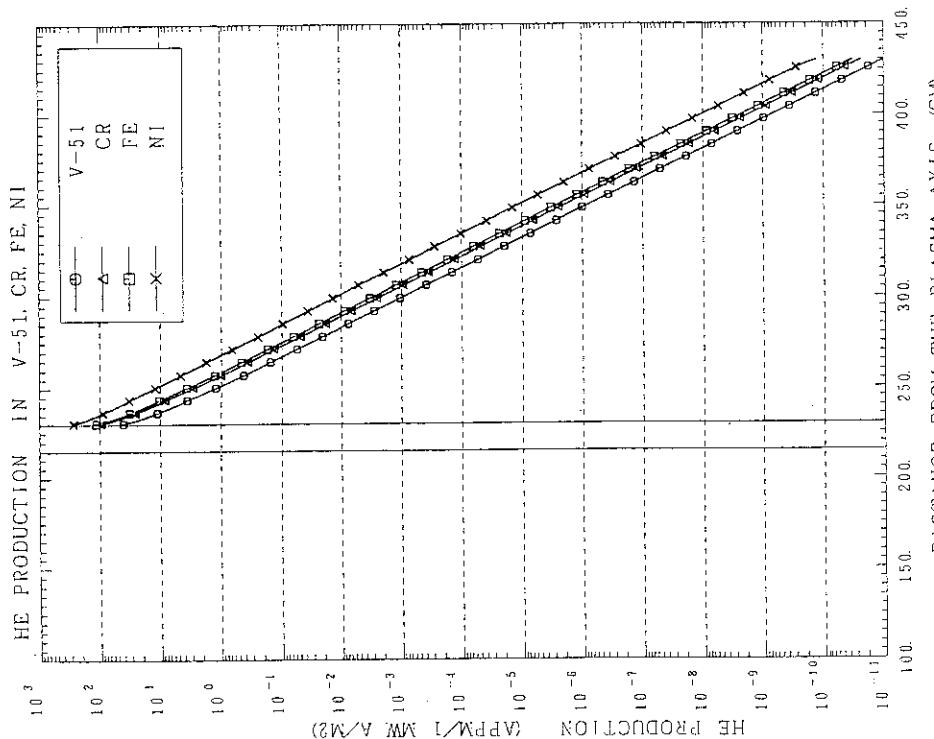


Fig.3.6 Helium production rates in V-51, Cr, Fe and Ni of the steel-rich (80% steel/20% water shield) composition versus the distance from the plasma axis.

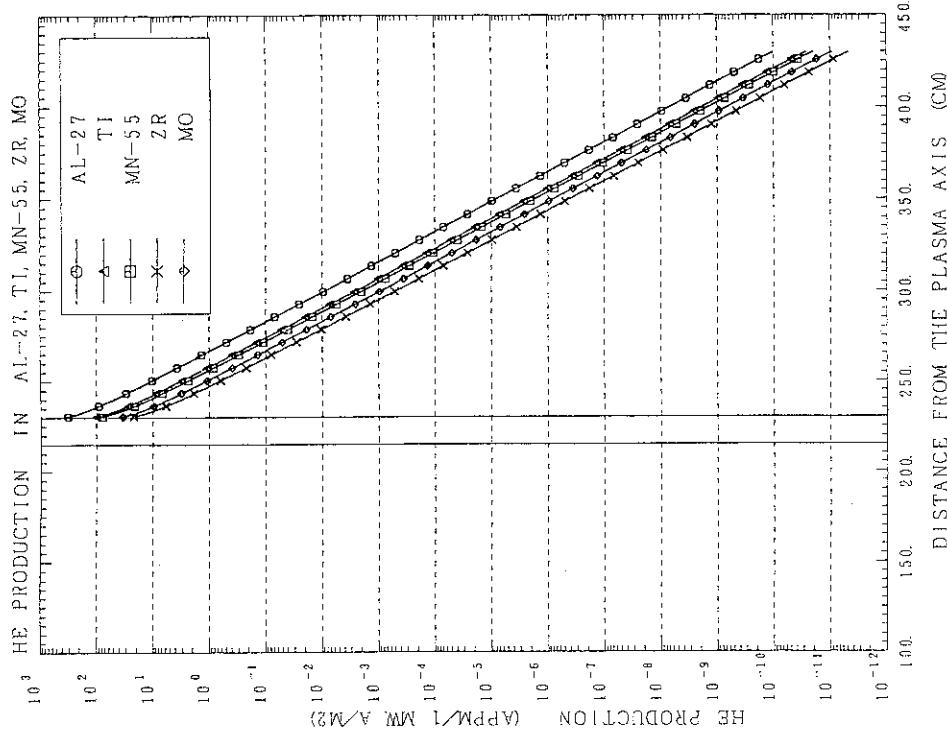


Fig.3.7 Helium production rates in Al-27, Ti, Mn-55, Zr and Mo of the steel-rich (80% steel/20% water shield) composition versus the distance from the plasma axis.

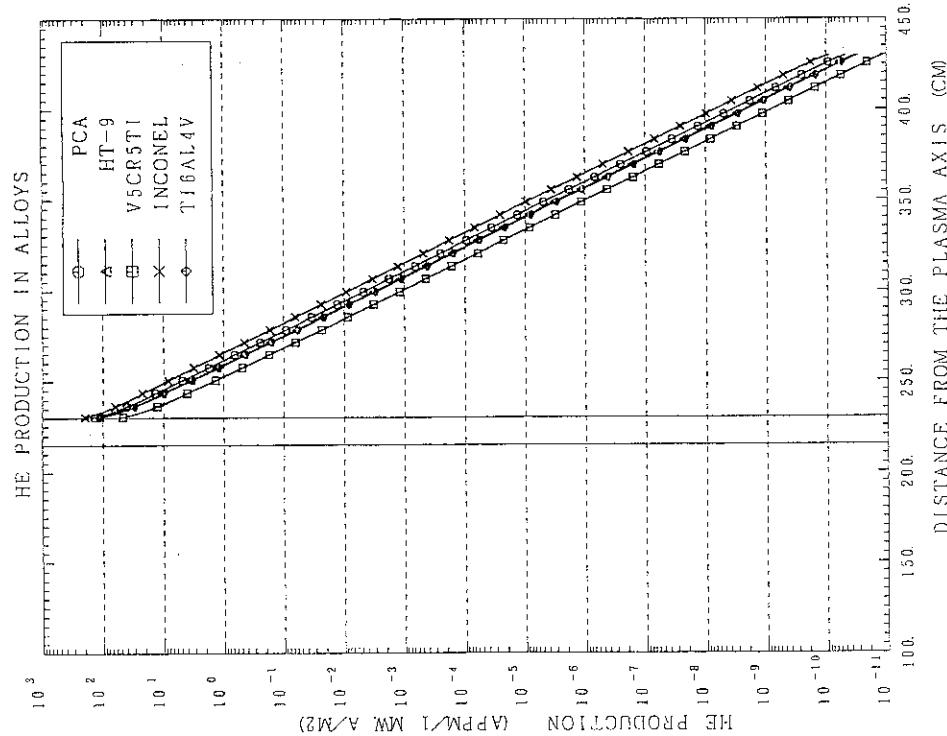


Fig.3.8 Helium production rates in alloys of the steel-rich (80% steel/20% water shield) composition versus the distance from the plasma axis.

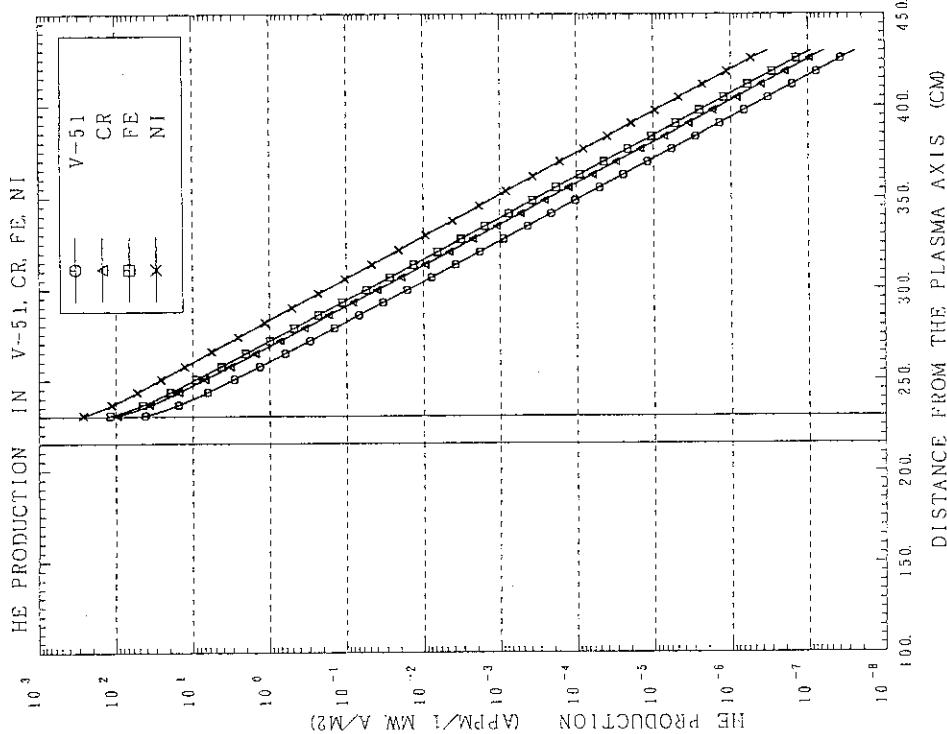


Fig.3.9 Helium production rates in V-51, Cr, Fe and Ni of the water-rich (80% water/20% steel shield) composition versus the distance from the plasma axis.

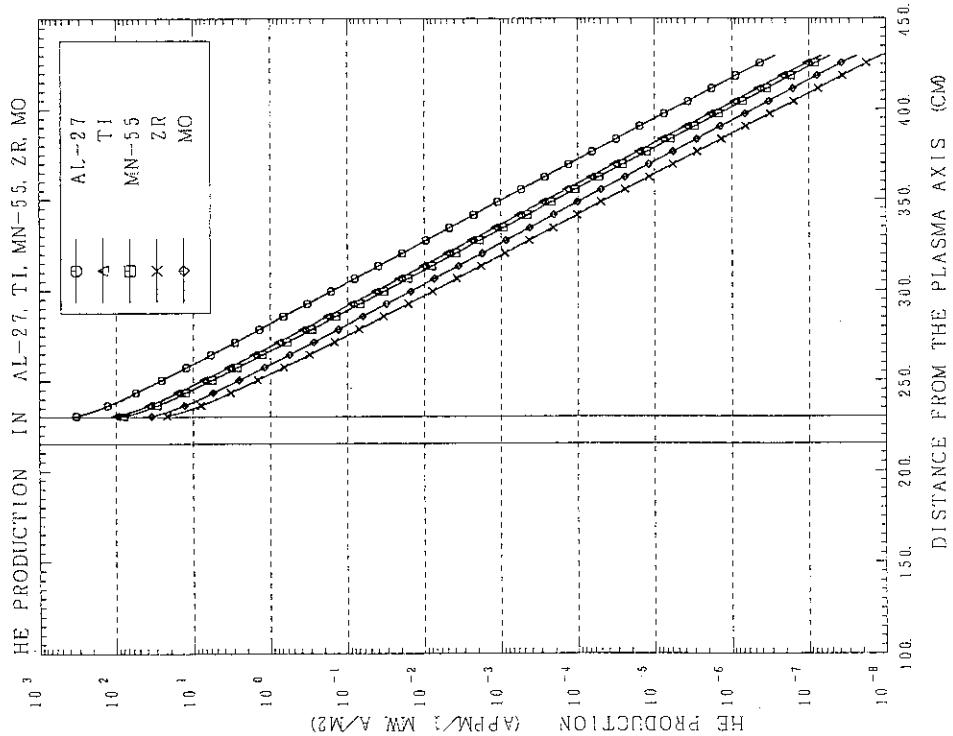


Fig.3.10 Helium production rates in Al-27, Ti, Mn-55, Zr and Mo of the water-rich (80% water/20% steel shield) composition versus the distance from the plasma axis.

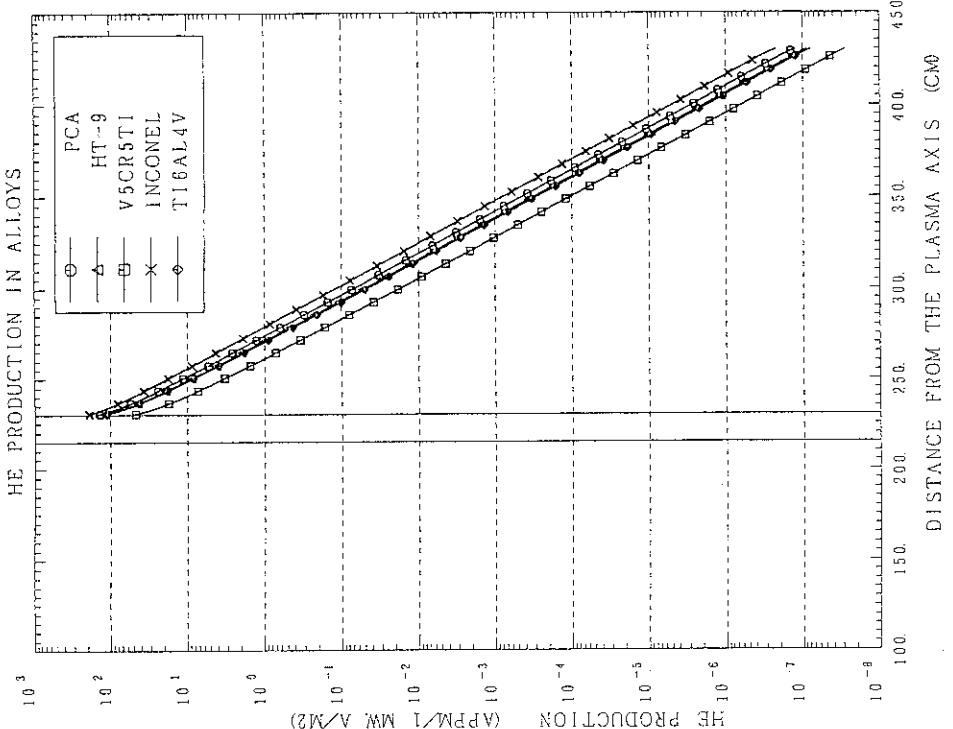


Fig.3.11 Helium production rates in alloys of the water-rich (80% water/20% steel shield) composition versus the distance from the plasma axis.

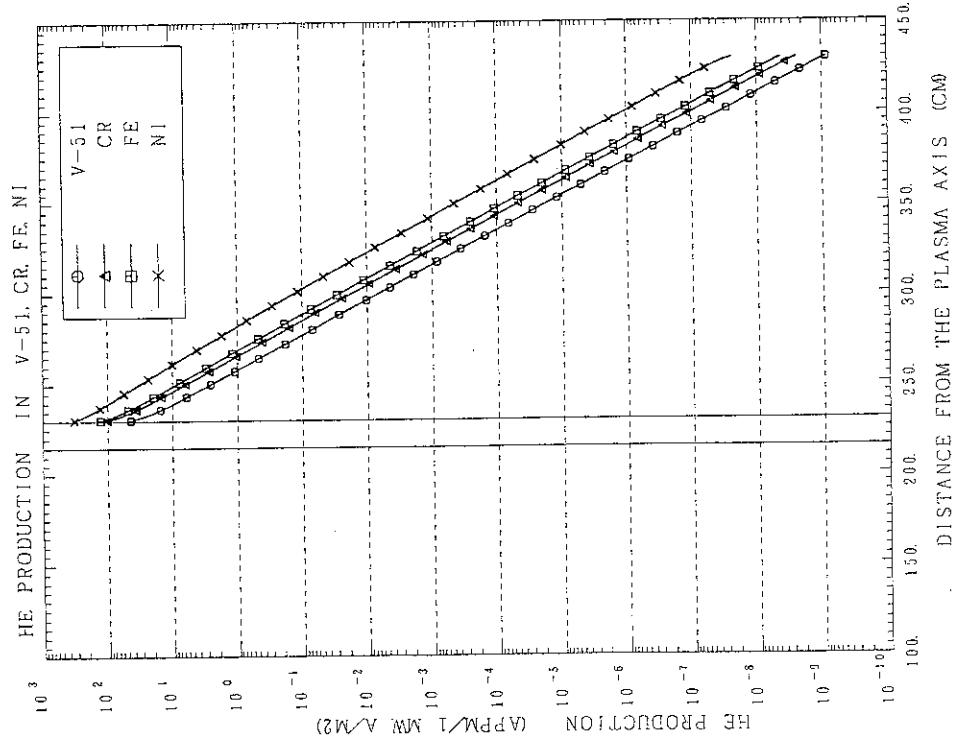


Fig.3.12 Helium production rates in V-51, Cr, Fe and Ni of the Li₂O/Be blanket(15%SS, 10% water, 15% Li₂O and 60% Be) composition versus the distance from the plasma axis.

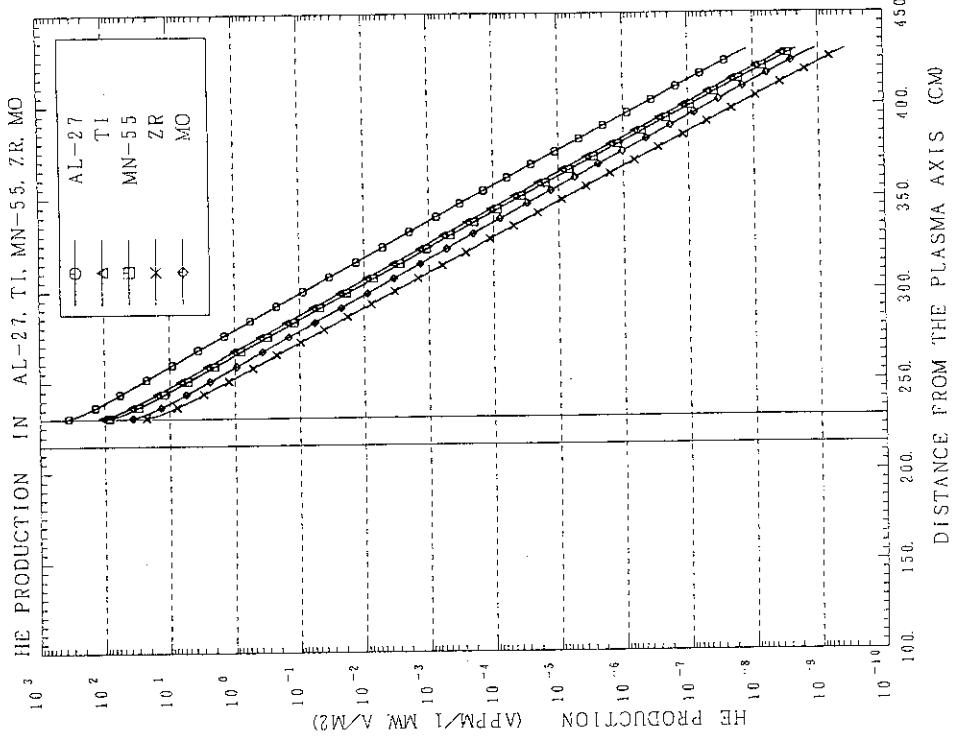


Fig.3.13 Helium production rates in Al-27, Ti, Mn-55, Zr and Mo of the Li₂O/Be blanket (15%SS, 10% water, 15% Li₂O and 60% Be) composition versus the distance from the plasma axis.

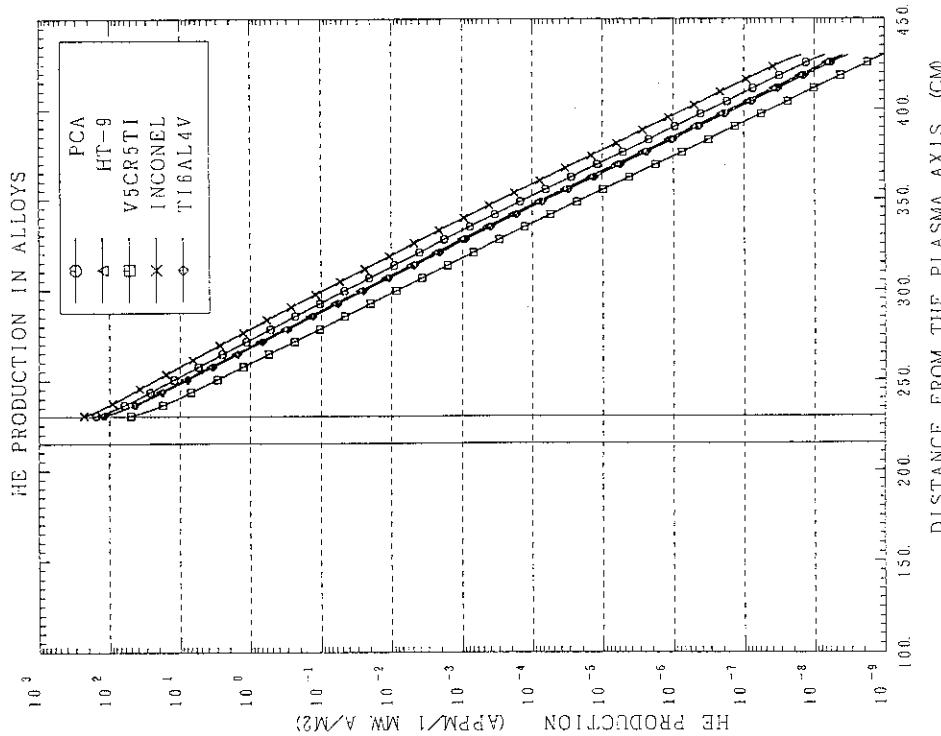


Fig.3.14 Helium production rates in alloys of the Li₂O/Be blanket (15%SS, 10% water, 15% Li₂O and 60% Be) composition versus the distance from the plasma axis.

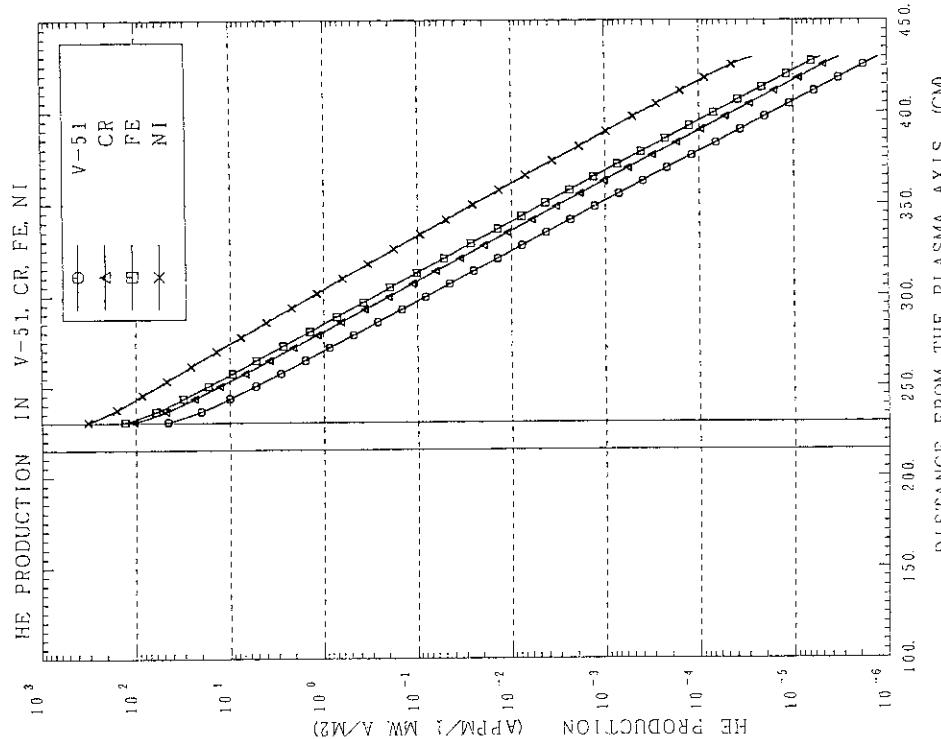


Fig.3.15 Helium production rates in V-51, Cr, Fe and Ni of the liquid lithium blanket (21.4% V, 20.3% Be and 58.3% Li) composition versus the distance from the plasma axis.

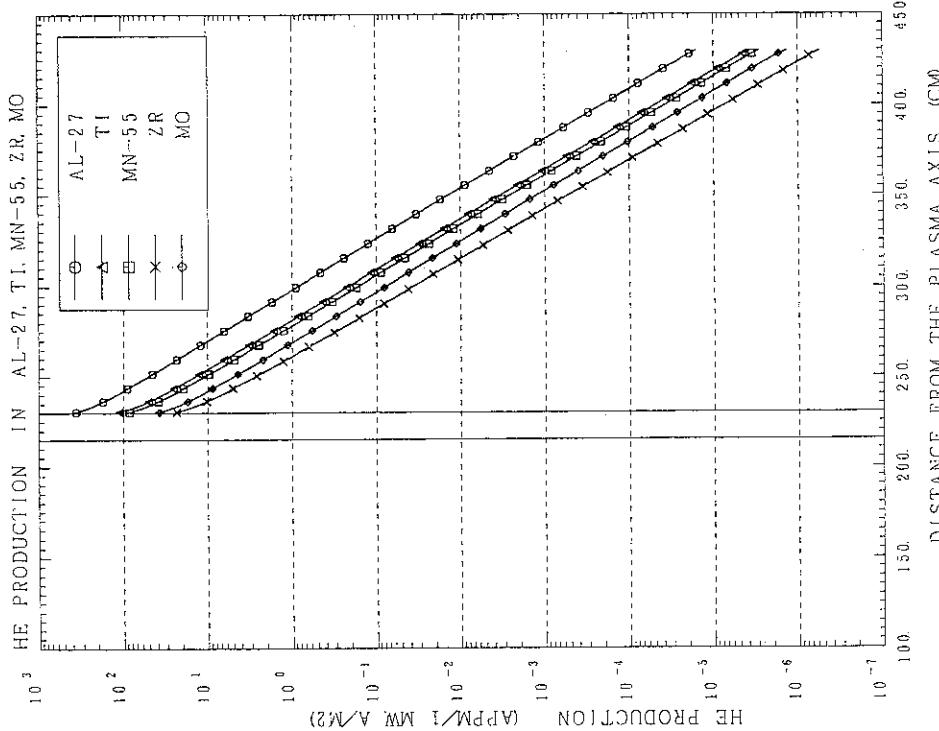


Fig.3.16 Helium production rates in Al-27, Ti, Mn-55, Zr and Mo of the liquid lithium blanket (21.4% V, 20.3% Be and 58.3% Li) composition versus the distance from the plasma axis.

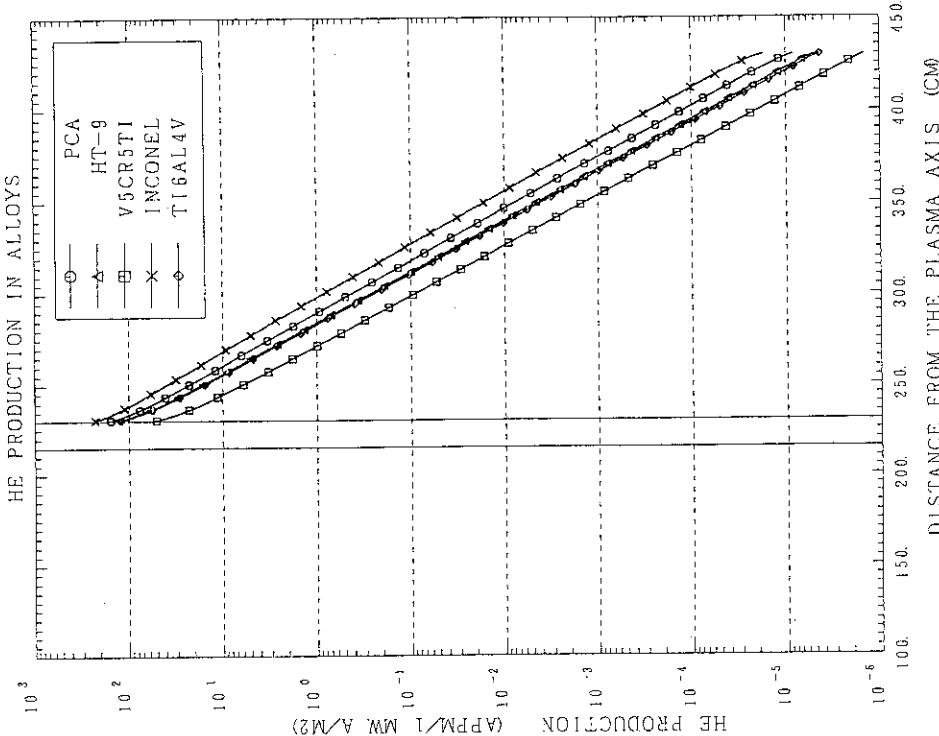


Fig.3.17 Helium production rates in alloys of the liquid lithium blanket (21.4% V, 20.3% Be and 58.3% Li) composition versus the distance from the plasma axis.

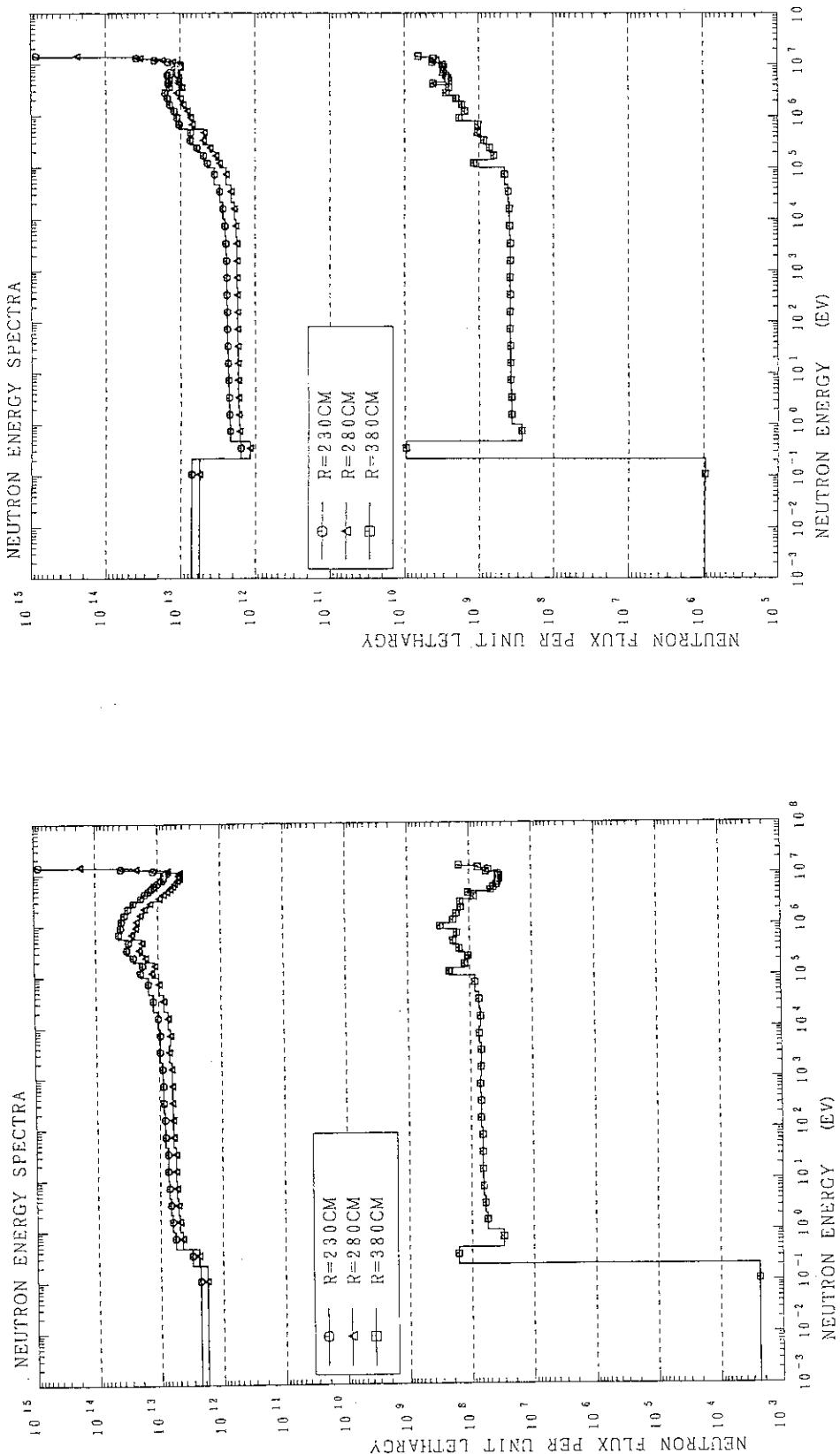


Fig.3.18 Neutron spectra in the steel-rich (80% steel/20% water shield) composition.

Fig.3.19 Neutron spectra in the water-rich (80% water/20% steel shield) composition.

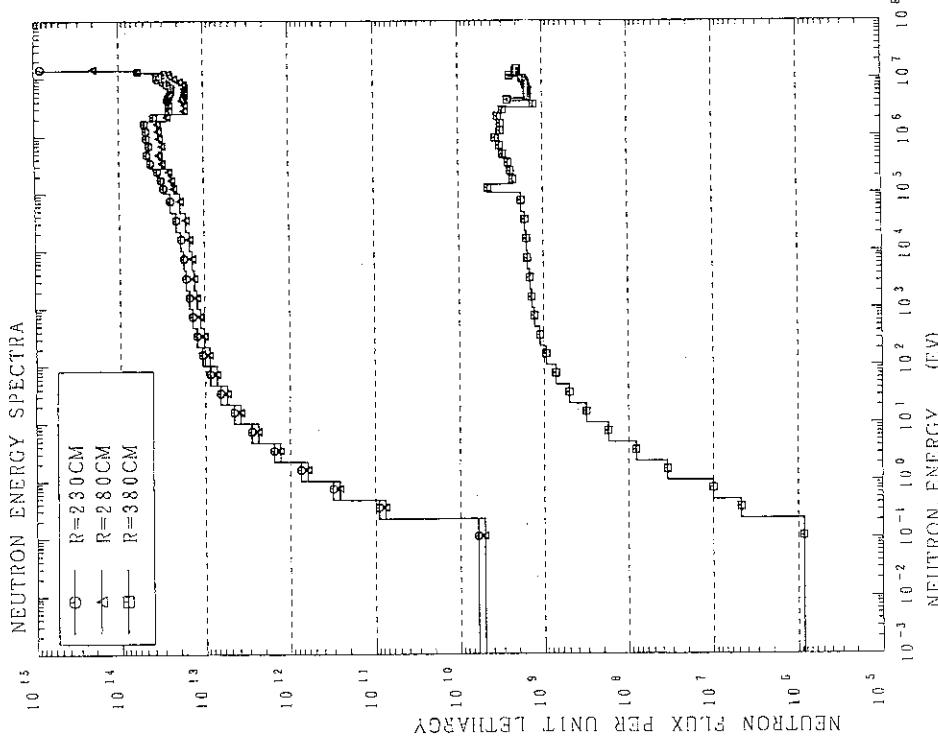


Fig.3.20 Neutron spectra in the the $\text{Li}_2\text{O}/\text{Be}$ blanket (15%SS, 10% water, 15% Li_2O and 60% Be) composition.

