The Abdus Salam International Centre for Theoretical Physics

2495-06

Joint ICTP-IAEA Workshop on Nuclear Data for Analytical Applications

21 - 25 October 2013

DIFFERENTIAL CROSS SECTIONS FOR ION BEAM ANALYSIS

Alexander Gurbich
Institute for Physics and Power Engineering
Obninsk
Russia

Strada Costiera, 11 - 34151 - Trieste - Italy • Tel. +39 0402240111 • Fax. +39 040224163 • sci_info@ictp.it • www.ictp.it
ICTP is governed by UNESCO, IAEA, and Italy, and it is a UNESCO Category 1 Institute

The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

WEDNESDAY, 23 OCTOBER 2013
11.00 - 12.30
The Denardo Lecture Hall

Workshop on Nuclear Data for Analytical Applications

DIFFERENTIAL CROSS SECTIONS FOR ION BEAM ANALYSIS

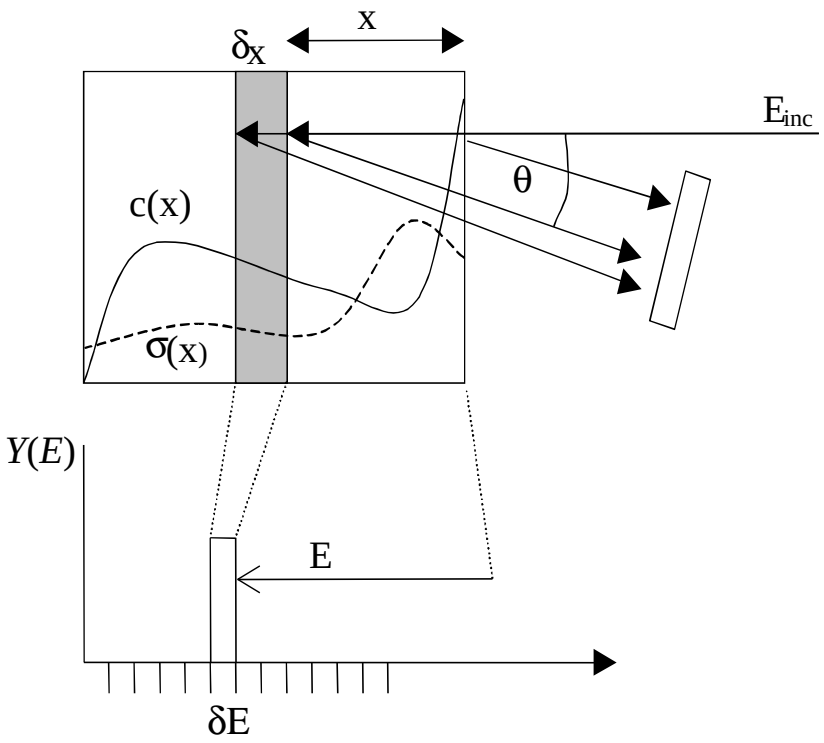
Alexander Gurbich

Institute for Physics and Power Engineering
Obninsk, Russia

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, ^{3}He, ^{4}He, heavy ions	All elements	Elastic scattering, nuclear reactions	0.5÷10 MeV

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.

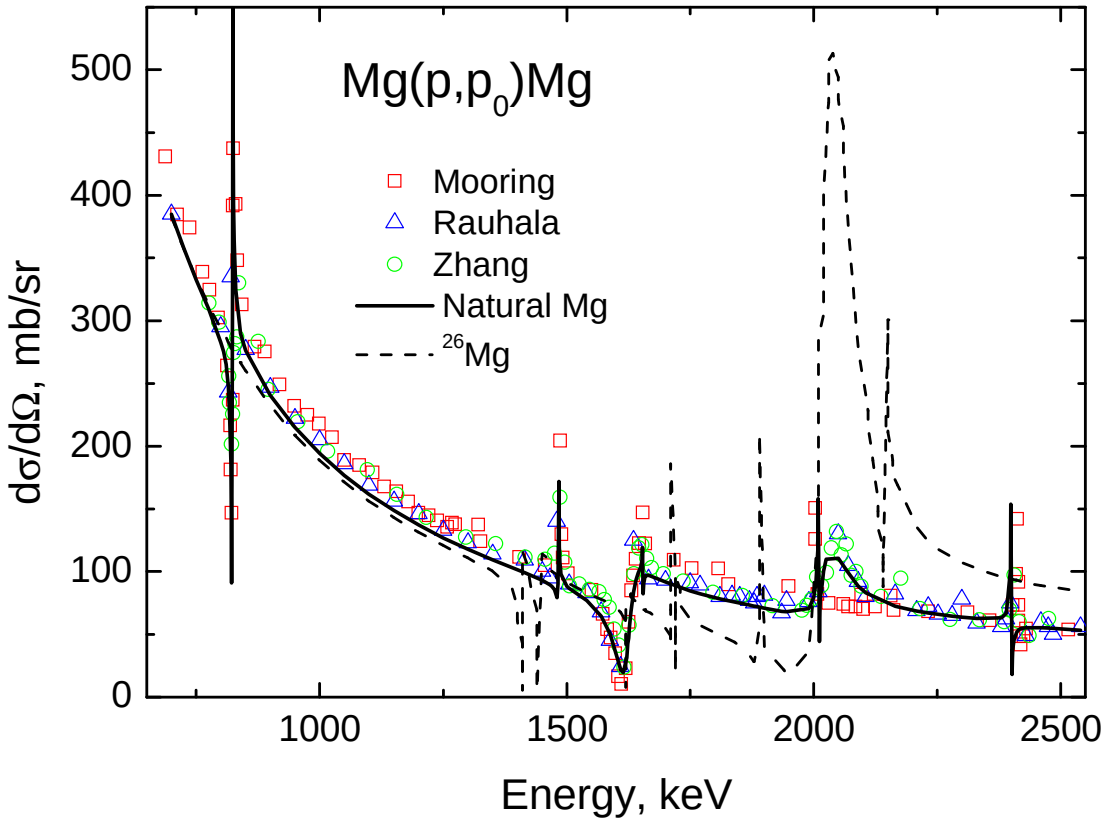
$$Y_i(E) = \int_0^\infty \frac{N_0 c(x)\sigma(\theta, E_1)\delta\Omega}{S(E')\left[\frac{-1}{\cos(\varphi+\theta)} + \frac{1}{\cos(\theta)}\frac{kS(E_1)}{S(kE_1)}\right]} \frac{1}{1.06\Gamma(x)} \exp\left(-\frac{(E'-E)^2}{0.36\Gamma^2(x)}\right) dE'$$

3

Distinctive feature of the nuclear data for IBA

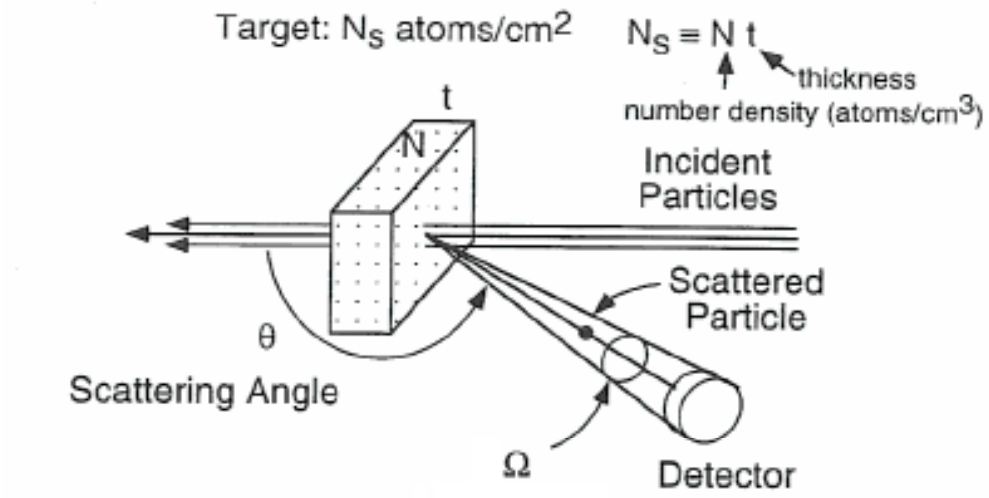
- IBA uses differential cross sections rather than total ones – data for different angles are needed
- IBA employs data mainly for elements of natural abundance rather than for separated isotopes – data acquired in nuclear physics studies are often not sufficient

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

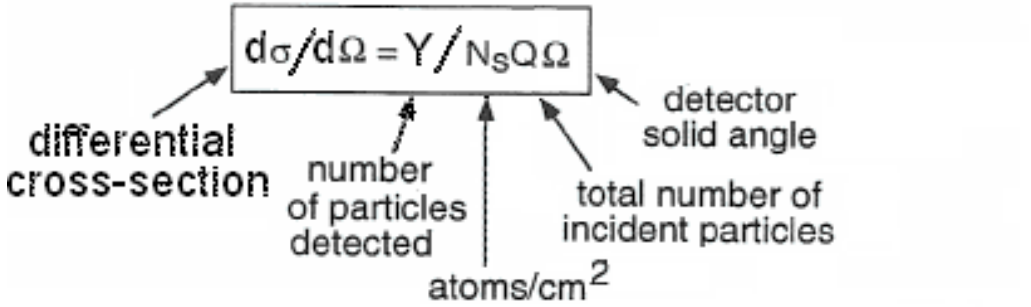


5

Cross-section measurements



The incident beam is mono-energetic.

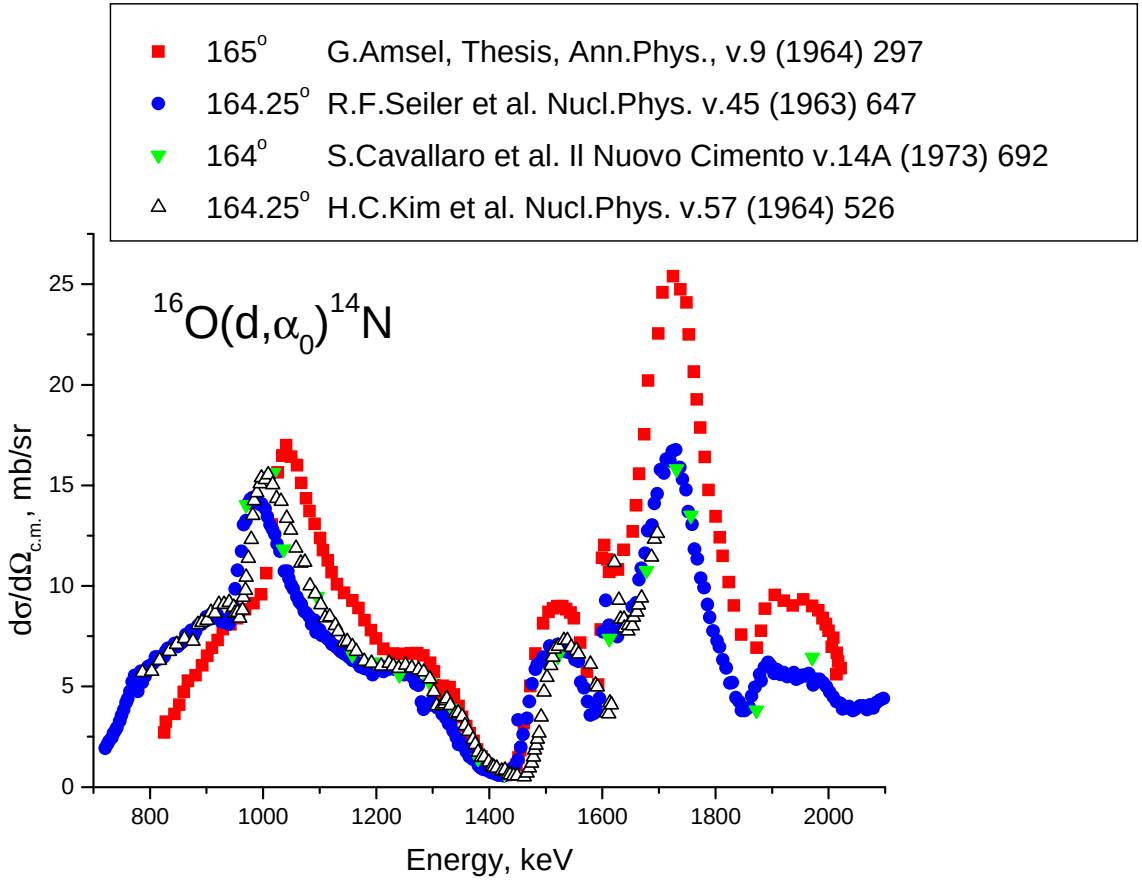


Given all the terms except $d\sigma/d\Omega$ are known the differential cross-section can be determined.

