FINDING NUCLEAR DATA: THE NATIONAL NUCLEAR DATA CENTER

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ABSTRACT

Nuclear reaction cross-sections and nuclear structure properties are useful for material analysis applications. The nuclear data requirements for material analysis overlap with the data requirements for other research fields, e.g. fission and fusion reactors, so that reference material may be used more widely than the original purpose in mind. The National Nuclear Data Center at Brookhaven National Laboratory, an outgrowth of data compilation and evaluation activities begun more than 40 years ago, specializes in indexing the bibliography, data compilation and data evaluation of nuclear reaction cross-sections and nuclear structure properties. Reference material that are available in many forms that include handbooks, data bases and on-line services are reviewed.

Introduction

There are about 2200 known nuclides each with different nuclear properties. Nuclear beam probes consisting of neutrons, gammas or charged particles can be used to change the state of target materials. Detecting the ensuing radiation provides information about the elements and isotopes contained in the target material. Nuclear reaction microanalysis uses known nuclear reaction properties to infer the presence of particular isotopes in a bombarded material. The success of this method requires that the radiation signatures be sufficiently unique.

The National Nuclear Data Center (NNDC) indexes the bibliography and compiles and evaluates data that are of interest to low energy nuclear physics research and applications. The main thrust of the NNDC effort has been directed toward the needs of fission and fusion applications, but these overlap the needs of material analysts and it is therefore worth summarizing the reference nuclear data that are available.

Nuclear Properties

Material analysis utilizes the characteristic resonance structure of probing reaction cross-sections. In searching for additional probing reactions it is useful to understand the general characteristics of cross-sections. As a tutorial example, neutron induced cross-sections on ^{27}Al [1] are shown in Fig. 1 over the range 1 KeV to 20 MeV. The four curves shown are the total, elastic scattering, nonelastic and inelastic scattering cross-sections. The total cross-section is the sum of all others and below 1000 keV consists almost entirely of the elastic scattering cross-section except at very low energies. The nonelastic cross-section consists of neutron capture in resonances at 6 and 34 keV and mostly inelastic neutron scattering above 1000 MeV. At high energies the elastic scattering and nonelastic cross-sections each approach πr^2 where $r \sim 0.13\ A^{1/3} \times 10^{-12}$ cm and A is the target mass in atomic mass units. The peaks of the resonances approximately fit within an envelope traced by the curve $4\pi\lambda\!\!\!^{-2}$, where $\lambda\!\!\!^{-}$ is the reduced neutron wavelength. With increasing energy, the resonance spacing decreases and above 5 MeV the resonances overlap so as to form a relatively smooth curve. The smoothness also results from worsening experimental resolution.

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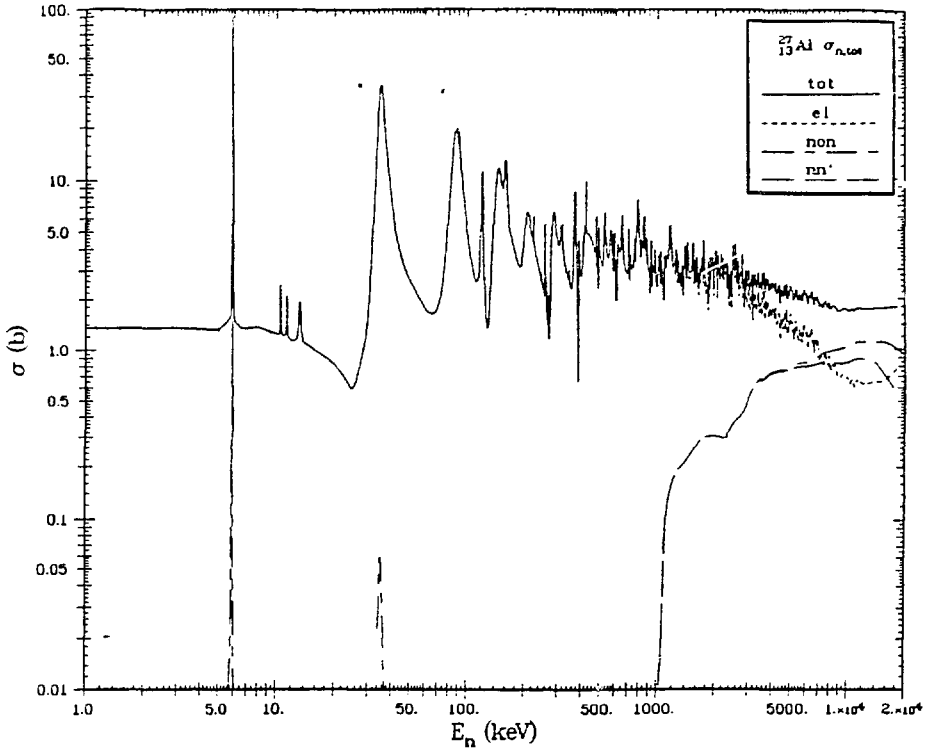