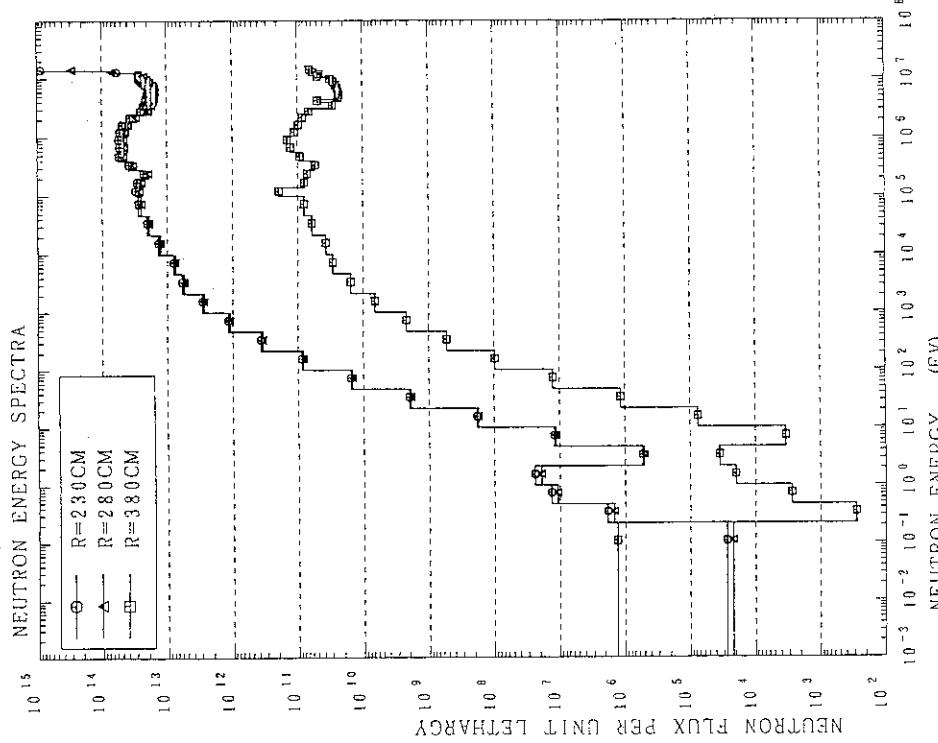


Fig.3.21 Neutron spectra in the liquid lithium blanket (21.4% V, 20.3% Be and 58.3% Li) composition.

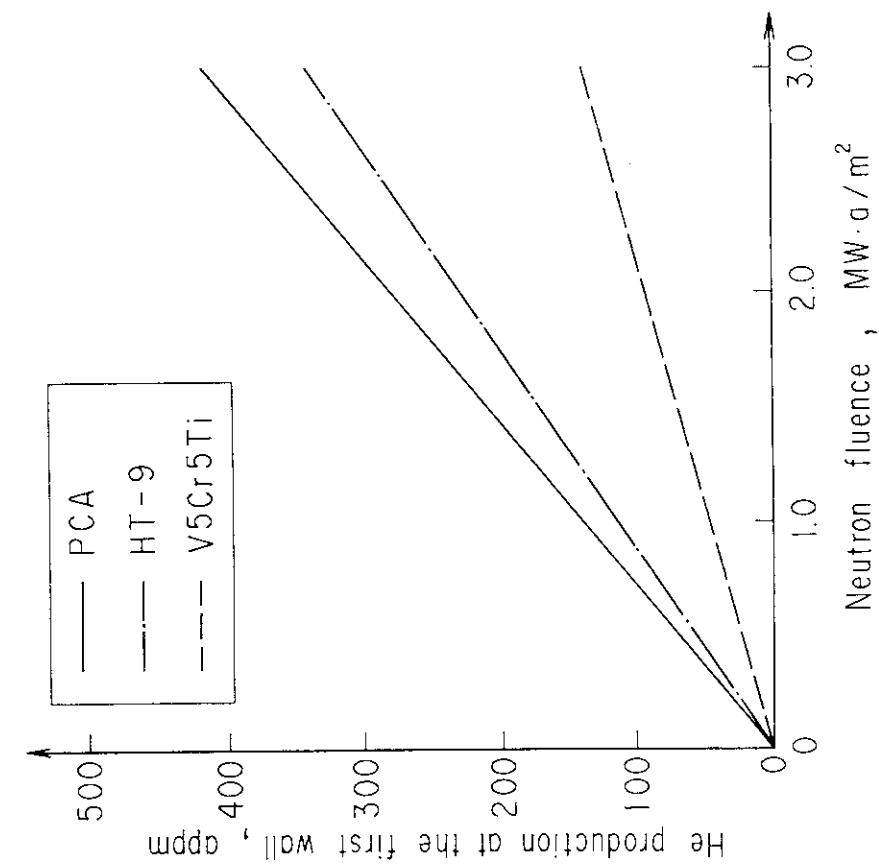


Fig.3.22 Helium production at the first wall of a fusion reactor containing the PCA, HT-9 and V-5Cr-5Ti alloys versus the operation time.

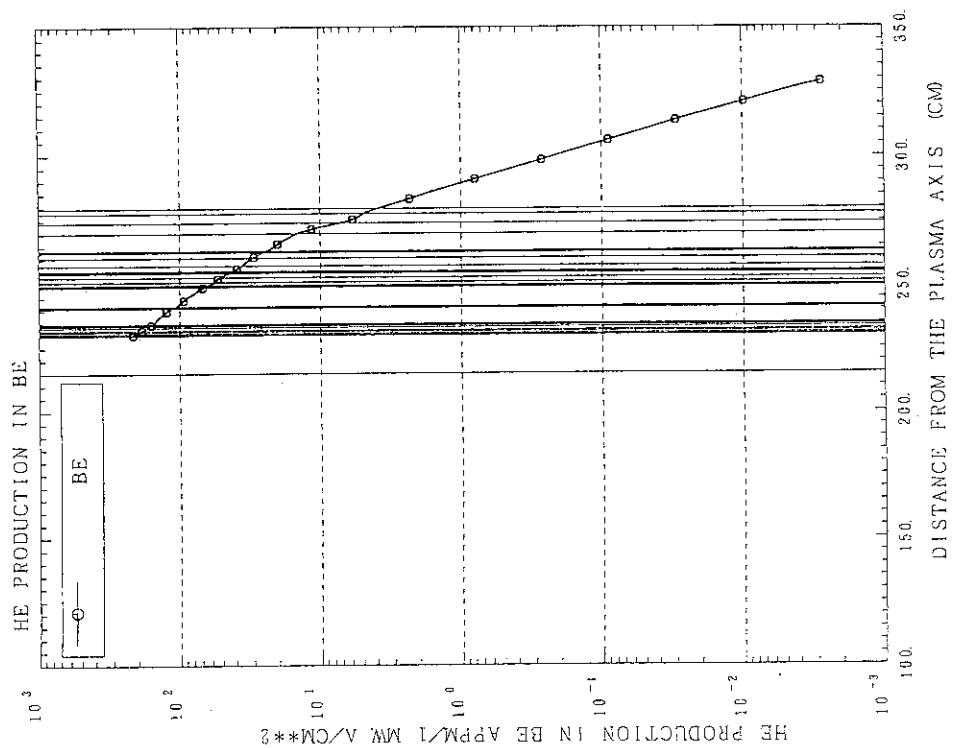


Fig.3.23 He production rate via (n, α) reaction in Be of the ITER outboard blanket (Ref.12) versus the distance from the plasma axis.

4. Conclusions

The main conclusions of this study are summarized as follows :

- (1) The helium and hydrogen production cross section libraries based on the JENDL-3 data file were compiled for use in neutronics/shielding design calculation of a fusion reactor.
- (2) These libraries have the same group structures as FUSION-J3 (neutron 125 groups and gamma-ray 40 groups) and FUSION-40 (neutron 42 groups and gamma-ray 21 groups) and can be used as the APPLE-3 response function libraries.
- (3) Some sample calculations using ANISN with these libraries were performed and it was found that they gave the appropriate results by comparing them with the existing results.

Acknowledgements

The authors would like to express their appreciation to Drs. S. Matsuda, Y. Seki and T. Tsunematsu for their continuous guidance and encouragement for this study. They also would like to thank Dr. T. Nakagawa of Nuclear Data Center for his helpful discussion and assistance in processing of the JENDL gas-production file with CRECTJ5.

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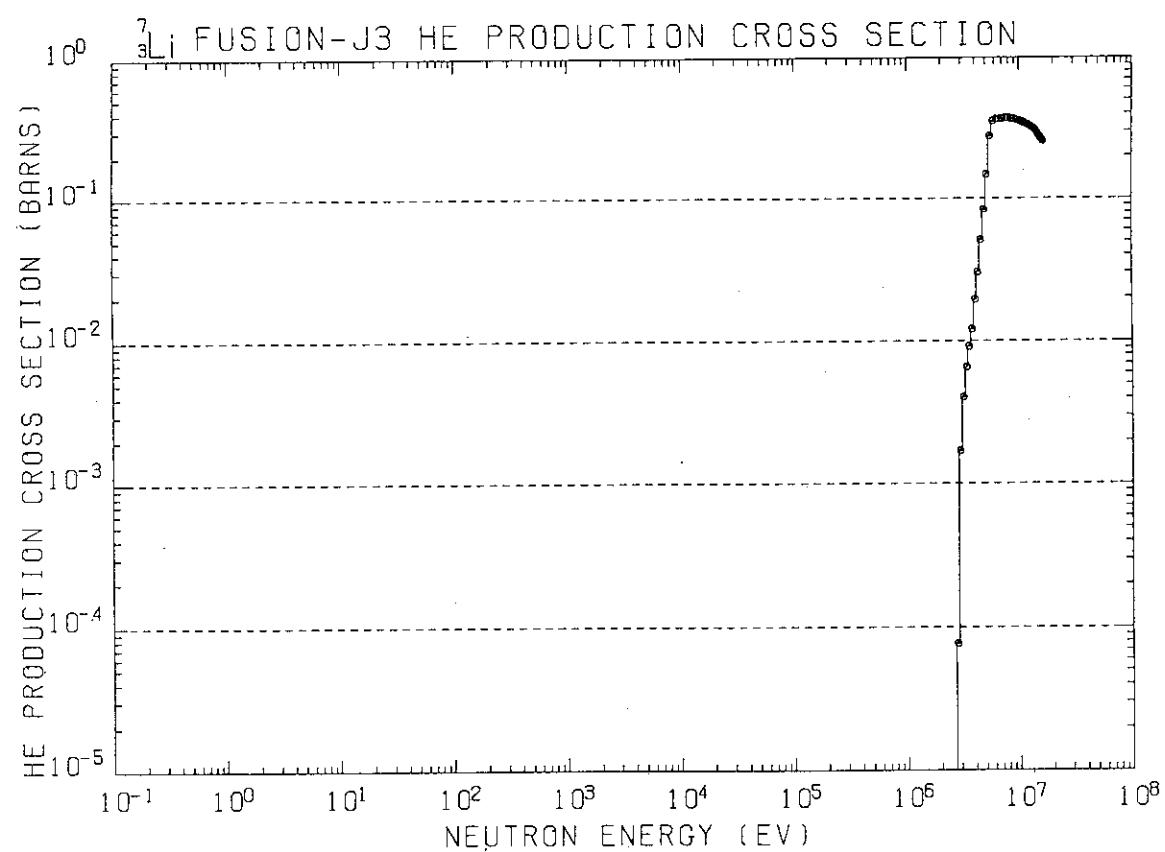
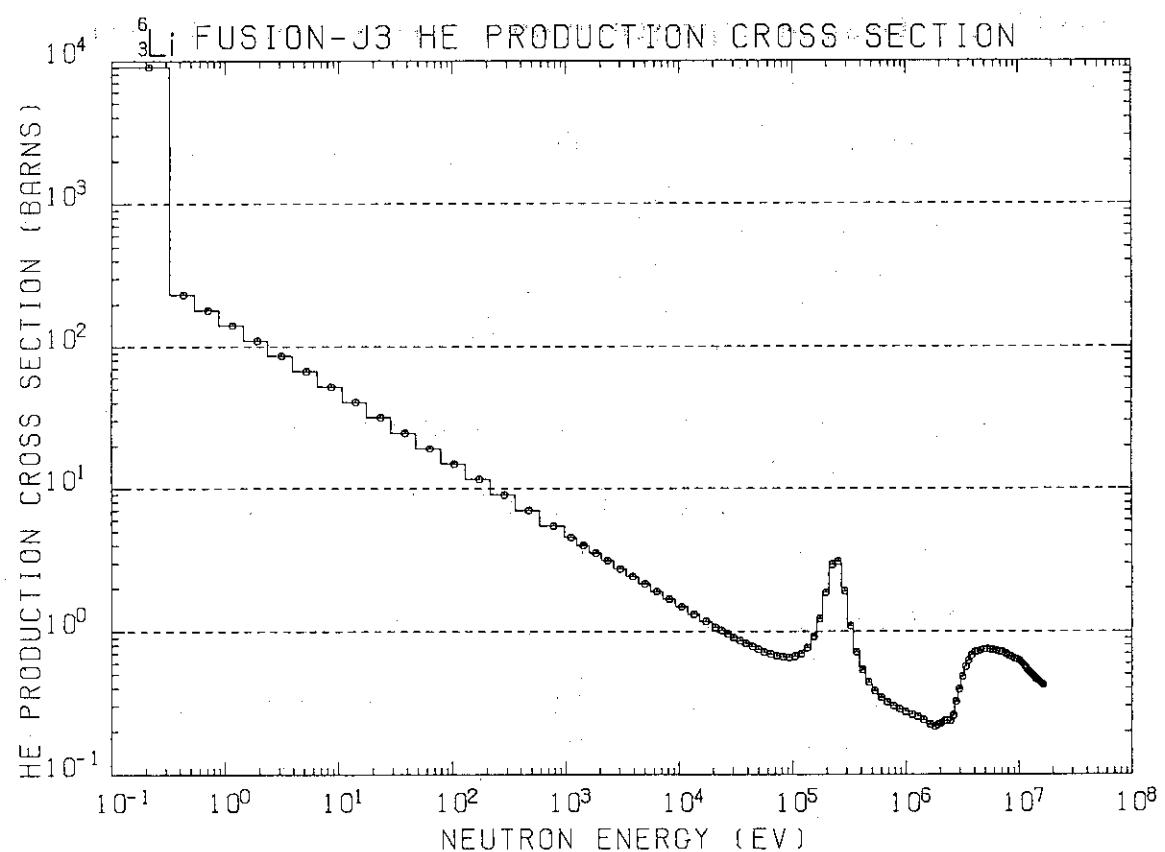
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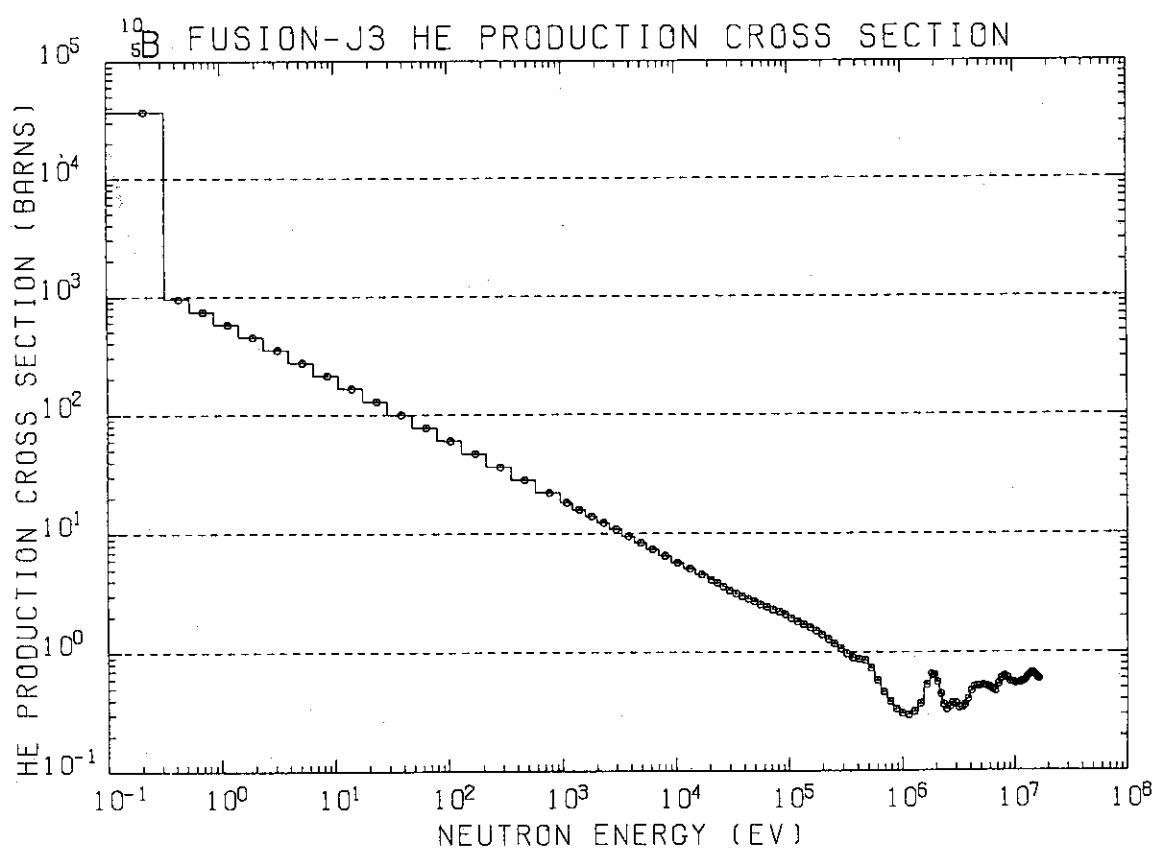
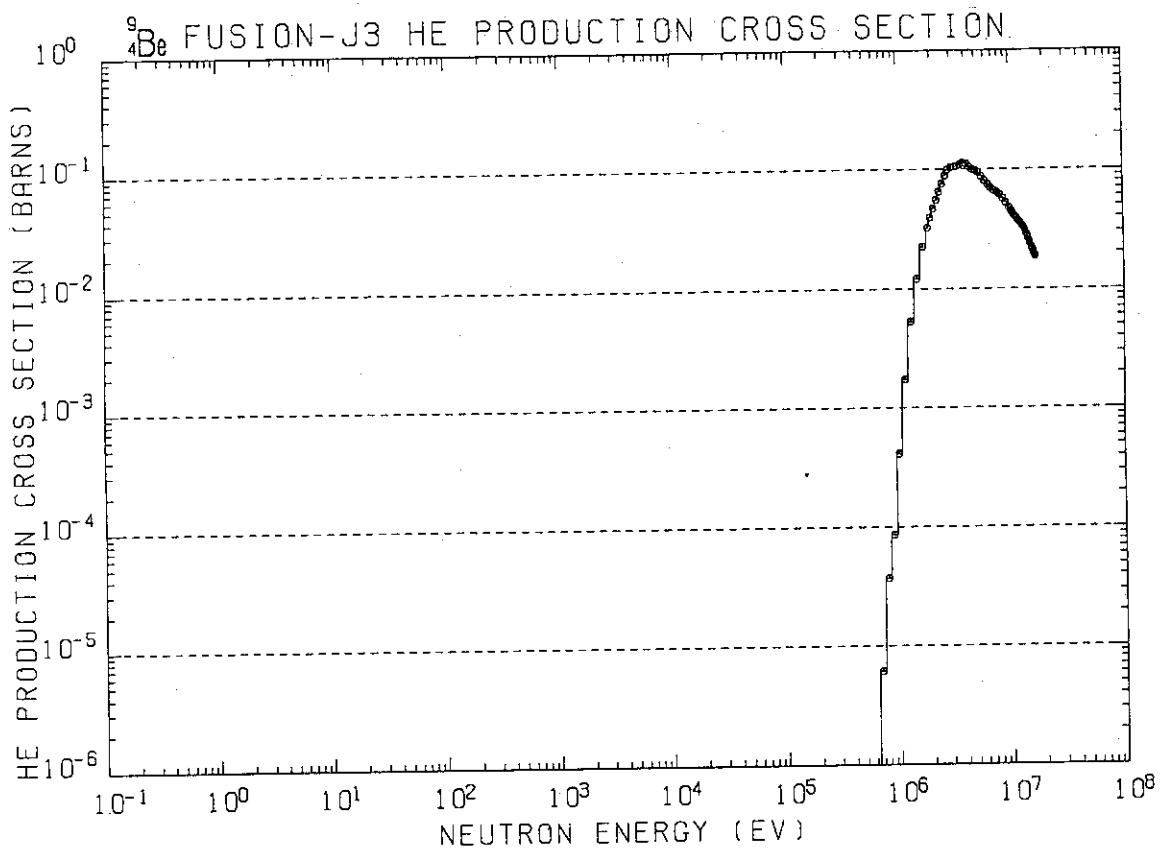
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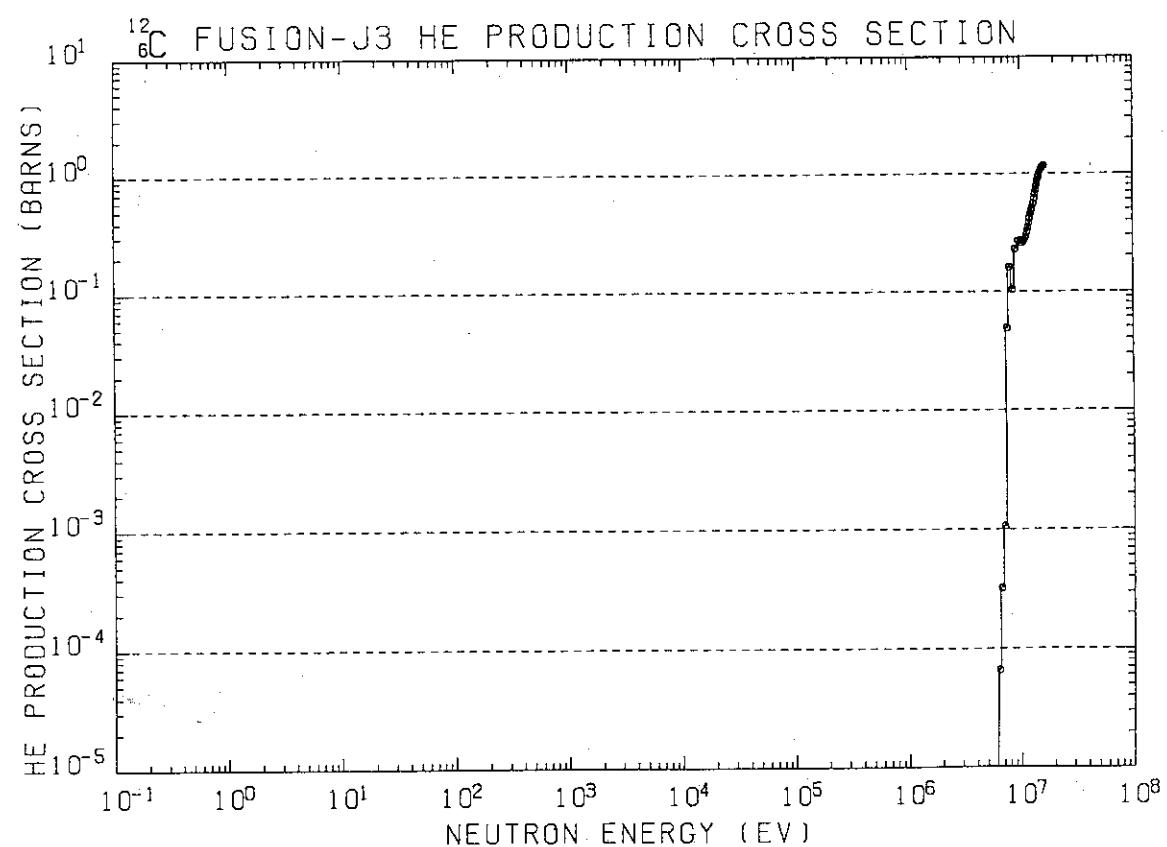
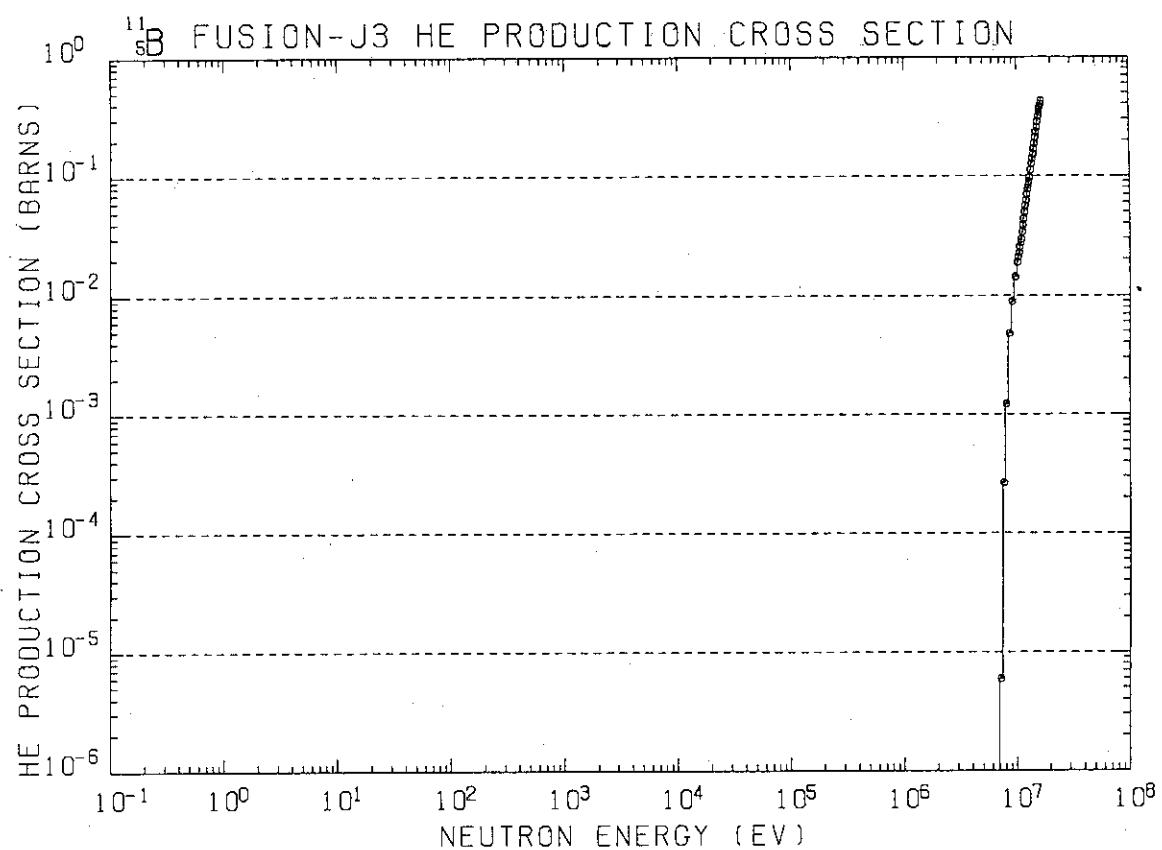
Appendix 1 Graphical presentation of cross section libraries

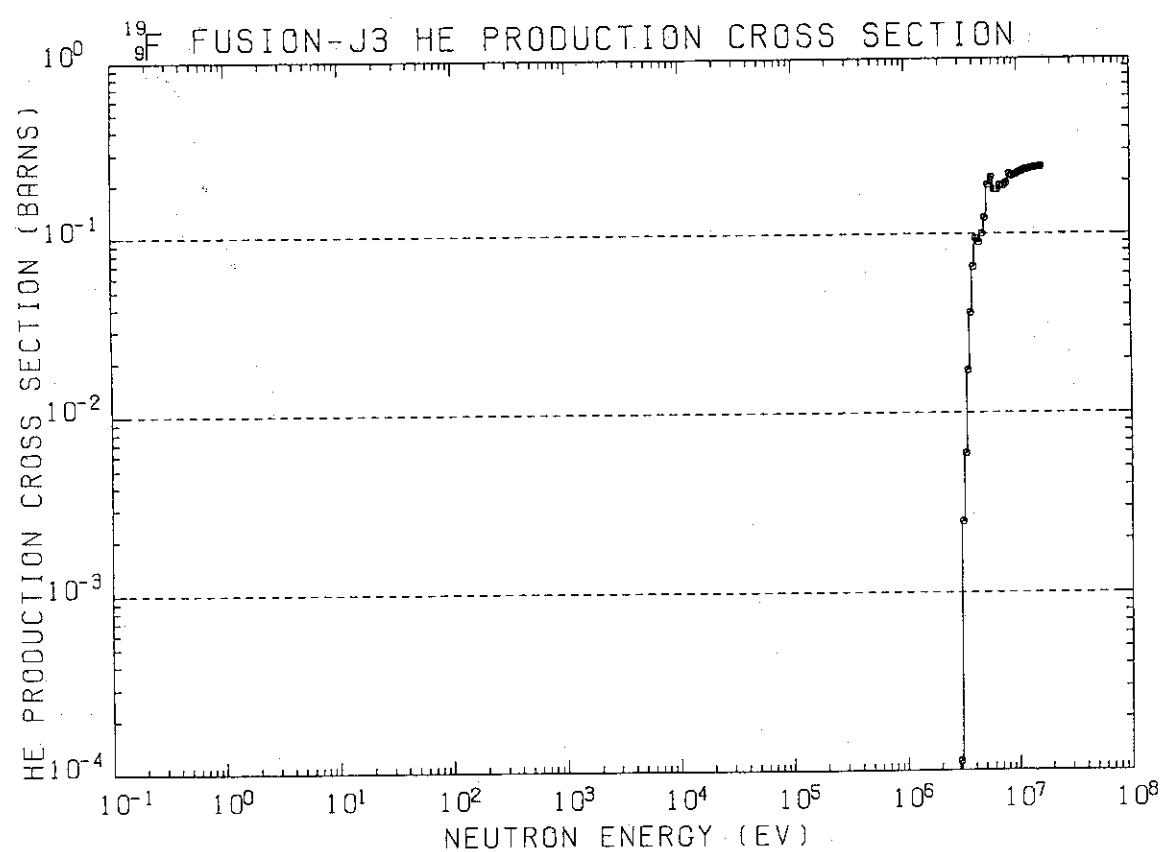
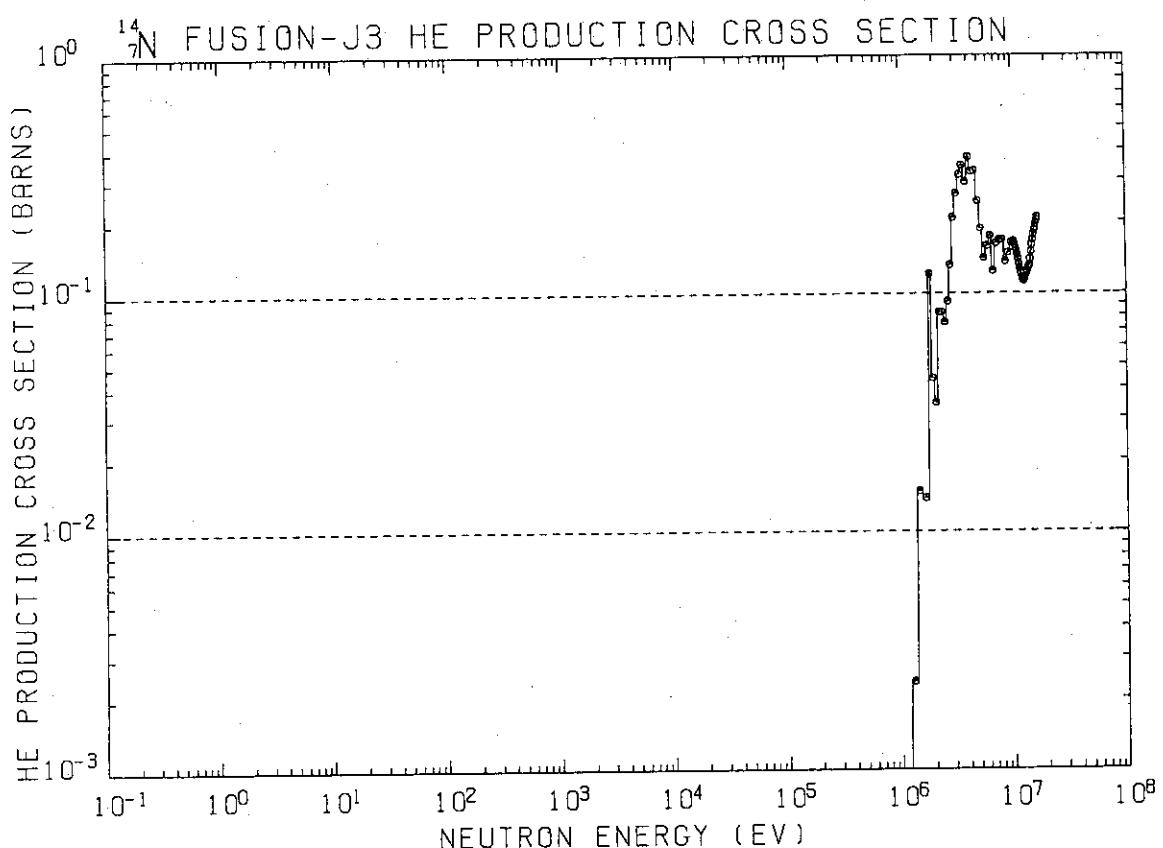
The three libraries are presented in graphs in the following order :