6

THE REASONS WHY EVALUATION IS NEEDED

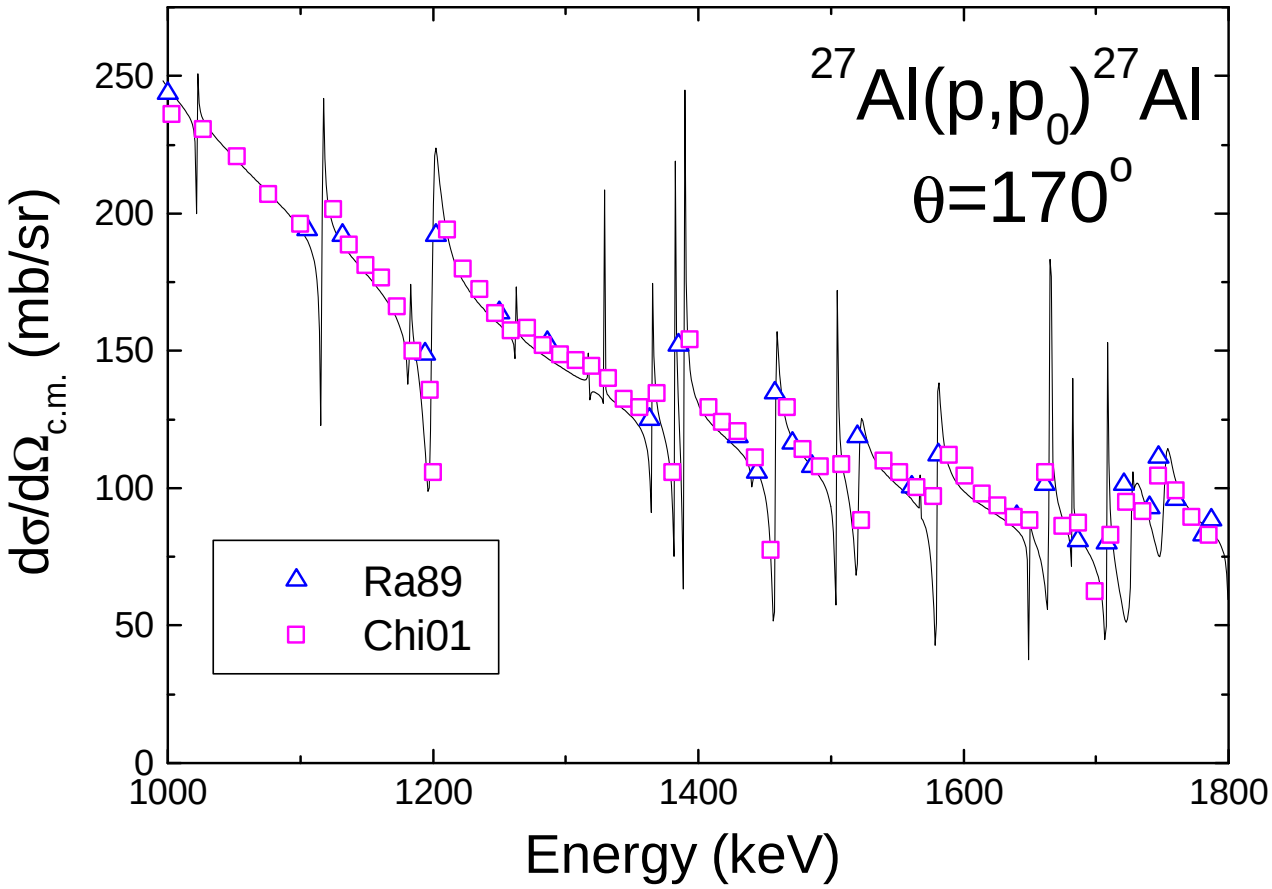
Reason 1: because of discrepancies between results of different measurements



7

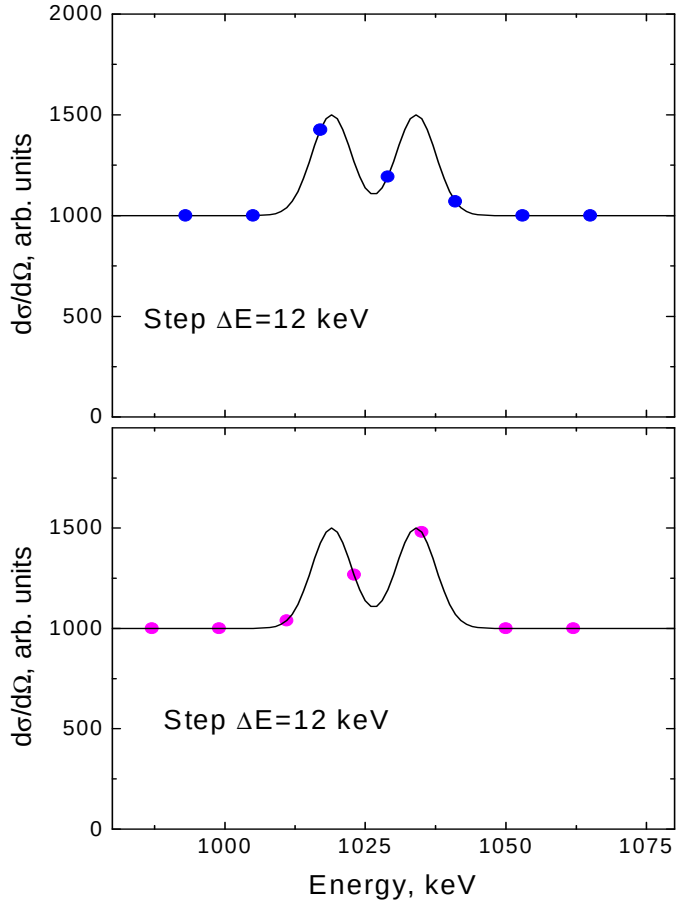
THE REASONS WHY EVALUATION IS NEEDED

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



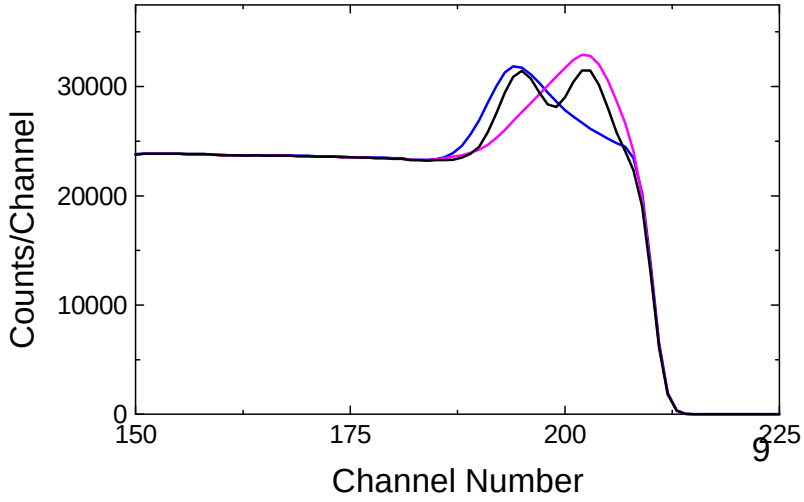
WHY IS A FINE STRUCTURE ESSENTIAL?

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



Simulated EBS spectra

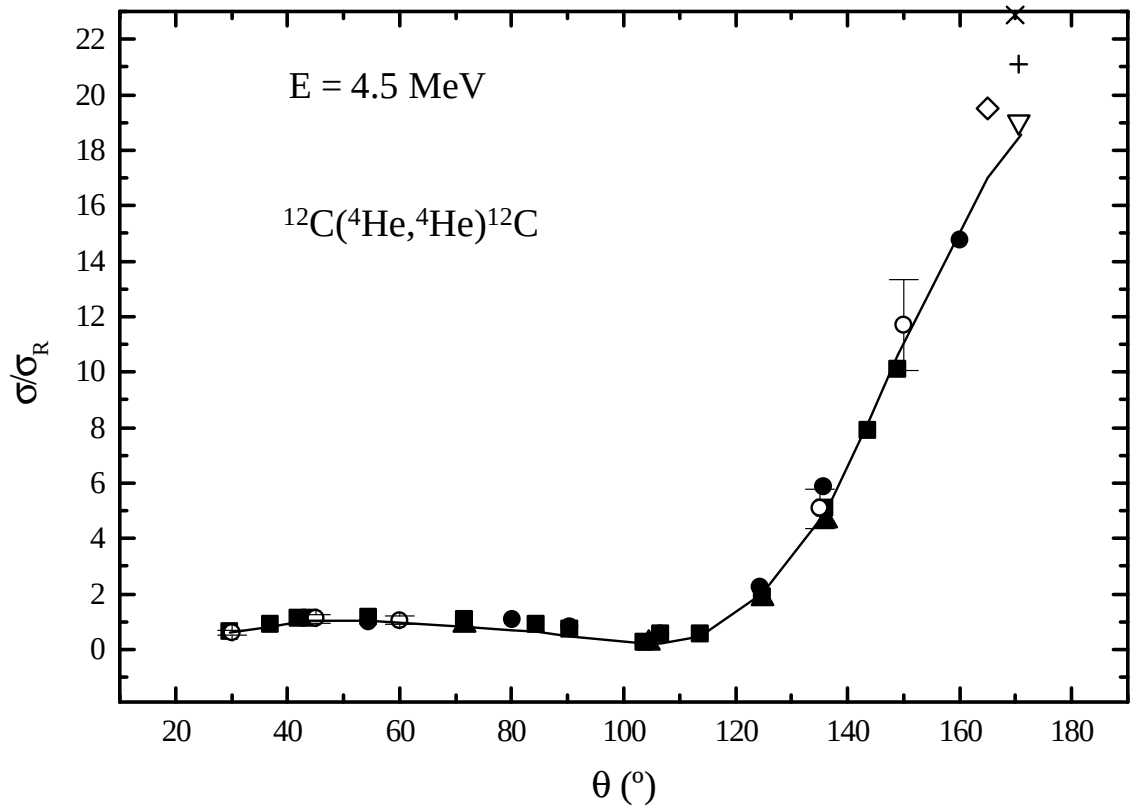
Black line – simulation with "true" cross section, blue and magenta – simulation with sparse point cross section measurements



9

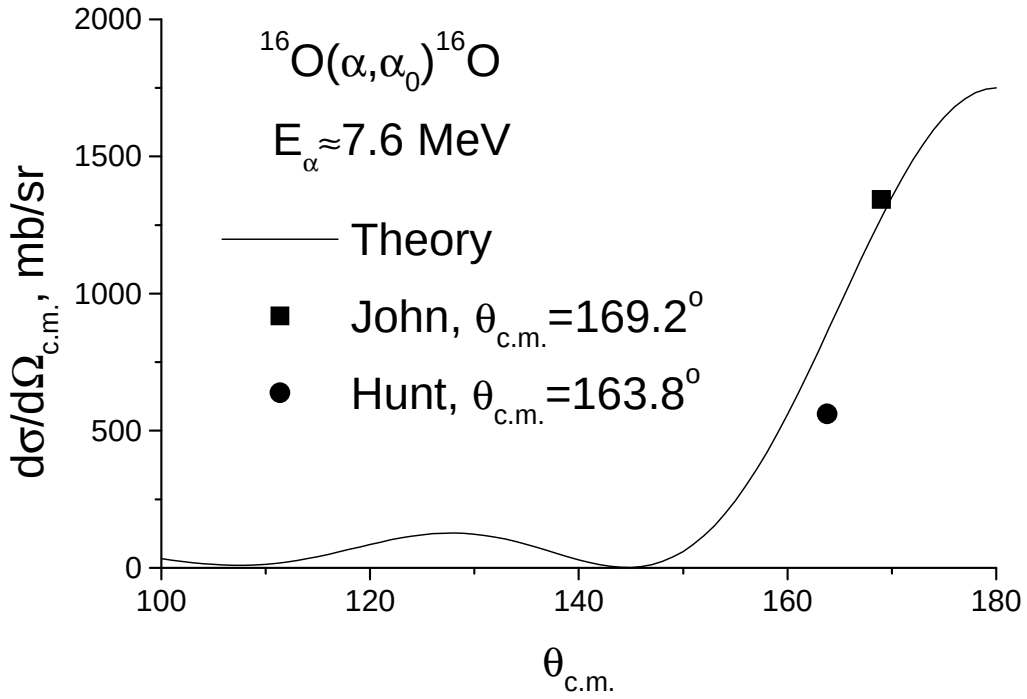
THE REASONS WHY EVALUATION IS NEEDED

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



10

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



11

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 $d\sigma/d\Omega(E,\theta)$

12

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.

