



**The Abdus Salam
International Centre for Theoretical Physics**



2172-6

**Joint ICTP-IAEA Workshop on Nuclear Data for Science and
Technology: Analytical Applications**

8 - 12 November 2010

Differential cross sections for ion beam analysis

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The Abdus Salam
International Centre for Theoretical Physics



FRIDAY, 12 NOVEMBER 2010
11.00 - 12.30
The GIAMBIAGI Lecture Hall

Workshop on Nuclear Data for Science and Technology: Analytical Applications

DIFFERENTIAL CROSS SECTIONS FOR ION BEAM ANALYSIS

Alexander Gurbich



Institute of Physics and Power Engineering
Obninsk, Russia

PLAN OF THE LECTURE

- Needs of IBA in nuclear data
- Ion Beam Analysis Nuclear Data Library (IBANDL)
- EXFOR data base
- Evaluation of nuclear data

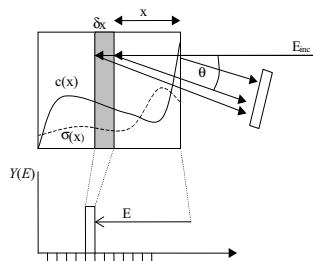
2

What nuclear data are needed for IBA?

Sort of data	Projectiles	Targets	Type of interaction	Energy range
Differential cross sections $d\sigma(E)/d\Omega$, γ -ray yields	p, d, ^3He , ^4He , heavy ions	All elements	Elastic scattering, nuclear reactions	0.5–10 MeV

3

NRA Depth Profiling



- A channel of width δE at energy E in the spectrum corresponds to a slice of width dx at depth x in the sample, with E and δE being inversely related to x and δx through a linear combination of the stopping powers for the incident and outgoing particle

- The number of particles accumulated into that histogram bin is proportional to $c(x)$, δx , and $\sigma(E_x)$, where E_x is the energy of the incident beam when it gets to depth x .

$$Y_i(E) = \int_0^{\infty} \frac{N_0 c(x) \sigma(\varphi, E_i) d\Omega}{S(E') \left[\frac{-1}{\cos(\varphi + \theta)} + \frac{1}{\cos(\theta)} \frac{k S(E_i)}{S(kE_i)} \right]} \frac{1}{1.06 \Gamma(x)} \exp\left(-\frac{(E' - E)^2}{0.36 \Gamma^2(x)}\right) dE'$$

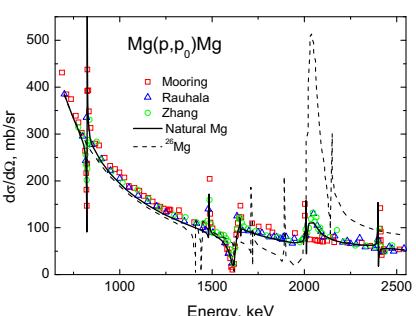
4

Distinctive feature of the nuclear data for IBA

- IBA uses differential cross sections rather than total ones – data for different angles are needed
- IBA employs data mainly for elements of natural abundance rather than for separated isotopes – data acquired in nuclear physics studies are often not sufficient

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The difference between cross sections for separate isotopes and for an element of natural abundance



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This is the IAEA Beam Analysis Nuclear Data Library produced according to the recommendations of the IAEA Technical Meeting held at the IAEA Headquarters in Vienna (29-30 October 2003). This data collection is a result of merging [SpectraBase](#) and [SNRBASE](#). It contains all of the available experimental data on nuclear reactions and cross sections for various isotopes and reaction types. The experimental data are in the [RD3](#) format. All the entries are supplied with a reference to the data source. The data published only in a graphical form were digitized using a precise technique. Where all efforts were made to ensure that the most accurate information was adopted, no guarantee can be given concerning the full validity of the data. The data are provided "as is".

Maintaining IBANDL as a dynamically developing collection of the IBA nuclear data significantly depends on the activity of all members of the IBA community. Contributions to IBANDL are welcome. If you have new experimental results [submit your data now](#).

The activity of the IBA community in the field of nuclear data is now supported by IAEA through the Coordinated Research Project (CRP). A [summary](#) of the first CRP meeting describes its place and goals. The recent [Research Coordination Meeting \(see the RCM homepage\)](#) was held on 18 - 21 June 2007 at IAEA headquarters in Vienna.

Automatic conversion from EXFOR to RD3 is now provided. When neutron and projectile are selected press "EXFOR" button in the left frame and the information available in the [EXFOR data base](#) will be displayed. Details of the conversion algorithm can be found [here](#). Please report any problems to [V.Zerkin](#).

A complete [CD version](#) of IBANDL is available on request.

Last update: 09.08.2010 4:09:02

No.	Reaction	Angle	Energy(eV)	Reference
1	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	180°	1650-4600	SternCalc
2	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	179°	9095-9590	Y. Qin, et al., Phys. Rev. A, 56, 234 (1997).
3	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	172°	5205-7500	M. Artigas, et al., Nucl. Inst. & Meth. B166 (1992) 217.
4	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	171.00°	4480-6180	W. Hwang, et al., U.S. Patent, 5,180,245.
5	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	171.00°	3990-9730	H. Bremmer, et al., U.S. Patent, 5,180,246.
6	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	167.20°	2010-3840	Hering, et al., Phys. Rev. D12 (1970) 1210.
7	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	167.00°	4555-6570	L.A. Foster, et al., Nucl. Inst. & Meth. B79 (1993) 454.
8	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	167°	5080-5970	C.J. Wenzel, et al., LA-UR-99-4887.
9	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	167°	7090-9070	L.A. Foster, et al., Nucl. Inst. & Meth. B79 (1993) 454.
10	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	167°	8760-9900	L.A. Foster, et al., Nucl. Inst. & Meth. B79 (1993) 454.
11	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	166.00°	920-1420	E.A. Silvertson, S.R. Sabolsky, G.Hawke and L.D. Ophouse, Phys. Rev. C44 (1991) 124.
12	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	166.00°	1400-1920	E.A. Silvertson, S.R. Sabolsky, G.Hawke and L.D. Ophouse, Phys. Rev. C44 (1991) 124.
13	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	166.00°	1900-2200	E.A. Silvertson, S.R. Sabolsky, G.Hawke and L.D. Ophouse, Phys. Rev. C44 (1991) 124.
14	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	165.90°	1900-9900	Feng, Y., Zhou, Z., Zhou, G. and Yang, Y., Nucl. Inst. and Meth. B64 (1994) 11.
15	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	165.00°	2540-3930	I. Bogdanovic Radovic, et al., unpublished.
16	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	165.00°	3420-5990	G. Terzagi, G. Geraci, M. Vozza and G.G. Ross, J. Appl. Phys. 64 (1990) 1040.
17	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	165.00°	2690-4700	J.Kader, P.D. Miller and J. Reiter, Phys. Rev. C12 (1975) 547.
18	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	165.00°	2540-3930	I. Bogdanovic Radovic, et al., unpublished.
19	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	159.00°	3140-3770	W. Jing, et al., Surf. Interface Anal. 37 (2005) 374.
20	$^{14}\text{N}(\alpha, \gamma)^{17}\text{N}$	159.00°	3090-3850	Morales, et al., Phys. Rev. A53 (1996) 2210.

The figure is a line graph titled "Cross section - Ratio to Rutherford" versus "Energy, keV". The y-axis has major ticks at 0.00, 1.00, 2.00, 3.00, and 4.00. The x-axis has major ticks at 1000, 2000, 3000, and 4000. There are three data series represented by colored lines: red, green, and blue. The red line has a sharp peak at approximately 2500 keV and a very tall peak at approximately 3800 keV. The green line has a broad peak around 3000 keV. The blue line is relatively flat near zero. Below the plot, there is a legend with three entries:

- Theta=150.0 Signals, L.R
- Theta=150.00, L. Bagrevardt Radovic et al.
- Theta=150.00, M. Jiang et al., Surf.

IBANDL - Microsoft Internet Explorer provided by IAEA

Upload your data

If your experimental data are already in the R33 format then upload them using the form on this page. Files should have r33 extension and should not exceed 25 kb per file.
An alternative way is to prepare a four column ASCII file:

Energy(eV), Energy error (zero if unknown), Sigma, Sigma error (zero if unknown)

with no headers, save it under an arbitrary name with r33 extension in a temporary folder and then use a template.