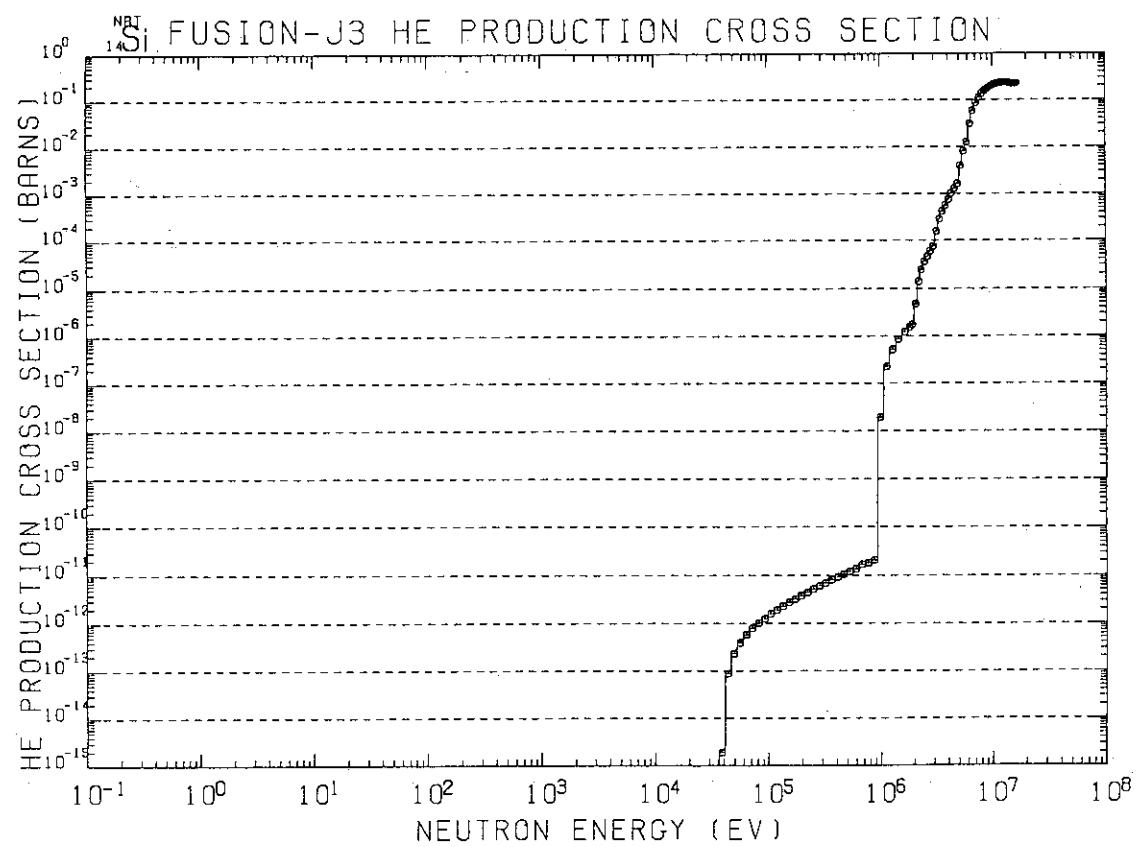
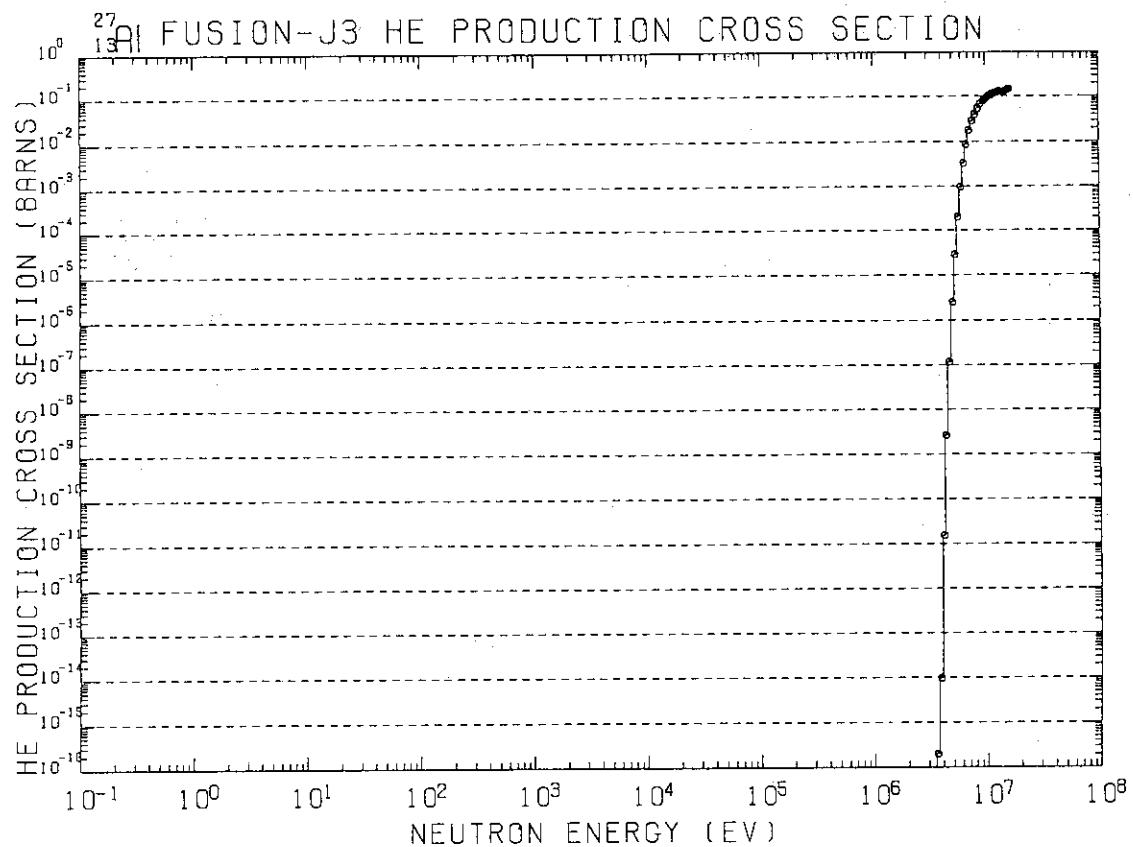
- (1) Helium production cross section library (I)
 Neutron 125 groups
 Group structure of FUSION-J3 (see Table 2.1)
 21 nuclides (see Table 2.3)
- (2) Helium production cross section library (II)
 Neutron 42 groups
 Group structure of FUSION-40 (see Table 2.2)
 21 nuclides (see Table 2.3)
- (3) Hydrogen production cross section library
 Neutron 42 groups
 Group structure of FUSION-40 (see Table 2.2)
 20 nuclides (see Table 2.3)

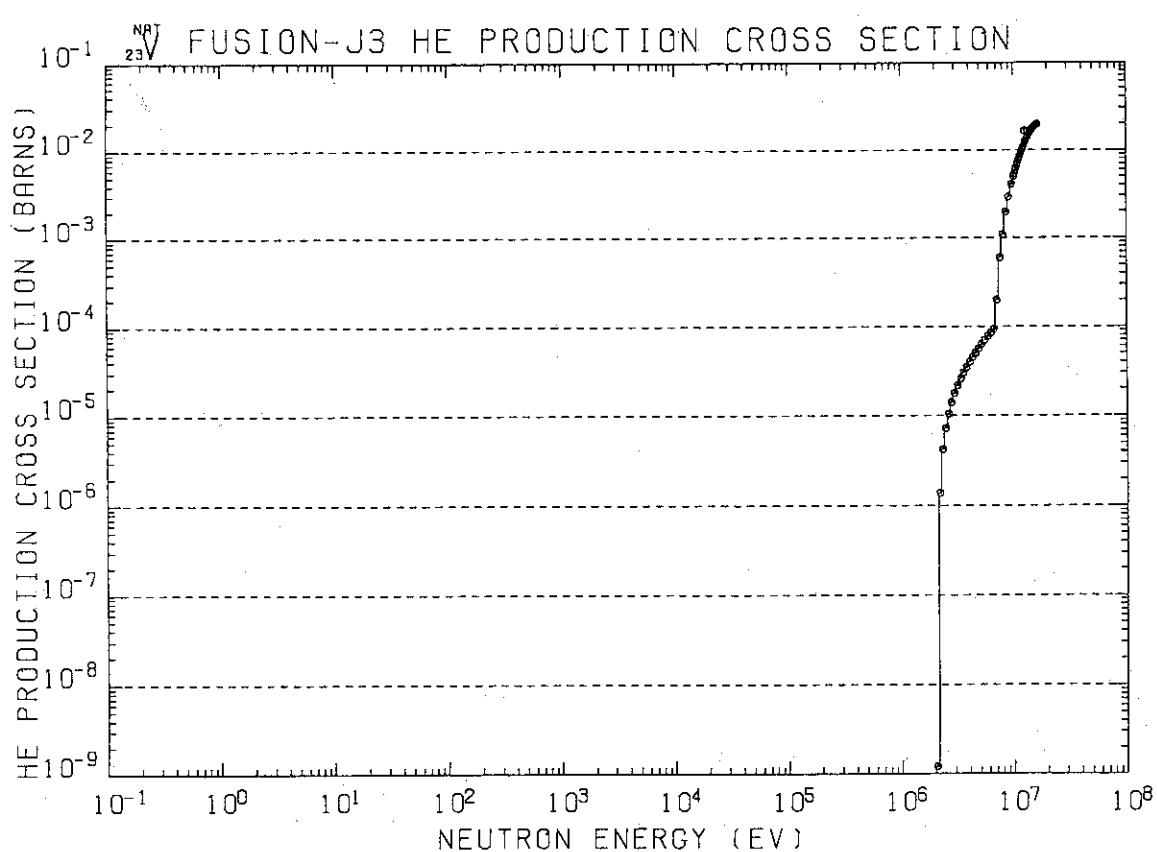
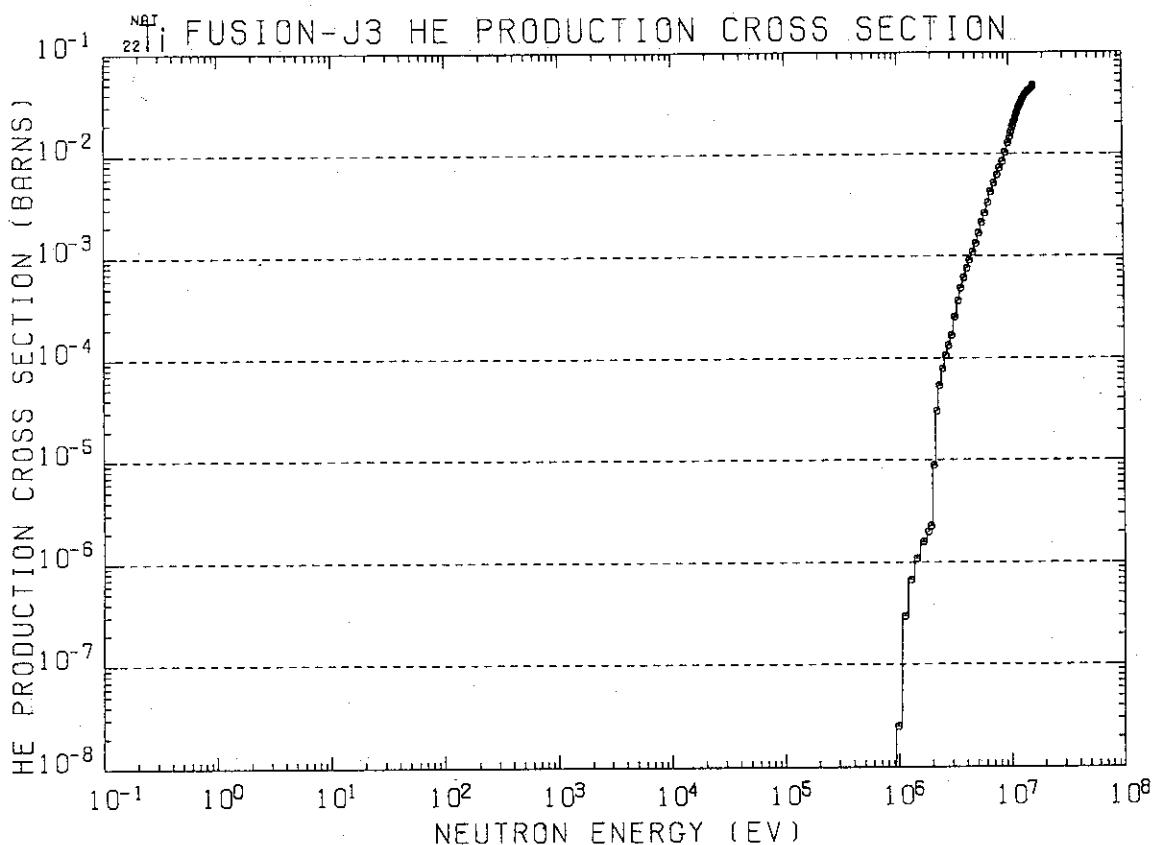


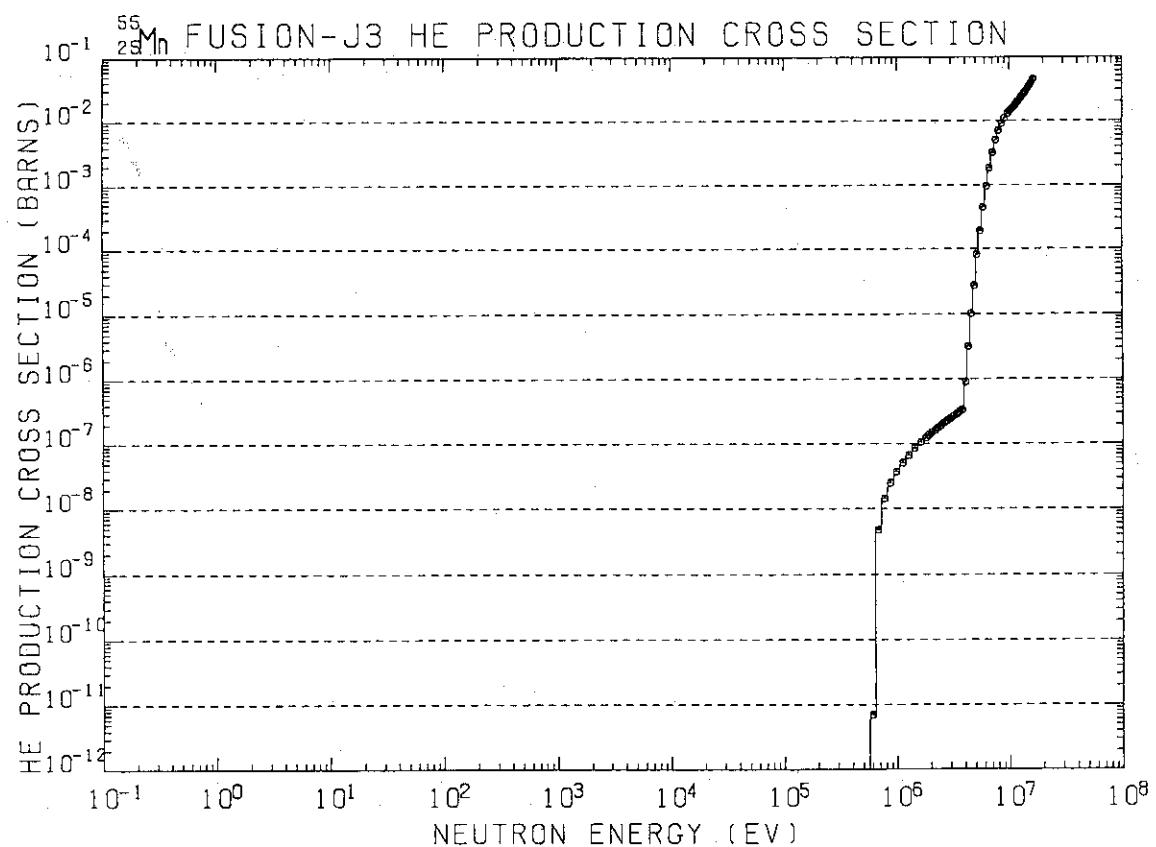
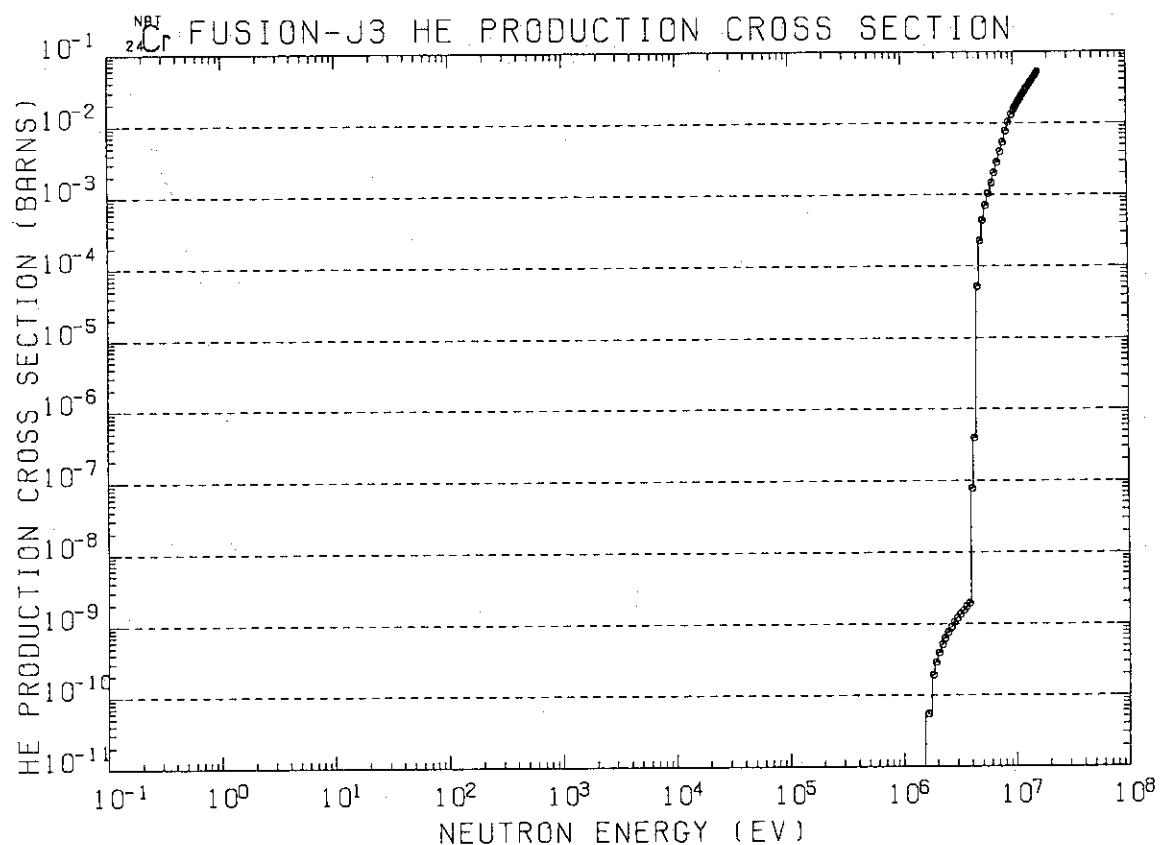


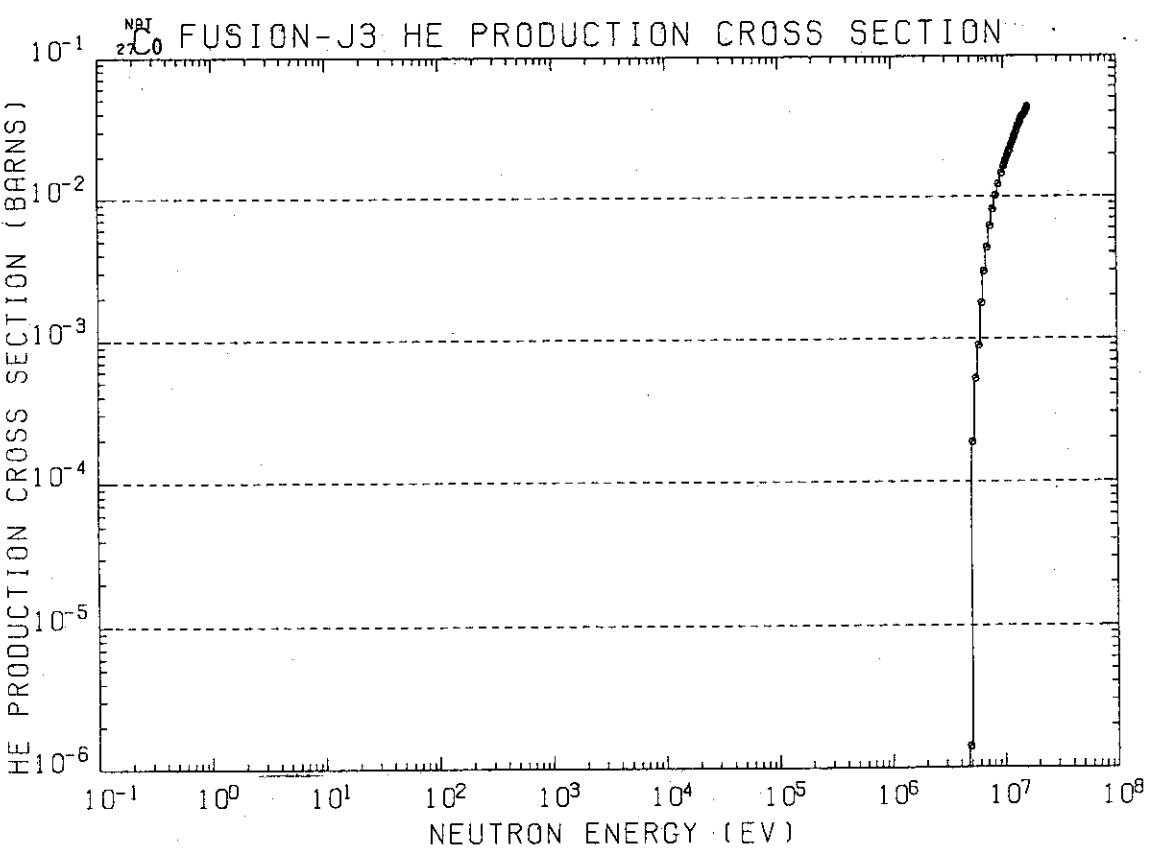
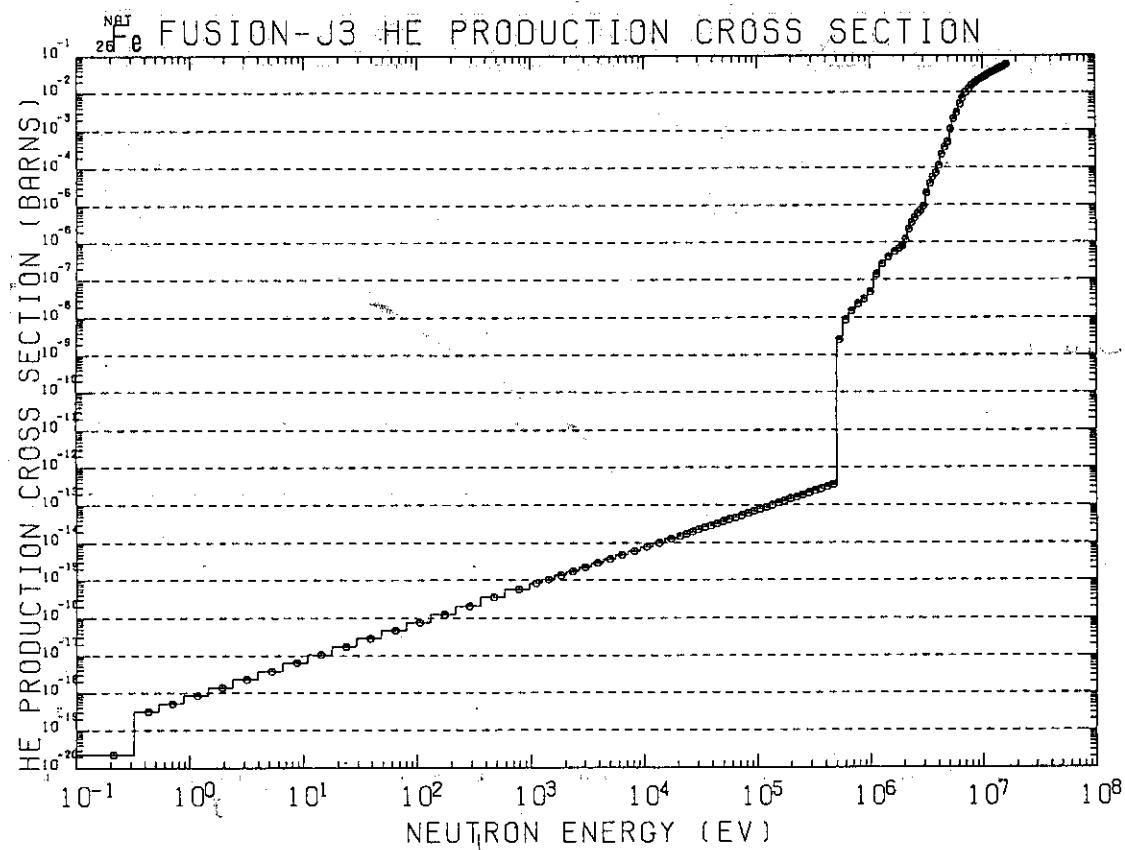


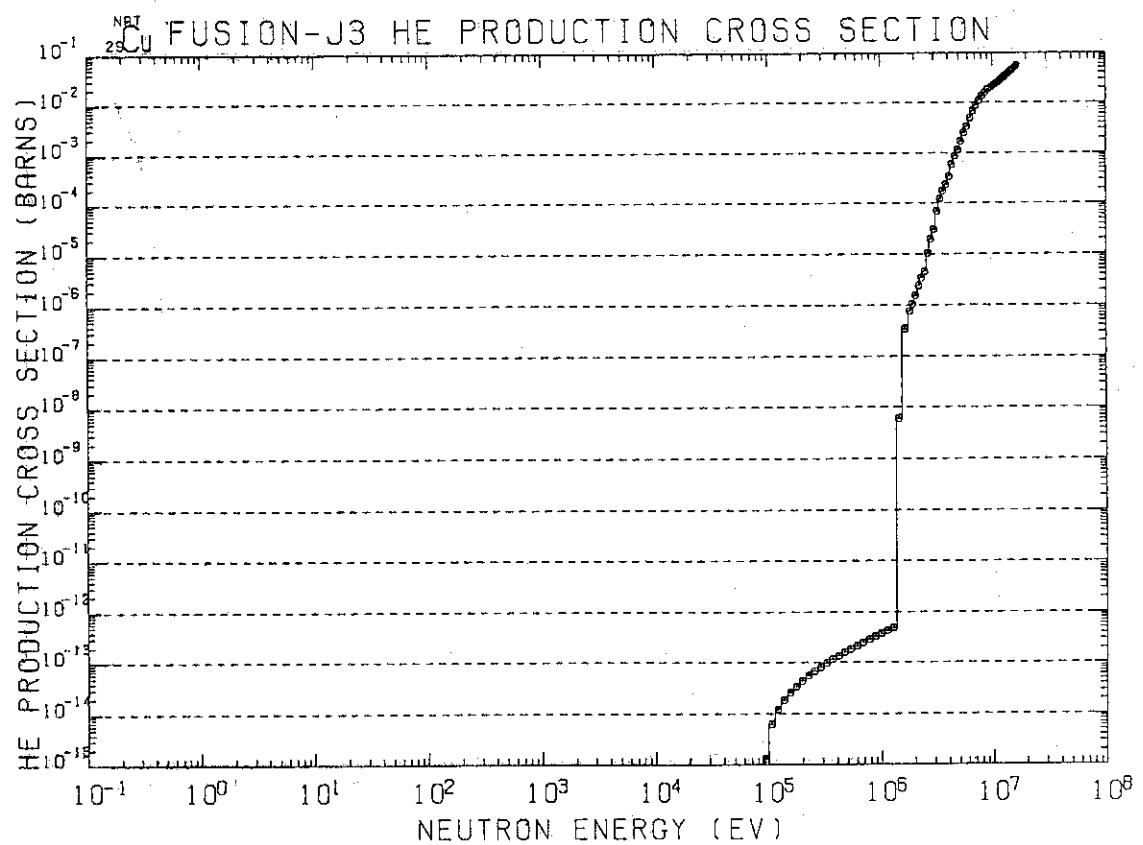
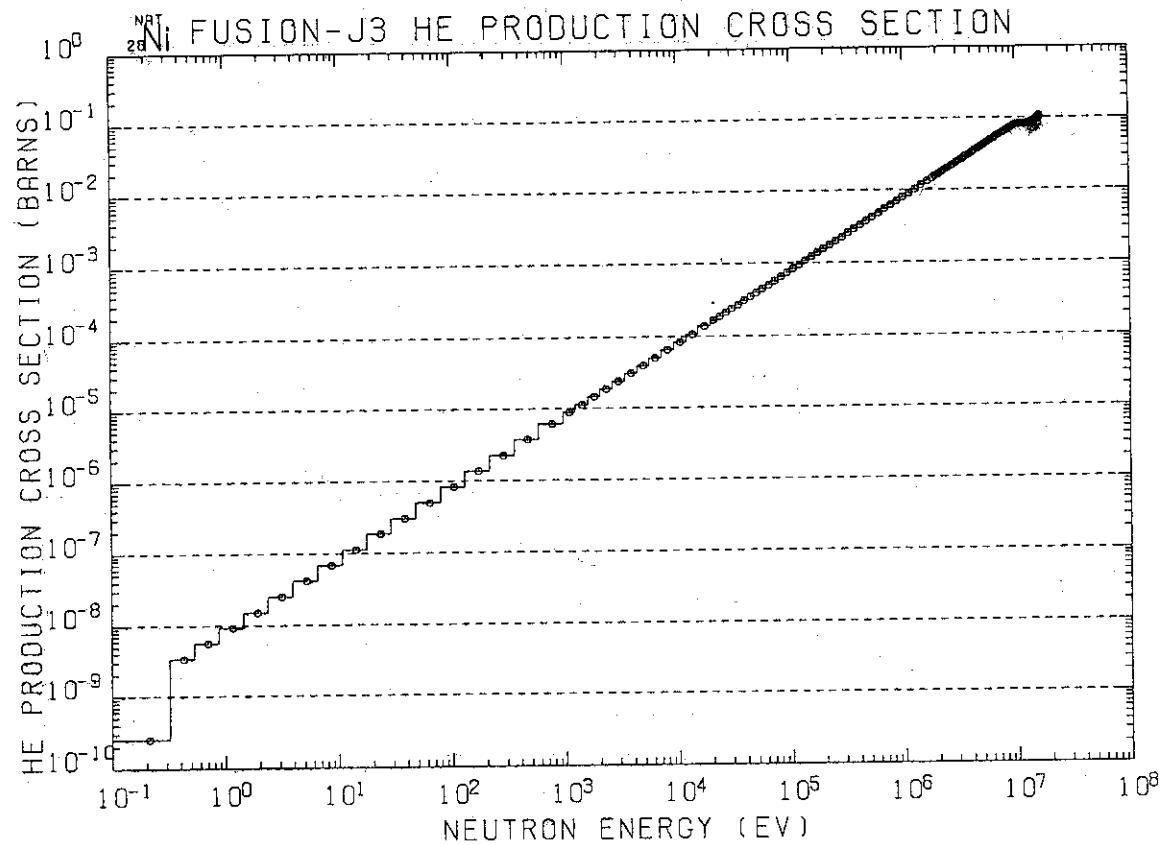


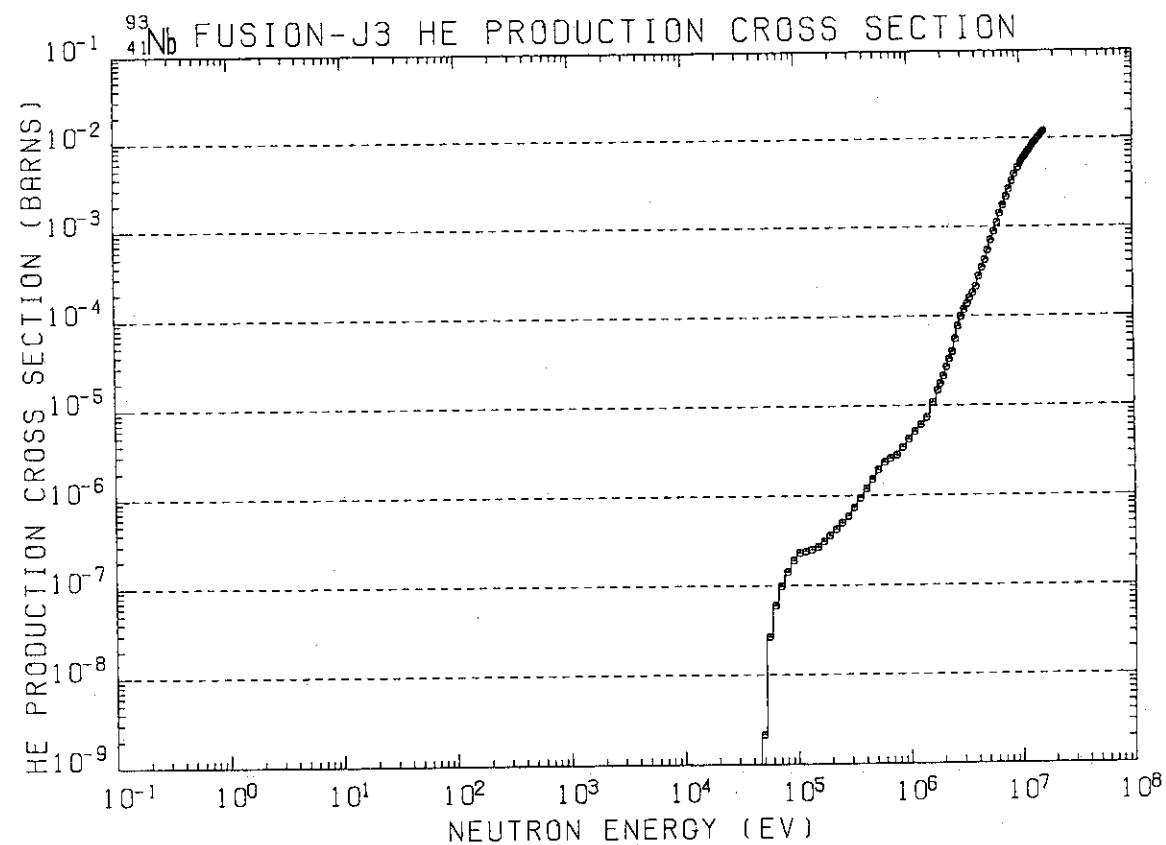
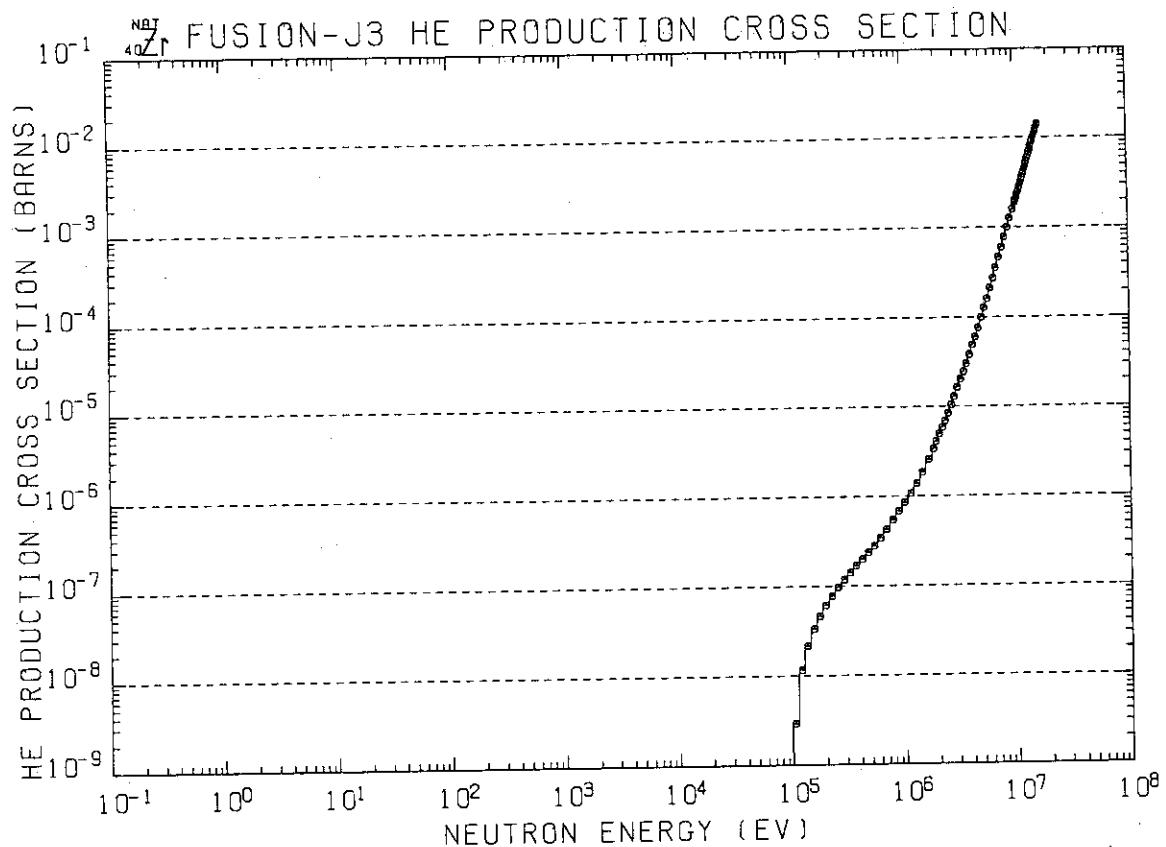