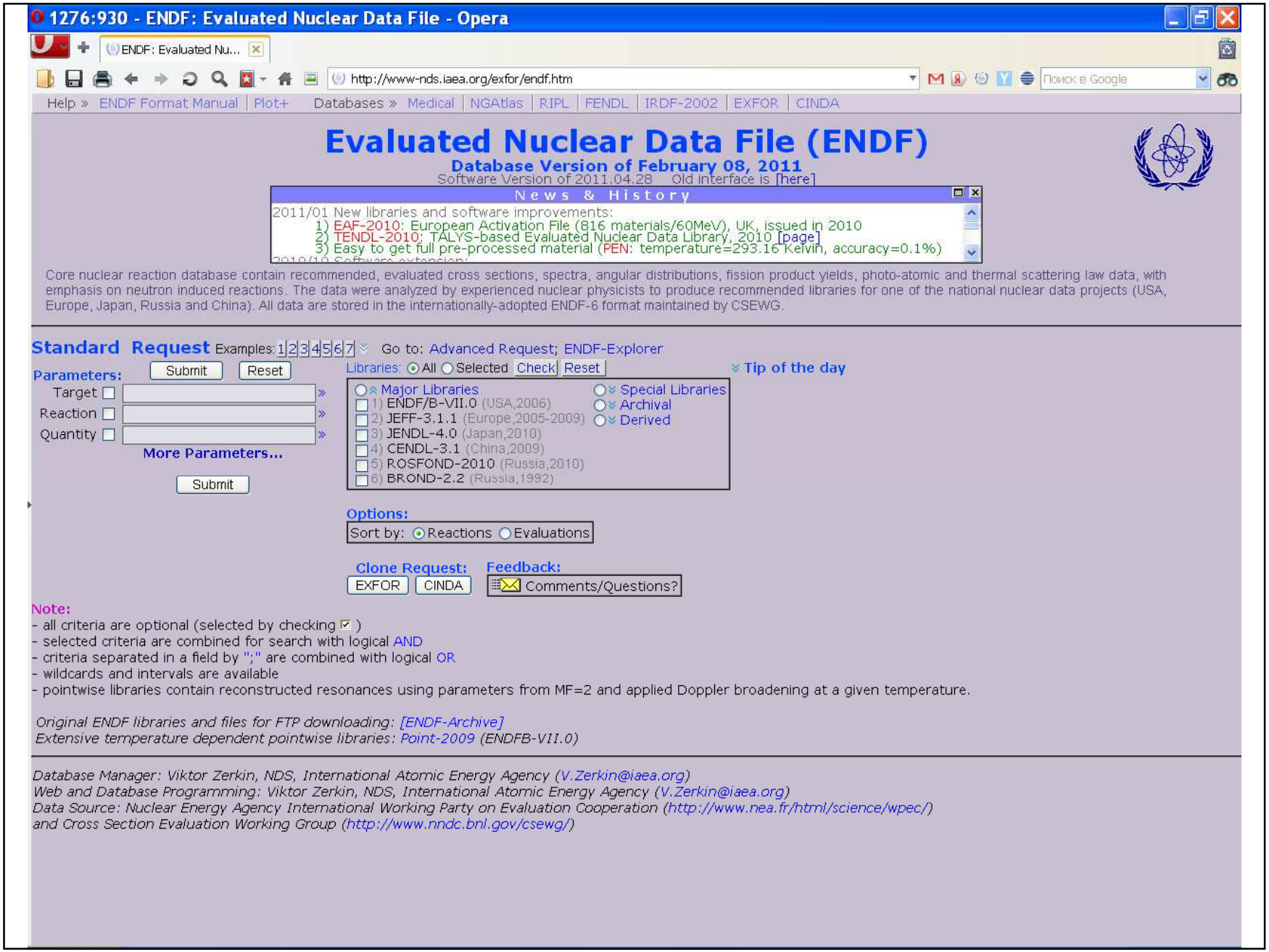
Step 7: fit free parameters of the theoretical model.

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

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.

14


1276:930 - ENDF: Evaluated Nuclear Data File - Opera
ENDF: Evaluated Nu...
http://www-nds.iaea.org/exfor/endf.htm
Help » ENDF Format Manual | Plot+ Databases » Medical | NGAtlas | RIPL | FENDL | IRDF-2002 | EXFOR | CINDA
Evaluated Nuclear Data File (ENDF)
Database Version of February 08, 2011
Software Version of 2011.04.28 Old interface is [here]
News & History
2011/01 New libraries and software improvements:
1) EAF-2010: European Activation File (816 materials/60MeV), UK, issued in 2010
2) TENDL-2010: TALYS-based Evaluated Nuclear Data Library, 2010 [page]
3) Easy to get full pre-processed material (PEN: temperature=293.16 Kelvin, accuracy=0.1%)
Core nuclear reaction database contain recommended, evaluated cross sections, spectra, angular distributions, fission product yields, photo-atomic and thermal scattering law data, with emphasis on neutron induced reactions. The data were analyzed by experienced nuclear physicists to produce recommended libraries for one of the national nuclear data projects (USA, Europe, Japan, Russia and China). All data are stored in the internationally-adopted ENDF-6 format maintained by CSEWG.
Standard Request Examples: 1 2 3 4 5 6 7 Go to: Advanced Request; ENDF-Explorer
Parameters:
Submit Reset
Target
Reaction
Quantity
More Parameters...
Submit
Libraries: All Selected Check Reset
Major Libraries
1) ENDF/B-VII.0 (USA,2006)
2) JEFF-3.1.1 (Europe,2005-2009)
3) JENDL-4.0 (Japan,2010)
4) CENDL-3.1 (China,2009)
5) ROSFOND-2010 (Russia,2010)
6) BROND-2.2 (Russia,1992)
Special Libraries
Archival
Derived
Tip of the day
Options:
Sort by: Reactions Evaluations
Clone Request:
EXFOR CINDA
Feedback:
Comments/Questions?
Note:
- all criteria are optional (selected by checking)
- selected criteria are combined for search with logical AND
- criteria separated in a field by ";" are combined with logical OR
- wildcards and intervals are available
- pointwise libraries contain reconstructed resonances using parameters from MF=2 and applied Doppler broadening at a given temperature.
Original ENDF libraries and files for FTP downloading: [ENDF-Archive]
Extensive temperature dependent pointwise libraries: Point-2009 (ENDFB-VII.0)
Database Manager: Viktor Zerkin, NDS, International Atomic Energy Agency (V.Zerkin@iaea.org)
Web and Database Programming: Viktor Zerkin, NDS, International Atomic Energy Agency (V.Zerkin@iaea.org)
Data Source: Nuclear Energy Agency International Working Party on Evaluation Cooperation (http://www.nea.fr/html/science/wpec/)
and Cross Section Evaluation Working Group (http://www.nndc.bnl.gov/csewg/)

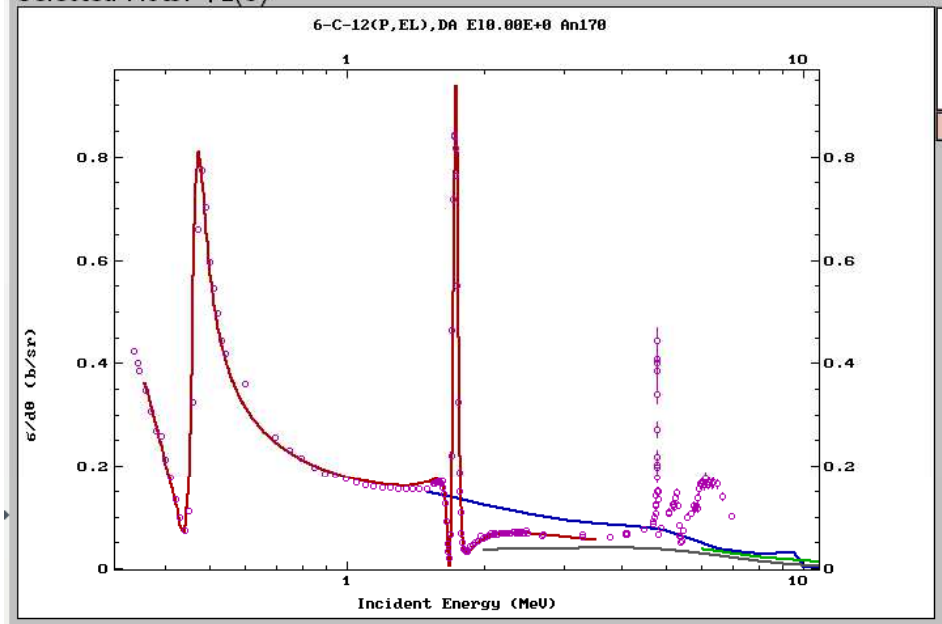
1276:930 - http://www-nds.iaea.org/exfor/servlet/X4sProcessC4make1zvd - Opera

http://www-nds.iae... | IBANDL

http://www-nds.iaea.org/exfor/servlet/X4sProcessC4make1zvd

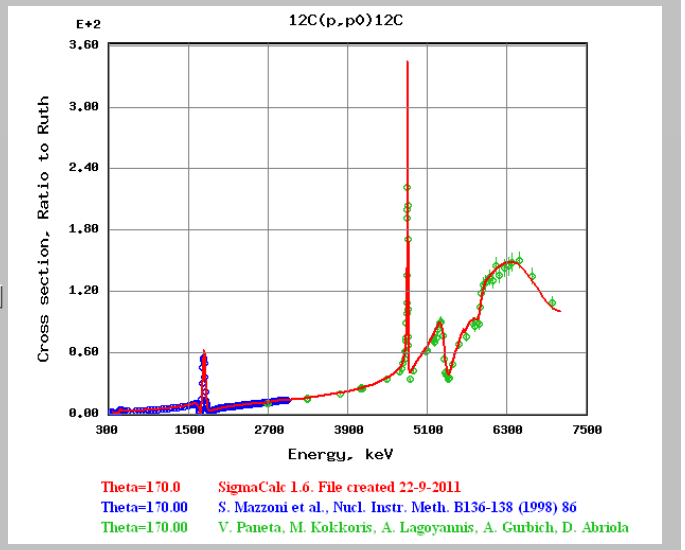
EXFOR-Request #-1 ENDF-Request #10400

Selected Plots: +1(3)



1) ENDF/B-VII.0:C-12 El0.00E+0 An170
2) JENDL/HE-2007:C-12 El0.00E+0 An170
3) IBA-EVAL:C-12 El0.00E+0 An170
4) TENDL-2010:C-12 El0.00E+0 An170
5) Use my data [example]

