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# NUCLEAR DATA SERVICES

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## MENDL-2

### **Neutron reaction data library for nuclear activation and transmutation at intermediate energies**

**by Yu.N. Shubin et al., Obninsk, Russia**

Summary description by H.D. Lemmel

The MENDL-2 nuclear data library contains for 505 stable and unstable target nuclides production cross-sections for the formation of radioactive product nuclides for incident neutrons with energies up to 100 MeV. The nuclides included cover the range from 13-Al-26 to 84-Po-210 with half-lives larger than one day. The data library is available from the IAEA Nuclear Data Section, costfree, upon request.

Revised by P.K.McLaughlin IAEA/NDS Jan. 2005

The file was revised to conform with ENDF/B format standards.. The merged file was corrected for format errors and processed through the code CHECKR to ensure, as far as possible, format compatibility.

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**Note:**

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IAEA-NDS-reports are updated whenever there is additional information of relevance to the users of the data library.

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96/11

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This data library should be cited as follows:

Yu.N. Shubin, V.P. Lunev, A.Yu. Konobeyev, A.I. Ditjuk, "Cross-section data library MENDL-2 to study activation as transmutation of materials irradiated by nucleons of intermediate energies", report INDC(CCP)-385 (International Atomic Energy Agency, May 1995). Data library MENDL-2 received from the IAEA Nuclear Data Section.

## MENDL-2

Neutron reaction data library for nuclear activation  
and transmutation at intermediate energies

by Yu.N. Shubin et al., Obninsk, Russia

This data library is described in the following references:

- MENDL-2: Yu.N. Shubin, V.P. Lunev, A.Yu. Konobeyev, A.I. Ditjuk, "Cross-section data library MENDL-2 to study activation as transmutation of materials irradiated by nucleons of intermediate energies", report INDC(CCP)-385 (International Atomic Energy Agency, May 1995).
- MENDL-1: A.Yu. Konobeyev, Yu.A. Korovin, V.P. Lunev, V.S. Masterov, Yu.N. Shubin. "The cross-section library for the study of transmutation and activation of materials irradiated with neutrons and protons of energies up to 100 MeV", Voprosy Atomnoj Nauki: Tekhniki, Jadernye Konstanty (Nuclear Constants), Moscow, issue 1992 3-4, p. 55.

A brief description of MENDL-1 which was distributed during the International Conference on Nuclear Data for Science and Technology, Gatlinburg, USA, May 1994, is attached.

The authors are from two institutes in Obninsk, Russia, i.e. Institut Atomnoi Energetiki (Nuclear Power Engineering, INPE) and the Fiziko-Energeticheskij Institut, FEI (Physics and Power Engineering, IPPE).

Contents: Neutron cross-sections for neutrons up to 100 MeV.

- 505 stable and unstable target nuclides from 13-Al-26 to 84-Po-210 with half-lives larger than one day.
- cross section for 57 500 threshold reactions for the production of product nuclides computed with the modified ALICE-92 code.

Format: The data are given in an ENDF similar format, but with a free choice of MT numbers to identify the different reactions; these are explained in each file. ENDF plotting codes will not function.

Libraries: There is an index file ("catalogue") listing the 57 500 reactions included, and a data file.

## MENDL

### ACTIVATION DATA LIBRARY FOR INTERMEDIATE ENERGIES

#### Version: 1 (1992)

Authors: Yu.N. Shubin, A.Yu. Konobeyev<sup>1</sup>, Yu.A. Korovin<sup>1</sup>, V.P. Lunev, V.S. Masterov  
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MENDL (Medium Energy Nuclear Data Library) has been elaborated in Theoretical Division of Institute of Physics and Power Engineering. The library is intended for activation and transmutation study for materials irradiated by intermediate energies particles.

MENDL contains neutron induced reaction cross-sections at energies 0-100 MeV for stable nuclei and unstable nuclei with half-life more than 1 day and atomic number from 13 up to 83. The library includes cross-sections for 497 nuclei and 31704 reactions.

The method to obtain cross-sections was based on geometry dependent hybrid exciton model [1] and Weisskopf-Ewing model. The multiple pre-compound nucleon emission was calculated using approach [1] with some corrections. The alpha-particle pre-compound emission was described in the framework of coalescence pick-up model [2] combined directly with hybrid exciton model. Exciton state density was defined according to the Ericson formula taking into account the Pauli principle and pairing of nuclear levels. To calculate intranuclear transition rate nucleon-nucleon interaction cross-sections corrected for the Pauli principle were used.

Level density calculations were performed according to Ignatyuk et al. [3] taking into account the shell effects. The individual level density parameters were used for all nuclei formed in the evaporation cascade.

Total reaction cross-section and inverse cross-sections were calculated using optical model.

Correction of calculated cross-sections was performed for some reaction channels to achieve the agreement with available experimental data. The calculated cross-sections were corrected to reproduce full experimental excitation functions or were normalized to known cross-section values at 14.5 MeV. For stable nuclei the experimental cross-sections and cross-sections obtained from systematics at 14.5 MeV presented in [4] were used.

Briefly this version of MENDL library is described in Ref. [5].

#### **The MENDL catalogue presented here includes the following information.**

The line beginning with symbol " \* " contains the characteristics of target nucleus with indication atomic number, name of element, atomic mass number, half-life and total number of reactions considered nucleus and contained in MENDL files.