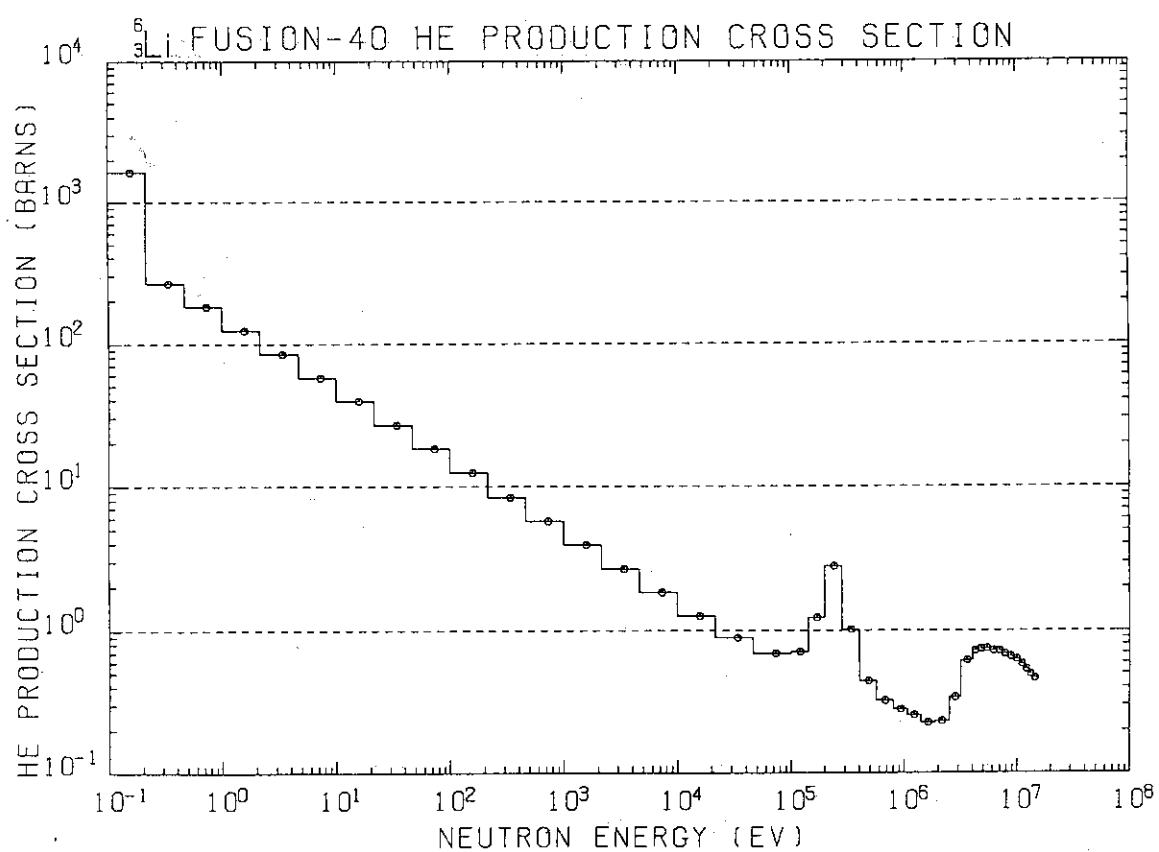
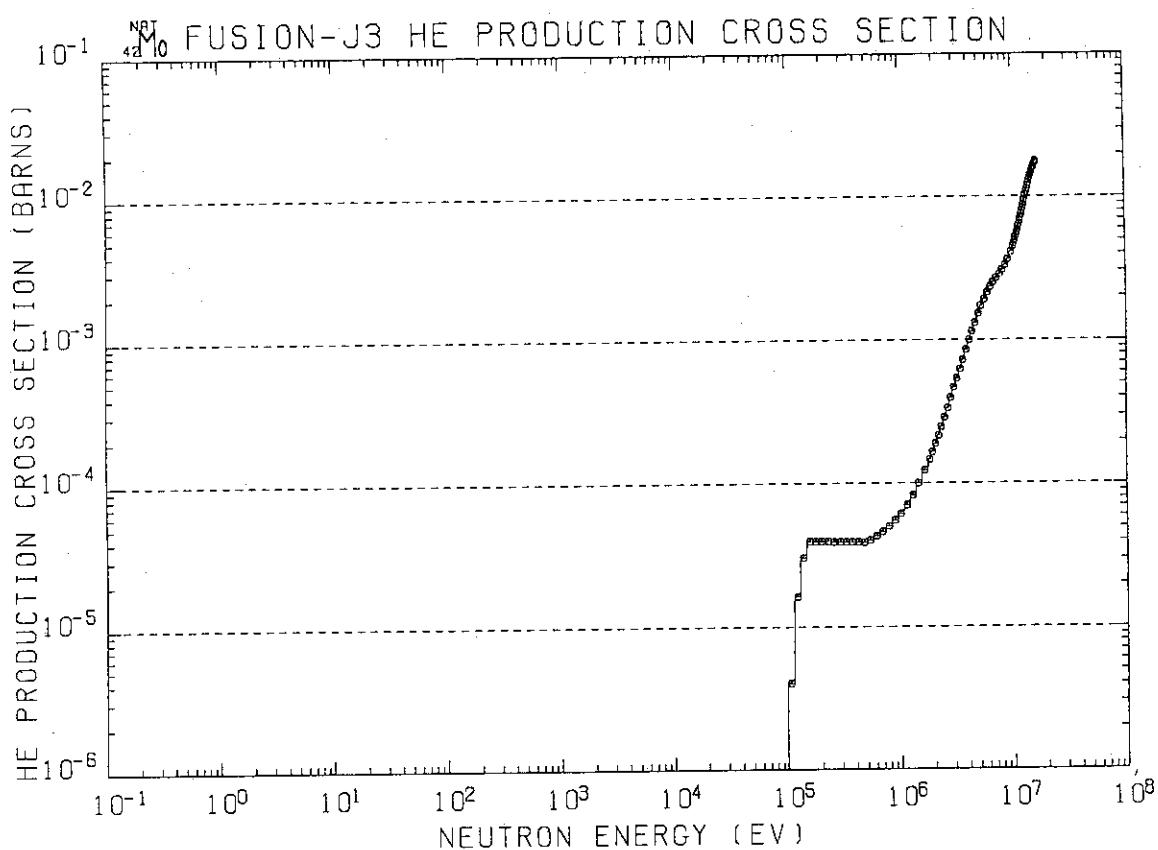


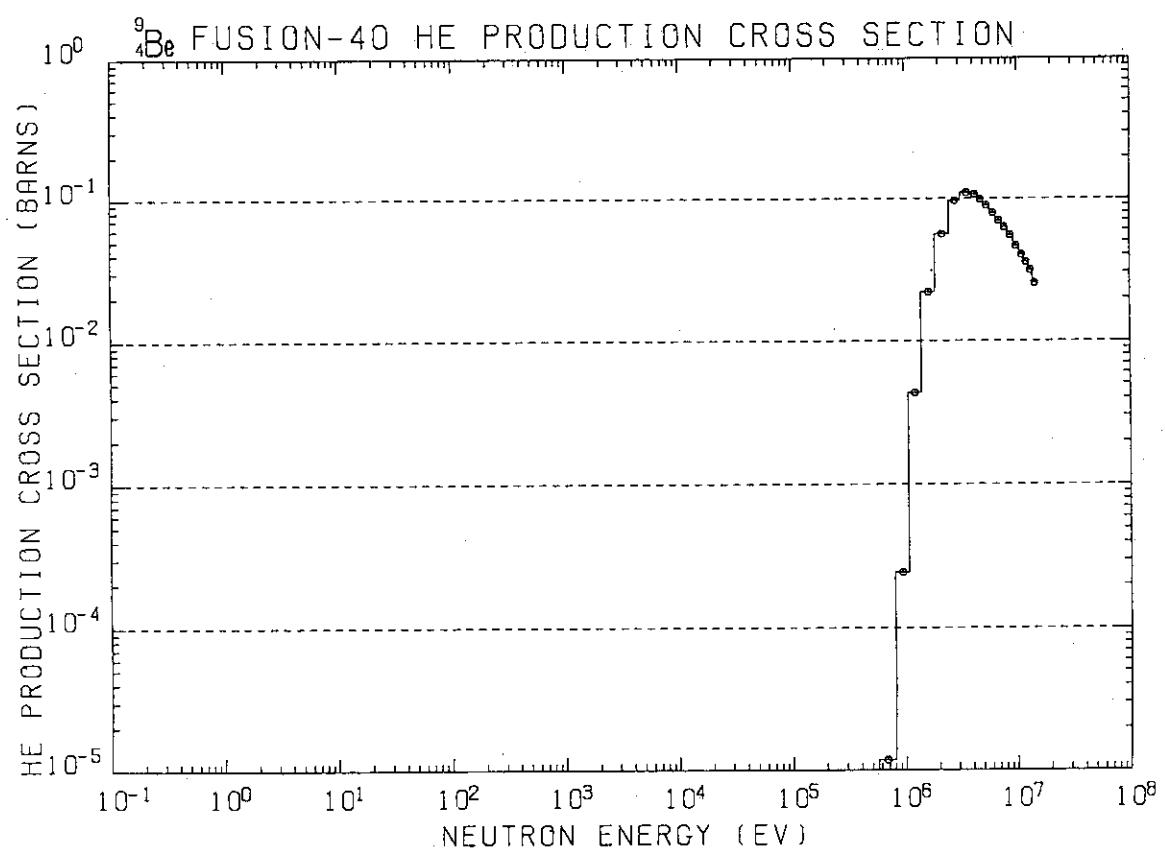
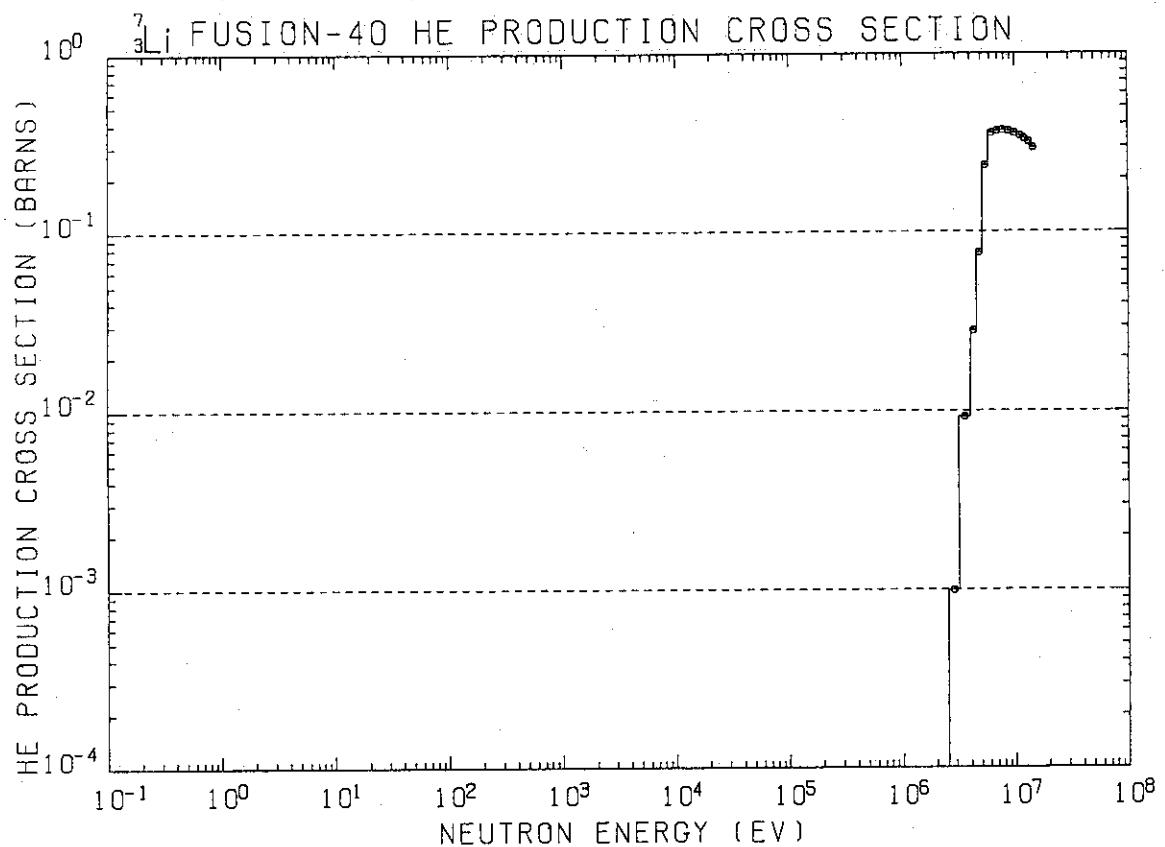


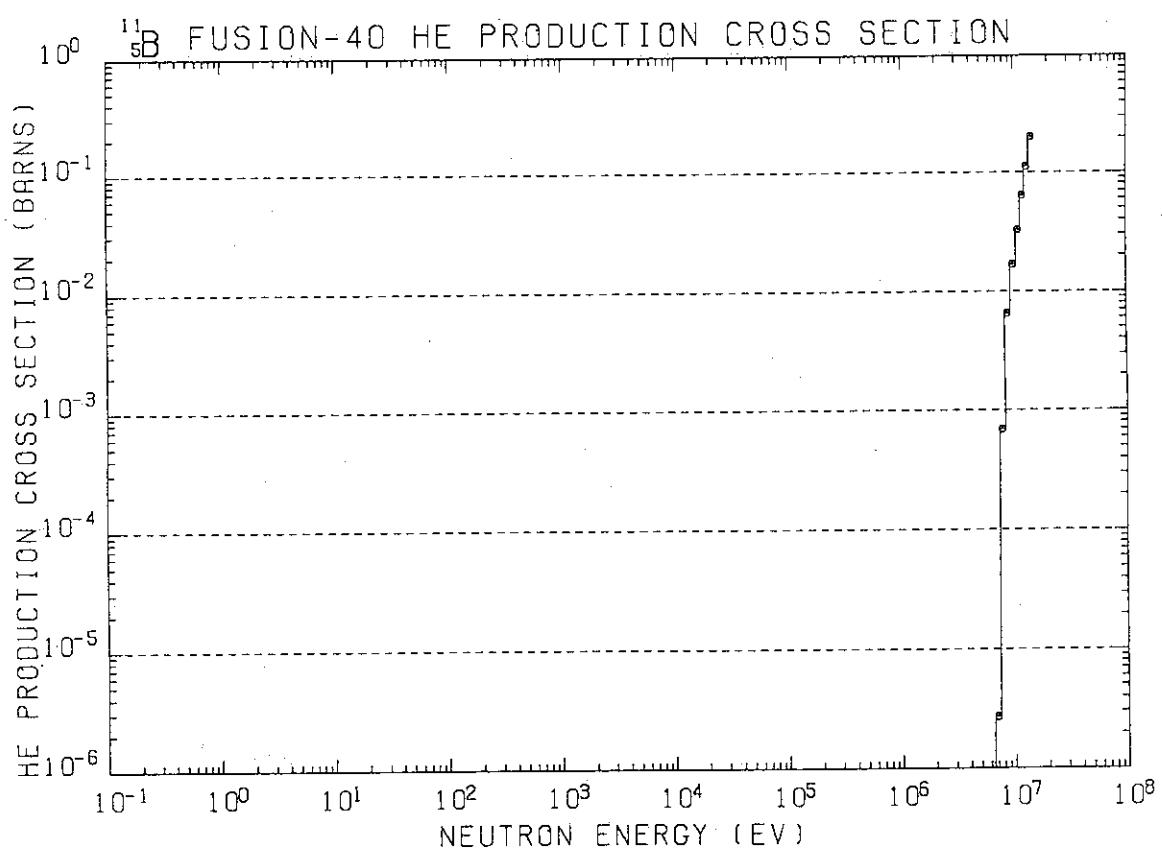
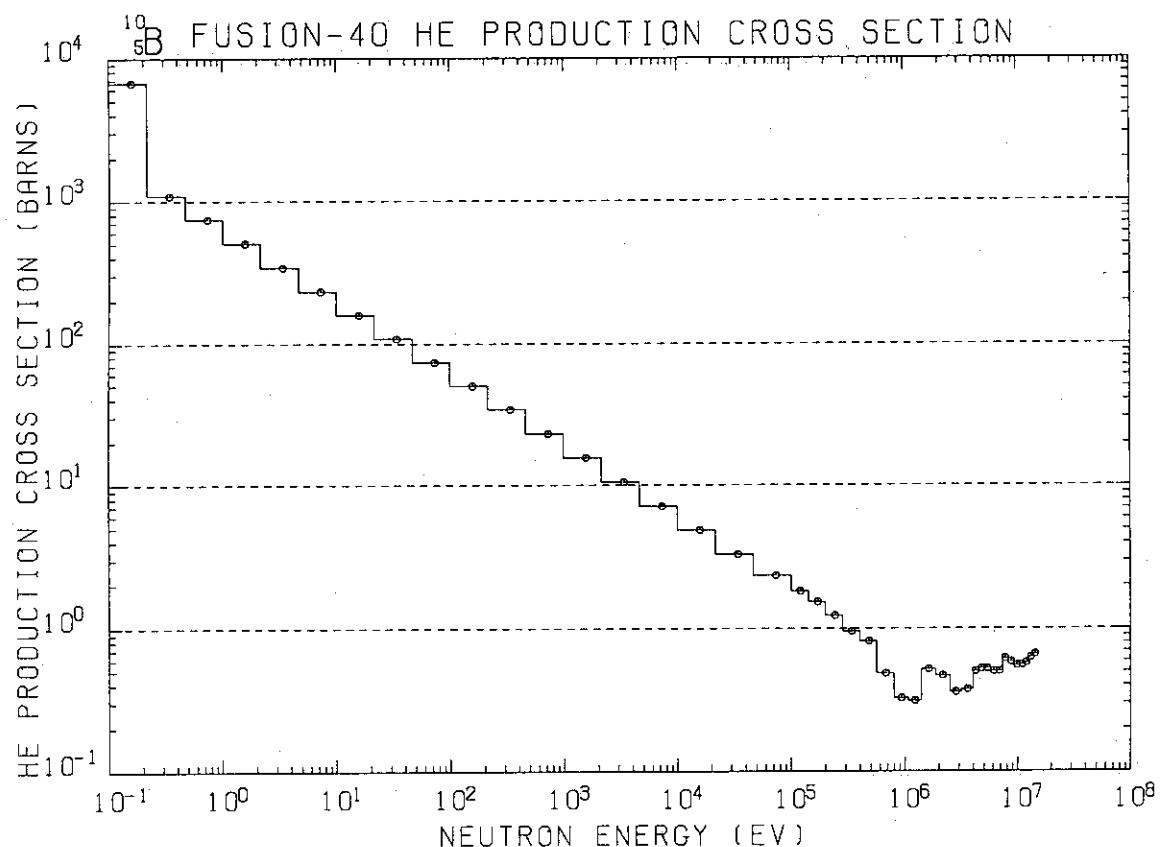


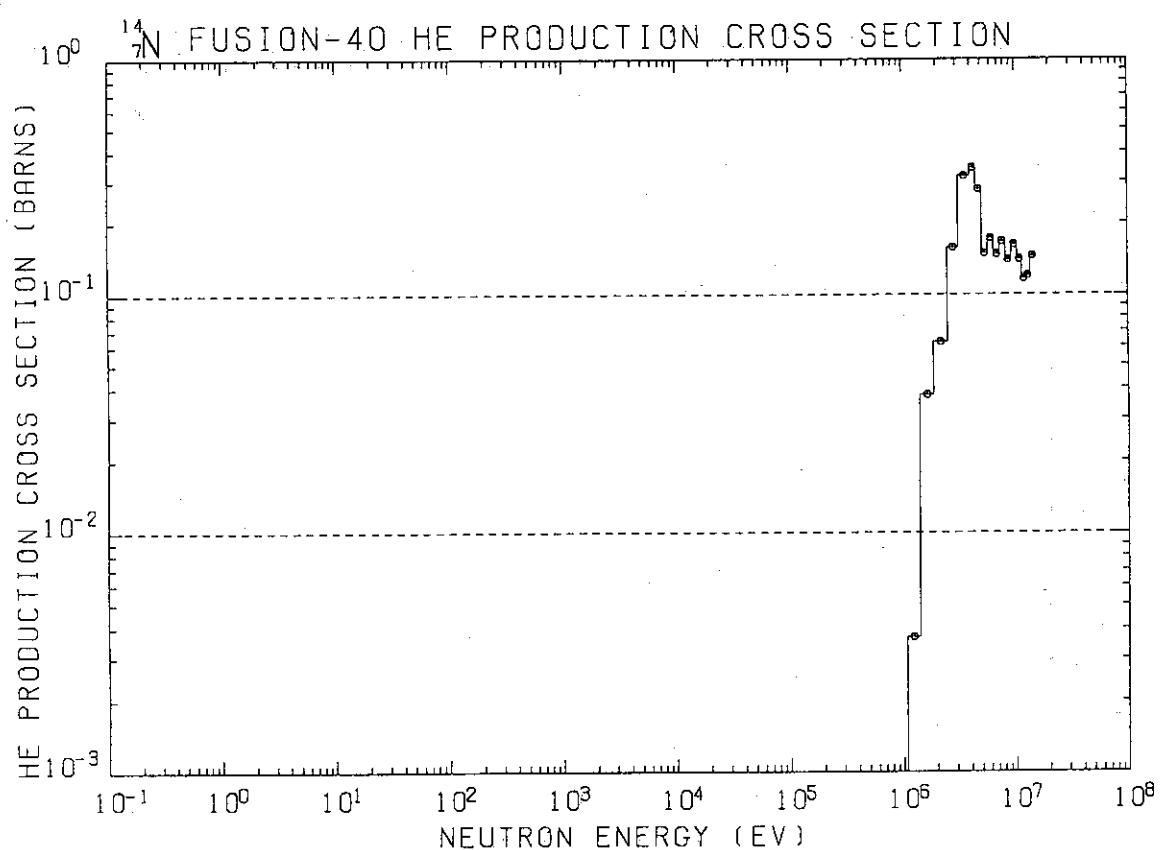
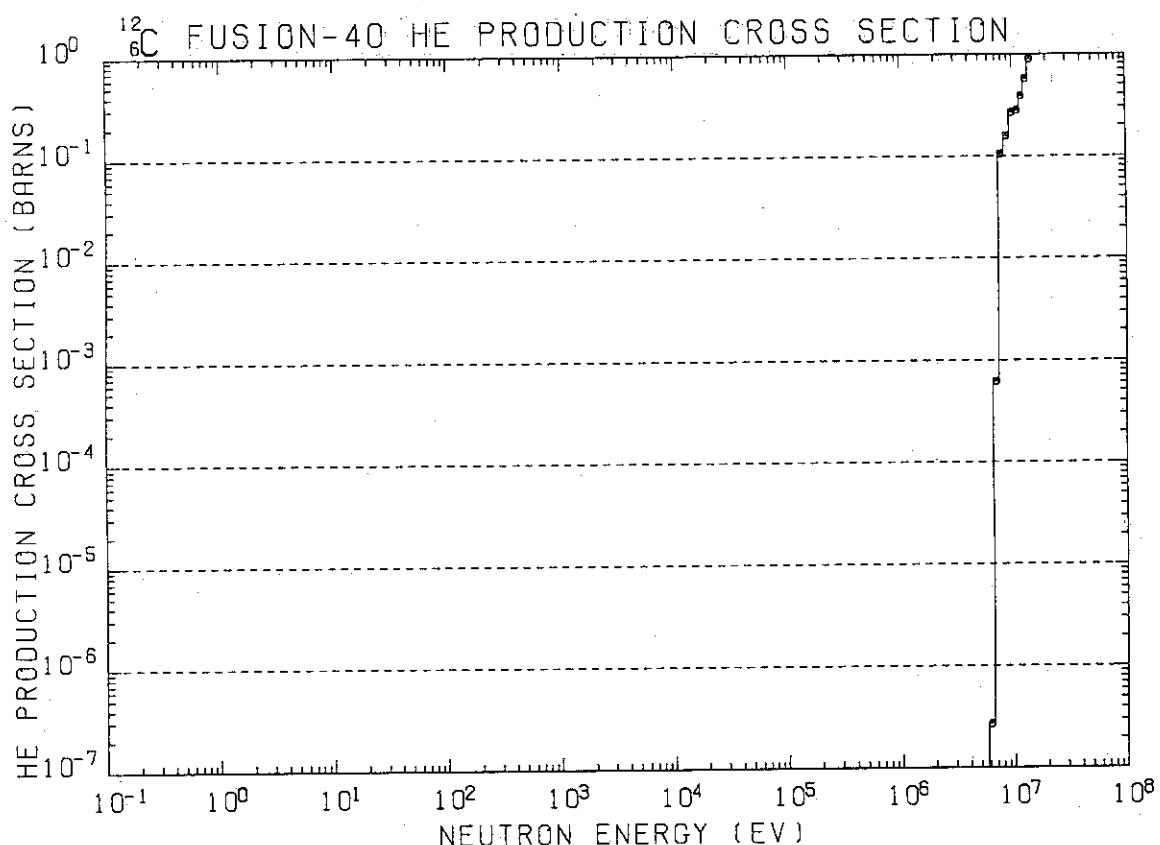


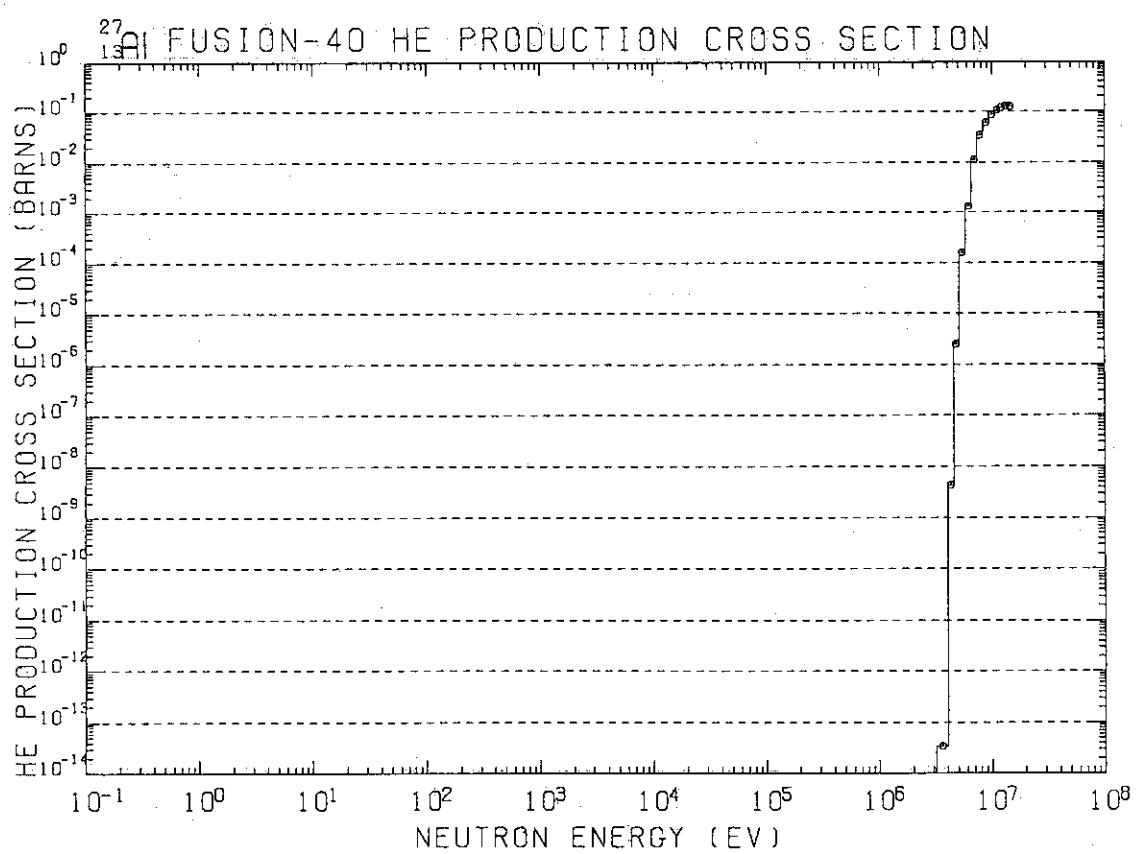
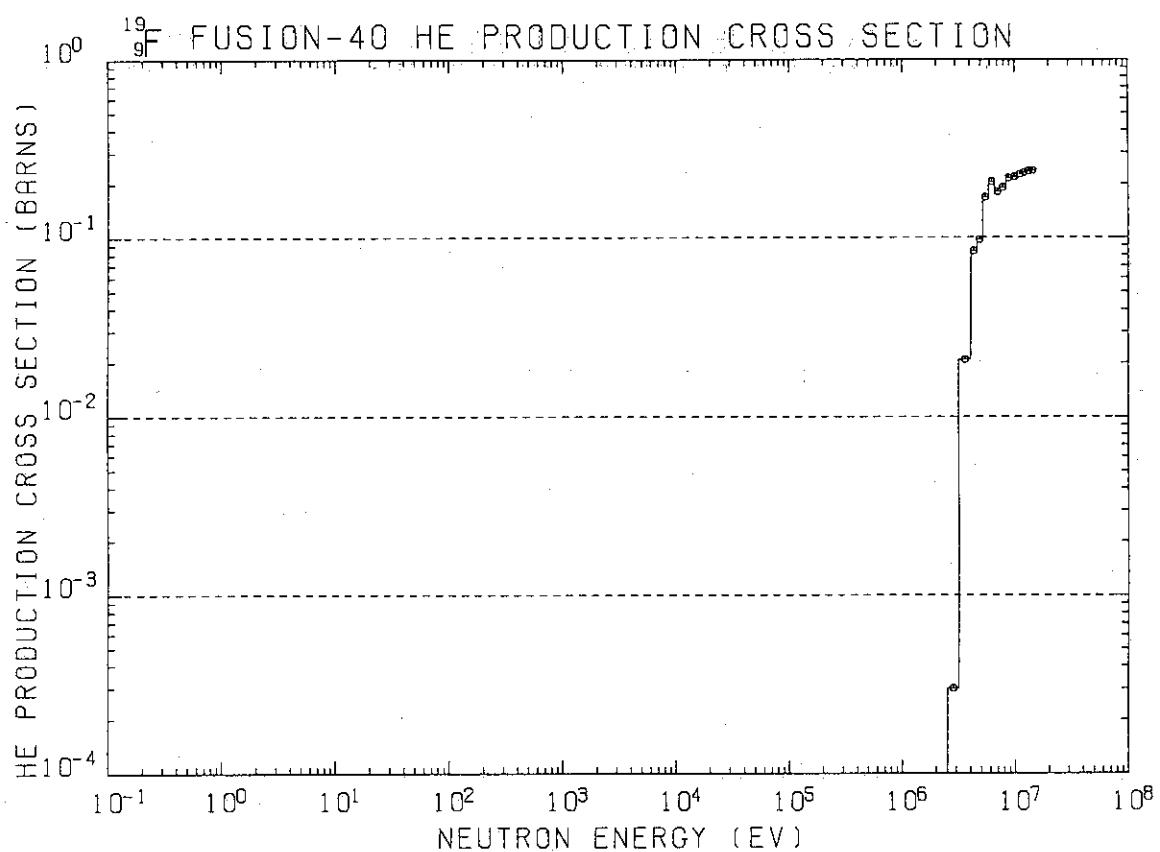