File 1: File 2: File 3: File 4: File 5: File 6: File 7: File 8: File 9:

Name
CD version
Upload your data
Update
Feedback
Header Data Services

Done Local intranet

R33 Format for Communication of Reaction Cross Sections in the IBA Community

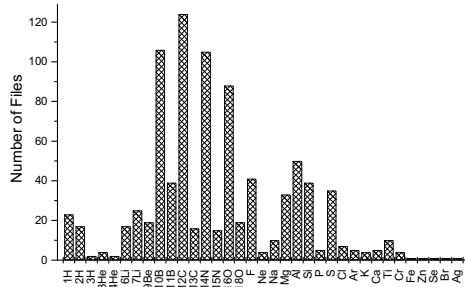
Comment: The thick film method was employed at different incident beam energies and the results were combined into a single cross section. The values agree with our chit film results, which generally exceed those of Saad et al (1966) by a factor of 2.

File created by R33 Manager Version 0.21

Version: R33
Source: M.J. Healy and D.W.Lane. Nucl. Instr & Meth B 136-138 (1998) 66-71
Name: Healy, M.J.
Address1: Cranfield University.
Address2: RMCS Shrewsbury
Address3: Swindon. SN4 8LA.
Address4: United Kingdom.
Address5: Tel +44 1793 785736 Fax: +44 1793 785774
Address6: email m.j.f.healy@rmcs.cranfield.ac.uk
Serial Number:
LogFile: 32sdg.r33
X400: 0
Reaction: 32S(d,p)33S
Distribution: Energy
Composition:
Bases: 3.000, 32.000, 1.000, 33.000
Depth: 1, 16, 4, 16
Qvalue: 6418.00, 0.00, 0.00, 0.00, 0.00
Theta: 150.00
Sigfactors: 1.00, 0.00
Ensfactors: 1.00, 0.00, 0.00, 0.00
Units: mb
Data:
1005.000, 0.000, 0.011, 0.000
1010.000, 0.000, 0.012, 0.000
1015.000, 0.000, 0.013, 0.000
1020.000, 0.000, 0.018, 0.000
1025.000, 0.000, 0.020, 0.000
1030.000, 0.000, 0.019, 0.000
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1040.000, 0.000, 0.015, 0.000
1045.000, 0.000, 0.015, 0.000

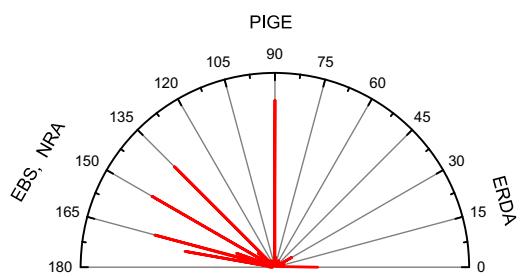
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The IBANDL content by element



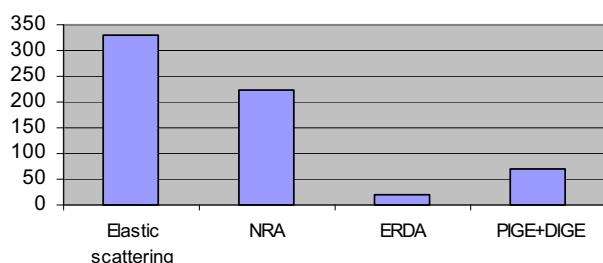
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The distribution of the available data on angle



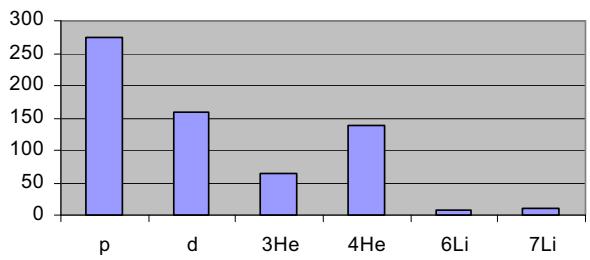
13

Content of IBANDL (by reaction)

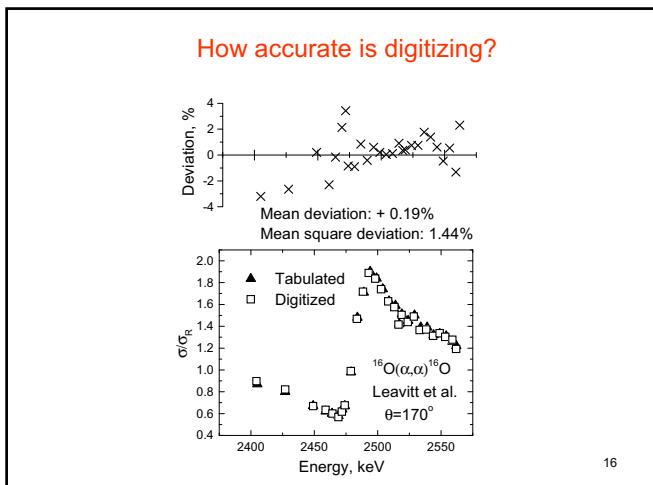


14

Content of IBANDL (by projectile)



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IBANDL - Windows Internet Explorer

Nucleus H-1

Projectiles

- D
- He
- Li
- H
- C
- O
- Ne
- Ar
- Li

Type of data

- CDBS
- NRA
- EXFOR
- RIA
- RIA

IBANDL

This is the Ion Beam Analysis Nuclear Data Library produced according to the recommendations of the IAEA Technical Meeting held at the IAEA Headquarters in Vienna (29 to 30 October 2003). This data collection is a result of merging SigmaBase and XNRBASE. It contains most of the available experimental nuclear cross-sections relevant to Ion Beam Analysis. Existing functions are presented both in graphs and data files. The numerical data are in the RIA format, which is the standard format for the exchange of nuclear data between different codes. The data were collected using different techniques. Where all efforts were made to ensure that the most accurate information was adopted, no guarantee can be given concerning the full validity of the data, and the IAEA accepts responsibility for usage of IBANDL.

More information about the quality of the data and the activity of the IBA nuclear data community depends on the activity of all members of the IBA community. Contributions to IBANDL are welcome. If you have new experimental results [upload your data now](#).

The activity of the IBA community in the field of nuclear data is now supported by IAEA through the Coordinated Research Project (CRP). A summary of the first CRP meeting [describes its plan and goals](#). The second Research Coordination Meeting ([see the RCM summary](#)) was held on 18 - 21 June 2007 at IAEA headquarters in Vienna.

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A complete [CD version](#) of IBANDL is available on request.

Last update: 09-08-2010 [A. Gordeev](#)

EXFOR

Home
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What is EXFOR

Database for all experimental nuclear reaction data, such as all total and differential cross section types, resonance parameters, fission and other product yields, production cross sections, spectra, polarization data, etc. etc.

Started in 1970 for neutron data, later extended to charged-particle and photonuclear data

Includes also structured abstract of experimental method and bibliographic information

EXFOR format

Data exchanged in 80-character ASCII files, managed with relational database system with sophisticated retrieval possibilities see <http://www-nds.iaea.org/exfor/>)

Data presentation very flexible (close to authors' presentation in publication): different units, varying number of data columns, etc.

Several "computational" output formats for processing and plotting; not yet working for differential data (but coming soon)

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Screenshot of the EXFOR interface showing the Data Selection screen. The interface includes a navigation bar, a search bar, and several dropdown menus. The main area displays a table of reaction data with columns for energy range, cross-section, reference, and other parameters. The table shows multiple entries for different reactions and energy ranges, with some rows highlighted in yellow.

Screenshot of the EXFOR interface showing the Data Selection screen. This version includes a note about being a beta version of the software. The table of reaction data is identical to the previous screenshot, showing multiple entries for different reactions and energy ranges.

EXFOR/CDNSC: Experimental Nuclear Reaction Data - Opera

File Edit View Bookmarks History Tools Help
EXFOR/CDNSC: Opera | http://www.ndc-bea.org/exfor/ndc.html
Help | EXFOR Manual | Contact | Privacy Policy | Database | ENDF | CENDF | BEENDF | CD-ROM | Search | Create | Download

NNDCC Experimental Nuclear Reaction Data (EXFOR)
Database Version of September 17, 2010

The EXFOR library contains an extensive compilation of experimental nuclear reaction data. Neutron reactions have been compiled systematically since the discovery of the neutron, while charged particle and photon reactions have been covered less extensively. The library contains data from 18883 experiments (see statistics and news compilation).