Fig. 1 Neutron cross-sections for ^{27}Al, 1 KeV to 20 Mev.

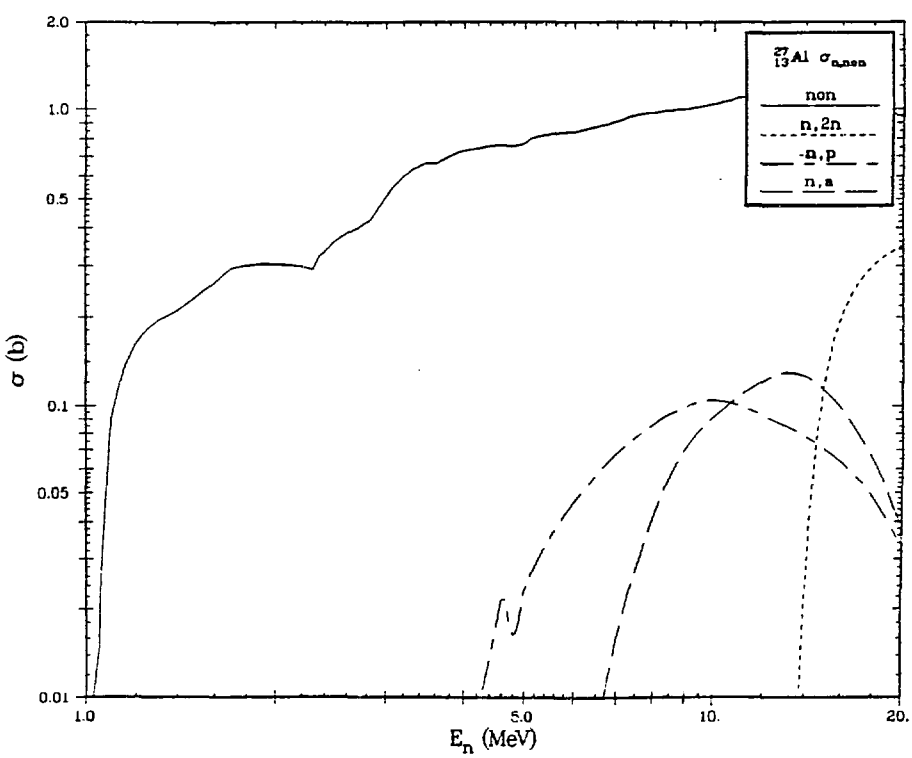

Fig. 2 Neutron cross-sections for ^{27}Al, 1 to 20 MeV.

At about 5 MeV the inelastic neutron cross-section decreases as competing reactions are energetically possible. The cross-section thresholds can be calculated from the nuclear binding energies. The contributions to the nonelastic cross-section by the (n,2n) (n,p) and (n,alpha) reactions are shown in Fig. 2.

At very low energies, e.g. 0.001 eV, the neutron total cross-section is dominated by the neutron capture cross-section which generally is proportional to the inverse square root of the neutron energy as a slowly moving neutron has a high probability of being captured. However, if the target has a crystalline structure, e.g. Beryllium, carbon, the total cross-section can sharply decrease with decreasing neutron energy since neutrons having wave lengths at multiples of the intra crystalline distances are reflected instead of absorbed. Only the evaluated curves are shown in Figs. 1 and 2. Comparisons with experimental data can be found in Neutron Cross Sections [2].