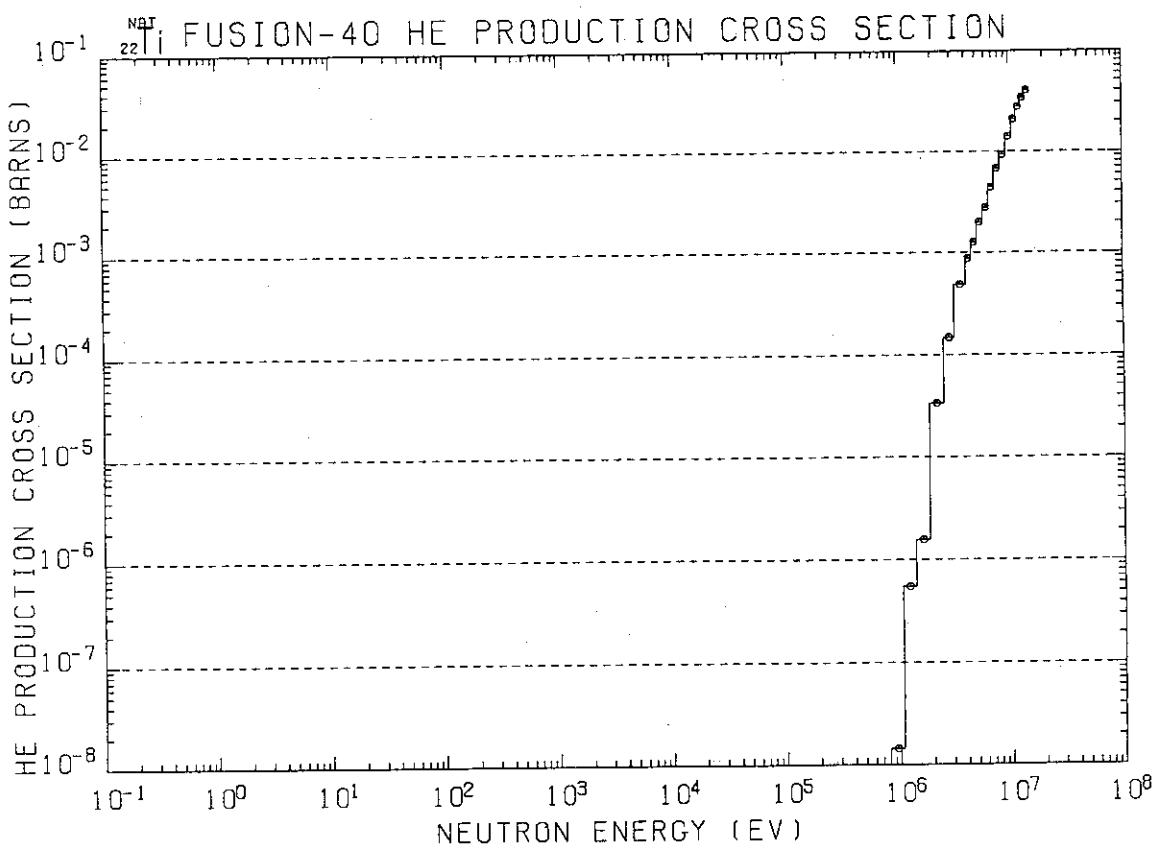
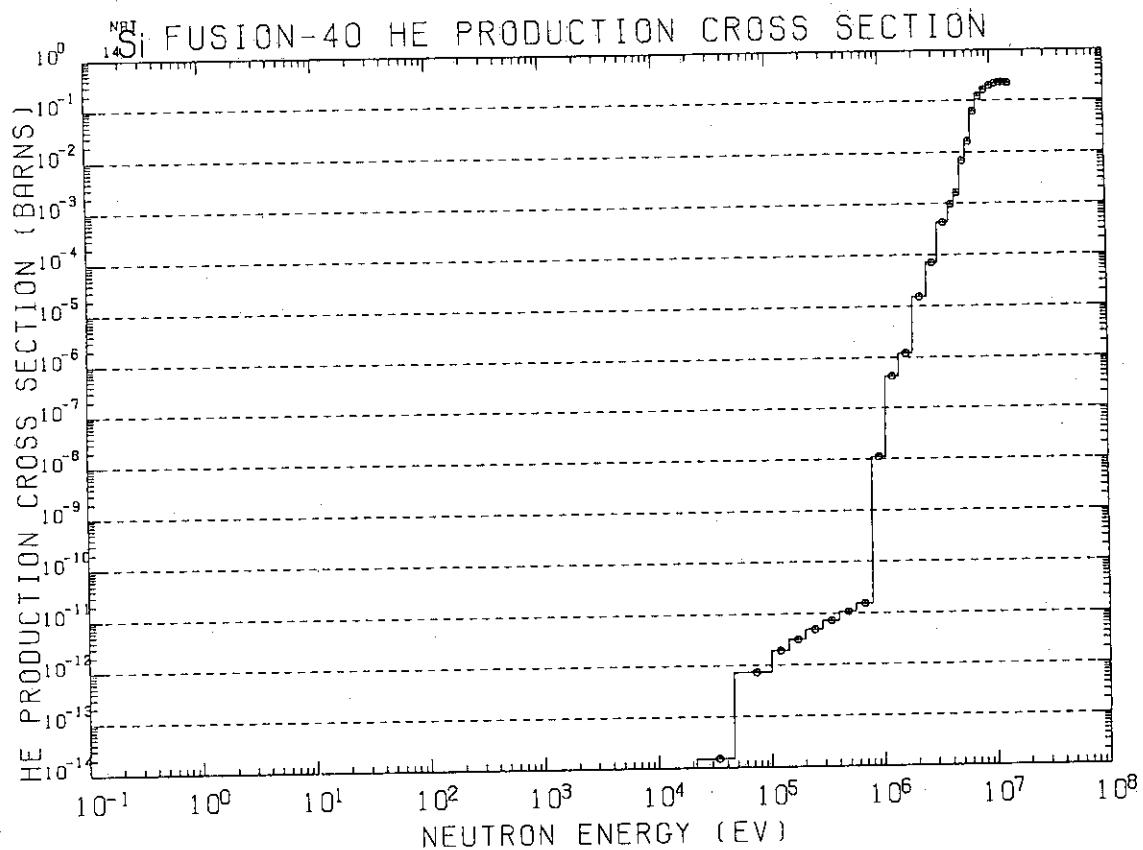


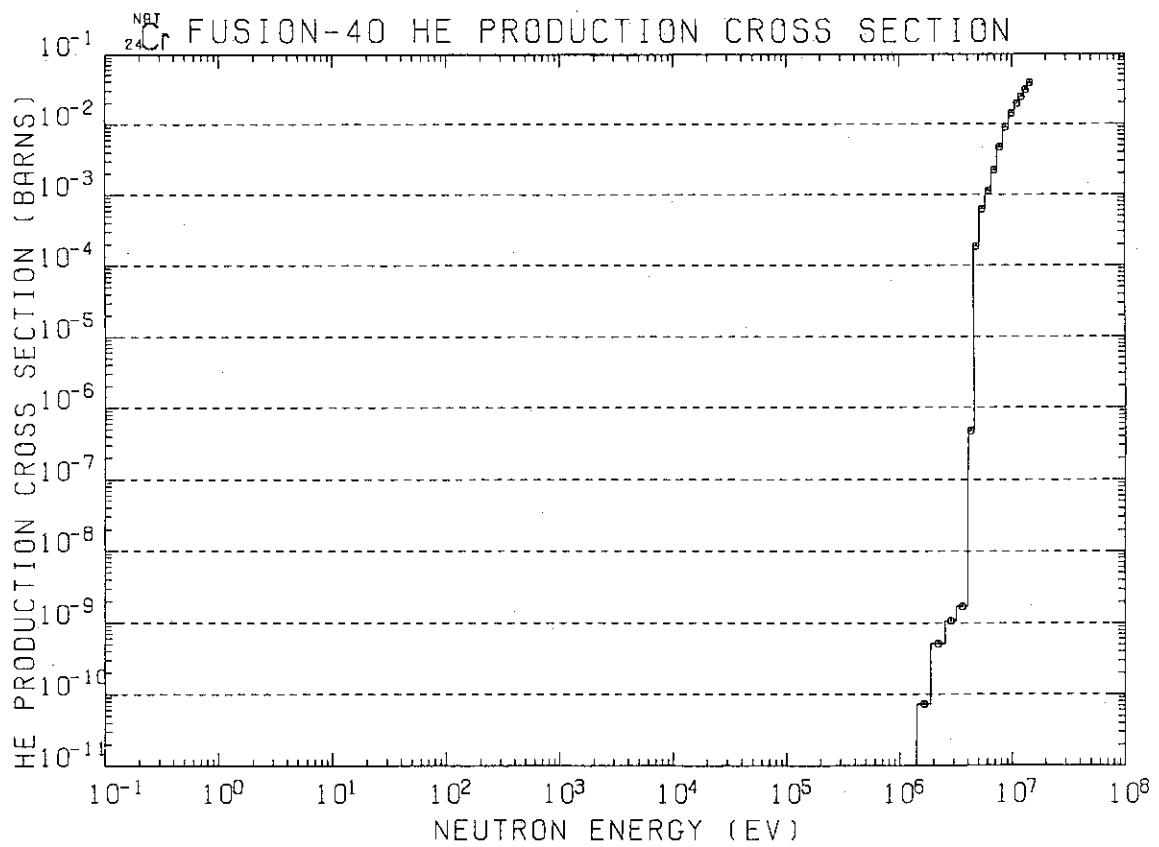
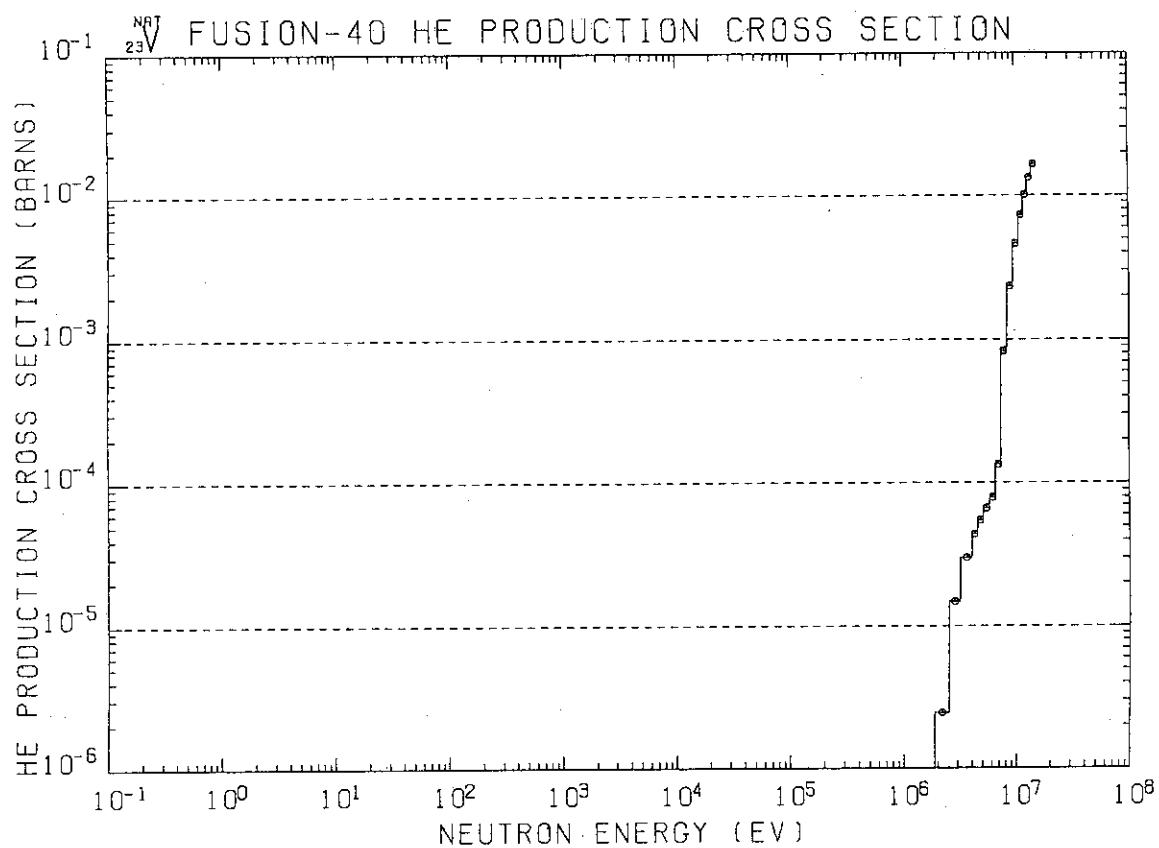


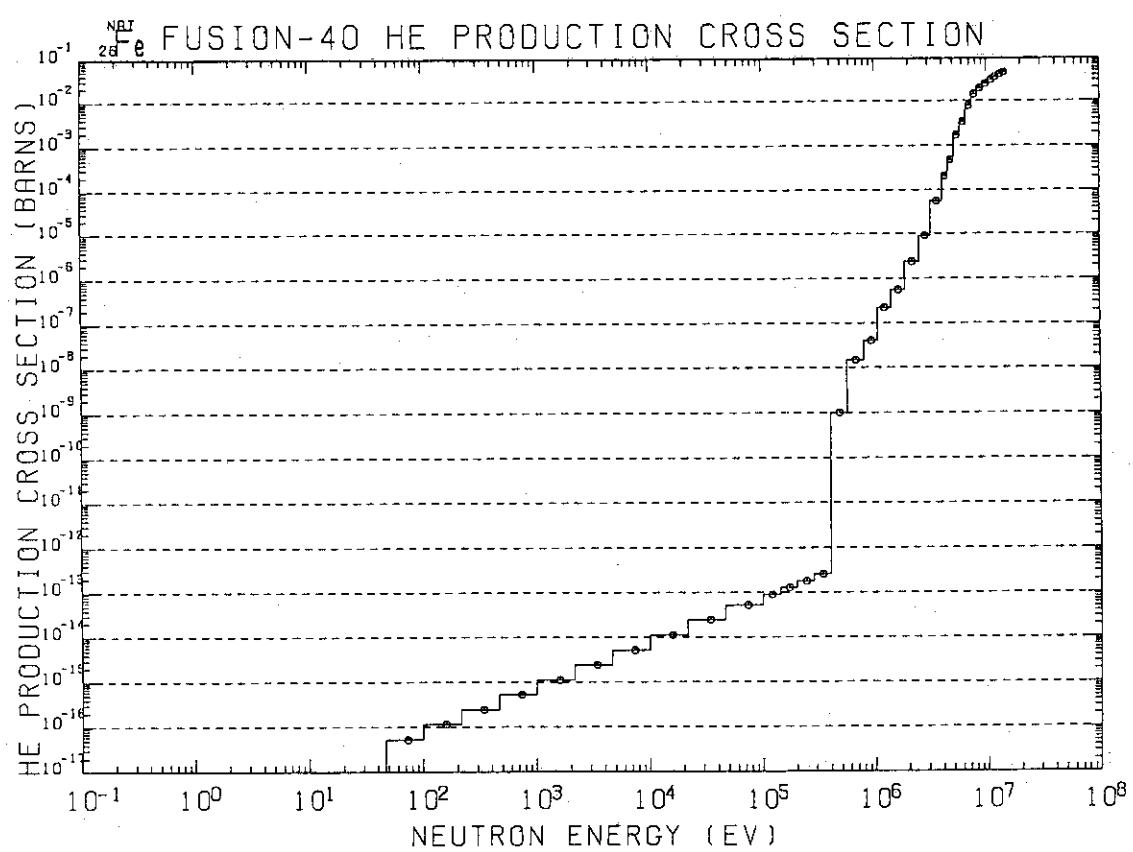
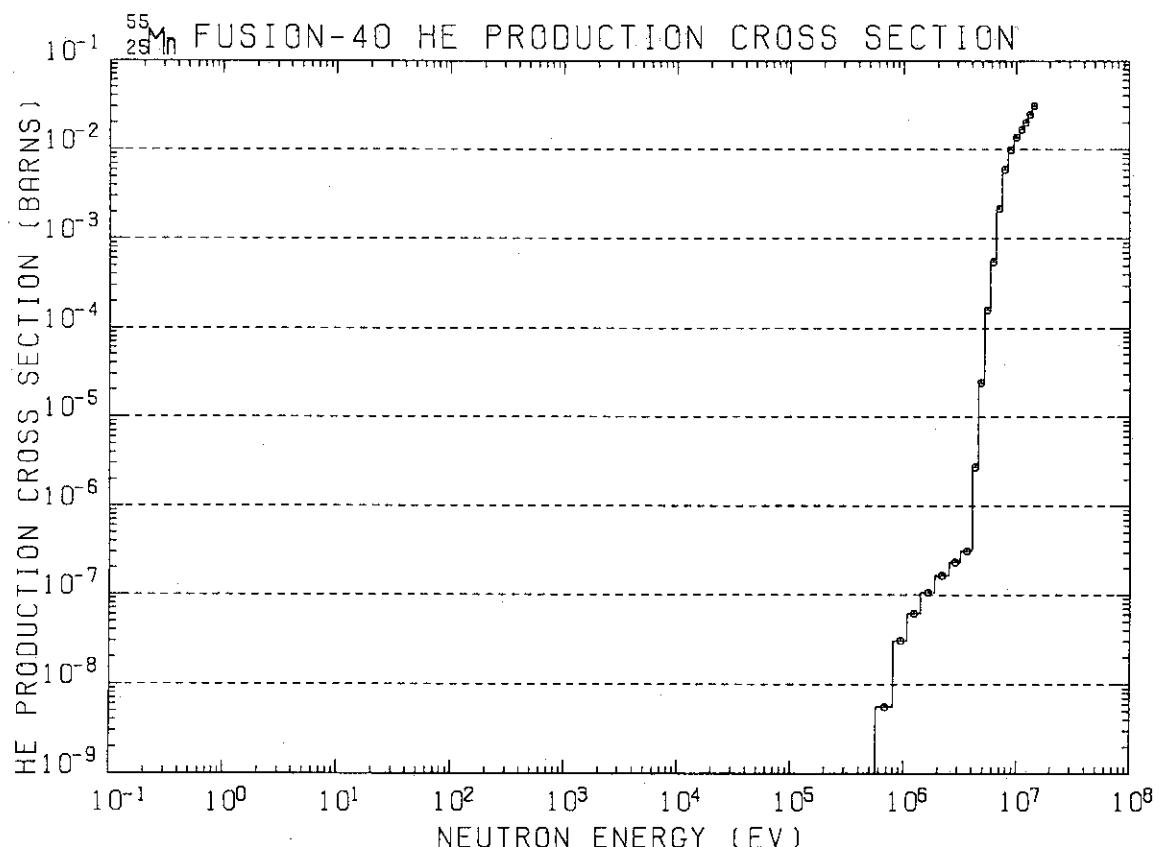


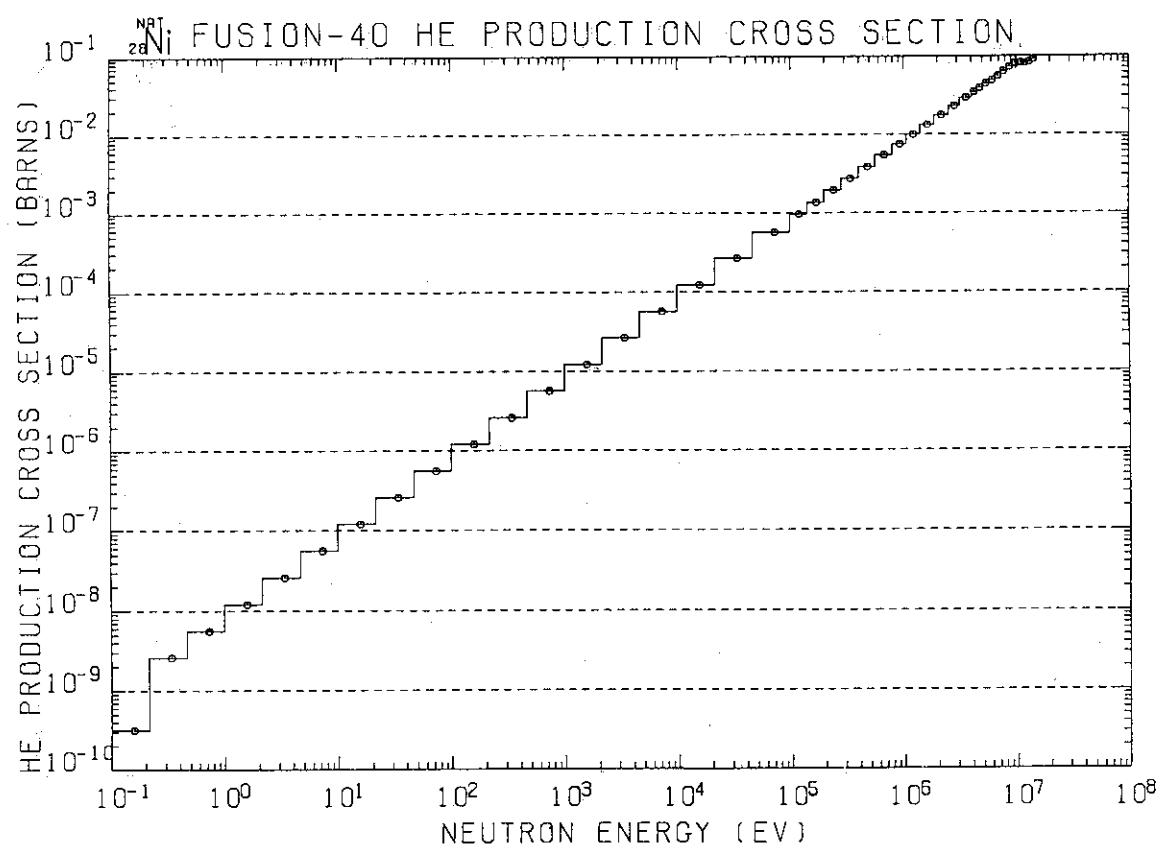
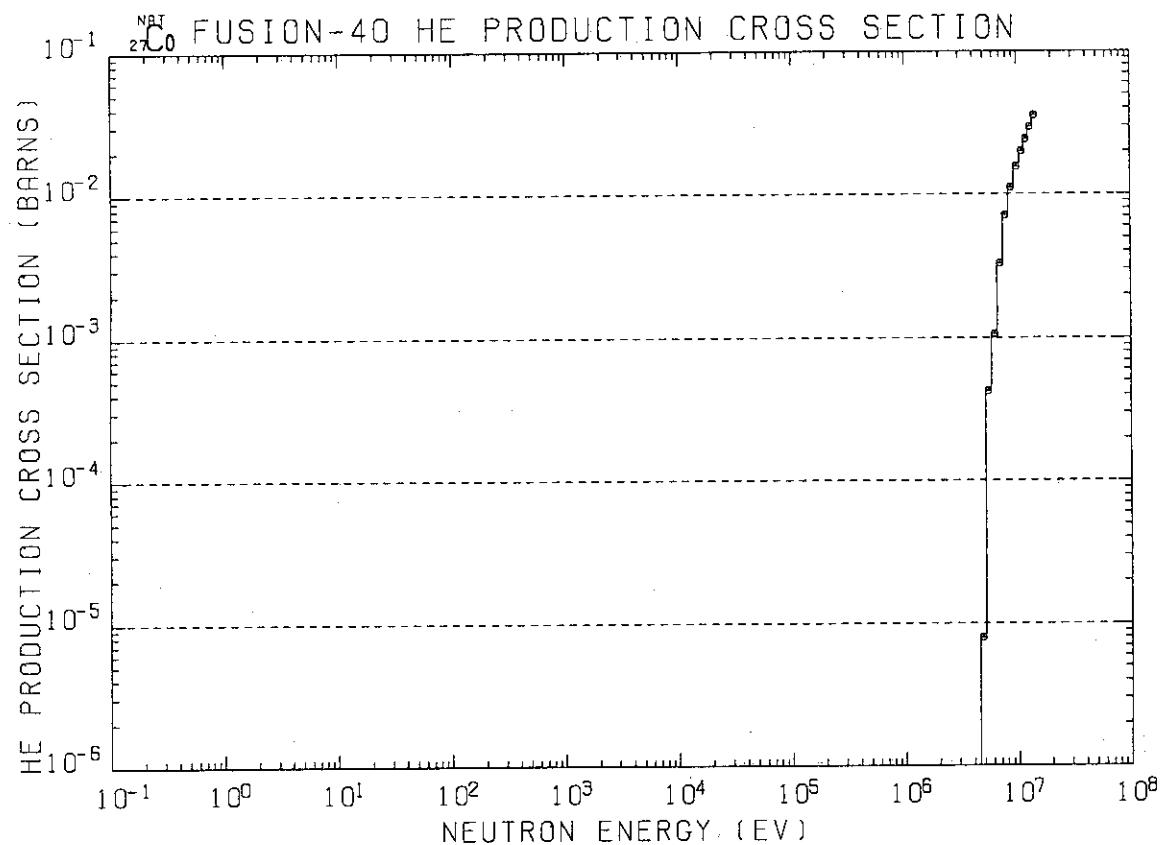


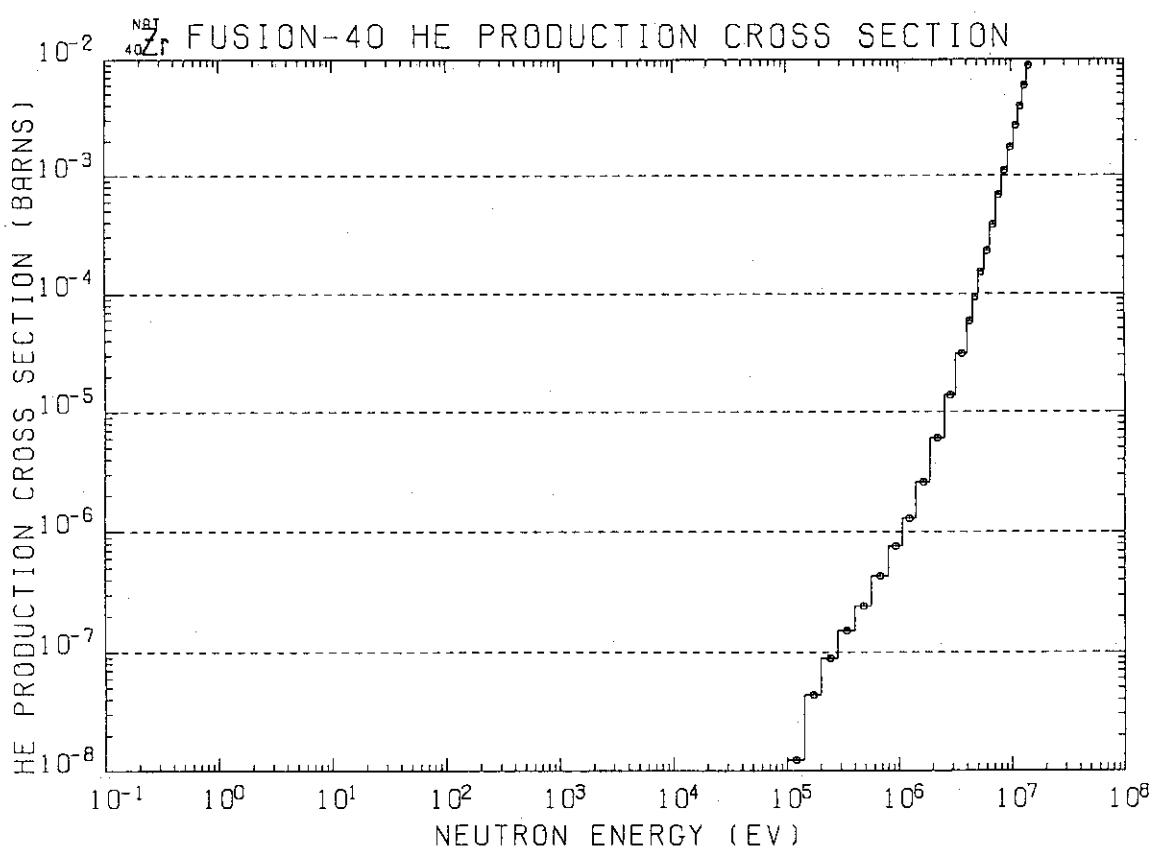
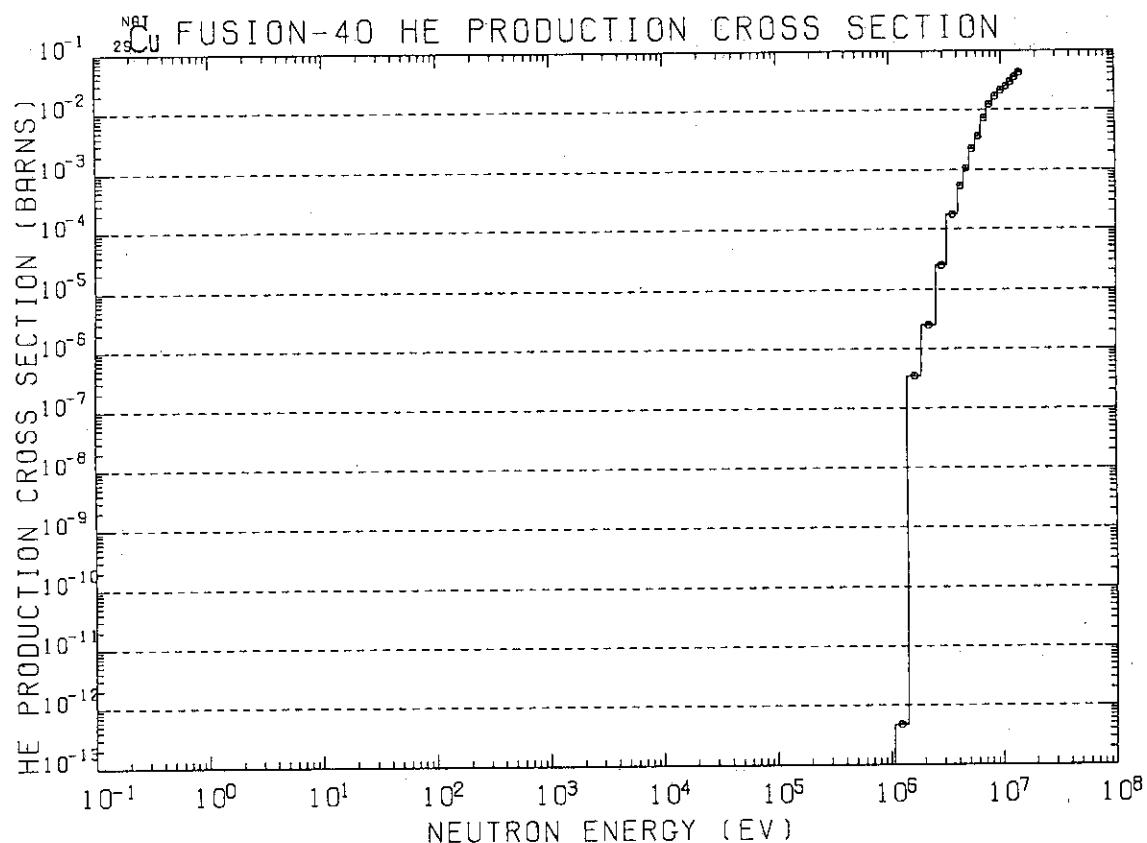


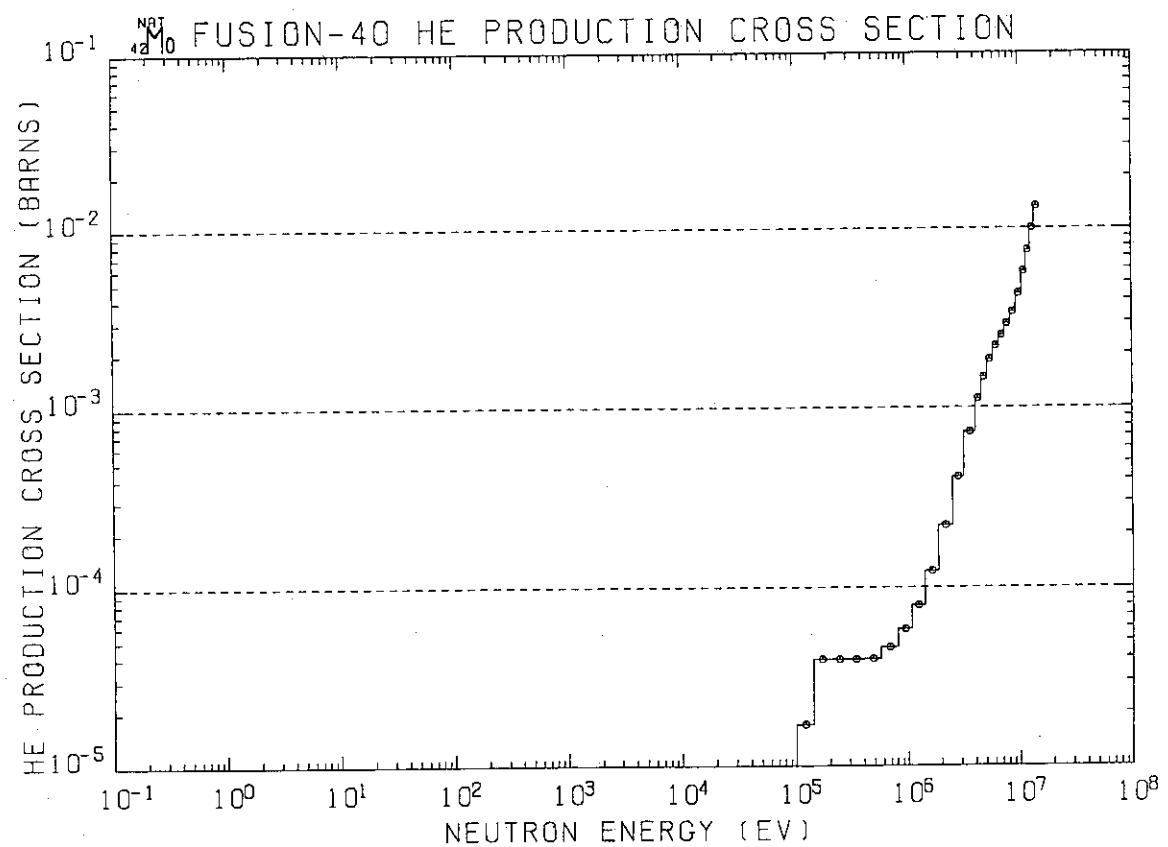
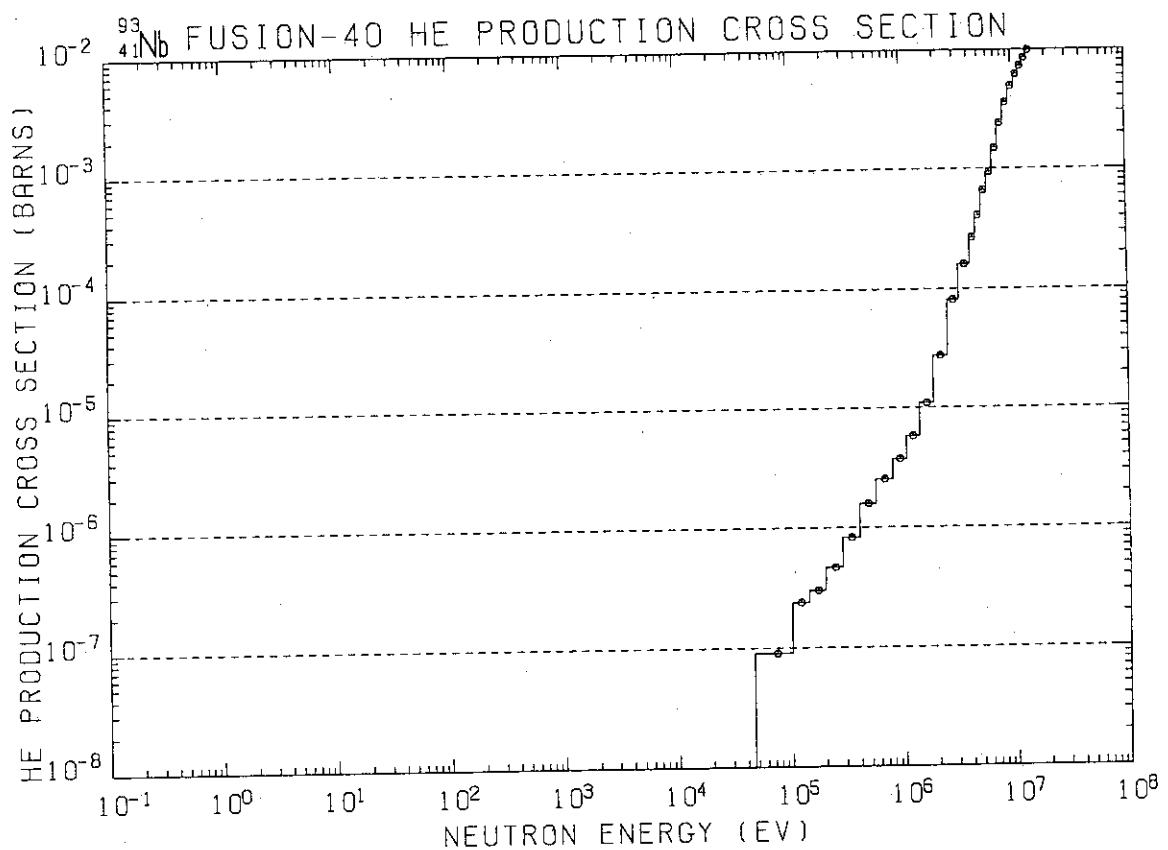