Request Example: A1495001

Target: Submit Reset Help
Reaction: Options
Quantity: Exclude unreported data
Product: Display range of products when coded as ELEM/MASS (example)
Energy (MeV): Display range of angles and secondary energies on "Data Selection" page
Author(s): Display range of angles and secondary energies on "Data Selection" page
Publication year: Sort by publication date
Accession #: Sort by accession date
Extended Options: Accession (Empty Subfield)
Keywords: Range (Z,A)
Experiment: Selection sub-fields
Reset: Feed-back and User's Input
CINDA | ENDF

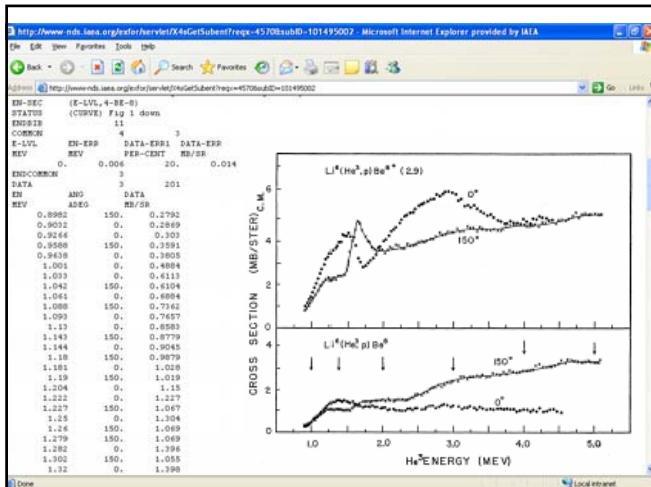
Note:
- criteria are optional (selected by clicking)
- selected criteria are combined for search with logical AND
- criteria separated in a field by "||" are combined with logical OR
- wildcards (*) and ranges are available.

http://www.ndc-bea.org/exfor/exfor.html
Data and Database design and implementation: Walter Zemann, AGO, International Atomic Energy Agency (Vienna, Austria)
Data and Database design and implementation: Walter Zemann, AGO, International Atomic Energy Agency (Vienna, Austria)
Data and Database design and implementation: Walter Zemann, AGO, International Atomic Energy Agency (Vienna, Austria) - coordinator: Naoko Onoaka, AGO (n.onoaka@iaea.org)

http://www.ndc-bea.org/exfor/hervlet/X4aGetSubent?req=4570subID=101495002 - Microsoft Internet Explorer provided by IAEA

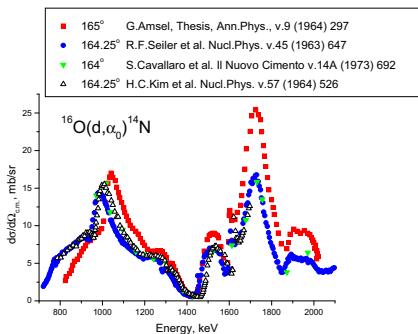
File Edit View Favorites Tools Help
Address: http://www.ndc-bea.org/exfor/hervlet/X4aGetSubent?req=4570subID=101495002

SUBENT A1495001 20031013 20040312
BIN ID 15
TITLE Study of the reaction mechanism for (He^3, F) reactions with Li-6-8-10 and C-13
AUTHOR J.A. Becker, T.W.Bunner, P.M.Davis, F.W.Prosseer, Jr.
INSTITUTE (USA/ARIC)
REFERENCE (J.Ph.,104,1044,195611)
FACILITY (VDF)
SAMPLE Target materials were evaporated on 2-mil foil backing, thick enough to stop the He-3 beam yet thin compared to the range of the proton groups studied
METHOD (EPR)
DETECTOR (SCIN) Thallium-activated CsI crystals mounted on DuMont 4291 photomultiplier tubes.
END-ANALYS (DATA-EPRI) The pulse-height resolution of the detectors
HISTORY (1980-2003) Compilation produced by Atomco NFMG-UNILIEF (20031013) Last checking has been done.
ENDSUB 15
CODE 1 3
DATA-EPRI
PER-CENT 4.
END-COMM 3
END-DAT 22
SUBENT A1495002 20031013 20040312
BIN ID 15
RACTION ($\text{Li}^{6-8}/(\text{He}^3, \text{P})\text{Be}^{8+}, \text{PAR}, \text{PAI}$)
SAMPLE Metallic Li-7 enriched to 96%. 10 microg/cm² thick.
END-ANALYS (END-EPRI) Digitizing error
(DATA-EPRI) Digitizing error
(END-EPRI) Uncertainty in the cross-section was introduced by not knowing precisely what fraction of the pulses to attribute to the 1.9-MeV state and what fraction to the continuous together with other uncertainties in target thickness and geometry.
END-SEC (E-LVL, 4-8K-8)
Done Local Intranet



THE REASONS WHY EVALUATION IS NEEDED

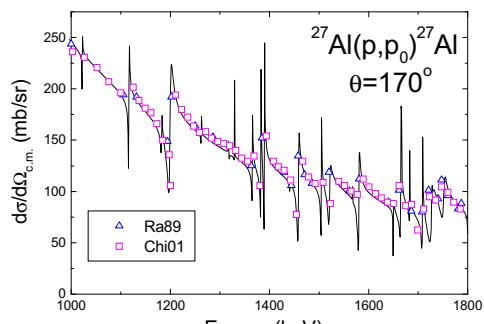
Reason 1: because of discrepancies between results of different measurements



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THE REASONS WHY EVALUATION IS NEEDED

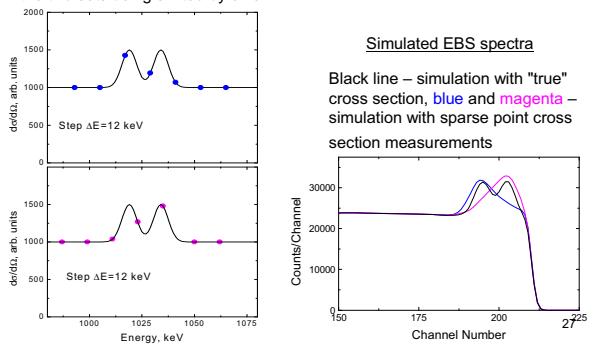
Reason 2: because cross section may has a fine structure missed in some measurements



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WHY IS A FINE STRUCTURE ESSENTIAL?

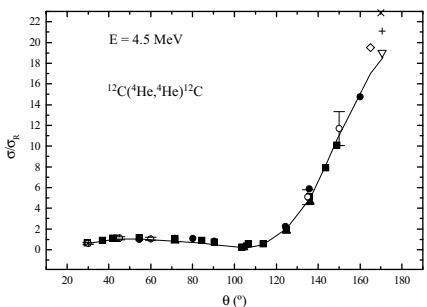
Suppose "true" cross section is as shown by a solid line and two measurements with 12 keV step are made, the measured points in the two sets being shifted by 6 keV



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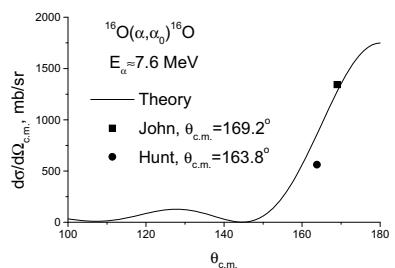
THE REASONS WHY EVALUATION IS NEEDED

Reason 3: because cross section may have a strong dependence on angle.



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Comparison of different results for $^{16}\text{O}(\alpha, \alpha_0)^{16}\text{O}$ cross section



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The comparison of the results obtained by «thin» and «thick» target methods for $\text{Si}(\alpha, \alpha)$ cross section

K.-M. Kallman, Z. Phys. A 356 (1996) 287

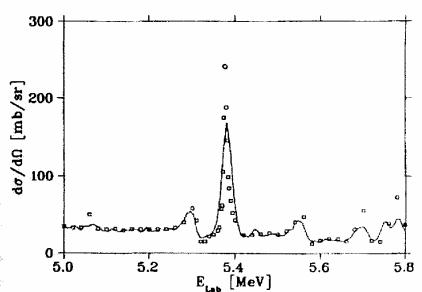


Fig. 2. The excitation function obtained with the thick-target method (full line) compared to the excitation function from [4] (dots)

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Evaluation Problem

Given:

Different sets of (generally inconsistent) experimental data measured at sparse points on energy and angle

Find:

The most accurate possible smooth curves of $d\sigma/d\Omega(E,\theta)$

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Solution

Step 1: search in the literature and nuclear data bases to find all relevant experimental data.

Step 2: digitize data published only as graphs.

Step 3: compare data from different sources.

Step 4: examine reported experimental conditions and errors assigned to the data.

Step 5: select the apparently reliable experimental points.

Step 6: identify nuclear physics processes corresponding to the case.

Step 7: fit free parameters of the theoretical model.