See: plotted data (12Kb)



Log: XY X Y Lin: XY X Y Auto-range: XY X Y Page: >> << Zoom: <> >< Grid: VH 0 V H Pts: Txt Box PL Print

Reset | Repaint | Legend | Authors | Info+ | PostScript | Manual options: [-]

Y: Axis: Auto Min: 0. Max: 0.96946 Units: b

X: Axis: Auto Min: 0.311654 Max: 10.8526 Units: MeV

Title: 6-C-12(P,EL),DA El0.00E+0 An170

Title-2:

Shift legend: lx=0 ly=0 Split: 0 0:none; 1:xy; 2:y

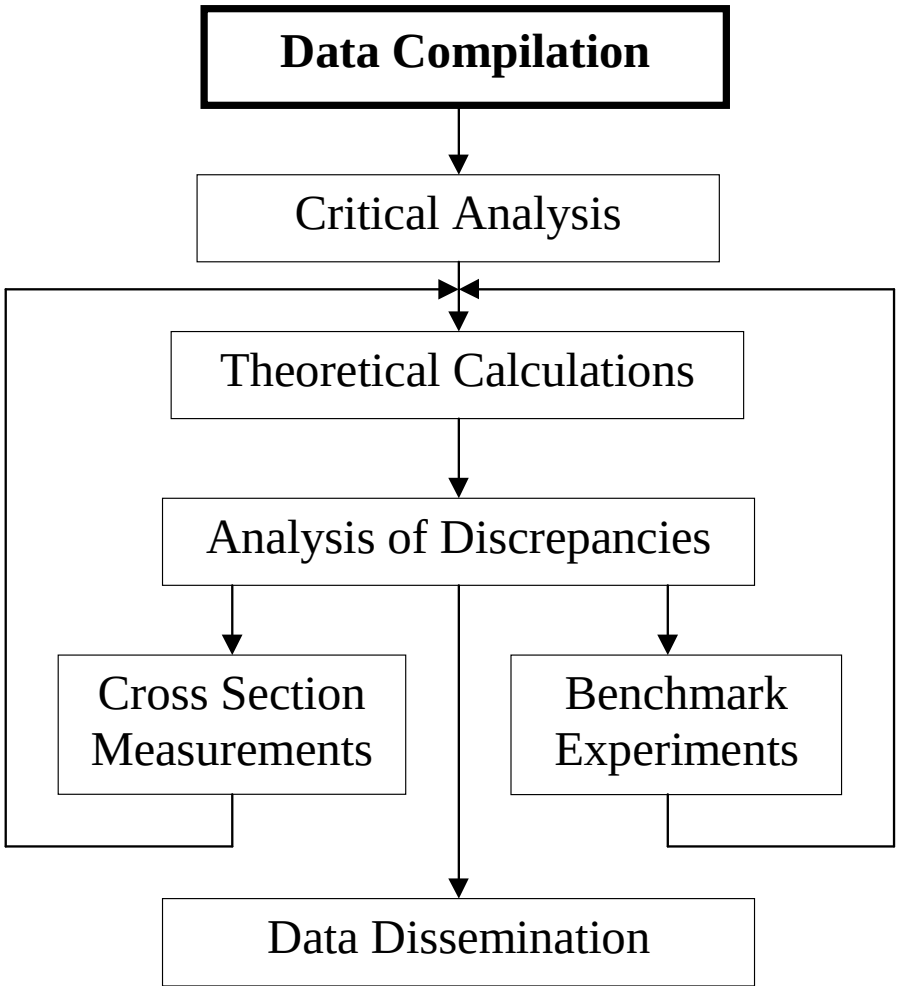
Picture-size: lx=700 ly=500 600*400 700*500 800*600 900*700

Data for plotting: ZVD (8Kb), send to ZVView; download ZVView; upload and plot your ZVD file

Note. Zoom and other interactive plotting features were tested under Web-browsers:
MS-Internet Explorer 5.5, Firefox 2.0, Safari, Opera 9.1, Netscape v-7.2

Page generated: 2011/09/22,15:15:01 by X4-Servlet on www-nds.iaea.org
Project: "Multi-platform EXFOR-CINDA-ENDF", V.Zerkin, IAEA-NDS, 1999-2011
Request from: robust.ippe.ru (212.193.160.62) [fwd:172.20.6.104]

Evaluation Scheme



17

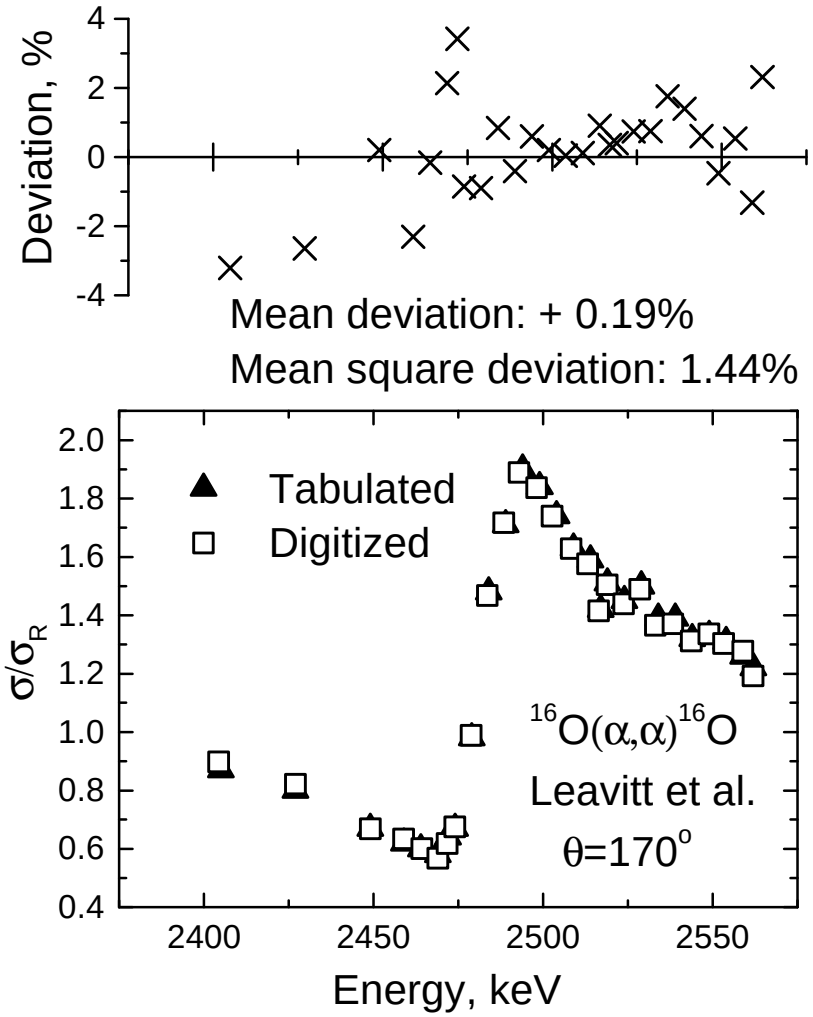
R33 Format for Communication of Reaction Cross Sections in the IBA Community

```
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 thin 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.F.Healy and D.W.Lane. Nucl. Instr & Meth B 136-138 (1998) 66-71
Name: Healy, M.J.F.
Address1: Cranfield University.
Address2: RMCS Shrivenham
Address3: Swindon. SN6 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:
SubFile: 32sdp.r33
X4Number:
Reaction: 32S(d,p0)33S
Distribution: Energy
Composition:
Masses:    2.000,   32.000,    1.000,   33.000
Zeds: 1, 16, 1, 16
Qvalue:   6418.00,      0.00,      0.00,      0.00,      0.00
Theta:    150.00
Sigfactors: 1.00, 0.00
Enfactors: 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,   0.016, 0.000
 1020.000,  0.000,   0.019, 0.000
 1025.000,  0.000,   0.020, 0.000
 1030.000,  0.000,   0.019, 0.000
 1035.000,  0.000,   0.017, 0.000
 1040.000,  0.000,   0.015, 0.000
 1045.000,  0.000,   0.015, 0.000
```

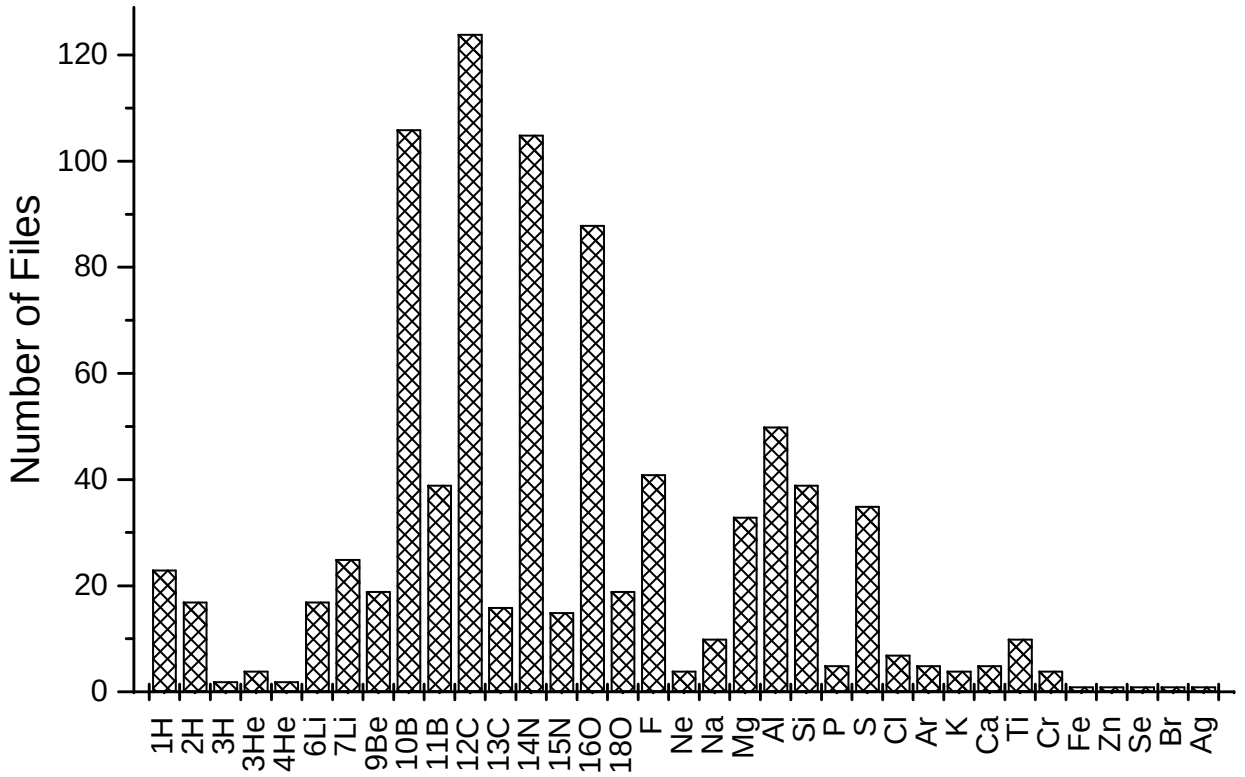

18

How accurate is digitizing?