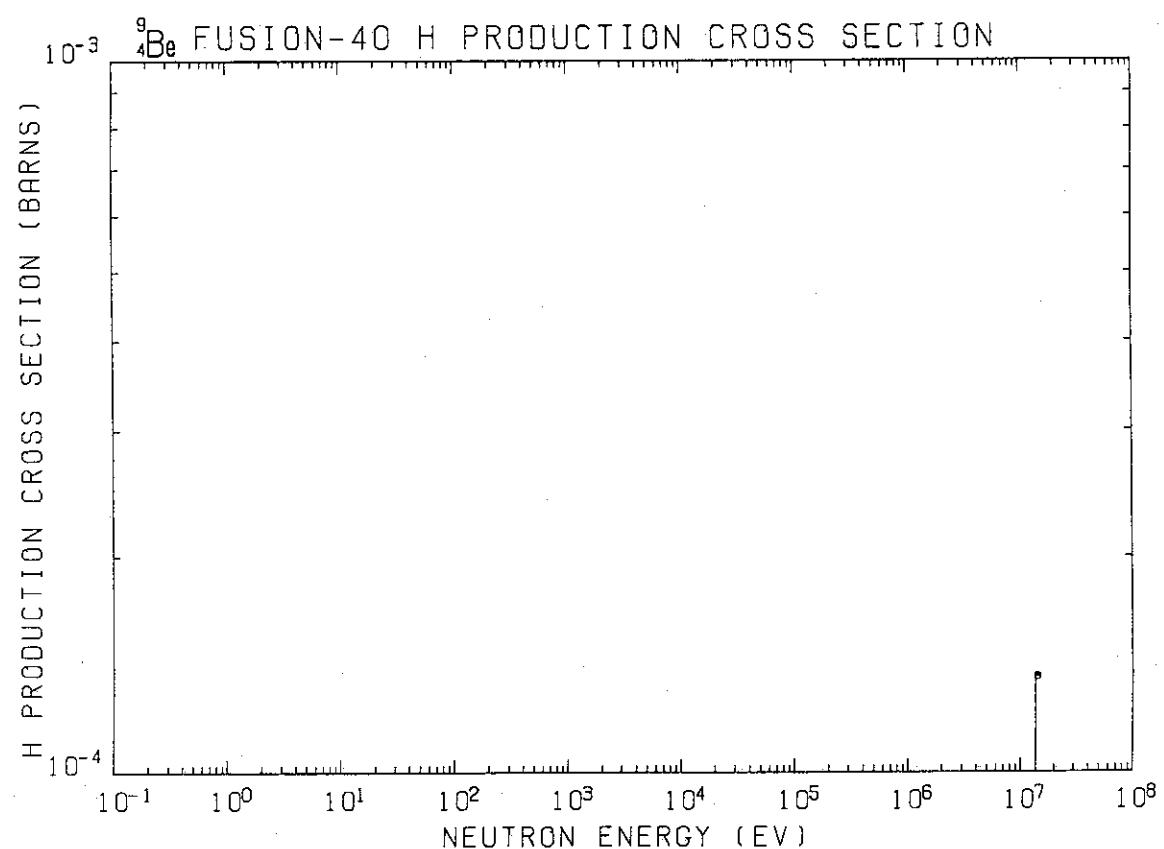
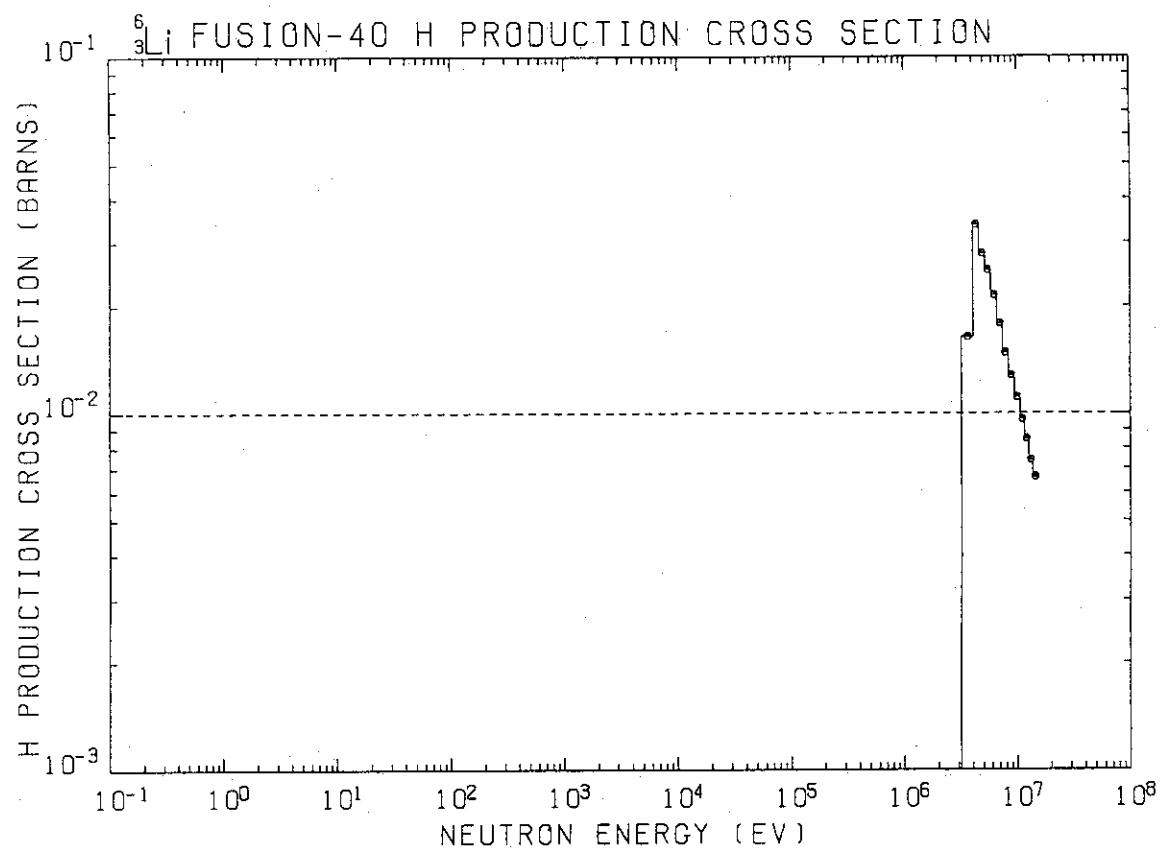


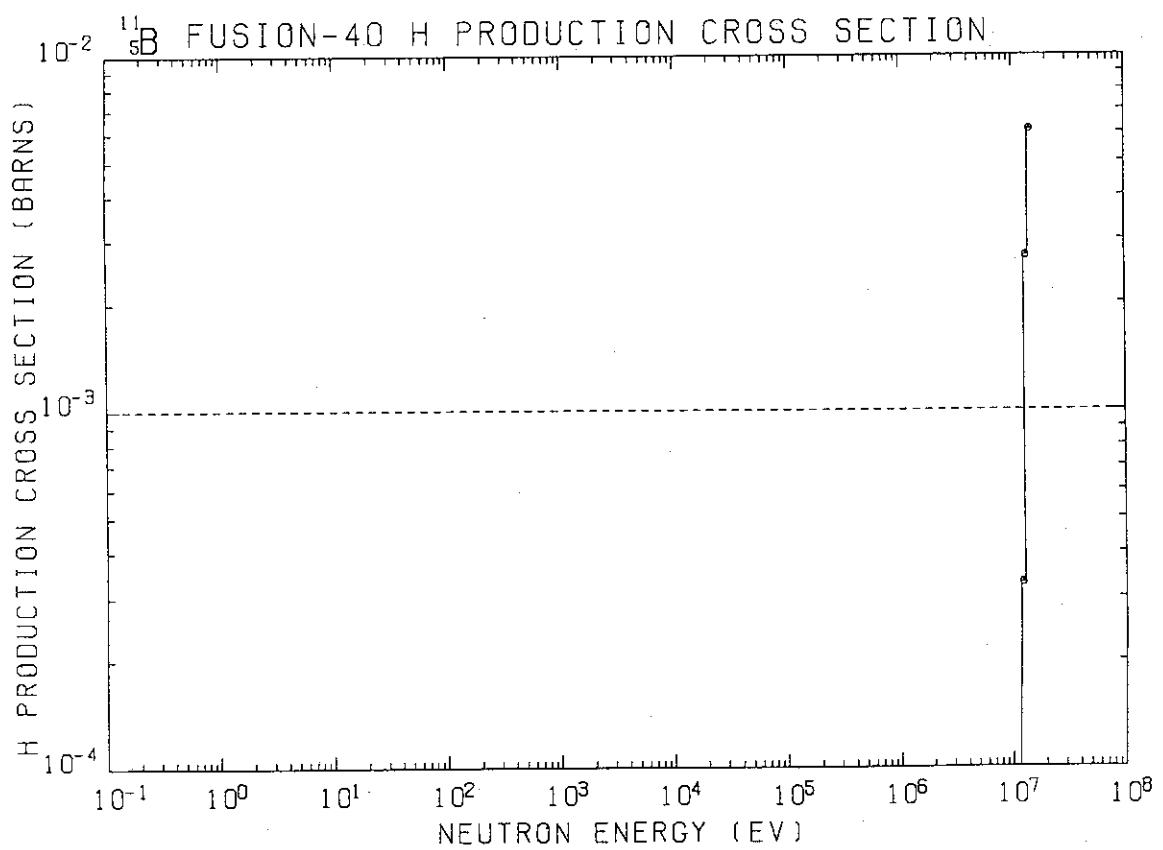
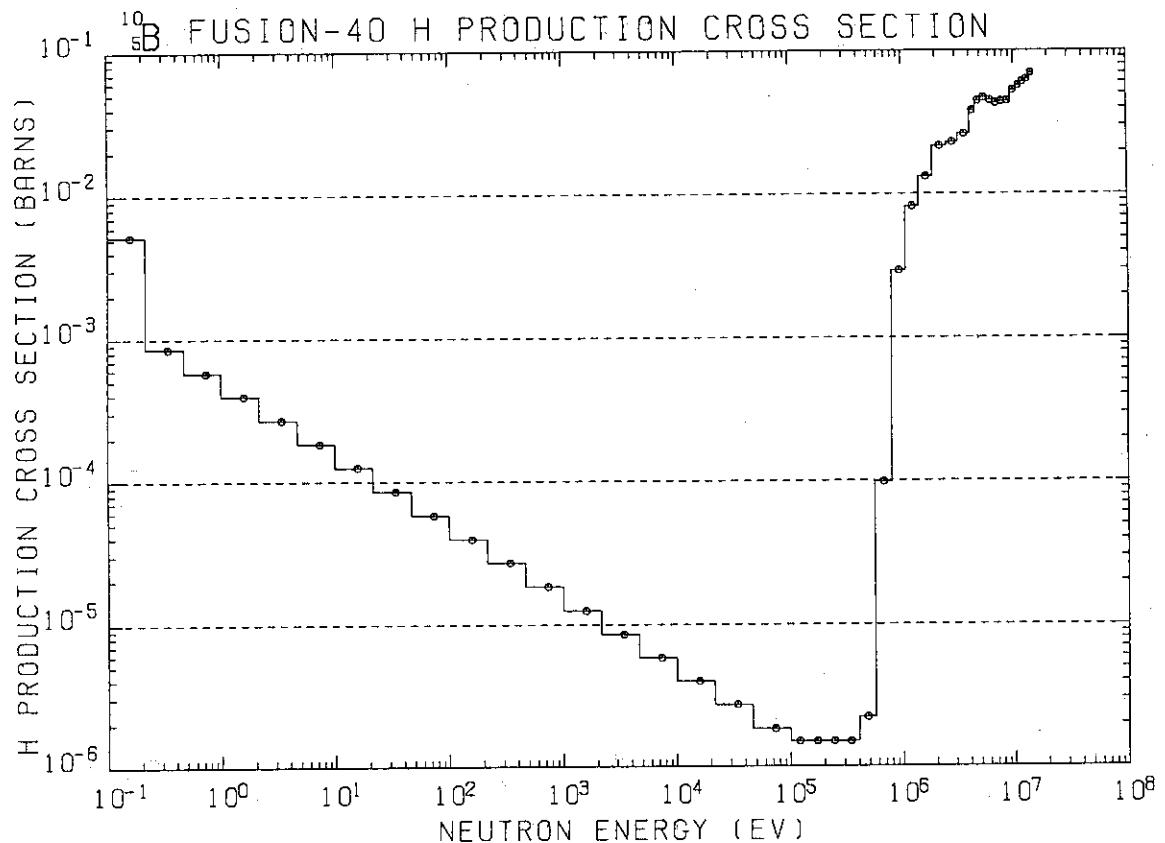


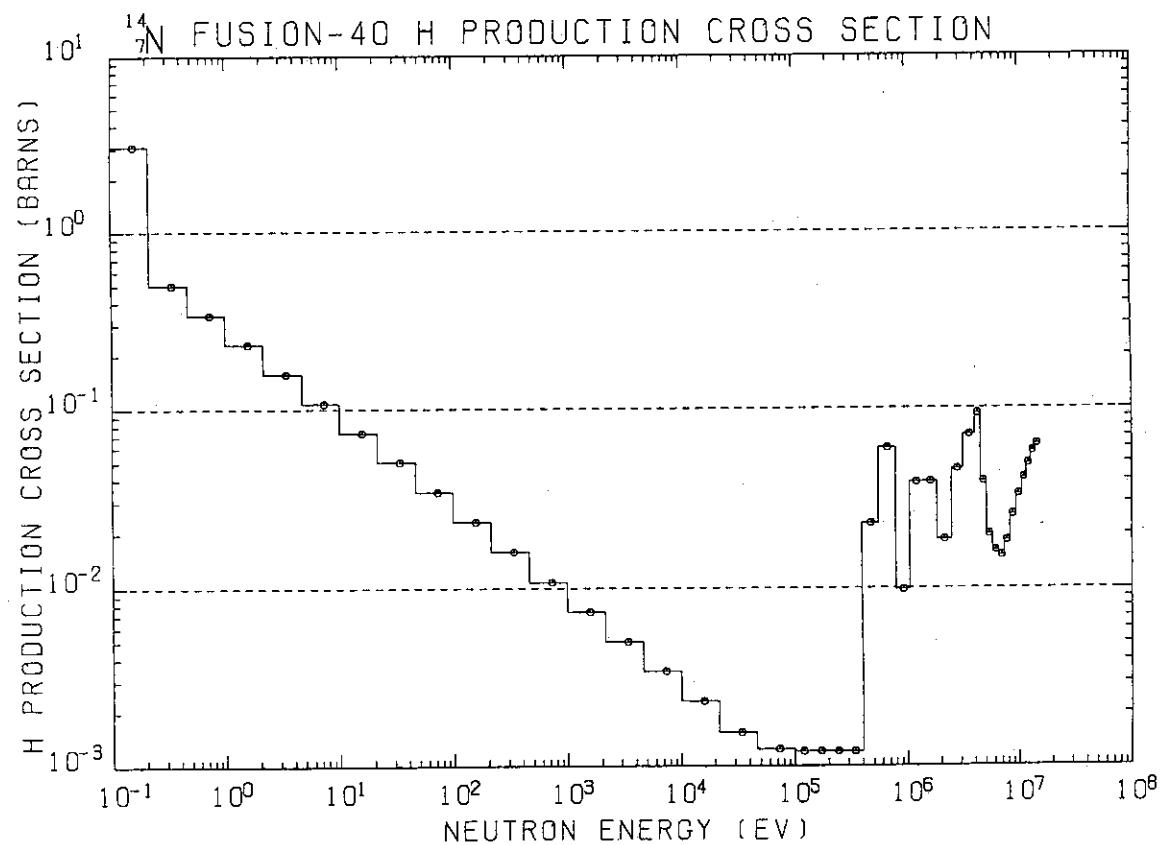
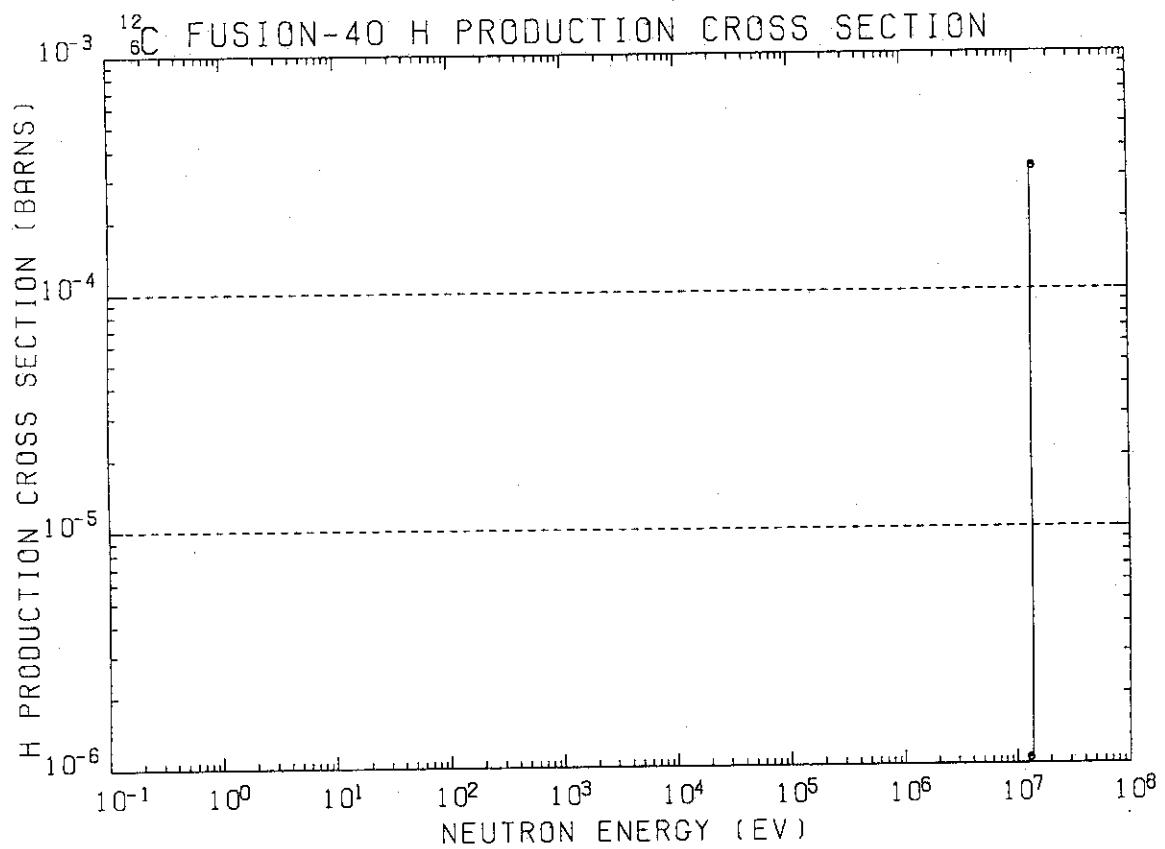


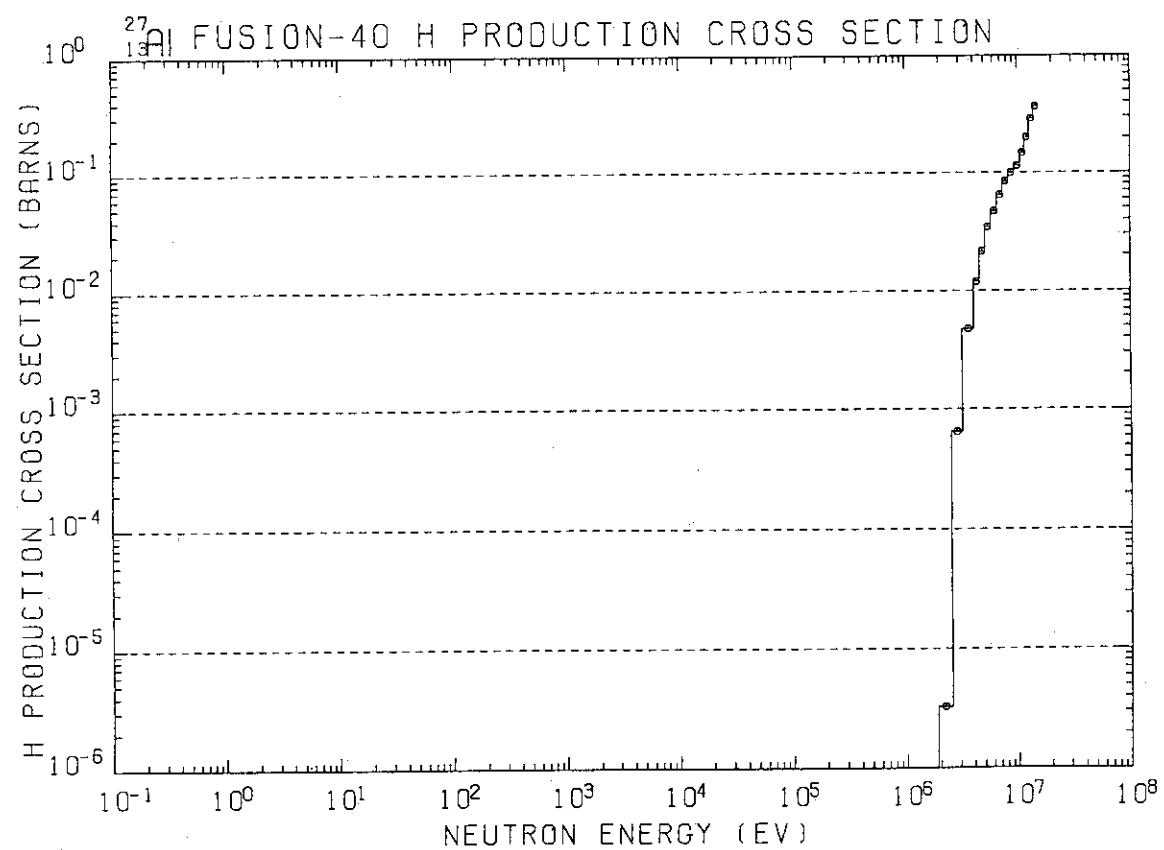
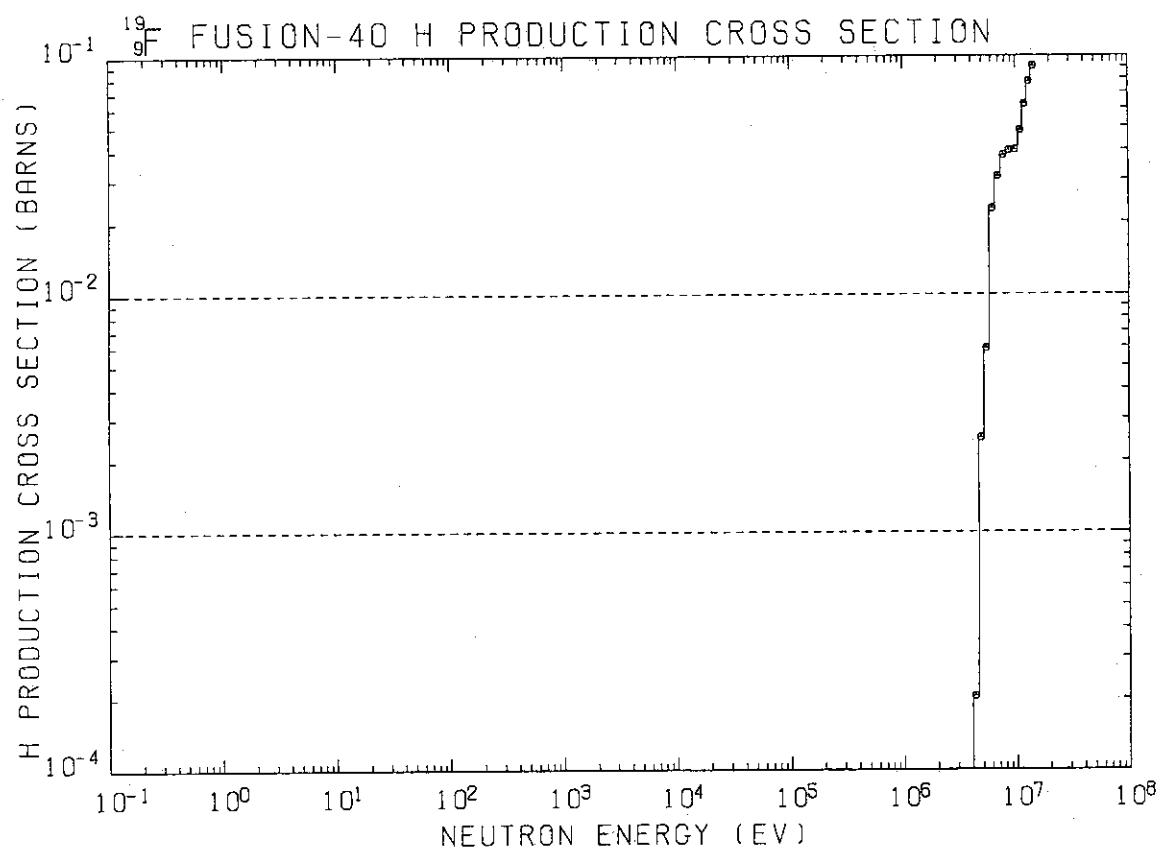


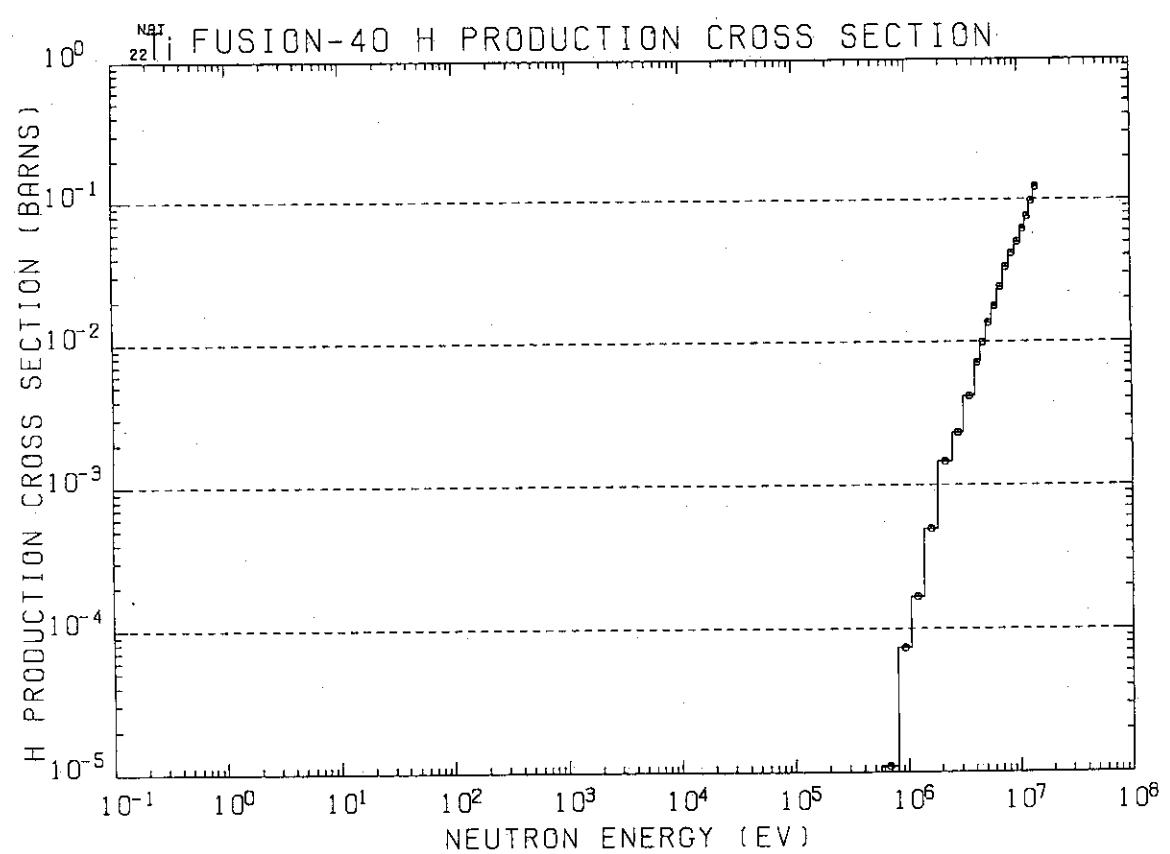
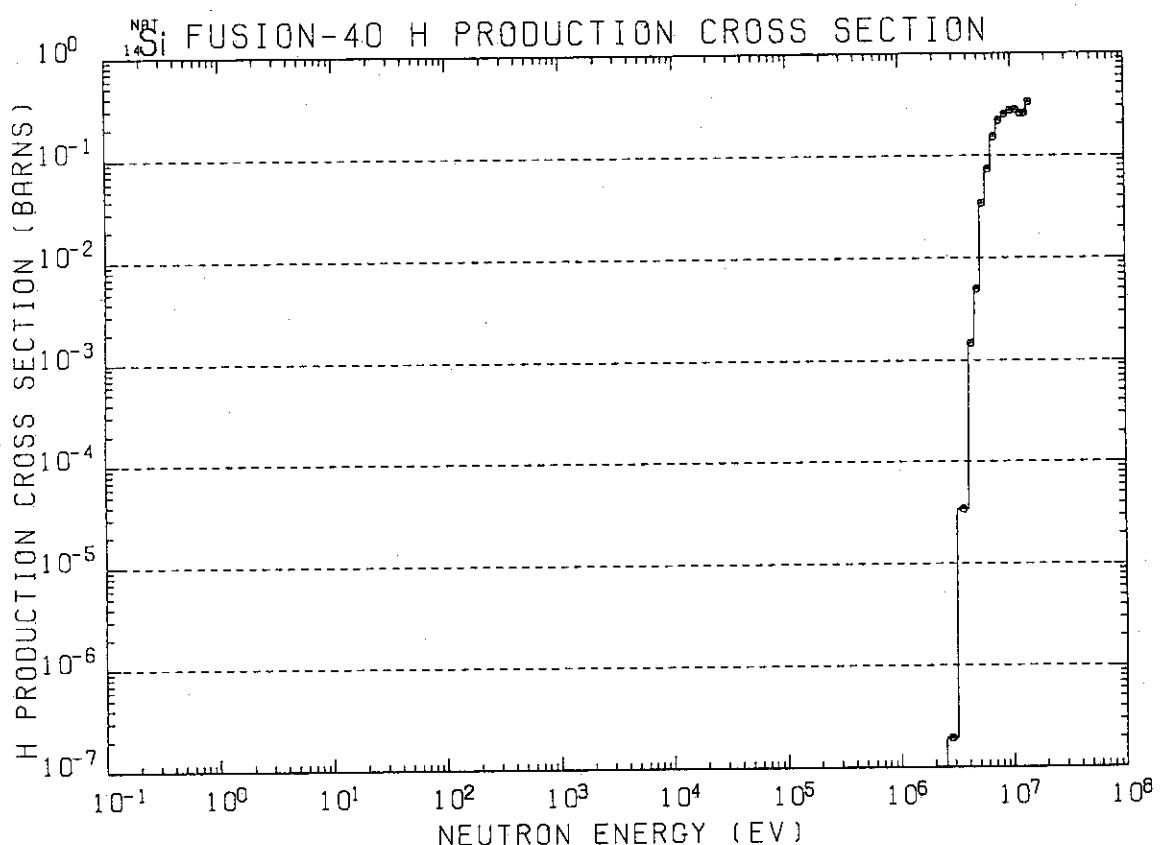


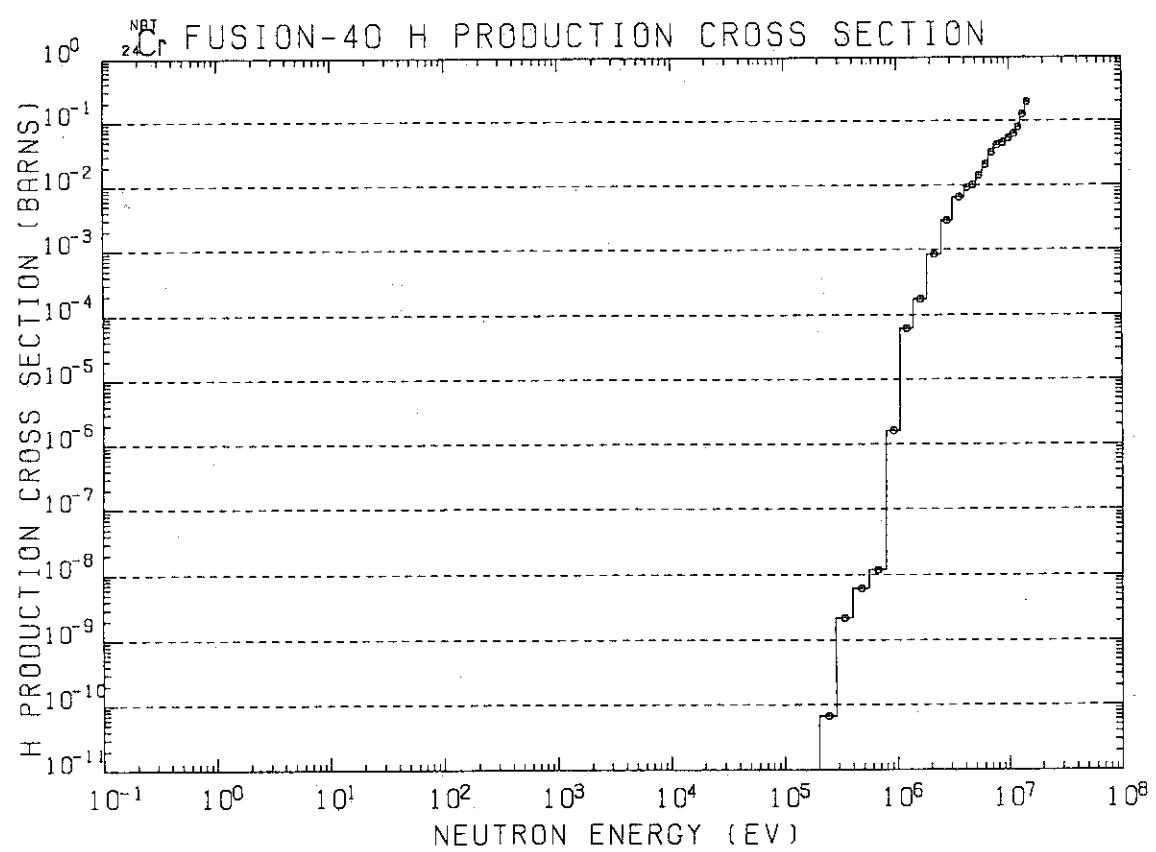
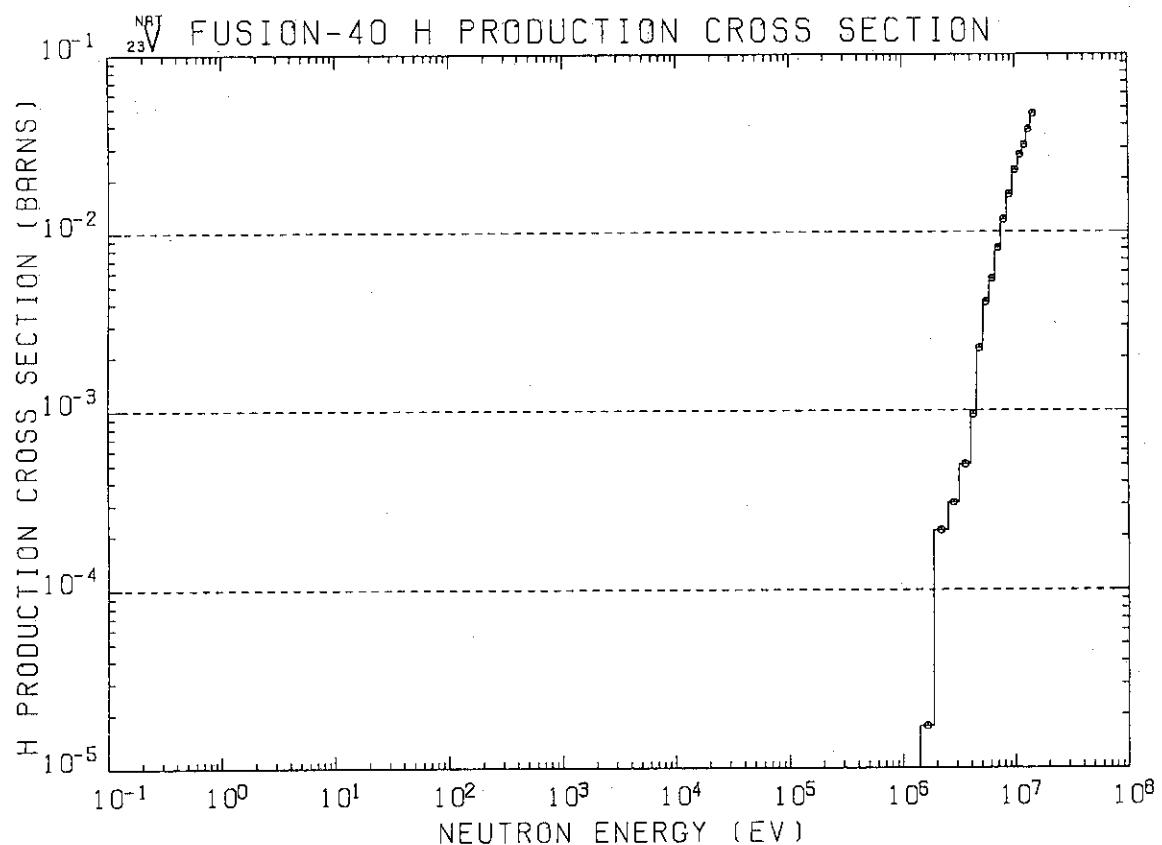