Step 8: produce the optimal theoretical differential cross-section.

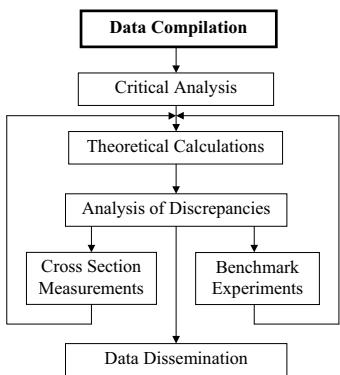
32

The Essence of Evaluation

To produce **evaluated** cross-section through incorporation of the data measured under different experimental conditions at different scattering angles into the frameworks of the unified theoretical approach.

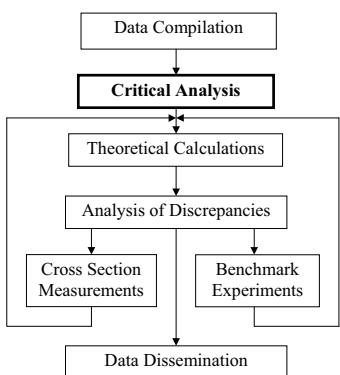
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Evaluation Scheme



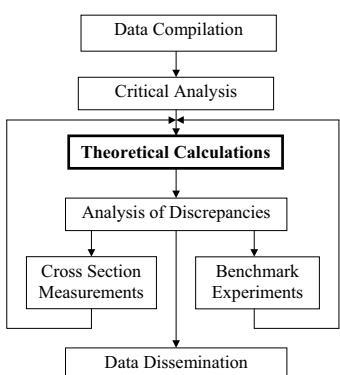
34

Evaluation Scheme

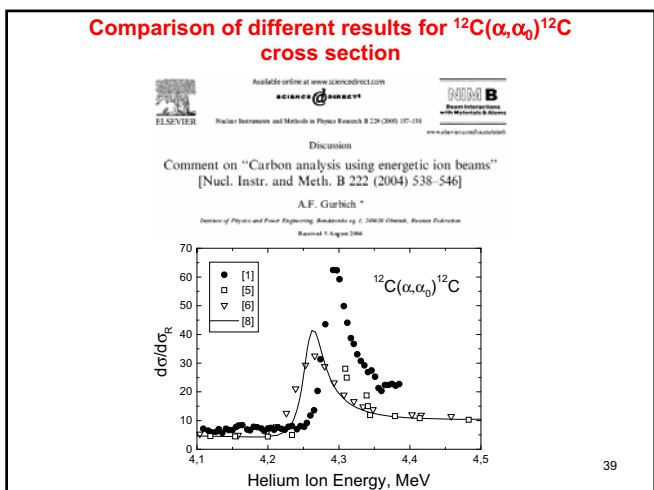
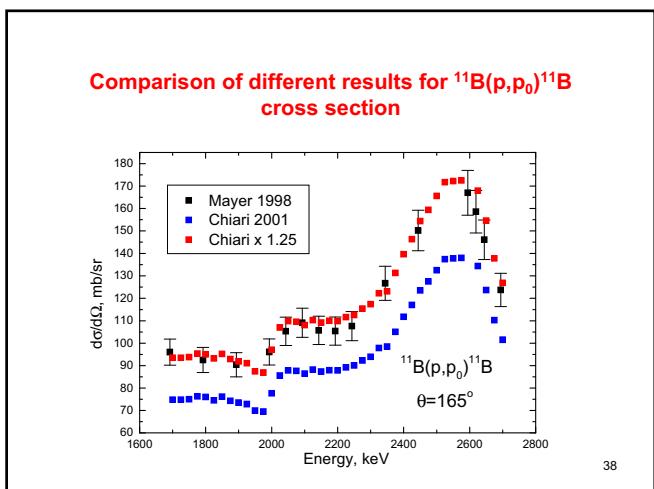
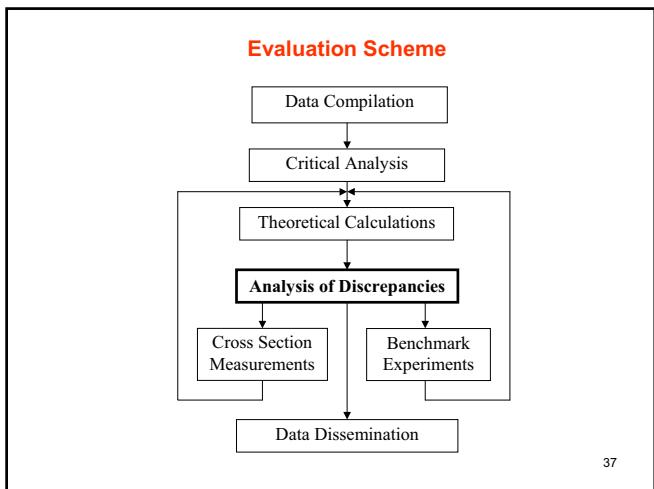


35

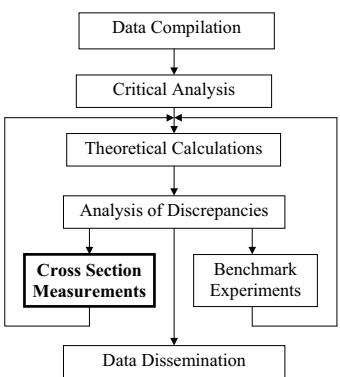
Evaluation Scheme



36

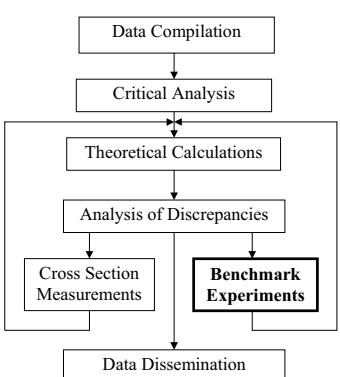


Evaluation Scheme



40

Evaluation Scheme



41

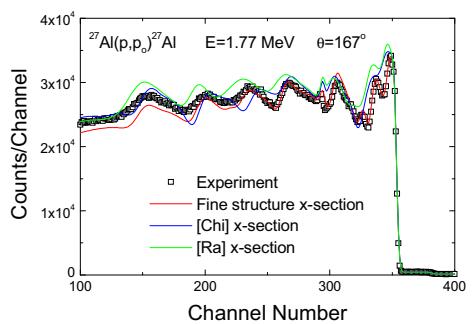
Benchmarks

A benchmark is an integral experiment which is compared with a standard direct simulation using microscopic cross-section data in order to verify the data.

This is an extension of the definition taken from reactor physics where microscopic neutron data are verified by comparison of calculated integral reactor characteristics such as e.g. neutron flux with results of direct measurements.

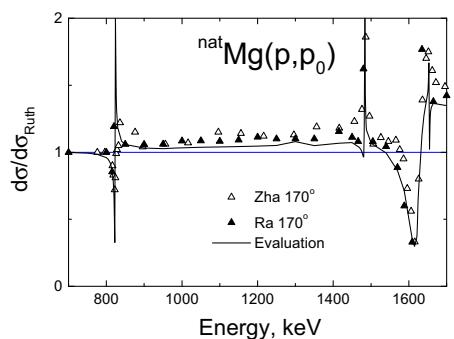
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The benchmark demonstrated the significance of the cross section fine structure



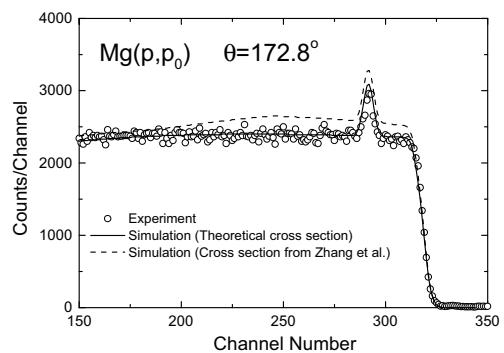
43

The deviation of the cross section for Mg(p,p₀) from Rutherford above 800 keV

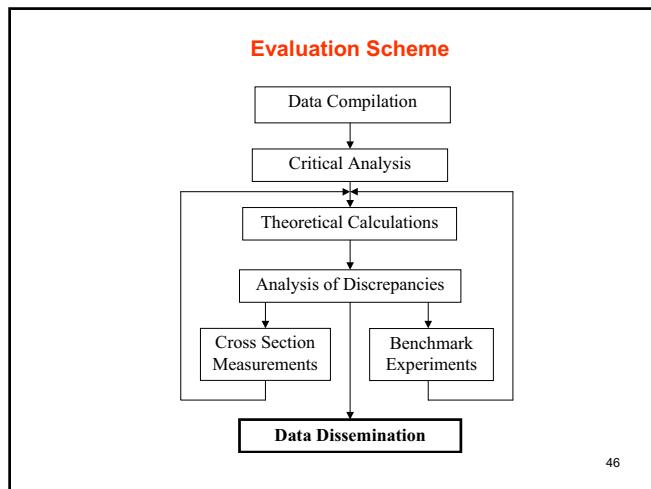


44

The benchmark for Mg(p,p₀)