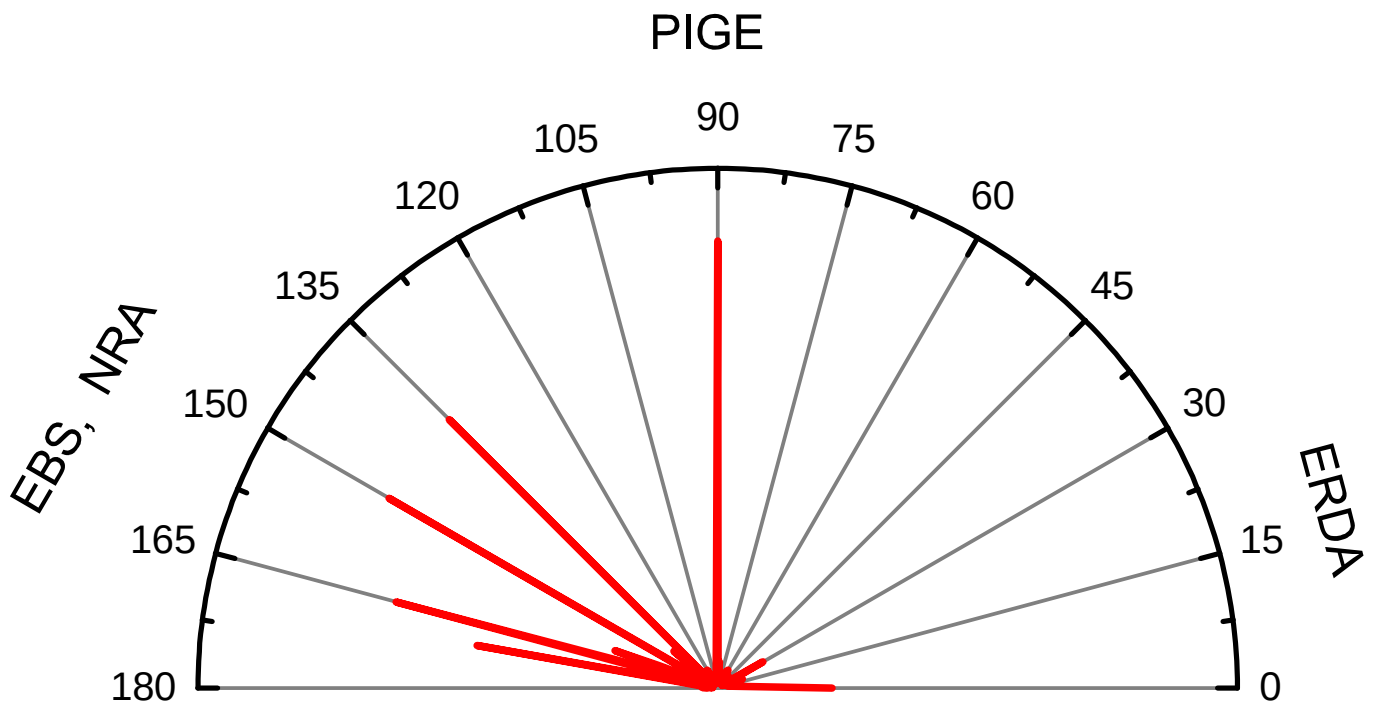


19

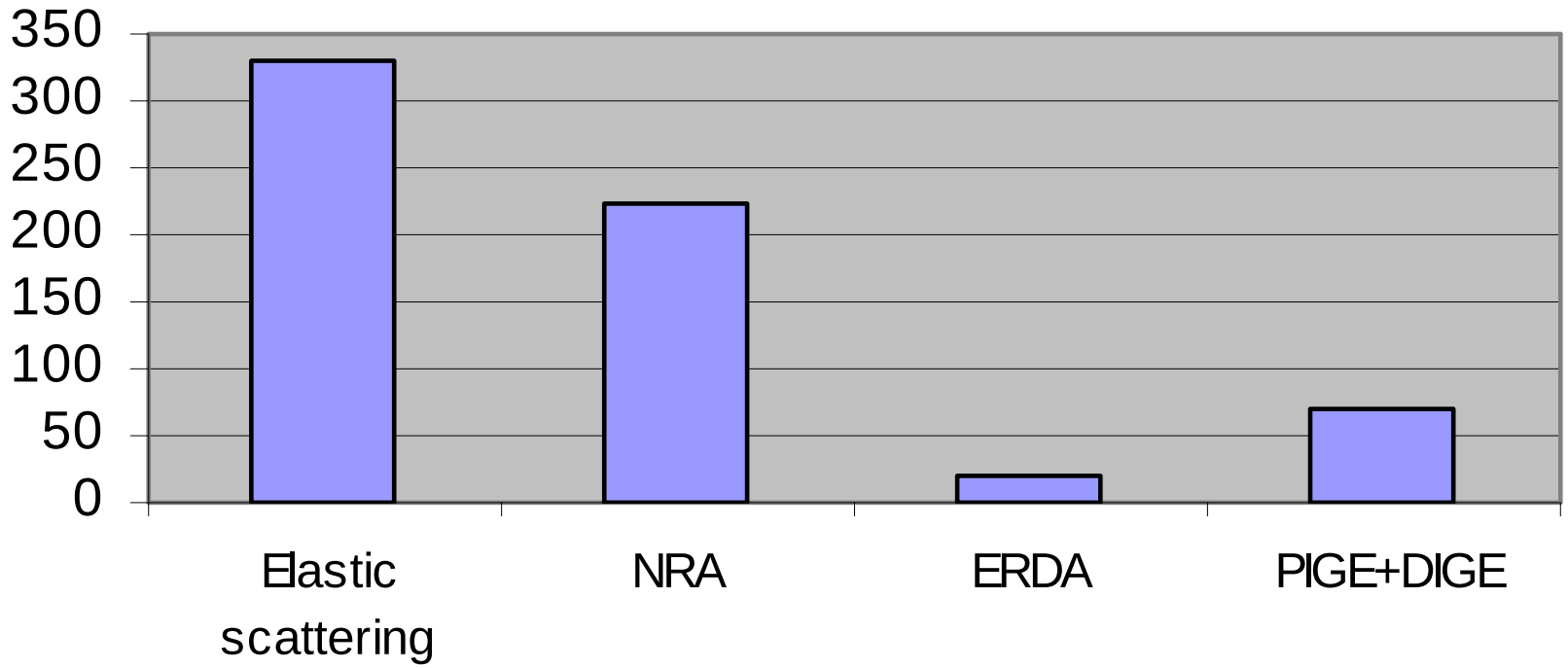
The IBANDL content by element



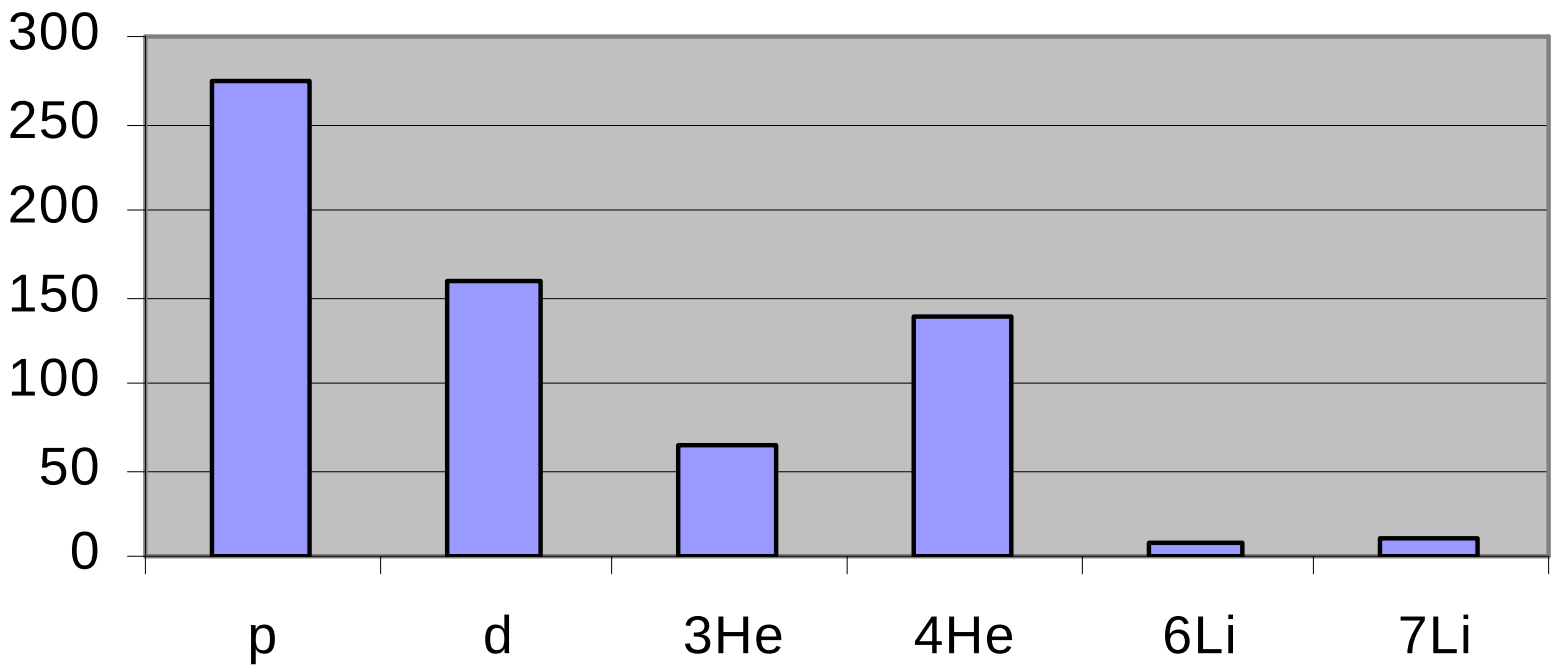
The distribution of the available data on angle



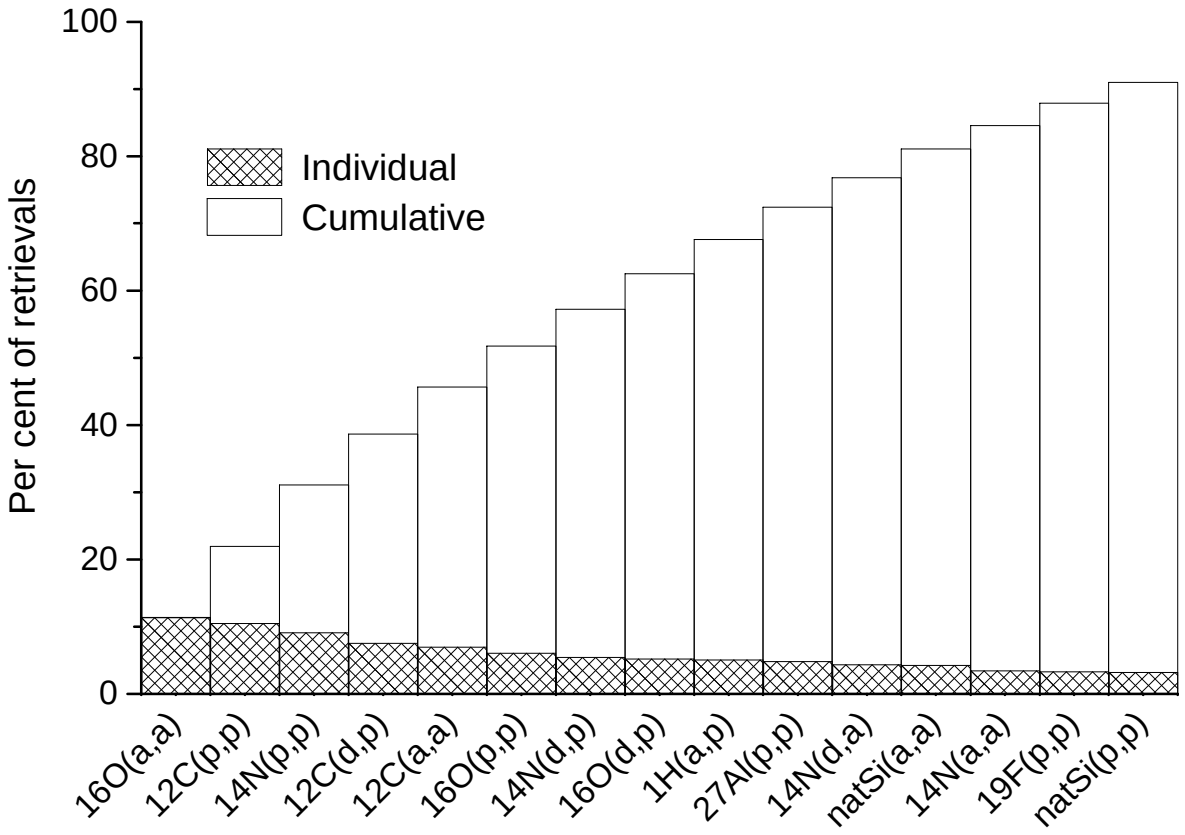
Content of IBANDL (by reaction)