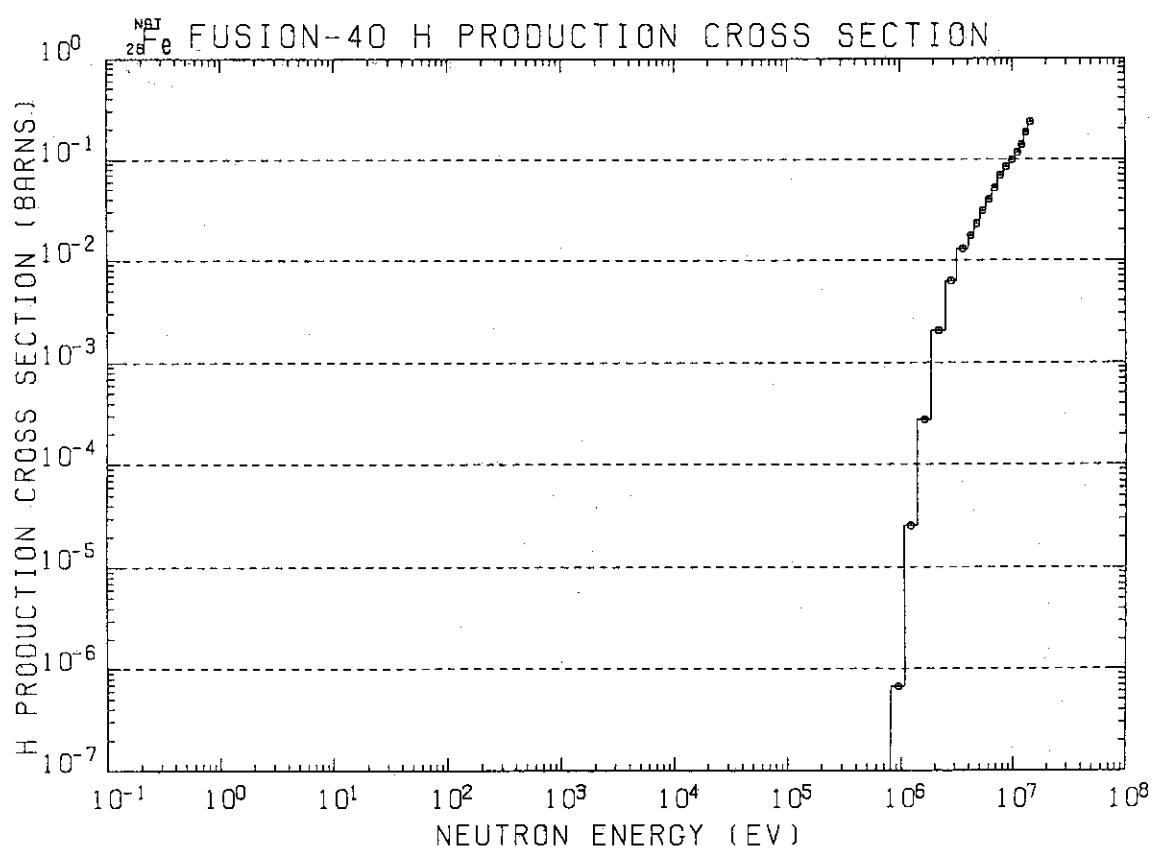
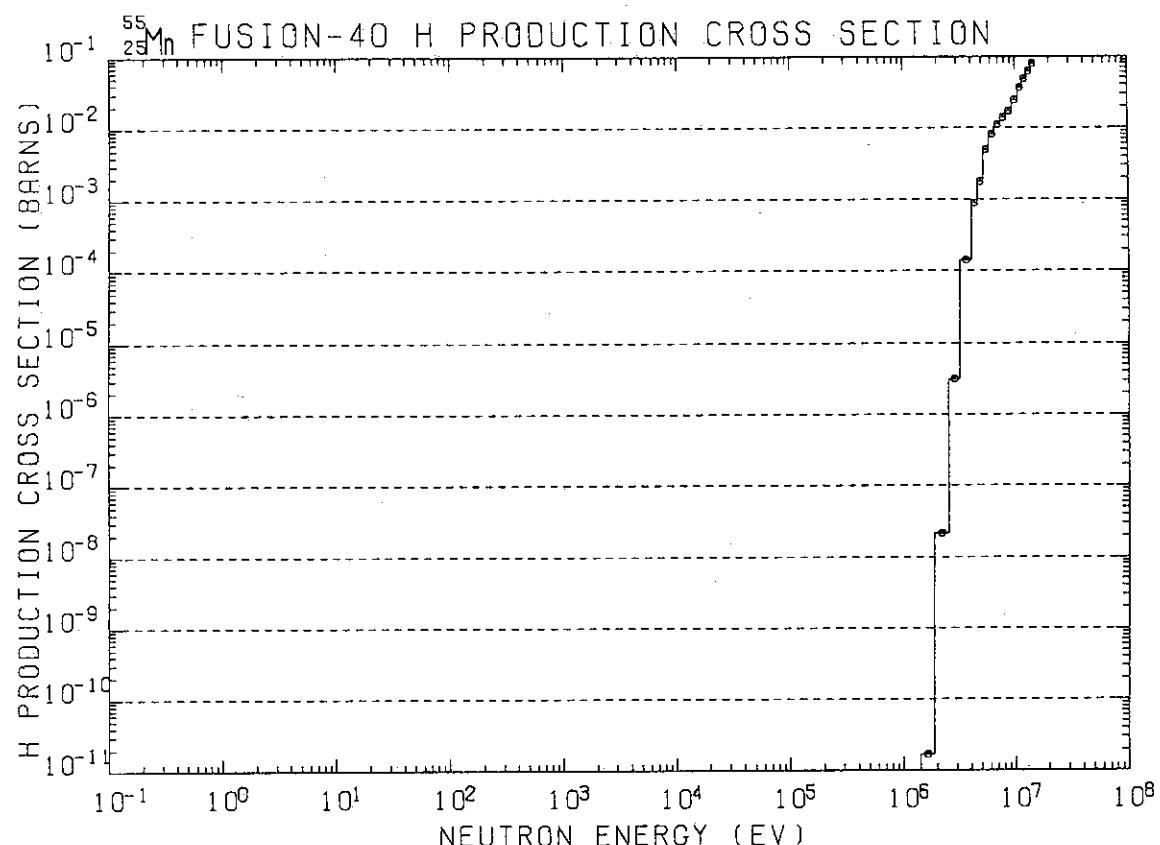


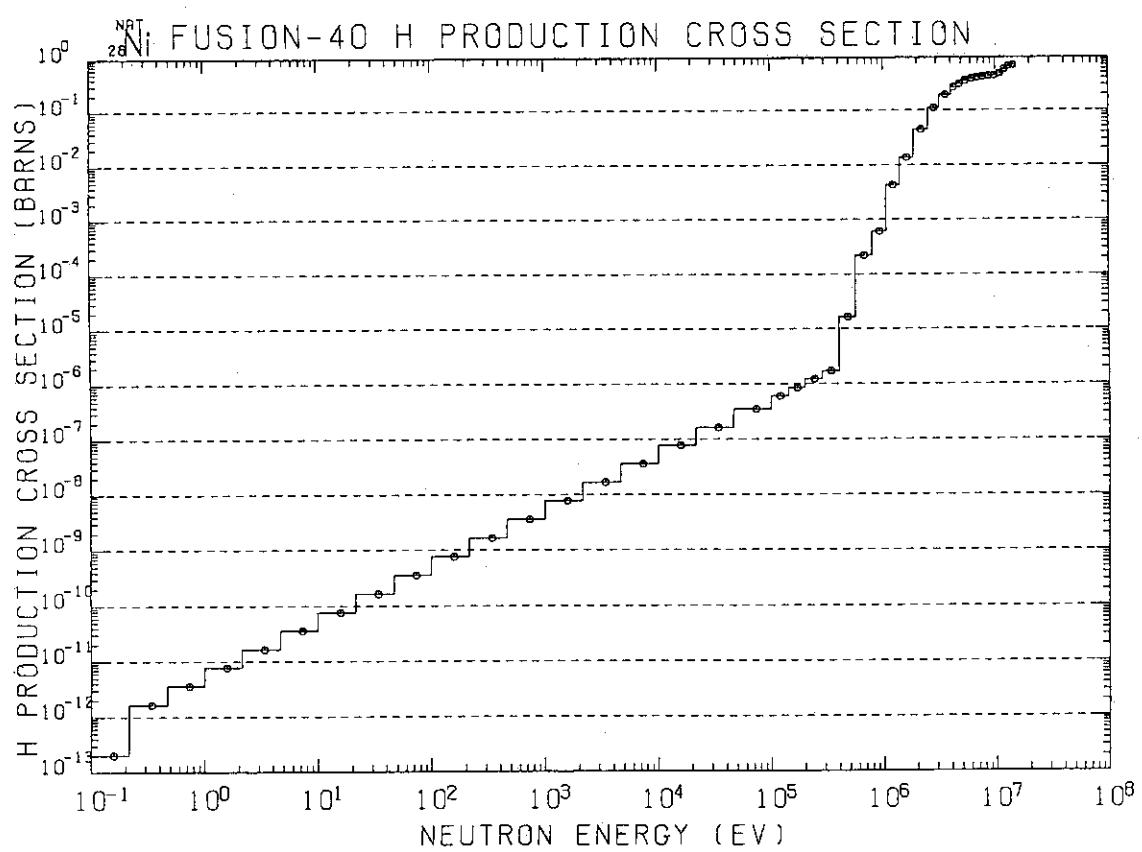
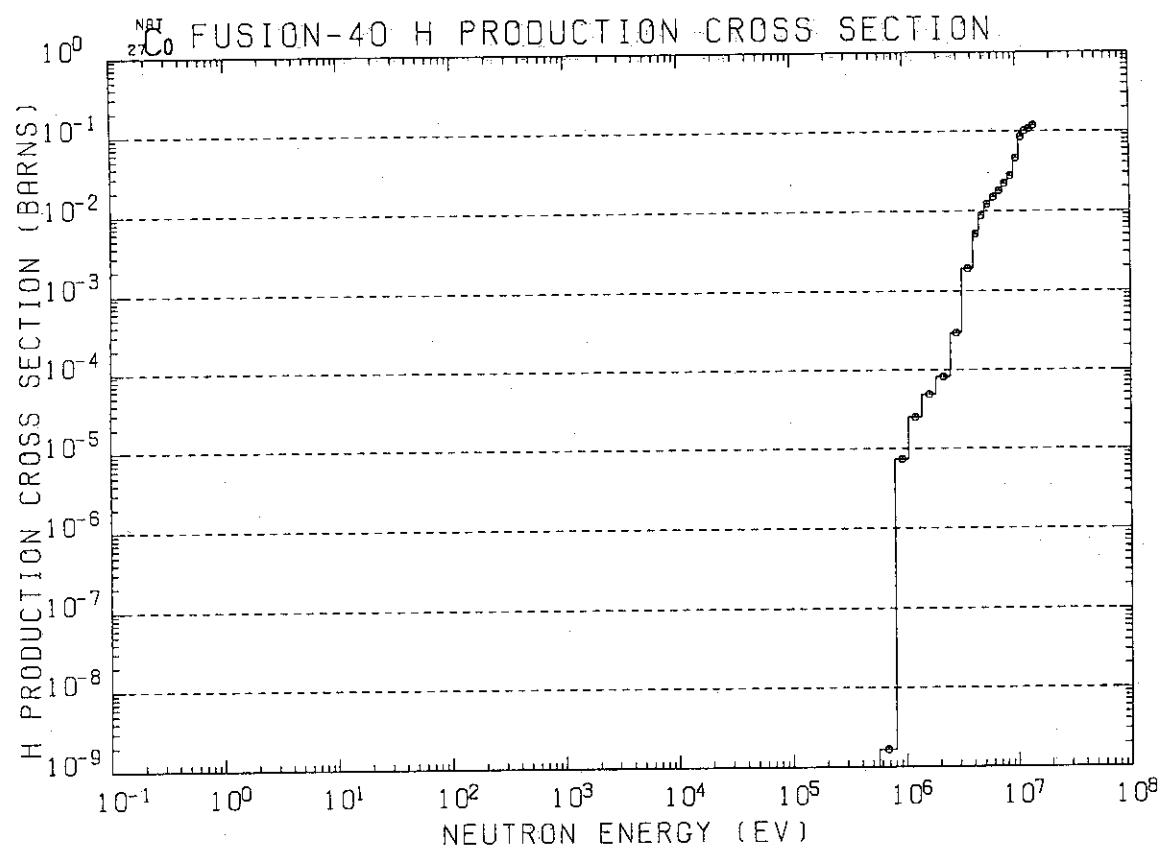


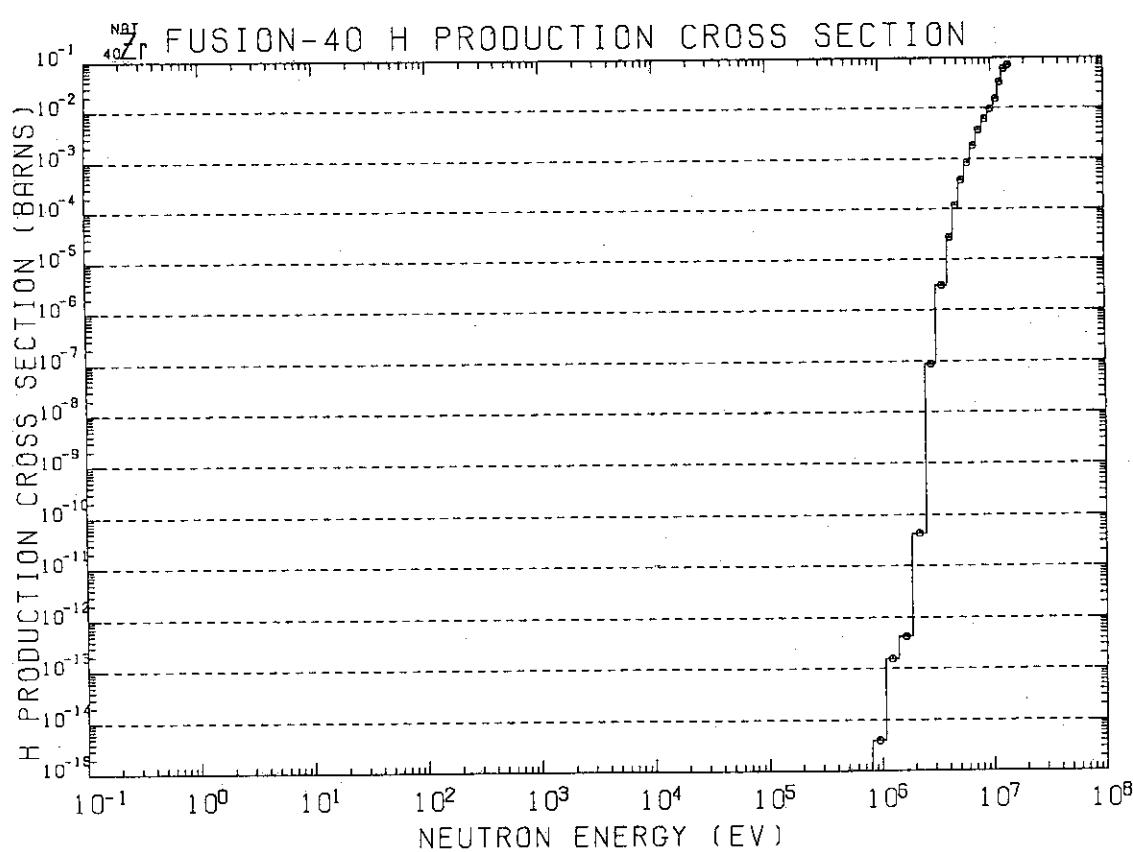
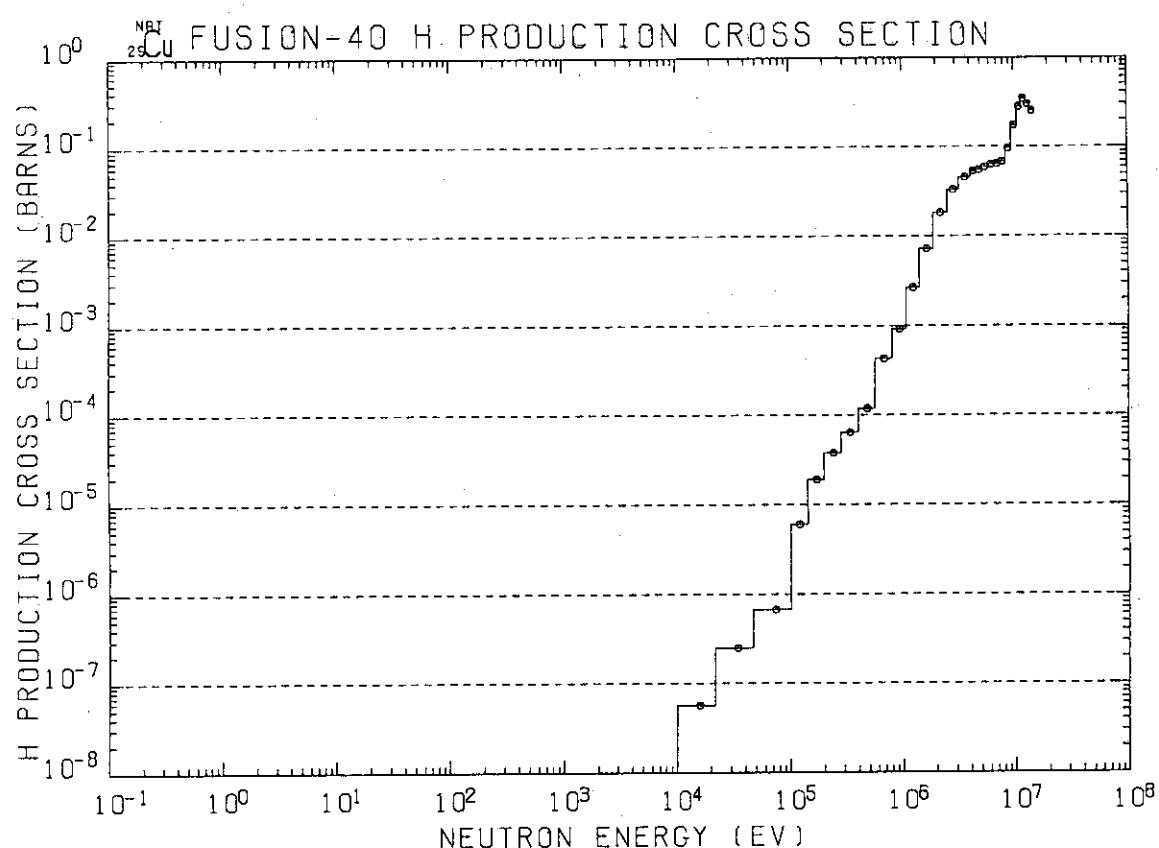


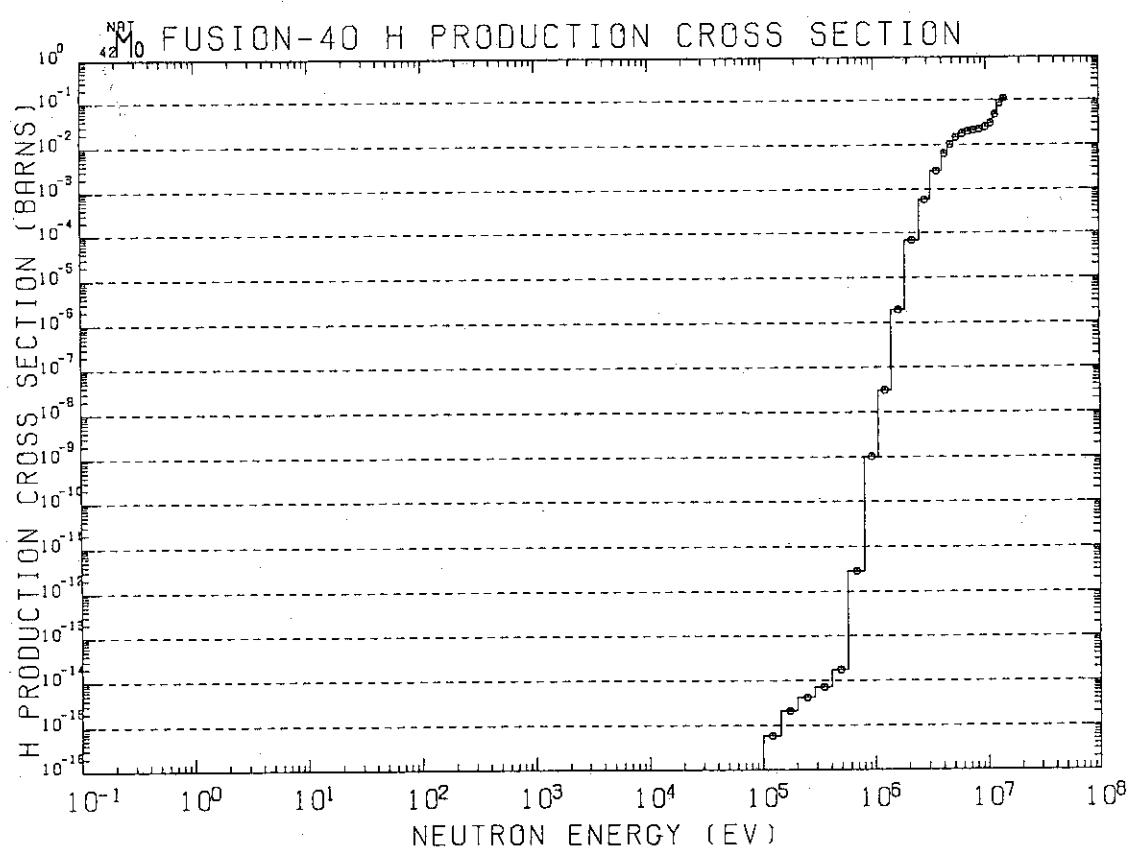
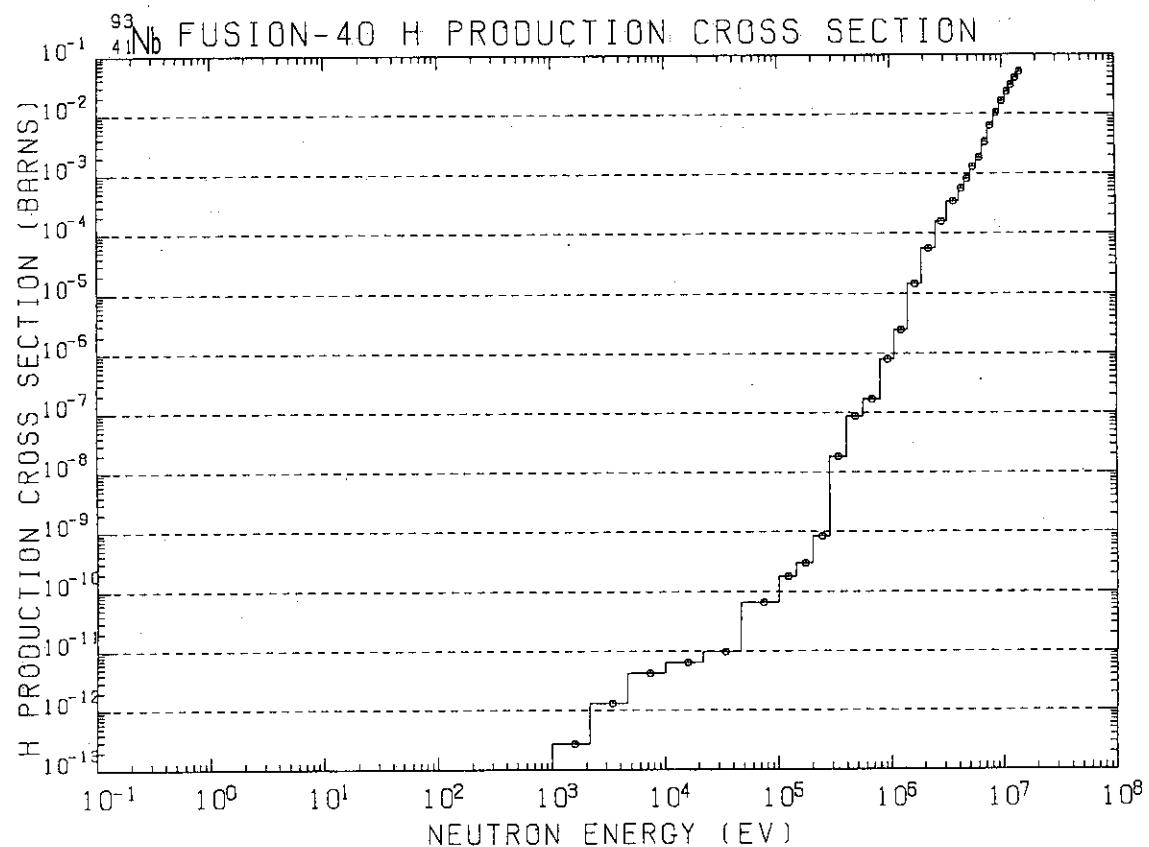












Appendix 2 Numerical data of cross section libraries

The three libraries are presented in tables in the following order ;

- (1) Helium production cross section library (I)
Neutron 125 groups (gamma-ray 40 groups)
Group structure of FUSION-J3 (see Table 2.1)
21 nuclides (see Table 2.3)
- (2) Helium production cross section library (II)
Neutron 42 groups (gamma-ray 21 groups)
Group structure of FUSION-40 (see Table 2.2)
21 nuclides and 5 alloys (see Table 2.3)
- (3) Hydrogen production cross section library
Neutron 42 groups (gamma-ray 21 groups)
Group structure of FUSION-40 (see Table 2.2)
20 nuclides and 3 alloys (see Table 2.3)

(1) Helium production cross section library (I)

1165	21							
14**								
REACTION NO. 1 LI6								
4.221-1	4.254-1	4.297-1	4.346-1	4.385-1	4.433-1	4.482-1		
4.521-1	4.570-1	4.619-1	4.661-1	4.722-1	4.786-1	4.849-1		
4.929-1	5.008-1	5.072-1	5.119-1	5.176-1	5.230-1	5.298-1		
5.400-1	5.507-1	5.614-1	5.694-1	5.775-1	5.875-1	5.941-1		
6.009-1	6.100-1	6.166-1	6.234-1	6.350-1	6.476-1	6.611-1		
6.766-1	6.961-1	7.160-1	7.267-1	7.365-1	7.438-1	7.492-1		
7.517-1	7.483-1	7.373-1	7.260-1	7.167-1	6.800-1	6.248-1		
5.666-1	4.863-1	3.923-1	3.234-1	2.560-1	2.354-1	2.380-1		
2.354-1	2.283-1	2.208-1	2.149-1	2.242-1	2.391-1	2.514-1		
2.624-1	2.729-1	2.846-1	2.993-1	3.183-1	3.445-1	3.825-1		
4.411-1	5.385-1	7.202-1	1.099	1.924	3.105	2.927		
1.869	1.229	9.261-1	7.676-1	7.012-1	6.688-1	6.588-1		
6.620-1	6.743-1	6.939-1	7.184-1	7.482-1	7.830-1	8.211-1		
8.643-1	9.102-1	9.612-1	1.016	1.074	1.174	1.322		
1.487	1.678	1.897	2.145	2.427	2.749	3.112		
3.521	3.996	4.531	5.472	7.024	9.015	1.158+1		
1.489+1	1.911+1	2.455+1	3.153+1	4.046+1	5.195+1	6.674+1		
8.573+1	1.100+2	1.412+2	1.815+2	2.331+2	9.063+3			
40R0.0								
REACTION NO. 2 LI7								
2.544-1	2.589-1	2.635-1	2.681-1	2.717-1	2.763-1	2.817-1		
2.870-1	2.933-1	2.987-1	3.029-1	3.070-1	3.111-1	3.144-1		
3.175-1	3.206-1	3.231-1	3.250-1	3.268-1	3.293-1	3.318-1		
3.343-1	3.368-1	3.393-1	3.411-1	3.429-1	3.451-1	3.465-1		
3.480-1	3.500-1	3.516-1	3.531-1	3.575-1	3.634-1	3.676-1		
3.687-1	3.690-1	3.674-1	3.646-1	3.618-1	3.512-1	2.777-1		
1.479-1	8.329-2	5.065-2	3.006-2	1.933-2	1.203-2	9.181-3		
6.541-3	4.020-3	1.686-3	7.663-5					
112R0.0								
REACTION NO. 3 BE9								
1.835-2	1.893-2	1.966-2	2.043-2	2.105-2	2.184-2	2.277-2		
2.361-2	2.475-2	2.590-2	2.690-2	2.788-2	2.891-2	3.000-2		
3.142-2	3.259-2	3.314-2	3.364-2	3.415-2	3.483-2	3.555-2		
3.634-2	3.712-2	3.791-2	3.850-2	3.904-2	3.998-2	4.086-2		
4.176-2	4.294-2	4.383-2	4.469-2	4.785-2	5.243-2	5.700-2		
6.140-2	6.369-2	6.636-2	6.989-2	7.468-2	8.055-2	8.782-2		
9.431-2	9.804-2	9.975-2	1.057-1	1.124-1	1.136-1	1.104-1		
1.065-1	1.039-1	1.029-1	9.933-2	8.826-2	7.561-2	6.438-2		
5.495-2	4.675-2	3.911-2	3.202-2	2.230-2	1.198-2	5.331-3		
1.721-3	4.131-4	8.716-5	3.712-5	6.095-6				
97R0.0								
REACTION NO. 4 B10								
5.948-1	5.961-1	6.033-1	6.144-1	6.233-1	6.344-1	6.453-1		
6.538-1	6.645-1	6.718-1	6.730-1	6.642-1	6.537-1	6.433-1		
6.301-1	6.165-1	6.051-1	5.965-1	5.887-1	5.789-1	5.723-1		
5.684-1	5.645-1	5.605-1	5.573-1	5.541-1	5.513-1	5.504-1		
5.496-1	5.483-1	5.474-1	5.466-1	5.556-1	5.699-1	6.033-1		
6.333-1	6.066-1	5.402-1	4.703-1	4.876-1	5.087-1	5.219-1		
5.291-1	5.219-1	5.215-1	5.103-1	4.697-1	4.042-1	3.602-1		
3.434-1	3.412-1	3.688-1	3.726-1	3.483-1	3.315-1	3.620-1		
4.473-1	5.599-1	6.447-1	6.566-1	5.337-1	3.722-1	3.173-1		
2.975-1	3.064-1	3.347-1	3.865-1	4.656-1	5.783-1	7.356-1		
8.528-1	8.730-1	9.022-1	9.725-1	1.0699	1.1791	1.290		
1.406	1.513	1.613	1.712	1.817	1.930	2.067		
2.177	2.281	2.392	2.517	2.656	2.806	2.963		