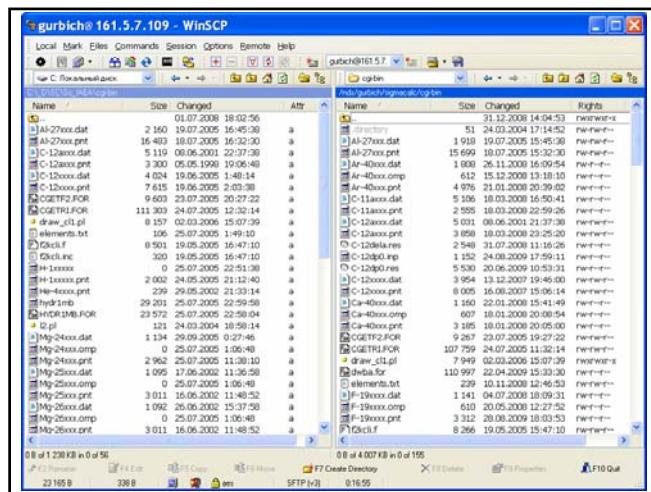


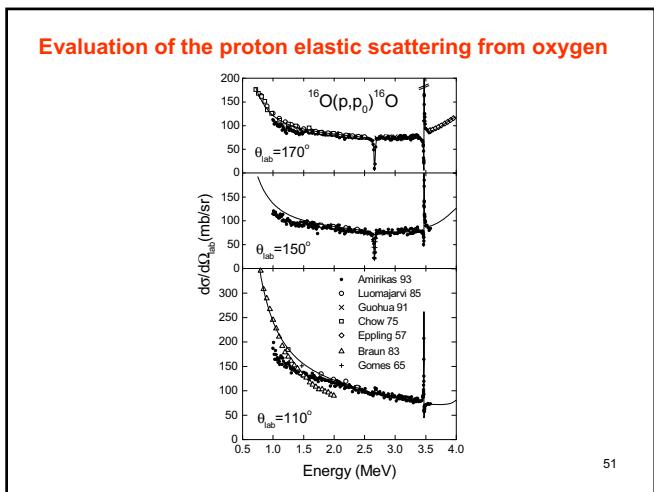
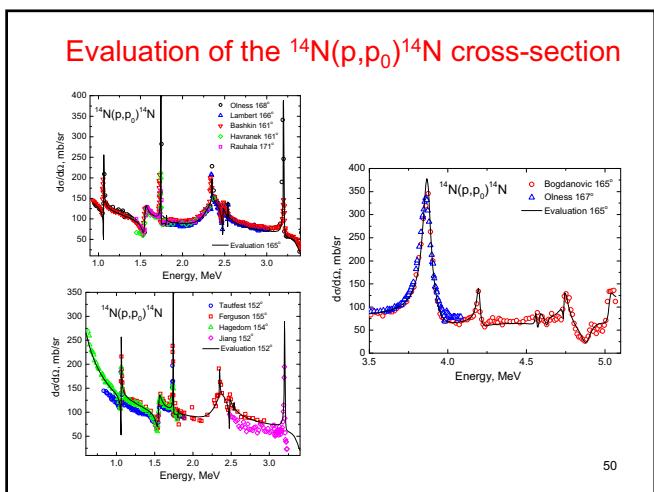
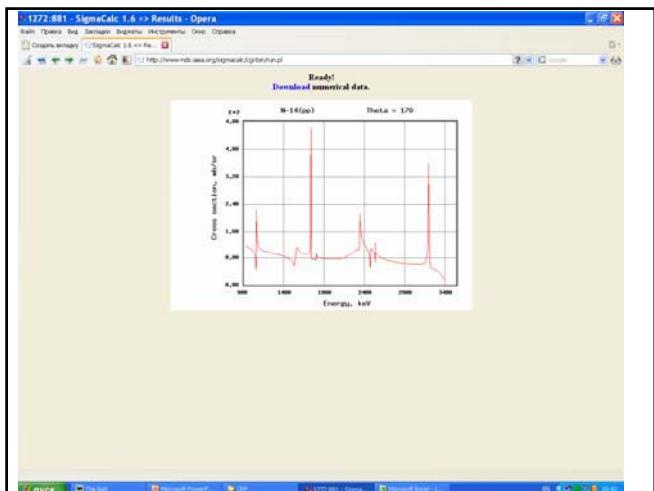
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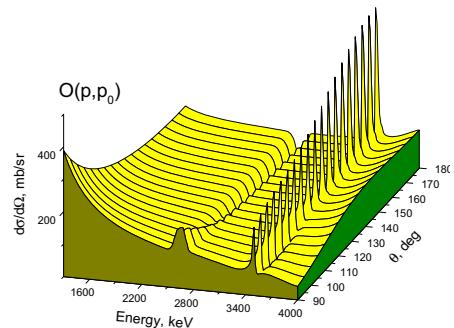
46





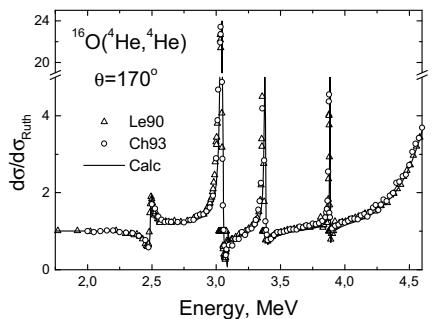


The evaluated cross section for proton elastic scattering from oxygen



52

Comparison of different results for $^{16}\text{O}(\alpha, \alpha_0)^{16}\text{O}$ cross section



53

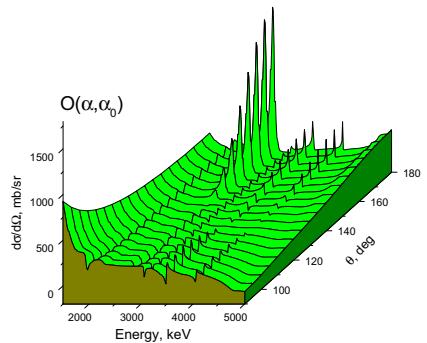
$^{16}\text{O}(\alpha, \alpha_0)^{16}\text{O}$

Resonance parameters reported in different works

E_α , keV	Γ_{lab} , keV	Reference
3.0317		Demarche et al. J. Appl. Phys. 100 (20060) 124909
3034±5		Leavitt, et al. NIM B 44 (1990) 260
3035±6		Cheng et al., NIM B 83 (1993) 449
3036±2.3	10.12±0.37	MacArthur et al., Phys. Rev. C 22 (1980) 356
3038±5.0	10.0	Soroka et al., NIM B 83 (1993) 311
3042±3.0	10.26±0.49	Jarjis, NIM B 12 (1985) 331
3042±3.0	10.20±0.40	Wang et al., NIM 211 (1993) 193
3045±10.0	10.0	Cameron, Phys. Rev. 90 (1953) 839
3038.2±2	10.1±0.4	Evaluated (1998, TUNL)