Content of IBANDL (by projectile)

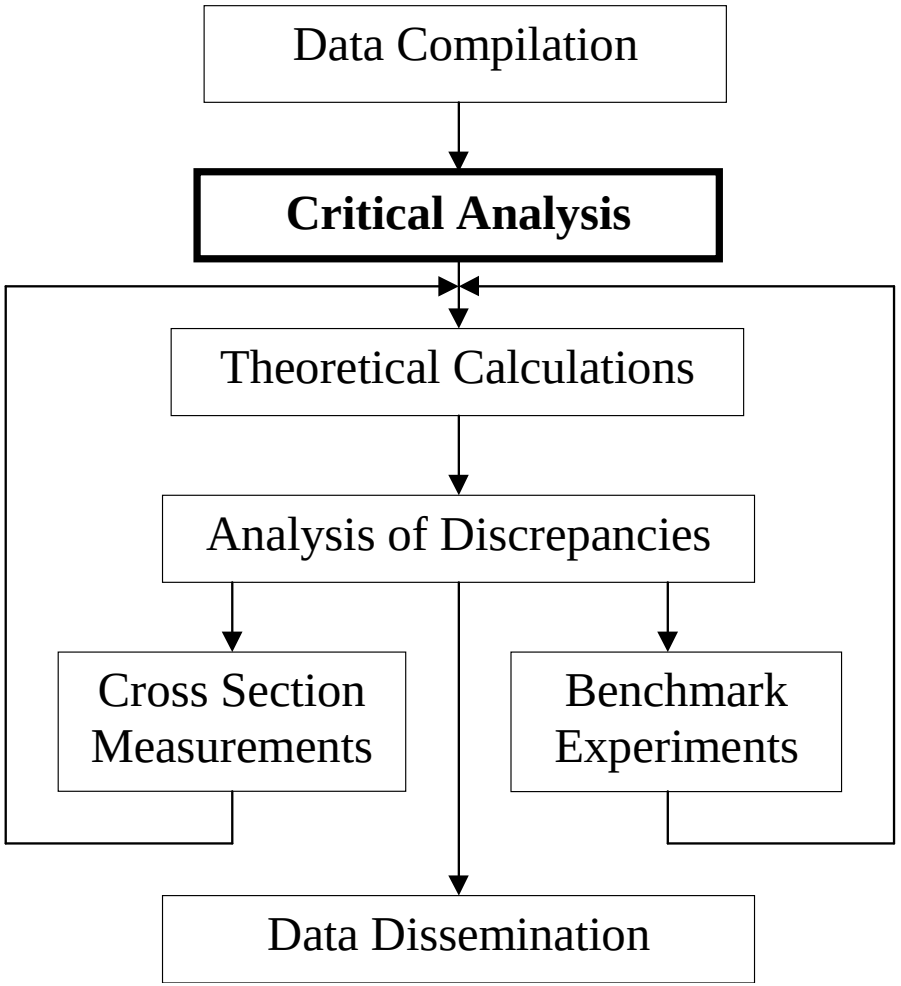


The IBANDL statistics showing most popular retrievals



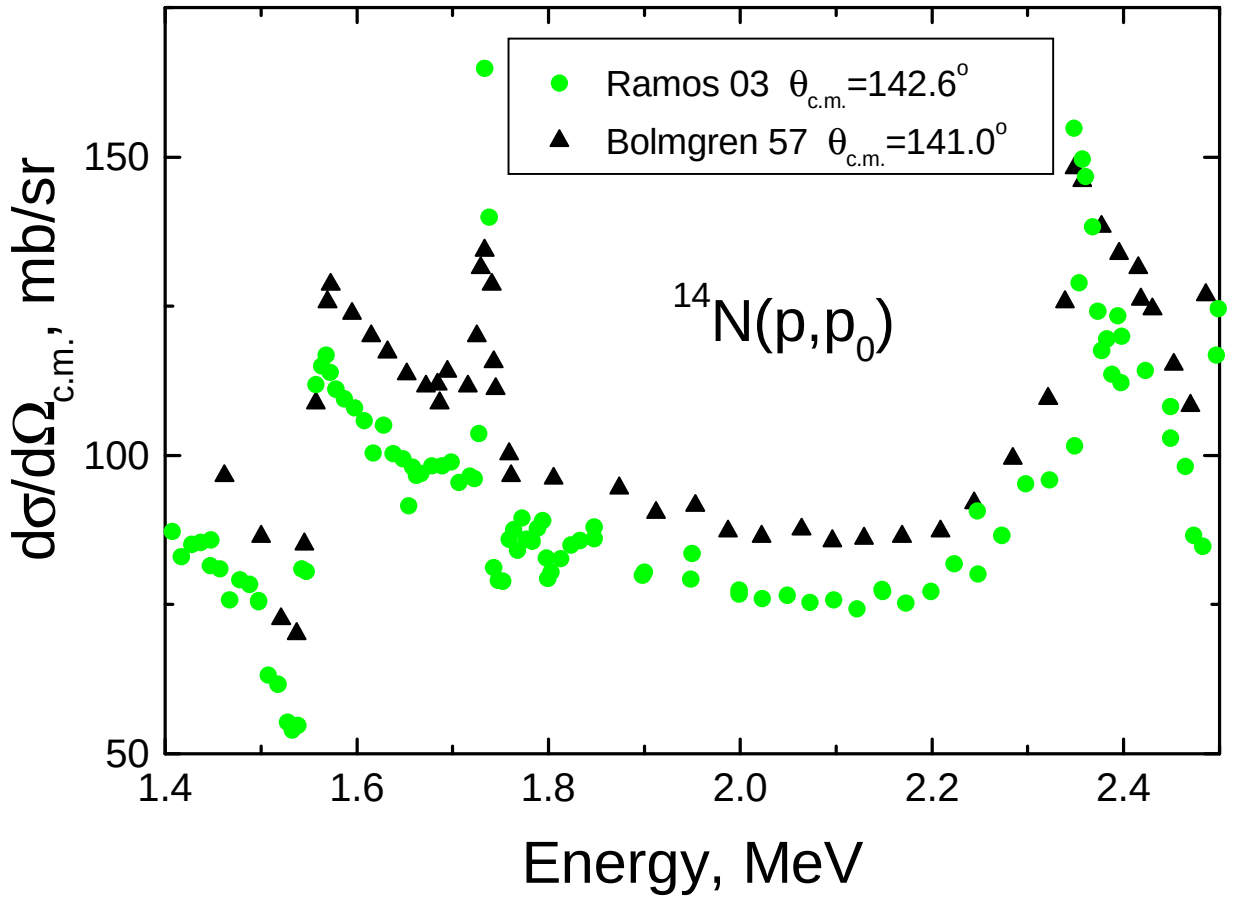
>90% of retrievals are for 7 elements / 15 cross sections

Evaluation Scheme



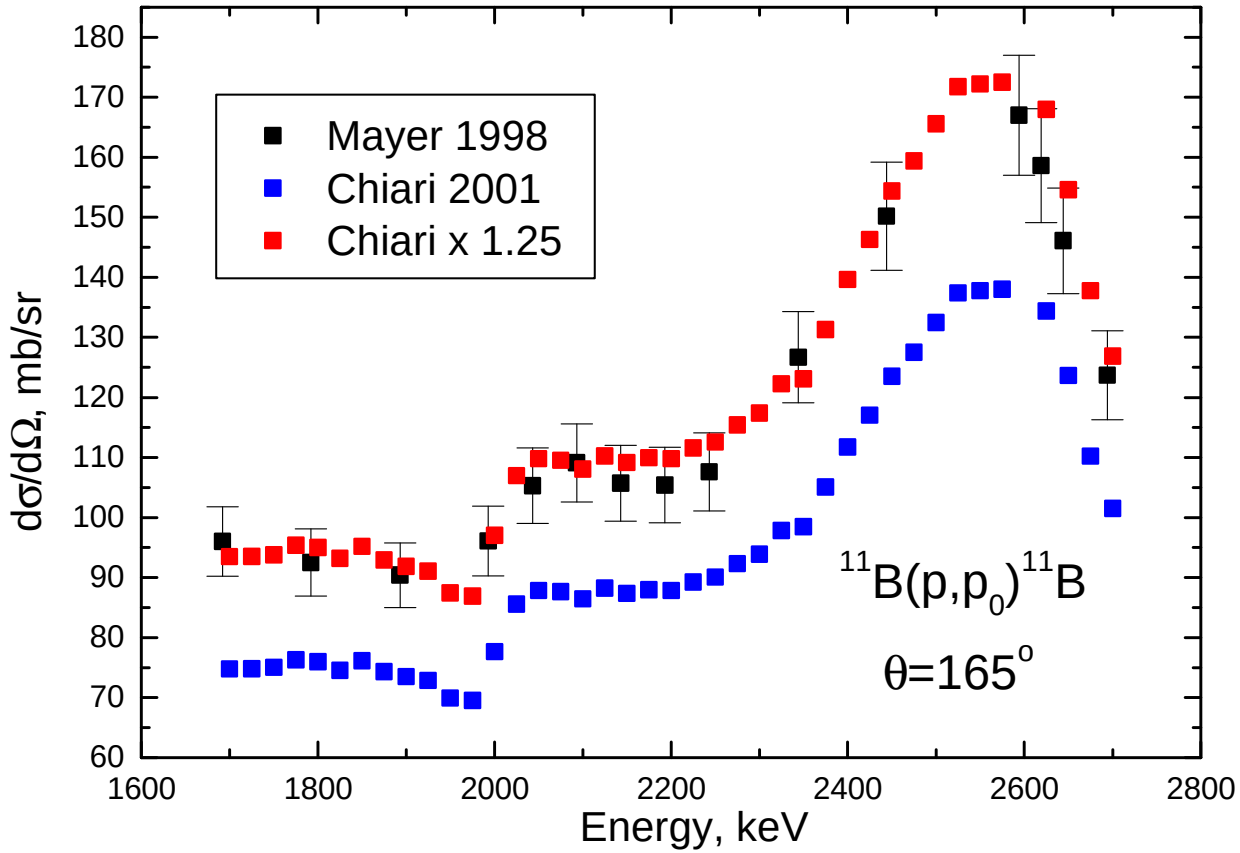
25

Comparison of different results for $^{14}N(p,p_0)^{14}N$ cross section at the scattering angle of ~140°