3.130	3.333	3.573	3.836	4.113	4.540	5.098
5.744	6.531	7.422	8.432	9.577	1.088+1	1.237+1
1.404+1	1.598+1	1.817+1	2.200+1	2.831+1	3.643+1	4.692+1
6.042+1	7.760+1	9.971+1	1.281+2	1.645+2	2.112+2	2.714+2
3.488+2	4.478+2	5.752+2	7.393+2	9.499+2	3.698+4	
40R0.0						
' REACTION NO. 5	B11					
4.222-1	3.986-1	3.696-1	3.403-1	3.153-1	2.837-1	2.528-1
2.333-1	2.100-1	1.868-1	1.683-1	1.527-1	1.403-1	1.279-1
1.123-1	9.719-2	8.893-2	8.329-2	7.762-2	7.009-2	6.279-2
5.626-2	4.987-2	4.348-2	3.870-2	3.389-2	2.938-2	2.741-2
2.542-2	2.277-2	2.079-2	1.881-2	1.417-2	8.870-3	4.811-3
1.225-3	2.663-4	5.904-6				
127R0.0						
' REACTION NO. 6	C12					
1.171	1.168	1.152	1.135	1.112	1.074	1.034
9.876-1	9.250-1	8.561-1	7.954-1	7.353-1	6.771-1	6.219-1
5.586-1	5.144-1	4.942-1	4.802-1	4.558-1	4.159-1	3.800-1
3.484-1	3.209-1	2.993-1	2.872-1	2.790-1	2.723-1	2.630-1
2.558-1	2.541-1	2.683-1	2.545-1	2.668-1	2.276-1	1.042-1
1.593-1	4.872-2	1.071-3	3.216-4	6.561-5		
125R0.0						
' REACTION NO. 7	N					
2.070-1	2.008-1	1.940-1	1.871-1	1.815-1	1.744-1	1.661-1
1.579-1	1.475-1	1.372-1	1.298-1	1.275-1	1.254-1	1.230-1
1.200-1	1.168-1	1.145-1	1.128-1	1.114-1	1.121-1	1.139-1
1.186-1	1.223-1	1.264-1	1.315-1	1.370-1	1.435-1	1.480-1
1.524-1	1.578-1	1.615-1	1.636-1	1.613-1	1.461-1	1.345-1
1.666-1	1.657-1	1.608-1	1.228-1	1.730-1	1.561-1	1.396-1
1.860-1	2.433-1	3.268-1	3.251-1	3.713-1	2.948-1	3.436-1
3.151-1	2.616-1	2.075-1	1.304-1	9.226-2	7.583-2	8.292-2
8.300-2	3.456-2	4.390-2	1.195-1	1.382-2	1.478-2	2.357-3
102R0.0						
' REACTION NO. 8	F19					
2.404-1	2.401-1	2.400-1	2.398-1	2.396-1	2.393-1	2.390-1
2.387-1	2.383-1	2.379-1	2.376-1	2.372-1	2.367-1	2.363-1
2.356-1	2.350-1	2.343-1	2.338-1	2.333-1	2.325-1	2.317-1
2.308-1	2.300-1	2.288-1	2.280-1	2.271-1	2.259-1	2.249-1
2.239-1	2.225-1	2.214-1	2.202-1	2.169-1	2.140-1	2.186-1
1.940-1	1.875-1	1.891-1	1.790-1	1.783-1	2.090-1	1.900-1
1.233-1	1.000-1	8.960-2	9.392-2	6.570-2	3.646-2	1.730-2
5.912-3	2.481-3	1.129-4				
113R0.0						
' REACTION NO. 9	AL27					
1.446-1	1.428-1	1.411-1	1.393-1	1.368-1	1.323-1	1.285-1
1.261-1	1.248-1	1.258-1	1.249-1	1.251-1	1.264-1	1.275-1
1.279-1	1.269-1	1.253-1	1.239-1	1.226-1	1.207-1	1.181-1
1.153-1	1.127-1	1.099-1	1.079-1	1.057-1	1.028-1	1.006-1
9.839-2	9.547-2	9.327-2	9.107-2	8.110-2	6.753-2	5.402-2
3.975-2	2.878-2	1.781-2	8.810-3	3.247-3	9.561-4	2.030-4
2.879-5	2.553-6	1.202-7	2.645-9	1.553-11	9.718-15	2.023-16
116R0.0						
' REACTION NO. 10	SI					
2.232-1	2.217-1	2.208-1	2.202-1	2.198-1	2.193-1	2.195-1
2.205-1	2.220-1	2.241-1	2.258-1	2.272-1	2.281-1	2.290-1
2.301-1	2.307-1	2.307-1	2.307-1	2.303-1	2.294-1	2.284-1
2.269-1	2.252-1	2.235-1	2.223-1	2.211-1	2.186-1	2.161-1
2.136-1	2.103-1	2.075-1	2.039-1	1.928-1	1.712-1	1.543-1

1.357-1	1.102-1	8.416-2	5.713-2	3.103-2	1.280-2	8.097-3
4.043-3	1.645-3	1.316-3	1.027-3	7.565-4	5.722-4	4.248-4
2.868-4	1.563-4	7.517-5	5.915-5	4.666-5	3.529-5	2.427-5
1.399-5	4.701-6	1.752-6	1.531-6	1.219-6	8.442-7	5.171-7
2.285-7	1.923-8	2.042-11	1.790-11	1.668-11	1.372-11	1.200-11
1.047-11	9.128-12	7.942-12	6.890-12	5.974-12	5.163-12	4.442-12
3.799-12	3.237-12	2.747-12	2.308-12	1.917-12	1.574-12	1.275-12
1.011-12	7.782-13	5.717-13	3.896-13	2.284-13	8.671-14	1.955-15

74R0.0

REACTION NO. 11 TI

4.663-2	4.494-2	4.386-2	4.318-2	4.264-2	4.196-2	4.129-2
4.077-2	4.012-2	3.947-2	3.887-2	3.778-2	3.662-2	3.545-2
3.399-2	3.254-2	3.138-2	3.051-2	2.963-2	2.847-2	2.729-2
2.599-2	2.467-2	2.335-2	2.237-2	2.138-2	2.006-2	1.907-2
1.807-2	1.675-2	1.576-2	1.477-2	1.270-2	1.026-2	8.417-3
7.287-3	6.222-3	5.178-3	4.216-3	3.326-3	2.593-3	2.108-3
1.664-3	1.313-3	1.078-3	9.020-4	7.511-4	6.125-4	4.856-4
3.668-4	2.536-4	1.670-4	1.339-4	1.053-4	7.918-5	5.368-5
3.025-5	8.895-6	2.286-6	1.997-6	1.591-6	1.101-6	6.745-7
2.980-7	2.506-8					

100R0.0

REACTION NO. 12 VS1

1.971-2	1.949-2	1.919-2	1.884-2	1.856-2	1.821-2	1.779-2
1.737-2	1.684-2	1.632-2	1.587-2	1.530-2	1.470-2	1.411-2
1.336-2	1.263-2	1.208-2	1.660-2	1.124-2	1.068-2	1.013-2
9.569-3	9.013-3	8.455-3	8.039-3	7.619-3	7.082-3	6.696-3
6.306-3	5.798-3	5.425-3	5.048-3	4.098-3	2.884-3	1.947-3
1.099-3	5.971-4	2.002-4	9.310-5	8.494-5	7.720-5	6.986-5
6.303-5	5.661-5	5.060-5	4.505-5	3.977-5	3.471-5	3.003-5
2.564-5	2.146-5	1.759-5	1.392-5	1.046-5	7.303-6	4.243-6
1.393-6	1.215-9					

107R0.0

REACTION NO. 13 CR

5.172-2	4.988-2	4.809-2	4.634-2	4.493-2	4.317-2	4.149-2
4.021-2	3.862-2	3.703-2	3.576-2	3.456-2	3.337-2	3.217-2
3.068-2	2.924-2	2.815-2	2.733-2	2.652-2	2.543-2	2.435-2
2.334-2	2.234-2	2.134-2	2.059-2	1.984-2	1.887-2	1.817-2
1.747-2	1.653-2	1.583-2	1.513-2	1.311-2	1.041-2	7.883-3
5.463-3	4.031-3	2.870-3	2.054-3	1.482-3	1.041-3	7.061-4
4.455-4	2.283-4	5.252-5	3.976-7	7.878-8	1.927-9	1.728-9
1.542-9	1.364-9	1.200-9	1.044-9	8.964-10	7.620-10	6.318-10
5.106-10	3.978-10	2.896-10	1.899-10	5.418-11		

104R0.0

REACTION NO. 14 MN55

4.452-2	4.255-2	4.067-2	3.888-2	3.744-2	3.563-2	3.395-2
3.272-2	3.123-2	2.981-2	2.871-2	2.774-2	2.679-2	2.583-2
2.464-2	2.353-2	2.274-2	2.215-2	2.155-2	2.076-2	1.999-2
1.932-2	1.867-2	1.802-2	1.754-2	1.705-2	1.643-2	1.600-2
1.556-2	1.498-2	1.455-2	1.411-2	1.283-2	1.098-2	9.089-3
7.052-3	5.021-3	3.195-3	1.839-3	9.695-4	4.470-4	1.916-4
8.139-5	2.757-5	1.006-5	3.233-6	9.148-7	3.372-7	3.127-7
2.898-7	2.679-7	2.477-7	2.285-7	2.104-7	1.938-7	1.779-7
1.629-7	1.490-7	1.358-7	1.235-7	1.062-7	8.552-8	6.742-8
5.147-8	3.763-8	2.544-8	1.448-8	4.781-9	7.017-12	

96R0.0

REACTION NO. 15 FE

5.849-2	5.666-2	5.486-2	5.310-2	5.168-2	4.991-2	4.836-2
4.737-2	4.613-2	4.489-2	4.392-2	4.303-2	4.216-2	4.129-2

4.020-2	3.910-2	3.819-2	3.751-2	3.682-2	3.591-2	3.500-2
3.405-2	3.310-2	3.214-2	3.143-2	3.072-2	2.973-2	2.897-2
2.820-2	2.718-2	2.642-2	2.565-2	2.359-2	2.086-2	1.824-2
1.555-2	1.272-2	9.965-3	7.341-3	4.887-3	2.975-3	1.972-3
1.058-3	4.899-4	3.531-4	2.296-4	1.164-4	7.406-5	5.537-5
3.759-5	2.122-5	9.261-6	7.283-6	5.884-6	4.608-6	3.373-6
2.221-6	1.176-6	7.923-7	6.979-7	5.646-7	4.039-7	2.639-7
1.405-7	4.914-8	3.200-8	2.321-8	1.543-8	8.607-9	2.593-9
3.513-13	3.102-13	2.737-13	2.414-13	2.134-13	1.885-13	1.664-13
1.466-13	1.293-13	1.143-13	1.008-13	8.886-14	7.837-14	6.918-14
6.108-14	5.392-14	4.758-14	4.199-14	3.704-14	3.270-14	2.887-14
2.546-14	2.246-14	1.983-14	1.751-14	1.545-14	1.281-14	9.973-15
7.777-15	6.058-15	4.717-15	3.675-15	2.865-15	2.229-15	1.737-15
1.355-15	1.053-15	8.185-16	5.679-16	3.447-16	2.093-16	1.269-16
7.684-17	4.665-17	2.828-17	1.714-17	1.041-17	6.319-18	3.829-18
2.321-18	1.409-18	8.552-19	5.179-19	3.141-19	2.328-20	
40R0.0						
' REACTION NO. 16 CO59						
4.339-2	4.207-2	4.090-2	3.983-2	3.898-2	3.791-2	3.715-2
3.687-2	3.617-2	3.513-2	3.400-2	3.312-2	3.228-2	3.120-2
2.955-2	2.812-2	2.721-2	2.653-2	2.585-2	2.495-2	2.406-2
2.323-2	2.242-2	2.162-2	2.101-2	2.041-2	1.960-2	1.900-2
1.840-2	1.760-2	1.700-2	1.640-2	1.466-2	1.233-2	1.022-2
8.146-3	6.208-3	4.388-3	2.988-3	1.788-3	8.956-4	5.229-4
1.883-4	1.409-6					
121R0.0						
' REACTION NO. 17 NI						
1.063-1	1.043-1	1.021-1	9.991-2	9.817-2	9.604-2	9.407-2
9.268-2	9.096-2	8.927-2	8.799-2	8.702-2	8.611-2	8.522-2
8.411-2	8.319-2	8.267-2	8.227-2	8.188-2	8.136-2	8.090-2
8.078-2	8.072-2	8.065-2	8.060-2	8.055-2	8.056-2	8.063-2
8.070-2	8.078-2	8.085-2	8.092-2	7.826-2	7.353-2	6.928-2
6.507-2	6.115-2	5.742-2	5.394-2	5.071-2	4.763-2	4.472-2
4.200-2	3.946-2	3.707-2	3.487-2	3.276-2	3.076-2	2.889-2
2.715-2	2.550-2	2.396-2	2.250-2	2.112-2	1.987-2	1.866-2
1.752-2	1.647-2	1.546-2	1.453-2	1.322-2	1.164-2	1.027-2
9.056-3	8.006-3	7.080-3	6.247-3	5.511-3	4.863-3	4.294-3
3.788-3	3.344-3	2.952-3	2.604-3	2.301-3	2.032-3	1.794-3
1.581-3	1.395-3	1.233-3	1.088-3	9.581-4	8.449-4	7.459-4
6.586-4	5.814-4	5.131-4	4.528-4	3.994-4	3.526-4	3.113-4
2.745-4	2.422-4	2.139-4	1.888-4	1.666-4	1.381-4	1.075-4
8.385-5	6.532-5	5.086-5	3.963-5	3.089-5	2.404-5	1.873-5
1.462-5	1.135-5	8.824-6	6.123-6	3.716-6	2.257-6	1.368-6
8.285-7	5.029-7	3.049-7	1.848-7	1.123-7	6.813-8	4.128-8
2.502-8	1.519-8	9.222-9	5.584-9	3.386-9	2.511-10	
40R0.0						
' REACTION NO. 18 CU						
5.486-2	5.333-2	5.169-2	5.001-2	4.865-2	4.696-2	4.541-2
4.431-2	4.294-2	4.157-2	4.048-2	3.937-2	3.825-2	3.714-2
3.574-2	3.439-2	3.334-2	3.256-2	3.157-2	3.073-2	2.970-2
2.876-2	2.783-2	2.691-2	2.622-2	2.552-2	2.470-2	2.415-2
2.361-2	2.288-2	2.234-2	2.179-2	2.029-2	1.826-2	1.589-2
1.341-2	1.109-2	8.894-3	6.823-3	4.895-3	3.363-3	2.495-3
1.700-3	1.133-3	8.460-4	5.830-4	3.405-4	2.349-4	1.762-4
1.213-4	6.896-5	3.016-5	1.934-5	1.042-5	4.510-6	3.357-6
2.406-6	1.537-6	1.055-6	7.591-7	3.422-7	6.098-9	4.970-13
4.337-13	3.791-13	3.308-13	2.875-13	2.491-13	2.154-13	1.857-13
1.594-13	1.364-13	1.159-13	9.788-14	8.209-14	6.813-14	5.571-14

4.458-14 3.492-14 2.651-14 1.892-14 1.219-14 6.299-15 1.307-15
81R0.0

REACTION NO. 19 ZR

1.422-2	1.362-2	1.287-2	1.207-2	1.150-2	1.084-2	1.019-2
9.664-3	9.024-3	8.385-3	7.895-3	7.379-3	6.889-3	6.438-3
5.919-3	5.425-3	5.039-3	4.768-3	4.512-3	4.192-3	3.912-3
3.633-3	3.368-3	3.127-3	2.962-3	2.805-3	2.600-3	2.450-3
2.309-3	2.133-3	2.011-3	1.896-3	1.601-3	1.265-3	1.002-3
7.804-4	6.020-4	4.671-4	3.569-4	2.766-4	2.150-4	1.630-4
1.275-4	9.931-5	7.622-5	6.045-5	4.867-5	3.808-5	3.023-5
2.443-5	1.994-5	1.628-5	1.292-5	1.036-5	8.478-6	7.009-6
5.868-6	4.968-6	4.091-6	3.369-6	2.574-6	1.852-6	1.391-6
1.081-6	8.632-7	6.889-7	5.555-7	4.324-7	3.431-7	2.798-7
2.353-7	2.002-7	1.692-7	1.417-7	1.178-7	9.661-8	7.776-8
6.090-8	4.623-8	3.345-8	2.195-8	1.173-8	2.896-9	

82R0.0

REACTION NO. 20 NB93

1.199-2	1.172-2	1.145-2	1.119-2	1.099-2	1.074-2	1.046-2
1.024-2	9.948-3	9.661-3	9.433-3	9.218-3	9.006-3	8.793-3
8.527-3	8.258-3	8.037-3	7.873-3	7.707-3	7.487-3	7.266-3
7.044-3	6.822-3	6.601-3	6.435-3	6.268-3	6.046-3	5.880-3
5.712-3	5.489-3	5.322-3	5.155-3	4.649-3	3.957-3	3.302-3
2.659-3	2.181-3	1.756-3	1.420-3	1.128-3	8.826-4	7.073-4
5.459-4	4.233-4	3.478-4	2.786-4	2.145-4	1.811-4	1.588-4
1.379-4	1.181-4	9.845-5	7.643-5	5.552-5	4.024-5	3.326-5
2.697-5	2.121-5	1.745-5	1.474-5	1.092-5	7.406-6	6.172-6
5.119-6	4.206-6	3.402-6	2.818-6	2.575-6	2.335-6	1.922-6
1.528-6	1.201-6	9.564-7	7.430-7	5.932-7	5.042-7	4.250-7
3.577-7	3.091-7	2.695-7	2.513-7	2.395-7	2.284-7	1.902-7
1.414-7	9.841-8	6.033-8	2.675-8	2.172-9		

76R0.0

REACTION NO. 21 MO

1.774-2	1.737-2	1.687-2	1.629-2	1.583-2	1.528-2	1.472-2
1.424-2	1.364-2	1.300-2	1.249-2	1.190-2	1.133-2	1.080-2
1.017-2	9.546-3	9.040-3	8.684-3	8.343-3	7.908-3	7.495-3
7.099-3	6.725-3	6.375-3	6.127-3	5.894-3	5.595-3	5.372-3
5.159-3	4.890-3	4.699-3	4.516-3	4.072-3	3.603-3	3.283-3
3.040-3	2.832-3	2.659-3	2.485-3	2.323-3	2.136-3	1.901-3
1.714-3	1.520-3	1.312-3	1.144-3	1.001-3	8.510-4	7.231-4
6.210-4	5.370-4	4.643-4	3.919-4	3.331-4	2.871-4	2.485-4
2.163-4	1.891-4	1.662-4	1.466-4	1.233-4	9.988-5	8.307-5
7.080-5	6.182-5	5.569-5	5.036-5	4.635-5	4.306-5	4.016-5
3.897-5	3.906-5	3.914-5	3.921-5	3.927-5	3.932-5	3.937-5
3.942-5	3.946-5	3.942-5	3.032-5	1.621-5	4.001-6	

82R0.0

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END 0

(2) Helium production cross section library (II)

1	63	26				
14**						
' REACTION NO. 1 LI6						
0.4594	0.4937	0.5320	0.5829	0.6278	0.6555	
0.6867	0.7246	0.7242	0.7499	0.7455	0.7246	0.6188
0.3406	0.2320	0.2260	0.2549	0.2799	0.3224	0.4411
1.0205	2.7917	1.2303	0.7115	0.6915	0.8955	1.2660
1.8301	2.6755	3.9234	5.7527	8.4513	12.413	18.206
26.746	39.281	57.609	84.616	124.25	182.21	267.63
1641.2	21R0.0					
' REACTION NO. 2 LI7						
2.951-1	3.177-1	3.319-1	3.442-1	3.552-1	3.658-1	
3.689-1	3.651-1	3.551-1	2.352-1	7.662-2	2.820-2	9.290-3
9.930-4						
49R0.0						
' REACTION NO. 3 BE						
2.526-2	3.132-2	3.559-2	3.976-2	4.629-2	5.508-2	
6.262-2	6.949-2	7.893-2	8.981-2	9.829-2	1.072-1	1.099-1
9.704-2	5.585-2	2.209-2	4.335-3	2.456-4	1.183-5	
44R0.0						
' REACTION NO. 4 B10						
6.626-1	6.285-1	5.751-1	5.567-1	5.526-1	5.892-1	
6.202-1	5.009-1	5.035-1	5.246-1	5.222-1	5.008-1	3.726-1
3.591-1	4.677-1	5.188-1	3.124-1	3.238-1	4.836-1	8.139-1
9.520-1	1.227	1.532	1.816	2.337	3.288	4.882
7.158	1.059+1	1.569+1	2.314+1	3.413+1	5.031+1	7.393+1
1.087+2	1.597+2	2.343+2	3.443+2	5.059+2	7.423+2	1.091+3
6.697+3		21R0.0				
' REACTION NO. 5 B11						
2.014-1	1.121-1	6.357-2	3.259-2	1.678-2	6.508-3	
6.947-4	2.708-6					
55R0.0						
' REACTION NO. 6 C11						
8.919-1	5.687-1	3.856-1	2.753-1	2.645-1	1.568-1	
1.046-1	6.091-4	2.692-7				
54R0.0						
' REACTION NO. 7 N						
1.445-1	1.196-1	1.158-1	1.404-1	1.610-1	1.396-1	
1.668-1	1.467-1	1.714-1	1.483-1	2.779-1	3.430-1	3.156-1
1.574-1	6.267-2	3.758-2	3.676-3			
44R0.0						
' REACTION NO. 8 F19						
2.382-1	2.356-1	2.317-1	2.264-1	2.187-1	2.160-1	
1.903-1	1.800-1	2.056-1	1.683-1	9.717-2	8.419-2	2.094-2
2.995-4						
49R0.0						
' REACTION NO. 9 AL27						
1.258-1	1.268-1	1.179-1	1.040-1	8.584-2	5.966-2	
3.407-2	1.111-2	1.310-3	1.590-4	2.523-6	4.304-9	3.403-14
50R0.0						
' REACTION NO. 10 SI						
2.231-1	2.298-1	2.281-1	2.190-1	1.984-1	1.613-1	
1.226-1	6.230-2	1.592-2	6.865-3	1.641-3	9.700-4	4.220-4
6.981-5	1.551-5	1.203-6	4.259-7	1.119-8	1.557-11	
1.072-11	7.294-12	4.872-12	3.151-12	1.941-12	7.307-13	1.513-14
37R0.0						
' REACTION NO. 11 TI						
3.976-2	3.384-2	2.724-2	2.060-2	1.391-2	9.195-3	

6.734-3	4.408-3	2.748-3	1.973-3	1.260-3	8.708-4	4.832-4
1.475-4	3.376-5	1.569-6	5.556-7	1.456-8		
45R0.0						
' REACTION NO. 12	V51					
	1.660-2	1.330-2	1.014-2	7.317-3	4.619-3	2.338-3
8.341-4	1.340-4	7.908-5	6.678-5	5.515-5	4.397-5	2.994-5
1.472-5	2.431-6					
48R0.0						
' REACTION NO. 13	CR					
	3.799-2	3.058-2	2.442-2	1.928-2	1.418-2	8.939-3
4.708-3	2.253-3	1.141-3	6.285-4	1.854-4	4.703-7	1.725-9
1.077-9	5.158-10	7.378-11				
47R0.0						
' REACTION NO. 14	MN55					
	3.073-2	2.460-2	2.008-2	1.671-2	1.350-2	9.878-3
5.998-3	2.182-3	5.508-4	1.625-4	2.452-5	2.740-6	3.121-7
2.326-7	1.636-7	1.054-7	6.239-8	3.062-8	5.591-9	
44R0.0						
' REACTION NO. 15	FE					
	4.564-2	4.009-2	3.500-2	3.011-2	2.470-2	1.933-2
1.409-2	7.859-3	3.356-3	1.694-3	4.723-4	2.052-4	5.502-5
8.919-6	2.381-6	5.574-7	2.250-7	4.043-8	1.506-8	9.868-10
2.539-13	1.800-13	1.267-13	8.961-14	5.247-14	2.434-14	1.129-14
5.247-15	2.434-15	1.113-15	5.247-16	2.434-16	1.128-16	5.247-17
29R0.0						
' REACTION NO. 16	C059					
	3.547-2	2.953-2	2.413-2	1.993-2	1.557-2	1.110-2
7.138-3	3.288-3	1.063-3	4.212-4	7.965-6		
52R0.0						
' REACTION NO. 17	NI					
	9.041-2	8.419-2	8.117-2	8.063-2	7.926-2	7.106-2
6.303-2	5.464-2	4.838-2	4.389-2	3.888-2	3.443-2	2.886-2
2.282-2	1.757-2	1.315-2	9.886-3	7.473-3	5.475-3	3.872-3
2.738-3	1.936-3	1.367-3	9.661-4	5.657-4	2.624-4	1.216-4
5.657-5	2.624-5	1.216-5	5.657-6	2.624-6	1.216-6	5.657-7
2.624-7	1.217-7	5.657-8	2.624-8	1.216-8	5.657-9	2.624-9
3.225-10	21R0.0					
' REACTION NO. 18	CU					
	4.238-2	3.563-2	2.979-2	2.510-2	2.109-2	1.689-2
1.220-2	7.235-3	3.677-3	2.253-3	1.073-3	5.309-4	1.751-4
2.503-5	2.510-6	3.510-7	4.770-13			
46R0.0						
' REACTION NO. 19	ZR					
	8.780-3	5.895-3	3.935-3	2.691-3	1.764-3	1.112-3
6.873-4	3.829-4	2.297-4	1.525-4	9.373-5	5.817-5	3.101-5
1.388-5	6.039-6	2.591-6	1.299-6	7.643-7	4.333-7	2.437-7
1.523-7	8.896-8	4.399-8	1.236-8			
39R0.0						
' REACTION NO. 20	NB93					
	9.833-3	8.497-3	7.270-3	6.135-3	4.912-3	3.576-3
2.409-3	1.492-3	9.362-4	6.583-4	4.066-4	2.649-4	1.584-4
8.078-5	2.757-5	1.093-5	5.839-6	3.744-6	2.553-6	1.597-6
8.283-7	4.720-7	3.030-7	2.402-7	9.043-8		
38R0.0						
' REACTION NO. 21	MO					
	1.336-2	1.012-2	7.530-3	5.727-3	4.321-3	3.417-3
2.932-3	2.519-3	2.190-3	1.845-3	1.468-3	1.116-3	7.309-4
4.106-4	2.203-4	1.232-4	7.938-5	5.832-5	4.622-5	3.945-5

3.918-5	3.934-5	3.933-5	1.708-5			
39R0.0						
' REACTION NO. 22 PCA						
5.15-2	4.55-2	4.07-2	3.64-2	3.18-2	2.59-2	
2.04-2	1.44-2	1.02-2	8.27-3	6.54-3	5.64-3	4.66-3
3.66-3	2.82-3	2.11-3	1.59-3	1.20-3	8.76-4	6.20-4
4.38-4	3.10-4	2.19-4	1.55-4	9.05-5	4.20-5	1.95-5
9.05-6	4.20-6	1.95-6	9.06-7	4.19-7	1.94-7	9.05-8
4.20-8	1.95-8	9.05-9	4.20-9	1.95-9	9.12-10	4.20-10
5.12-11						
21R0.0						
' REACTION NO. 23 HT-9						
4.48-2	3.90-2	3.38-2	2.88-2	2.35-2	1.82-2	
1.31-2	7.24-3	3.11-3	1.58-3	4.41-4	1.83-4	4.90-5
7.94-6	2.12-6	4.96-7	2.00-7	3.60-8	1.34-8	8.78-10
2.23-13	1.60-13	1.13-13	7.98-14	4.70-14	2.17-14	1.00-14
4.66-15	2.17-15	9.88-16	4.67-16	2.16-16	1.00-16	4.67-17
29R0.0						
' REACTION NO. 24 V-5CR-5TI						
1.87-2	1.52-2	1.17-2	8.58-3	5.56-3	3.01-3	
1.33-3	4.53-4	2.65-4	1.89-4	1.22-4	8.31-5	5.12-5
2.06-5	3.88-6	7.85-8	2.78-8	7.28-10		
45R0.0						
' REACTION NO. 25 INCONEL 625						
6.70-2	6.07-2	5.68-2	5.47-2	5.22-2	4.57-2	
3.95-2	3.37-2	2.96-2	2.71-2	2.39-2	2.11-2	1.76-2
1.39-2	1.07-2	8.02-3	6.03-3	4.56-3	3.34-3	2.36-3
1.67-3	1.18-3	8.34-4	5.89-4	3.45-4	1.60-4	7.42-5
3.45-5	1.60-5	7.42-6	3.45-6	1.60-6	7.42-7	3.45-7
1.60-7	7.42-8	3.45-8	1.60-8	7.42-9	3.45-9	1.60-9
1.97-10						
21R0.0						
' REACTION NO. 26 TI-6AL-4V						
4.40-2	3.86-2	3.20-2	2.51-2	1.78-2	1.20-2	
8.14-3	4.63-3	2.55-3	1.78-3	1.14-3	7.84-4	4.35-4
1.33-4	3.04-5	1.41-6	5.00-7	1.31-8		
45R0.0						

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(3) Hydrogen production cross section library

1 63 23
 14**
 ' REACTION NO. 1 LI6
 6.62-3 7.41-3 8.49-3 9.61-3 1.11-2 1.28-2
 1.48-2 1.79-2 2.14-2 2.52-2 2.79-2 3.37-2 1.64-2
 50R0.0
 ' REACTION NO. 2 BE
 1.35785-4
 62R0.0
 ' REACTION NO. 3 B10
 6.991-2 6.265-2 5.991-2 5.636-2 5.223-2 4.431-2
 4.381-2 4.285-2 4.461-2 4.693-2 4.452-2 3.789-2 2.619-2
 2.294-2 2.161-2 1.320-2 8.175-3 2.927-3 9.879-5 2.207-6
 1.509-6 1.509-6 1.509-6 1.509-6 1.838-6 2.700-6 3.965-6
 5.813-6 8.539-6 1.253-5 1.838-5 2.700-5 3.965-5 5.814-5
 8.539-5 1.254-4 1.838-4 2.700-4 3.965-4 5.814-4 8.539-4
 5.236-3 21R0.0
 ' REACTION NO. 4 B11
 6.125-3 2.695-3 3.292-4
 60R0.0
 ' REACTION NO. 5 C11
 3.258-4 1.063-6
 61R0.0
 ' REACTION NO. 6 N
 6.292-2 5.741-2 4.889-2 4.059-2 3.297-2 2.557-2
 1.824-2 1.500-2 1.612-2 1.986-2 3.914-2 9.296-2 7.092-2
 4.540-2 1.851-2 3.889-2 3.857-2 9.776-3 5.959-2 2.282-2
 4R1.207-3 1.246-3 1.548-3 2.309-3 3.416-3 5.017-3
 7.367-3 1.080-2 1.586-2 2.329-2 3.416-2 5.017-2 7.367-2
 1.080-1 1.586-1 2.329-1 3.416-1 5.017-1 3.077
 21R0.0
 ' REACTION NO. 7 F19
 9.037-2 7.764-2 6.233-2 4.827-2 4.006-2 3.984-2
 3.798-2 3.102-2 2.269-2 5.911-3 2.483-3 2.043-4
 51R0.0
 ' REACTION NO. 8 AL27
 3.664-1 2.882-1 2.001-1 1.468-1 1.142-1 1.003-1
 8.485-2 6.455-2 4.742-2 3.443-2 2.123-2 1.193-2 4.762-3
 6.511-4 3.277-6
 48R0.0
 ' REACTION NO. 9 SI
 3.266-1 2.559-1 2.564-1 2.760-1 2.750-1 2.519-1
 2.162-1 1.497-1 7.297-2 3.397-2 5.019-3 1.474-3 3.461-5
 1.940-7
 49R0.0
 ' REACTION NO. 10 TI
 1.222-1 9.770-2 7.555-2 6.179-2 5.050-2 4.153-2
 3.339-2 2.414-2 1.765-2 1.349-2 9.932-3 7.118-3 4.138-3
 2.316-3 1.455-3 4.951-4 1.674-4 7.349-5 1.101-5
 44R0.0
 ' REACTION NO. 11 V51
 4.623-2 3.757-2 3.092-2 2.724-2 2.230-2 1.633-2
 1.177-2 8.115-3 5.480-3 4.052-3 2.235-3 9.522-4 5.009-4
 3.089-4 2.143-4 1.727-5
 47R0.0
 ' REACTION NO. 12 CR
 1.953-1 1.254-1 7.879-2 6.247-2 5.403-2 4.620-2
 4.244-2 3.313-2 2.116-2 1.439-2 1.018-2 9.354-3 6.530-3

2.829-3	8.398-4	1.723-4	6.105-5	1.618-6	1.179-8	6.157-9
2.173-9	6.731-11					
41R0.0						
' REACTION NO. 13 MN55						
7.930-2	6.234-2	4.847-2	3.599-2	2.407-2	1.724-2	
1.388-2	1.100-2	8.068-3	5.001-3	1.769-3	8.865-4	1.415-4
3.156-6	2.168-8	1.699-11				
47R0.0						
' REACTION NO. 14 FE						
2.342-1	1.850-1	1.396-1	1.165-1	9.845-2	8.415-2	
6.869-2	5.179-2	3.984-2	3.043-2	2.269-2	1.734-2	1.289-2
6.233-3	2.039-3	2.766-4	2.563-5	6.719-7		
45R0.0						
' REACTION NO. 15 CO59						
1.184-1	1.077-1	1.003-1	8.434-2	4.595-2	2.762-2	
2.218-2	1.798-2	1.483-2	1.210-2	8.696-3	5.141-3	1.883-3
2.912-4	8.062-5	4.858-5	2.493-5	7.449-6	1.690-9	
44R0.0						
' REACTION NO. 16 NI						
7.127-1	6.723-1	5.887-1	4.889-1	4.478-1	4.417-1	
4.322-1	4.160-1	3.909-1	3.561-1	3.106-1	2.687-1	1.947-1
1.106-1	4.446-2	1.388-2	4.384-3	6.117-4	2.181-4	1.651-5
1.731-6	1.224-6	8.642-7	6.109-7	3.577-7	1.659-7	7.692-8
3.577-8	1.659-8	7.692-9	3.577-9	1.659-9	7.692-10	3.577-10
1.659-10	7.692-11	3.577-11	1.659-11	7.692-12	3.577-12	1.659-12
2.039-13		21R0.0				
' REACTION NO. 17 CU						
2.510-1	2.966-1	3.385-1	2.769-1	1.725-1	9.564-2	
6.842-2	6.493-2	6.410-2	5.977-2	5.539-2	5.315-2	4.572-2
3.322-2	1.819-2	7.194-3	2.678-3	9.111-4	4.281-4	1.187-4
6.378-5	3.768-5	1.914-5	6.107-6	6.733-7	2.520-7	5.649-8
36R0.0						
' REACTION NO. 18 ZR						
7.023-2	5.897-2	3.196-2	1.506-2	9.662-3	6.068-3	
3.661-3	1.827-3	8.424-4	3.768-4	1.197-4	2.785-5	3.043-6
8.680-8	4.318-11	4.319-13	1.555-13	4.077-15		
45R0.0						
' REACTION NO. 19 NB93						
5.122-2	4.027-2	3.081-2	2.328-2	1.647-2	1.045-2	
6.283-3	3.378-3	1.891-3	1.314-3	8.244-4	5.723-4	3.432-4
1.596-4	5.576-5	1.455-5	2.505-6	8.112-7	1.693-7	8.863-8
1.846-8	8.561-10	3.014-10	1.785-10	6.516-11	9.770-12	6.474-12
4.215-12	1.323-12	2.731-13				
33R0.0						
' REACTION NO. 20 MO						
1.102-1	8.491-2	4.723-2	3.049-2	2.490-2	2.247-2	
2.126-2	1.984-2	1.792-2	1.495-2	1.037-2	6.370-3	2.622-3
5.822-4	6.762-5	1.951-6	3.035-8	1.029-9	2.889-12	1.751-14
7.266-15	4.245-15	2.099-15	5.898-16			
39R0.0						
' REACTION NO. 21 PCA						
3.04-1	2.53-1	2.01-1	1.67-1	1.47-1	1.35-1	
1.23-1	1.07-1	9.29-2	7.99-2	6.68-2	5.62-2	4.08-2
2.24-2	8.62-3	2.48-3	7.28-4	9.85-5	3.49-5	2.64-6
2.77-7	1.95-7	1.38-7	9.76-8	5.73-8	2.64-8	1.23-8
5.73-9	2.66-9	1.23-9	5.72-10	2.66-10	1.23-10	5.71-11
2.64-11	1.23-11	5.71-12	2.66-12	1.23-12	5.73-13	2.64-13
3.25-14						

21R0.0
REACTION NO. 22 HT-9
2.30-1 1.78-1 1.33-1 1.11-1 9.36-2 7.99-2
6.58-2 4.97-2 3.78-2 2.87-2 2.13-2 1.65-2 1.22-2
5.86-3 1.91-3 2.65-4 2.95-5 7.76-7 1.29-9 6.77-10
2.39-10 7.37-12
41R0.0
REACTION NO. 23 V-5CR-5T1
5.75-2 4.50-2 3.55-2 3.07-2 2.53-2 1.91-2
1.44-2 1.02-2 6.87-3 5.04-3 3.02-3 1.68-3 9.83-4
5.35-4 3.08-4 4.89-5 1.14-5 3.76-6 5.85-10 3.08-10
1.08-10 3.34-12
41R0.0
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