The line with reaction description indicates:

- a) Atomic number (Z), name of element and mass number (A) for target nucleus;
- b) Reaction type; "(N,X)" symbols mean the sum of cross sections for all possible reactions resulted in the same residual nucleus without taking into account radioactive decay chains;
- c) Z, name and A for nucleus produced;
- d) Half-life of the product nucleus; Symbols "S", "M", "H", "D" and "Y" signify Second, Minute, Hour, Day and Year, correspondingly;
- e) The number of energy points for which the cross-sections for given reaction are available in MENDL;
- f) The minimum reaction energy (Q) in MeV for all reactions resulting in considered product nucleus;
- g) The indication of the origin of cross sections presented.

#### EXAMPLE

13-Al-26 (N,X) 11-Na-22 2.60E+00Y 62 -9.450E+00 Original
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#### Meaning:

- 13-Al-26 : target nucleus is aluminium isotope with A=26  
(N,X) : sum of (n,n *alpha*) and (n,3n2p) reaction cross-sections  
11-Na-22 : product nucleus is sodium isotope with A=22  
2.60E+00Y : half-life of <sup>22</sup>Na is equal 2.6 year  
62 : the number of energy points for this reaction is equal to 62  
-9.450E+00: Q-value for (n,n *alpha*) reaction  
Original : reaction cross-section has been obtained by authors

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#### CONTENT

Target	Reaction	Product	Half-live	Points	Q value	Comments
*13-AI-26	unstable		7.205E+05Y	57 reactions		
13-AI-26	(N,2N)	13-AI-25	7.18E+OOS	65	-1.137E+01	Original
13-AI-26	(N,3N)	13-AI-24	2.07E+OOS	45	-2.830E+01	Original
13-AI-26	(N,4N)	13-AI-23	4.70E-OIS	25	-4.319E+01	Original
13-AI-26	(N,P)	12-Mg-26	stable	77	4.786E+00	Original
13-AI-26	(N,X)	12-Mg-25	stable	67	-6.306E+00	Original
13-AI-26	(N,X)	12-Mg-24	stable	60	-1.364E+01	Original
13-AI-26	(N,X)	12-Mg-23	1.13E+OIS	41	-3.017E+01	Original
13-AI-26	(N,X)	12-Mg-22	3.86E+OIS	24	-4.332E+01	Original
13-AI-26	(N,X)	12-Mg-21	1.23E-OIS	7	-6.238E+01	Original
13-AI-26	(N,2P)	11-Na-25	5.96E+OIS	64	-9.358E+00	Original
13-AI-26	(N,X)	11-Na-24	1.50E+OIH	54	-1.837E+01	Original
13-AI-26	(N,X)	11-Na-23	stable	77	2.968E+00	Original
13-AI-26	(N,X)	11-Na-22	2.60E+OOY	62	-9.450E+00	Original
13-AI-26	(N,X)	11-Na-21	2.25E+OIS	50	-2.052E+01	Original

(see full contents in a special file)

\*13-AI-26 13 24 99 0\*MENDL92 \* 0 45-2.82976E+01

31.000	0.0	32.000	3.55E-03	33.000	1.55E-02	34.000	5.26E-02	35.000	1.10E-01
36.000	1.50E-01	37.000	2.50E-01	38.000	3.51E-01	39.000	4.88E-01	40.000	6.25E-01
41.000	6.79E-01	42.000	7.62E-01	43.000	8.35E-01	44.000	9.39E-01	45.000	1.01E+00
46.000	1.04E+00	47.000	1.07E+00	48.000	1.14E+00	49.000	1.20E+00	50.000	1.21E+00
52.000	1.29E+00	54.000	1.27E+00	56.000	1.28E+00	58.000	1.28E+00	60.000	1.28E+00
62.000	1.20E+00	64.000	1.16E+00	66.000	1.12E+00	68.000	1.13E+00	70.000	1.04E+00
72.000	9.94E-01	74.000	9.46E-01	76.000	9.36E-01	78.000	8.67E-01	80.000	8.66E-01
82.000	8.56E-01	84.000	7.96E-01	86.000	7.65E-01	88.000	7.37E-01	90.000	7.36E-01
92.000	6.87E-01	94.000	6.88E-01	96.000	6.64E-01	98.000	6.69E-01	100.000	6.28E-01

\*13-AI-26 13 23 99 0\*MENDL92\* 0 25-4.31910E+01

52.000	0.0	54.000	1.44E-03	56.000	2.45E-03	58.000	5.36E-03	60.000	8.79E-03
62.000	1.04E-02	64.000	1.24E-02	66.000	1.41E-02	68.000	1.54E-02	70.000	1.59E-02
72.000	1.66E-02	74.000	1.78E-02	76.000	1.82E-02	78.000	1.82E-02	80.000	1.78E-02
82.000	1.94E-02	84.000	1.94E-02	86.000	2.05E-02	88.000	2.15E-02	90.000	2.34E-02
92.000	2.41E-02	94.000	2.42E-02	96.000	2.39E-02	98.000	2.53E-02	100.000	2.59E-02

## Experimental Data

Nuclide	Ref.	Comments
27-Al	1,2	
45-Sc	3	
55-Mn	1	
56-Fe	4,5	
59-Co	1,5	
68-Zn	3	
75-As	6	
88-Sr	7	Quoted as in [9]
89-Y	8	
90-Zr	9	
96-Mo	10	
127-I	11-17	(p,3n),(p,5n):[11,17]; (p,6n):[13,14]; (p,7n):[14,16]; (p,3np):[13]. Data [11,12,15] quoted as in [17]
141-Pr	18	
202-Hg	19	
209-Bi	20	

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