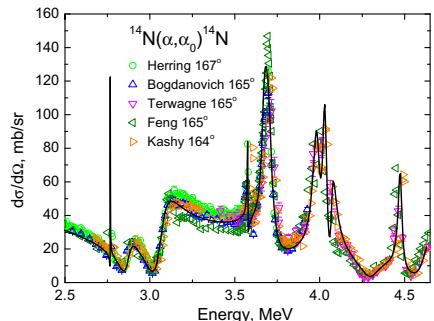
54

The evaluated cross section for alpha elastic scattering from oxygen



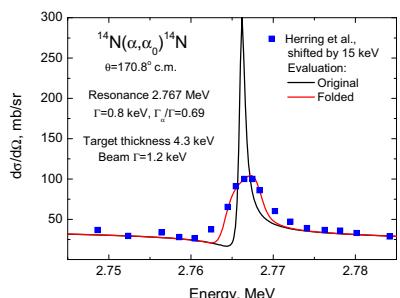
55

Evaluation of the $^{14}\text{N}(\alpha, \alpha_0)^{14}\text{N}$ cross-section



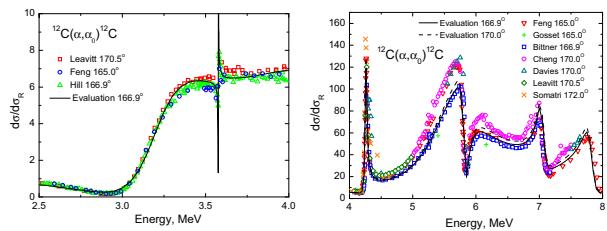
56

$^{14}\text{N}(\alpha, \alpha_0)^{14}\text{N}$ narrow resonance

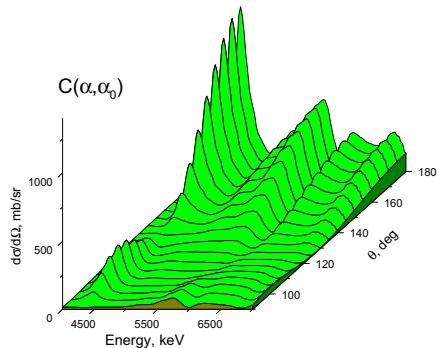


57

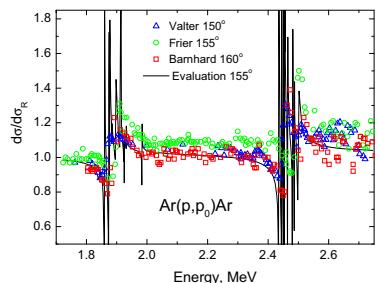
Evaluation of the $^{12}\text{C}(\alpha, \alpha_0)^{12}\text{C}$ cross-section



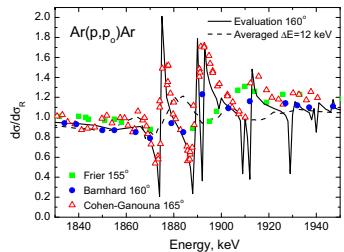
The evaluated cross section for alpha elastic scattering from carbon



Evaluation of the Ar(p, p₀)Ar cross-section



Ar(p,p₀)Ar fine structure



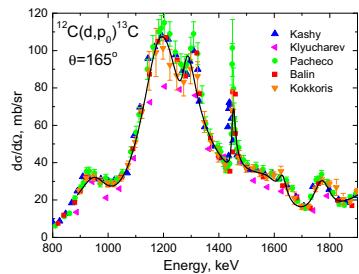
61

Most useful reactions with deuterons

$^2\text{H}(\text{d},\text{p})^3\text{H}$	$Q = 4.03 \text{ MeV}$
$^{12}\text{C}(\text{d},\text{p})^{13}\text{C}$	$Q = 2.72 \text{ MeV}$
$^{14}\text{N}(\text{d},\text{p})^{15}\text{N}$	$Q = 8.62 \text{ MeV } (\text{p}_0)$
$^{14}\text{N}(\text{d},\alpha)^{12}\text{C}$	$Q = 13.57 \text{ MeV } (\alpha_0)$
$^{16}\text{O}(\text{d},\text{p})^{17}\text{O}$	$Q = 1.92 \text{ MeV } (\text{p}_0)$
$^{16}\text{O}(\text{d},\alpha)^{14}\text{N}$	$Q = 3.11 \text{ MeV}$
$^{27}\text{Al}(\text{d},\text{p})^{28}\text{Al}$	$Q = 5.50 \text{ MeV } (\text{p}_0)$
$^{27}\text{Al}(\text{d},\alpha)^{25}\text{Mg}$	$Q = 6.71 \text{ MeV } (\alpha_0)$
$^{28}\text{Si}(\text{d},\text{p})^{29}\text{Si}$	$Q = 6.25 \text{ MeV}$

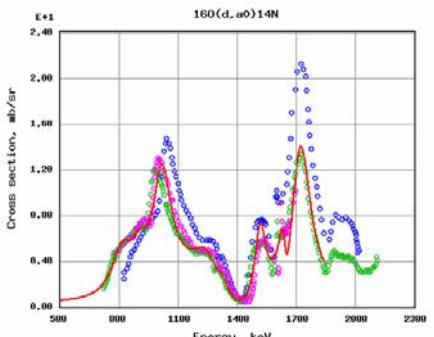
62

Evaluation of the $^{12}\text{C}(\text{d},\text{p}_0)^{13}\text{C}$ cross-section



63

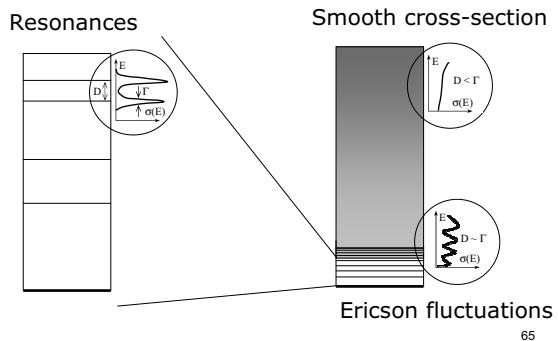
$^{16}\text{O}(\text{d},\alpha_0)^{14}\text{N}$ cross-section at 165°



Theta=165.0 SigmaCalc 1.6 File created 9-6-2010
 Theta=165.00 G.Auerl, Thesis, Ann.Phys., 9(1964), 297
 Theta=164.25 R.F.Sedler et al. Nucl.Phys. v.45 (1963) 647
 Theta=164.25 H.C. Kim et al. Nucl. Phys. 57 (1964) 526

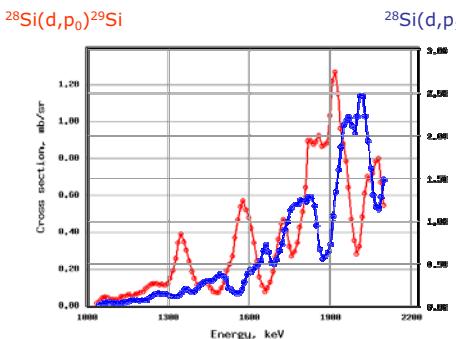
64

Three regions in the compound nucleus excitation and corresponding cross-section behavior



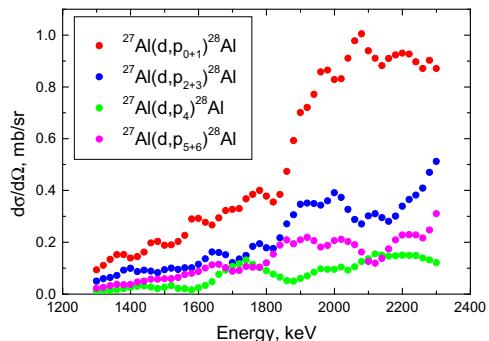
65

Ericson fluctuations in the $^{28}\text{Si}(\text{d},\text{p}_0)^{29}\text{Si}$ reaction



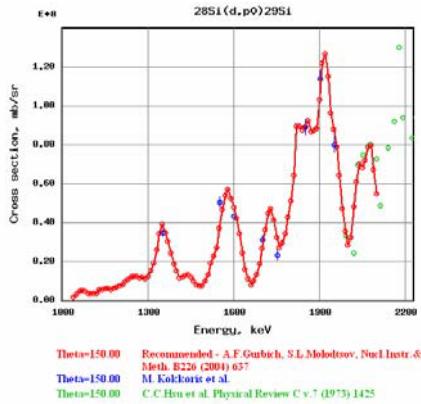
66

Ericson fluctuations in the $^{27}\text{Al}(\text{d},\text{p})^{28}\text{Al}$ reaction



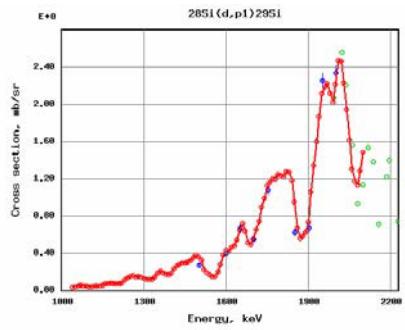
67

"Recommended" cross-section for $^{28}\text{Si}(\text{d},\text{p}_0)^{29}\text{Si}$ at 150°



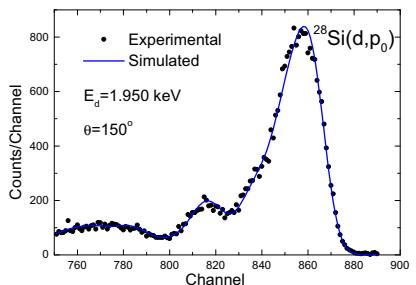
68

"Recommended" cross-section for $^{28}\text{Si}(\text{d},\text{p}_1)^{29}\text{Si}$ at 150°