It is the resonance structure that is the important feature for material analysis. An aluminum surface will strongly reflect neutrons at the predominently scattering resonances at approximately 6,35,90, etc. KeV. Another surface material would have a different resonance structure. Incident particles having incident energies less than a few MeV tend to form a compound nucleus. In this case, the neutrons incident on ^{27}Al form ^{28}Al and the resonance structure in the neutron cross-section reflects the ^{28}Al level structure at energies approximately 7.73 MeV and more above the ground state. It is also energetically possible for the compound state to prompt decay to ^{28}Al by cascade emission of gamma rays with the spectra being dependent on the level energies, spins and parities of ^{28}Al. At incident neutron energies above ~ 1.8 MeV, in the zero momentum frame, proton emission is possible leaving ^{27}Mg as the residual nucleus and at incident energies above ~ 3.1 MeV, alpha emission is possible leaving ^{24}Na, as shown in Fig. 3. However, the Coulomb barrier against proton and alpha emission prevent the reaction cross-sections from rising until higher energies as shown in Fig. 2.

The foregoing discussion illustrates how nuclear binding energies, reaction cross-sections and nuclear structure properties are used to determine suitable probes for material analysis.

For incident charged particles the discussion is modified in two ways. The cross-sections at zero incident energy are zero and become appreciable only as the incident particles can tunnel through the Coulomb barrier. Above the Coulomb barrier the neutron and charged particle induced cross-sections are similar except the resonances are characteristic of the new compound nucleus formed. In the case of protons on ^{27}Al the compound nucleus formed is ^{28}Si as shown in Fig. 4 together with the energy relationships for neutron and alpha emission.

Data Bases

Evaluated nuclear data files are useful to material scientists since the task of reviewing experimental data is performed by nuclear data experts who recommend values for applications. The ENDF/B library contains evaluated neutron-induced data for most materials. Evaluated charged particle data are not yet widely available in ENDF/B but are planned for the future. Evaluated data for measured nuclear structure data for all known nuclides are contained in the Evaluated Nuclear Structure Data File (ENSDF) [3]. The contents of ENSDF are the same as published in the Nuclear Data Sheets [4] for A>44 and are compiled from Nuclear Physics [5] for the remaining A's. An index to the most recent publications of evaluated nuclear structure data appears in each issue of the Nuclear Data Sheets.