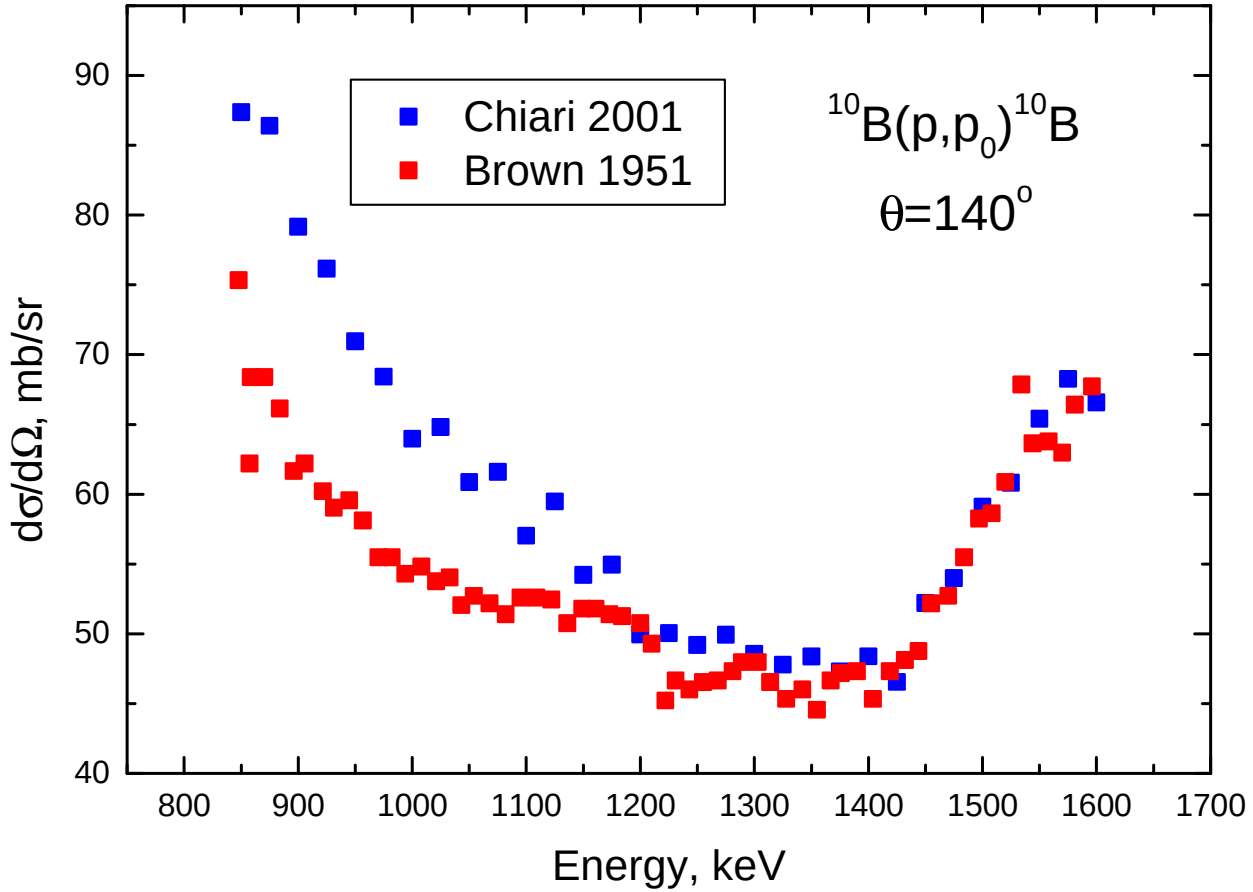
26

Comparison of different results for $^{11}B(p,p_0)^{11}B$ cross section



27

Comparison of different results for $^{10}B(p,p_0)^{10}B$ cross section at the scattering angle of ~140°



28

Comparison of different results for $^{12}C(\alpha,\alpha_0)^{12}C$ cross section

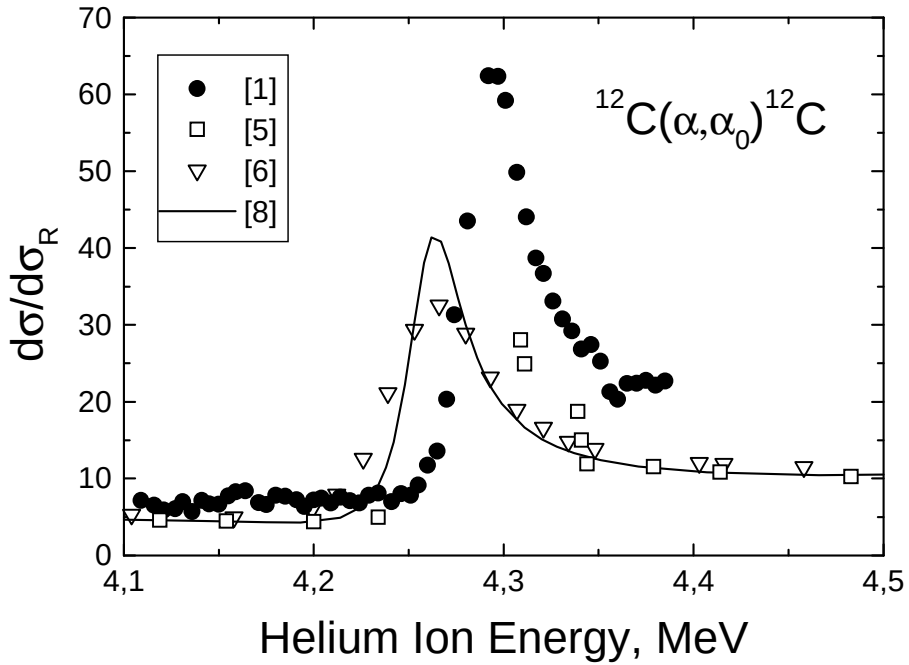
Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Nuclear Instruments and Methods in Physics Research B 229 (2005) 157–158
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Discussion

Comment on "Carbon analysis using energetic ion beams" [Nucl. Instr. and Meth. B 222 (2004) 538–546]

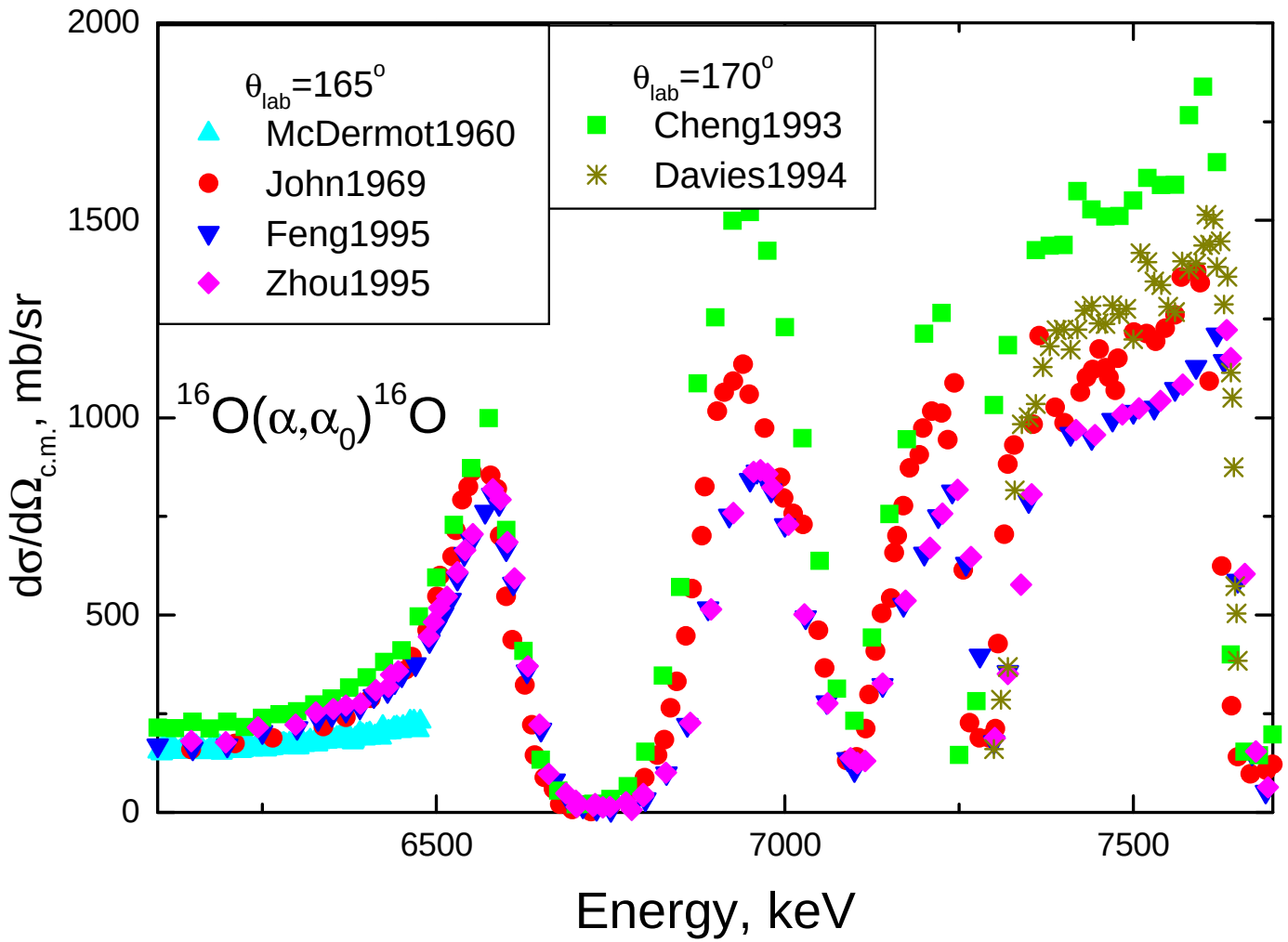
A.F. Gurbich *
Institute of Physics and Power Engineering, Bondarenko sq. 1, 249020 Obninsk, Russian Federation

Received 5 August 2004



29

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



30

The comparison of the results obtained by «thin» and «thick» target methods for Si(α,α) cross section

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

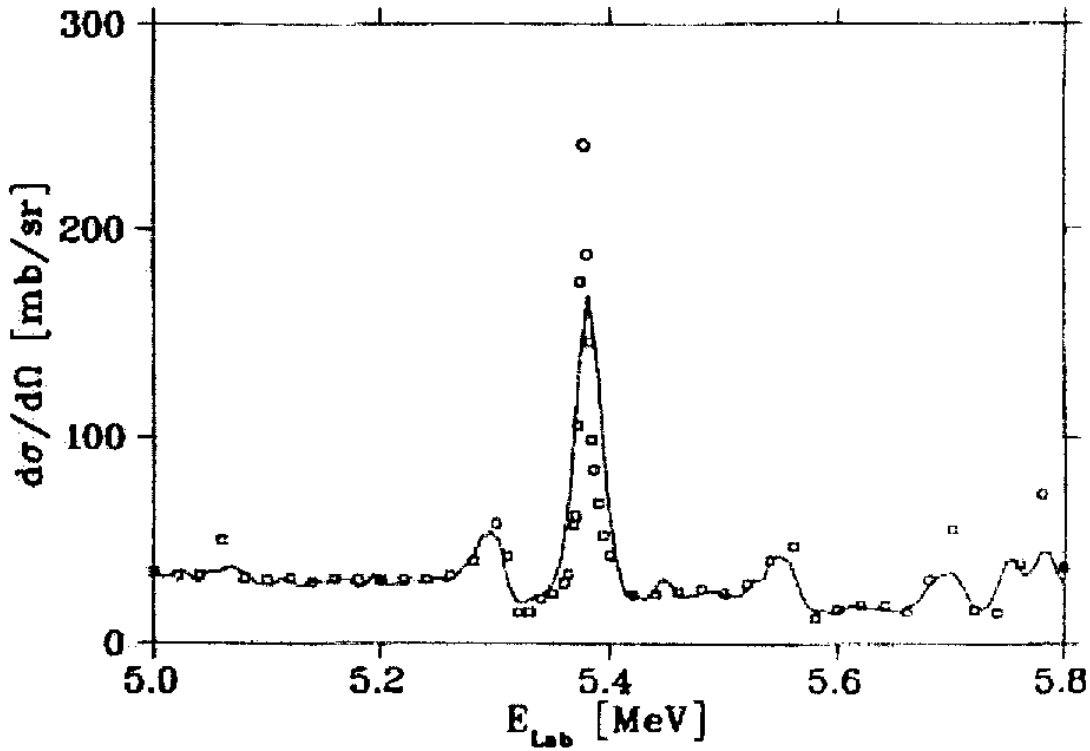
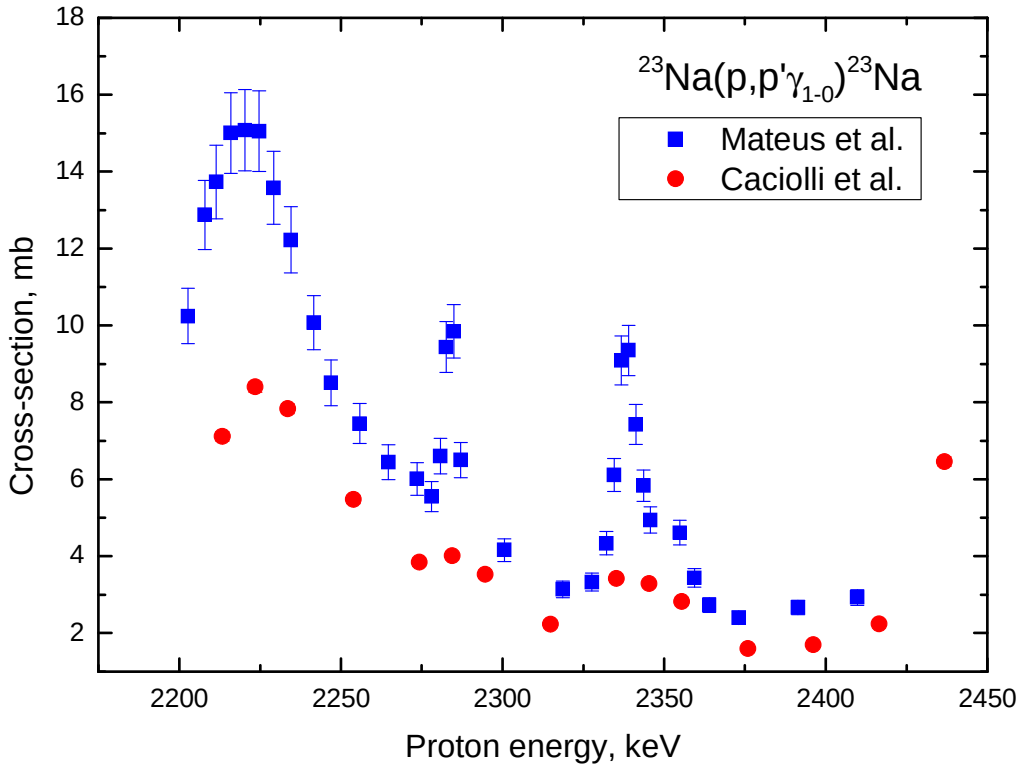