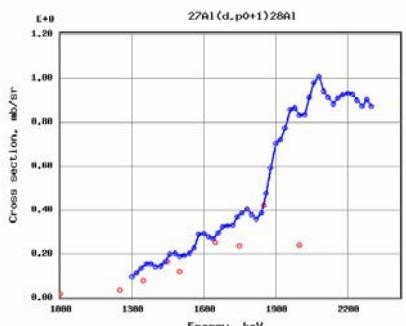
69

Benchmark for the $^{28}\text{Si}(\text{d},\text{p}_0)^{29}\text{Si}$ cross-section



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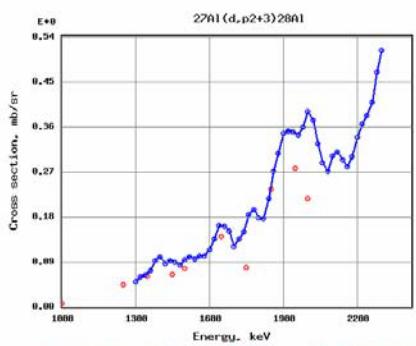
"Recommended" cross-section for $^{27}\text{Al}(\text{d},\text{p}_{0+1})^{28}\text{Al}$ at 150°



Theta=150.00 S. Pellegrino et al., Nucl. Instr. and Meth. B 266 (2008) 2268
Theta=150.00 Recommended - A.F.Gurich, S.L.Molodtsov, Nucl. Instr. & Meth. B266 (2008) 3535

71

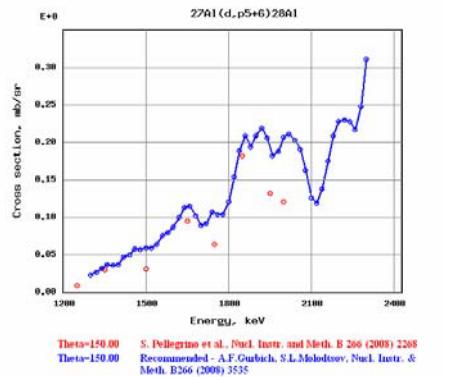
"Recommended" cross-section for $^{27}\text{Al}(\text{d},\text{p}_{2+3})^{28}\text{Al}$ at 150°



Theta=150.00 S. Pellegrino et al., Nucl. Instr. and Meth. B 266 (2008) 2268
Theta=150.00 Recommended - A.F.Gurich, S.L.Molodtsov, Nucl. Instr. & Meth. B266 (2008) 3535

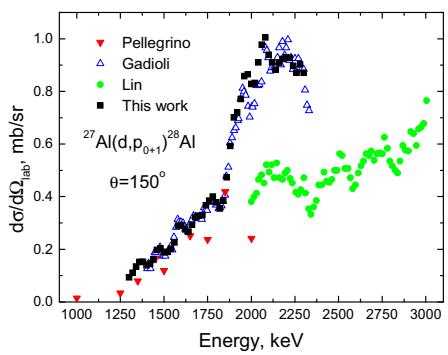
72

**"Recommended" cross-section for
 $^{27}\text{Al}(\text{d},\text{p}_{5+6})^{28}\text{Al}$ at 150°**



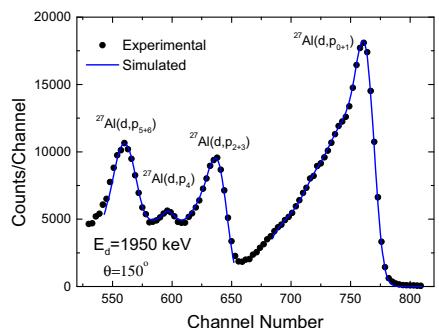
73

The comparison of the results of a new measurement with other data for $^{27}\text{Al}(\text{d},\text{p}_{0+1})^{28}\text{Al}$



74

Benchmark for the $^{27}\text{Al}(\text{d},\text{p})^{28}\text{Al}$ cross-section



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Most useful reactions with ${}^3\text{He}$

${}^2\text{H}({}^3\text{He}, \text{p}){}^4\text{He}$	Q = 18.35 MeV
${}^2\text{H}({}^3\text{He}, \alpha){}^1\text{H}$	Q = 18.35 MeV
${}^9\text{Be}({}^3\text{He}, p_0){}^{10}\text{B}$	Q = 10.32 MeV (p_0)
${}^{12}\text{C}({}^3\text{He}, \text{p}){}^{14}\text{N}$	Q = 4.78 MeV (p_0)

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1276-910 - ENDF: Evaluated Nuclear Data File - Opera

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Evaluated Nuclear Data File (ENDF)
Database Version of May 31, 2010

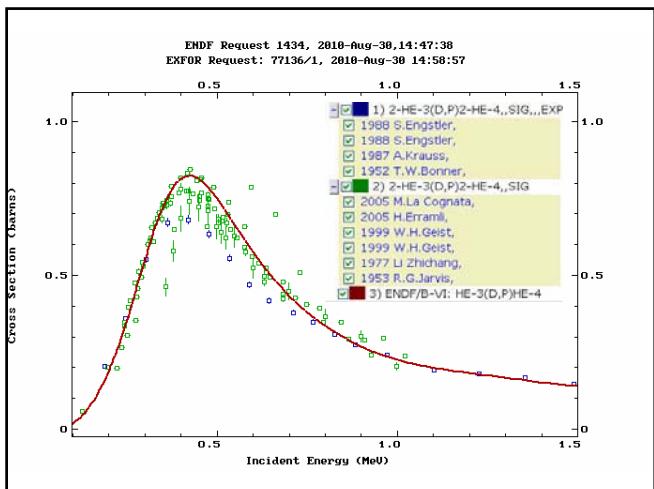
2010-09-16: New library
2010-09-16: ENDF-2010 Japanese evaluated nuclear data library, 2010 [page]
2010-09-16: Updated version of the neutron library, 696 materials, Olenov, Russia, issued in 2010 [page]

Core nuclear reaction database contain recommended values for cross sections, spectra, angular distributions, fission product yields, multi-atomic, and thermal scattering law data, with emphasis on neutron induced reactions. The data were analyzed by experimental nuclear physicists to produce recommended libraries for one of the nation's nuclear data projects (USA, Europe, Japan, Russia and China). All data are stored in the internationally-adopted ENDF-6 format maintained by CNSD.

Standard Request: Examples: [1276-910](#) | Go to: Advanced Request; ENDF-Explorer