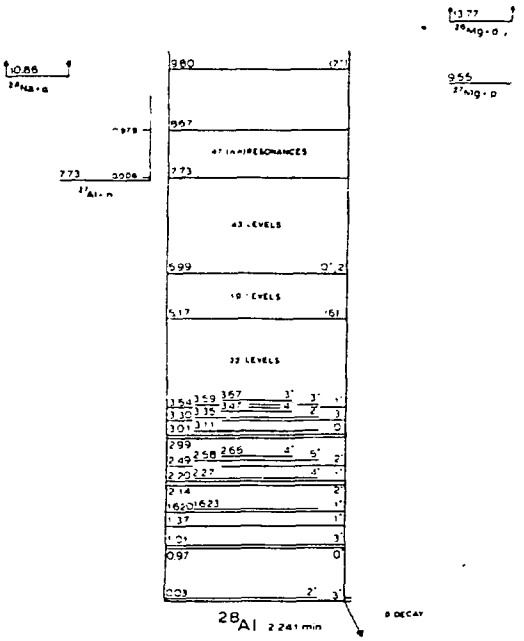

Fig. 3 Energy levels of ^{28}Al

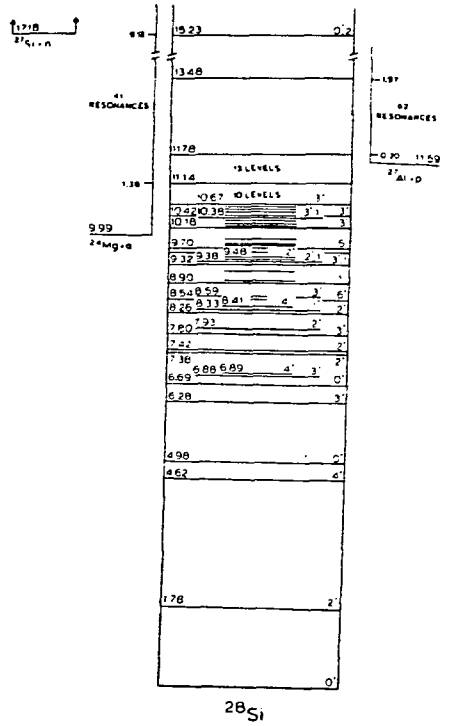

Fig. 4 Energy levels of ^{28}Si

Where evaluated data are not available, compilations of experimental data are helpful. Neutron and charged particle reaction data are compiled and exchanged through an international network of centers [6]. The NNDC maintains these data in the Cross Section Information Storage and Retrieval System (CSISRS). An example of ^{16}O (p, alpha) data contained in CSISRS is shown in Fig. 5. For the independent measurements shown, there is generally good agreement as to the location of the first two resonances but the peak cross-sections are different. CSISRS contains many energy and angular dependent reaction data sets for incident charged particles.

Whereas for incident neutrons the compilation of experimental data is quite complete, the compilation of experimental data for incident charged particles and heavy ions is not. However, indexed bibliography to the nuclear physics literature can be helpful to locate appropriate references. The Cross-section Index to Neutron Data (CINDA) is a data base and publication [7] that contains references to the literature and data compilations for neutron-induced reactions. The Nuclear Structure References (NSR) data base is an index to the literature on low energy nuclear physics and is the source of information for the triannual sections of Recent References and the Reaction Index published in Nuclear Data Sheets. NSR also provides the source material for the annual report Integral Charged Particle Nuclear Data Bibliography [8]. There are also comprehensive reports on nuclear reactions induced by light charged particles [9,10].

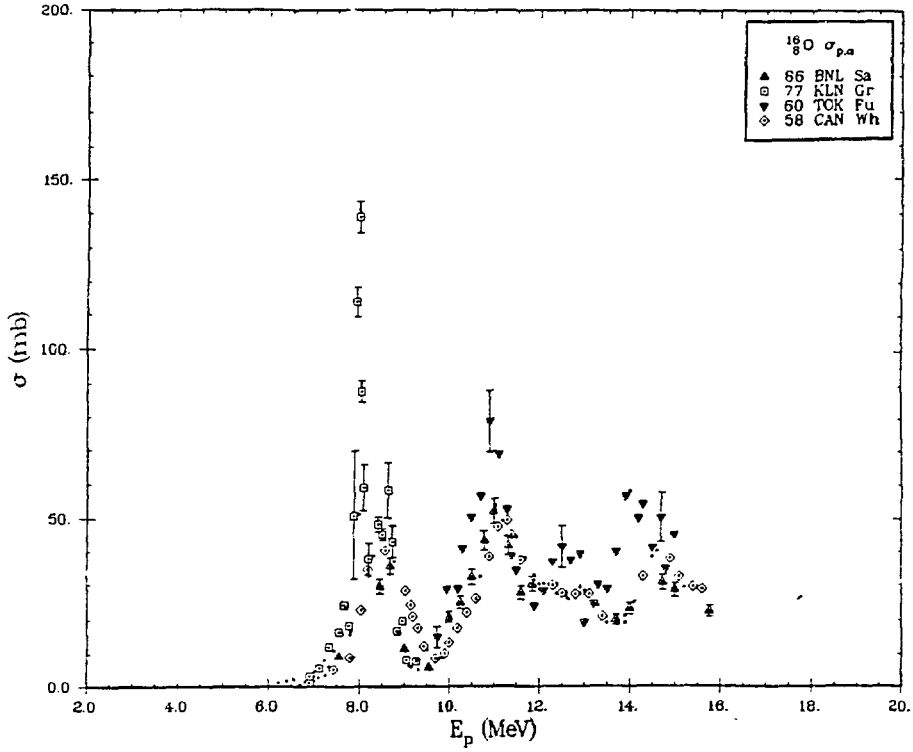

Fig. 5 ^{16}O (p, alpha) cross-section, 2 to 20 MeV. References: 86 BNL-radiochim. Acta 38,57 (1986); 77 KLN-Nucl. Phys. A286,523 (1977); 60 TOK-J. Phys. Soc. Jap. 15,2167 (1960); 58 CAN-Can. J. Phys. 36,1276 (1958).