Parameters: Submit | Reset

Target: ${}^3\text{He}$ | ${}^1\text{H}$ | ${}^2\text{H}$ | ${}^4\text{He}$ | ${}^7\text{Li}$ | ${}^{10}\text{B}$ | ${}^{14}\text{N}$ | ${}^{19}\text{F}$ | ${}^{23}\text{Na}$ | ${}^{235}\text{U}$ | ${}^{238}\text{U}$ | ${}^{239}\text{Pu}$ | ${}^{241}\text{Am}$ | ${}^{252}\text{Cf}$ | ${}^{26}\text{Al}$ | ${}^{27}\text{Al}$ | ${}^{28}\text{Si}$ | ${}^{30}\text{Si}$ | ${}^{31}\text{P}$ | ${}^{32}\text{S}$ | ${}^{36}\text{Ar}$ | ${}^{37}\text{Cl}$ | ${}^{38}\text{Ar}$ | ${}^{40}\text{K}$ | ${}^{41}\text{Ca}$ | ${}^{42}\text{Mg}$ | ${}^{44}\text{Ca}$ | ${}^{46}\text{Ti}$ | ${}^{48}\text{Cr}$ | ${}^{50}\text{Fe}$ | ${}^{52}\text{Ni}$ | ${}^{54}\text{Cr}$ | ${}^{56}\text{Fe}$ | ${}^{58}\text{Ni}$ | ${}^{60}\text{Ni}$ | ${}^{62}\text{Ni}$ | ${}^{64}\text{Ni}$ | ${}^{66}\text{Ni}$ | ${}^{68}\text{Ni}$ | ${}^{70}\text{Ni}$ | ${}^{72}\text{Ni}$ | ${}^{74}\text{Ni}$ | ${}^{76}\text{Ni}$ | ${}^{78}\text{Ni}$ | ${}^{80}\text{Ni}$ | ${}^{82}\text{Ni}$ | ${}^{84}\text{Ni}$ | ${}^{86}\text{Ni}$ | 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${}^{628}\text{Ni}$ | ${}^{630}\text{Ni}$ | ${}^{632}\text{Ni}$ | ${}^{634}\text{Ni}$ | ${}^{636}\text{Ni}$ | ${}^{638}\text{Ni}$ | ${}^{640}\text{Ni}$ | ${}^{642}\text{Ni}$ | ${}^{644}\text{Ni}$ | ${}^{646}\text{Ni}$ | ${}^{648}\text{Ni}$ | ${}^{650}\text{Ni}$ | ${}^{652}\text{Ni}$ | ${}^{654}\text{Ni}$ | ${}^{656}\text{Ni}$ | ${}^{658}\text{Ni}$ | ${}^{660}\text{Ni}$ | ${}^{662}\text{Ni}$ | ${}^{664}\text{Ni}$ | ${}^{666}\text{Ni}$ | ${}^{668}\text{Ni}$ | ${}^{670}\text{Ni}$ | ${}^{672}\text{Ni}$ | ${}^{674}\text{Ni}$ | ${}^{676}\text{Ni}$ | ${}^{678}\text{Ni}$ | ${}^{680}\text{Ni}$ | ${}^{682}\text{Ni}$ | ${}^{684}\text{Ni}$ | ${}^{686}\text{Ni}$ | ${}^{688}\text{Ni}$ | ${}^{690}\text{Ni}$ | ${}^{692}\text{Ni}$ | ${}^{694}\text{Ni}$ | ${}^{696}\text{Ni}$ | ${}^{698}\text{Ni}$ | ${}^{700}\text{Ni}$ | ${}^{702}\text{Ni}$ | ${}^{704}\text{Ni}$ | ${}^{706}\text{Ni}$ | ${}^{708}\text{Ni}$ | ${}^{710}\text{Ni}$ | ${}^{712}\text{Ni}$ | ${}^{714}\text{Ni}$ | ${}^{716}\text{Ni}$ | ${}^{718}\text{Ni}$ | ${}^{720}\text{Ni}$ | ${}^{722}\text{Ni}$ | ${}^{724}\text{Ni}$ | ${}^{726}\text{Ni}$ | ${}^{728}\text{Ni}$ | ${}^{730}\text{Ni}$ | ${}^{732}\text{Ni}$ | ${}^{734}\text{Ni}$ | ${}^{736}\text{Ni}$ | ${}^{738}\text{Ni}$ | ${}^{740}\text{Ni}$ | ${}^{742}\text{Ni}$ | ${}^{744}\text{Ni}$ | ${}^{746}\text{Ni}$ | ${}^{748}\text{Ni}$ | ${}^{750}\text{Ni}$ | ${}^{752}\text{Ni}$ | ${}^{754}\text{Ni}$ | ${}^{756}\text{Ni}$ | ${}^{758}\text{Ni}$ | ${}^{760}\text{Ni}$ | ${}^{762}\text{Ni}$ | ${}^{764}\text{Ni}$ | ${}^{766}\text{Ni}$ | ${}^{768}\text{Ni}$ | ${}^{770}\text{Ni}$ | ${}^{772}\text{Ni}$ | ${}^{774}\text{Ni}$ | ${}^{776}\text{Ni}$ | ${}^{778}\text{Ni}$ | ${}^{780}\text{Ni}$ | ${}^{782}\text{Ni}$ | ${}^{784}\text{Ni}$ | ${}^{786}\text{Ni}$ | ${}^{788}\text{Ni}$ | ${}^{790}\text{Ni}$ | ${}^{792}\text{Ni}$ | ${}^{794}\text{Ni}$ | ${}^{796}\text{Ni}$ | ${}^{798}\text{Ni}$ | ${}^{800}\text{Ni}$ | ${}^{802}\text{Ni}$ | ${}^{804}\text{Ni}$ | ${}^{806}\text{Ni}$ | ${}^{808}\text{Ni}$ | ${}^{810}\text{Ni}$ | ${}^{812}\text{Ni}$ | ${}^{814}\text{Ni}$ | ${}^{816}\text{Ni}$ | ${}^{818}\text{Ni}$ | ${}^{820}\text{Ni}$ | ${}^{822}\text{Ni}$ | ${}^{824}\text{Ni}$ | ${}^{826}\text{Ni}$ | ${}^{828}\text{Ni}$ | ${}^{830}\text{Ni}$ | ${}^{832}\text{Ni}$ | ${}^{834}\text{Ni}$ | ${}^{836}\text{Ni}$ | ${}^{838}\text{Ni}$ | ${}^{840}\text{Ni}$ | ${}^{842}\text{Ni}$ | ${}^{844}\text{Ni}$ | ${}^{846}\text{Ni}$ | ${}^{848}\text{Ni}$ | ${}^{850}\text{Ni}$ | ${}^{852}\text{Ni}$ | ${}^{854}\text{Ni}$ | ${}^{856}\text{Ni}$ | ${}^{858}\text{Ni}$ | ${}^{860}\text{Ni}$ | ${}^{862}\text{Ni}$ | ${}^{864}\text{Ni}$ | ${}^{866}\text{Ni}$ | ${}^{868}\text{Ni}$ | ${}^{870}\text{Ni}$ | ${}^{872}\text{Ni}$ | ${}^{874}\text{Ni}$ | ${}^{876}\text{Ni}$ | ${}^{878}\text{Ni}$ | ${}^{880}\text{Ni}$ | ${}^{882}\text{Ni}$ | ${}^{884}\text{Ni}$ | ${}^{886}\text{Ni}$ | ${}^{888}\text{Ni}$ | ${}^{890}\text{Ni}$ | ${}^{892}\text{Ni}$ | ${}^{894}\text{Ni}$ | ${}^{896}\text{Ni}$ | ${}^{898}\text{Ni}$ | ${}^{900}\text{Ni}$ | ${}^{902}\text{Ni}$ | ${}^{904}\text{Ni}$ | ${}^{906}\text{Ni}$ | ${}^{908}\text{Ni}$ | ${}^{910}\text{Ni}$ | ${}^{912}\text{Ni}$ | ${}^{914}\text{Ni}$ | ${}^{916}\text{Ni}$ | ${}^{918}\text{Ni}$ | ${}^{920}\text{Ni}$ | ${}^{922}\text{Ni}$ | ${}^{924}\text{Ni}$ | <math



Most useful reactions with protons

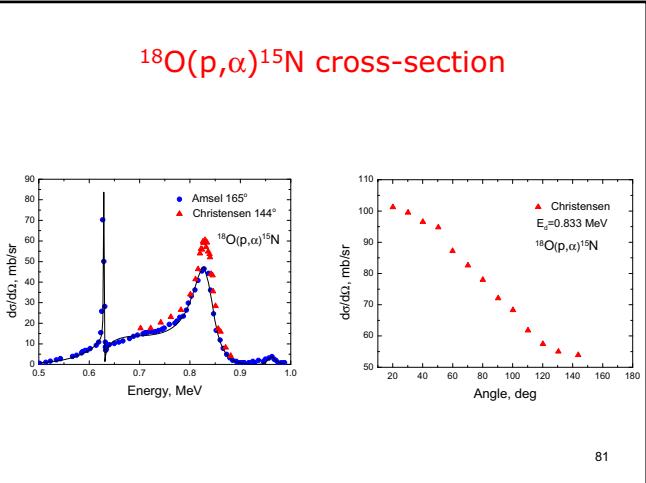
$^7\text{Li}(\text{p},\alpha)^4\text{He}$ $Q = 17.3 \text{ MeV}$

$^{11}\text{B}(\text{p},\alpha)^8\text{Be}$ $Q = 8.5 \text{ MeV}$

$^{18}\text{O}(\text{p},\alpha)^{15}\text{N}$ $Q = 4.0 \text{ MeV}$

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$^{18}\text{O}(\text{p},\alpha)^{15}\text{N}$ cross-section



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COORDINATED RESEARCH PROJECT ON NUCLEAR DATA FOR IBA



International Atomic Energy Agency

INDC International Nuclear Data Committee

INDC (NDS) 0481

Dest. G, HC

Development of a Reference Database
for Ion Beam Analysis

Summary Report of the First Research Coordination
Meeting

IAEA Headquarters
Vienna, Austria
21 – 23 November 2005

Prepared by
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January 2006

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Conclusions

- IBANDL is a main source of the cross section data for IBA
- There are a lot of discrepancies in the compiled data
- The evaluation of the IBA cross sections provides the most reliable data
- New measurements and benchmarks are under way to resolve the problems
- Some of the most wanted cross sections have been evaluated and the work on evaluation is in progress

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