On-Line Access

Selective searches of the aforementioned data bases may be requested of the NNDC. These data bases are also available on-line and may be accessed via telephone or networks. Information for contacting the NNDC and on-line access is given in Table 1.

Conclusions

The general characteristics of nuclear reactions and nuclear structure data that are useful to nucleonic material analysis have been described. The contents and ways of accessing relevant nuclear data bases have been indicated. Excellent reviews of nucleonic material analysis data and techniques have appeared [11,12] but accessing data bases to determine what new information is available is a way to update knowledge of the field.

Table 1

ON-LINE ACCESS

On-line access to computerized numeric and bibliographic nuclear physics information is available through the National Nuclear Data Center (NNDC) at Brookhaven National Laboratory to users in the United States and Canada. Similar services also may be available from other members of the International Network for Nuclear Structure Data Evaluation.

ACCESS: PHYSNET/HEPNET, INTERNET, MFENET networks or remote modem and commercial telephone (300 and 1200 BAUD).

DATA FILES:

NSR — Nuclear Structure Reference file – bibliographic information for low and intermediate energy nuclear physics, covering the period from 1910 to the present. The data file is updated monthly.

ENSDF — Evaluated Nuclear Structure Data File – evaluated experimental data on nuclear level properties, radiations, radioactive decay and reaction data for $1 \leq A \leq 266$.

NUDAT — Nuclear Data – evaluated numeric data extracted or derived from the ENSDF and the Nuclear Wallet Cards.

CINDA — Computer Index of Neutron Data – bibliographic references to neutron reaction data.

CSISRS — Cross Section Information Storage and Retrieval System – experimental data on neutron, photon, and charged particle reactions.

ENDF — Evaluated Nuclear Data File – evaluated nuclear reaction and decay data.

RETRIEVAL SYSTEM:

Access to the NNDC VAX/780 computer is available as follows:

Telephone:	(516) 282-5390
HEPNET	BNLNDC (address 43.405 or 44437)
INTERNET	BNLNDC.DNE, BNL.GOV, or (192.12.15.131)

The username is NNDC and it is a no-password account. No further special authorization is needed to access the on-line newsletter, mail facility, and HELP files to become acquainted with the system.

A user-friendly system provides ample help to the user who specifies the retrieval criteria in response to step-by-step prompts by the system. A user's guide to the on-line services, BNL-NCS-39756, also is available. The output can be obtained on the user's terminal or saved as a computer file and transferred later to the user's computer.

Contact NNDC for authorization to access the data bases listed above and for more information contact:

ON-LINE ACCESS
National Nuclear Data Center
Brookhaven National Laboratory
Upton, NY 11973
Tel (516) 282-2901 or FTS: 666-2901

S. Pearlstein

References

1. Evaluated Nuclear Data File (ENDF/B)* Version V. Maintained and distributed by the National Nuclear Data Center, Brookhaven National Laboratory, Upton, N.Y. 11973. ENDF/B Summary Documentation, BNL-NCS-17541, (ENDF-201), Third Edition. Evaluation for ^{27}Al, MAT=1313, by P. G. Young and D. G. Foster, Jr., LA-4726 (1973).

2. V. McLane, C. L. Dunford and P. F. Rose, Neutron Cross Sections, Volume 2, Neutron Cross Section Curves. Published by Academic Press, Inc. (1988).

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6. V. McLane et al., "Nuclear Reaction Data Centers," pp. 1157-1160, Conference: Nuclear Data for Science and Technology (1988 MITO), Saikon Publishing Co., LTD, Tokyo, Japan (1988).

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