Fig. 2. The excitation function obtained with the thick-target method (full line) compared to the excitation function from [4] (dots)

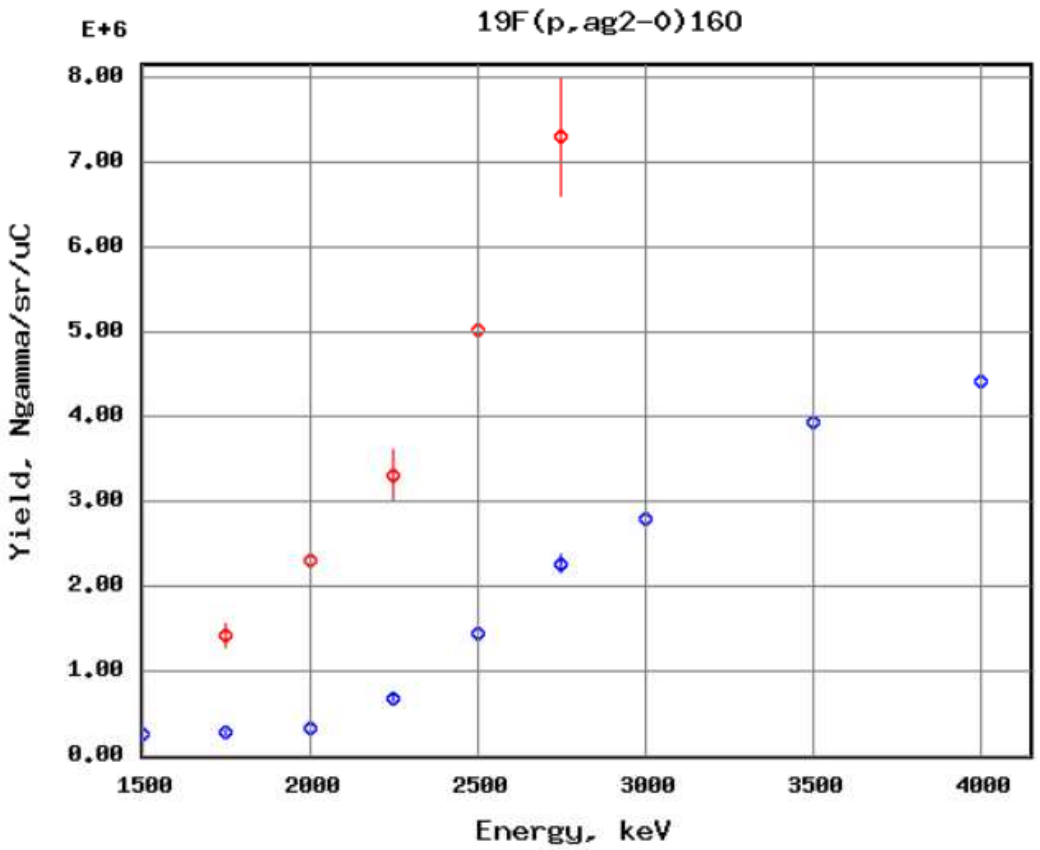
31

PIGE data problems



32

PIGE data problems

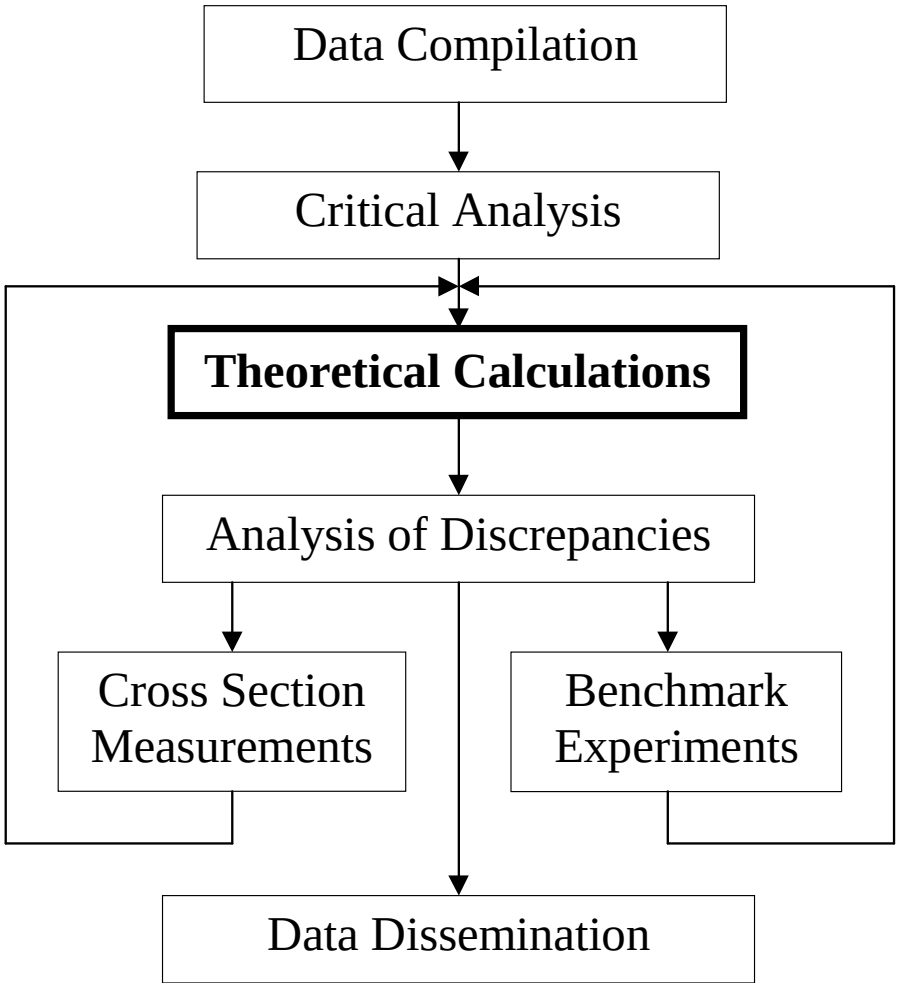


Theta=90 M.J. Kenny, Aust. J. Phys. 34 (1981) 35

Theta=90 A. Fessler et al., NIM A450 (2000) 353

33

Evaluation Scheme

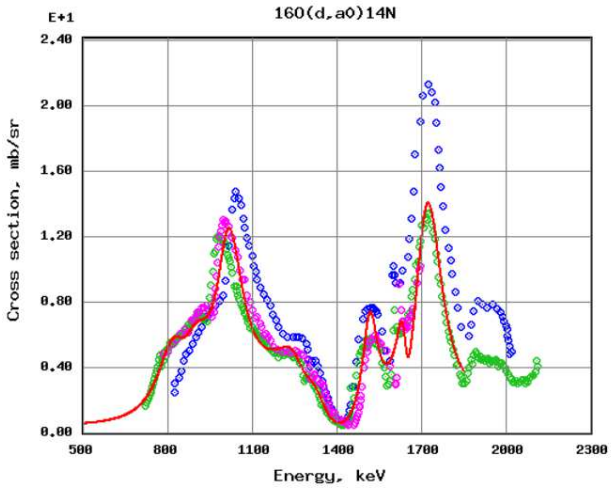


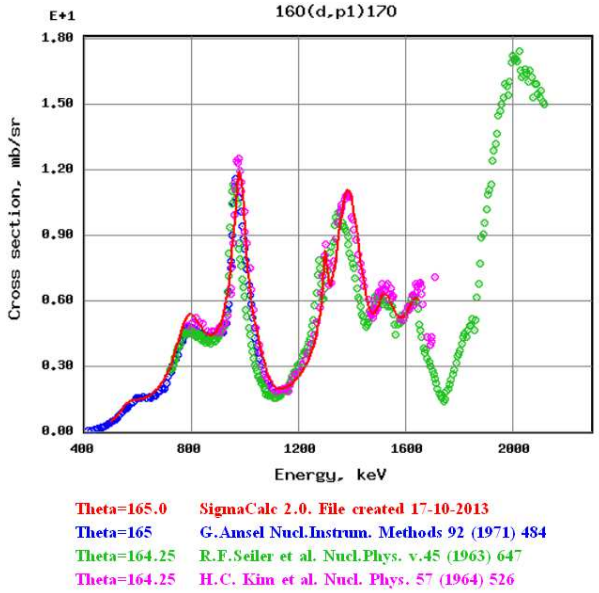
34

Ajzenberg-Selove

Table 18.15: Maxima in the yields of $^{16}O + d$ [a]

E_d (MeV ± keV)	Particles out	$\Gamma_{c.m.}$ (keV)	J^π; T	E_x (MeV)	Refs.
0.895	p_1, α_0	210 ± 25		(8.321)	(64AM1A)
1.048	p_1, d_0, α_0	88 ± 10	1^+	8.457	(60AM1A, 64AM1A, 68MA1D)
1.199	α_0	230 ± 30		(8.591)	(64AM1A, 65MA1A)
1.298	p_1, d_0, α_0	13 ± 3		(8.679)	(60AM1A, 64AM1A)
1.325	d_0, α_0			(8.703)	(64AM1A)
1.482	α_0	40 ± 5		(8.843)	(60AM1A, 64AM1A)
1.563	d_0, α_0	121 ± 15		(8.914)	(60AM1A, 64AM1A)
1.616	α_0	19 ± 15		(8.962)	(60AM1A, 64AM1A)
1.765	d_0, α_0	141 ± 10		(9.094)	(60AM1A, 64AM1A)
1.885	p_0, p_1, d_0, α_0	108 ± 12	3, 4⁻; 0	9.20	(56RO1A, 64AM1A, 65MA1A, 73JO13)
2.22	n_0, α_0		2, 3⁺; 0	9.50	(55MA1C, 61DI1A, 73JO13)
2.28	α_0		2, 3⁺; 0	(9.55)	(73JO13)
2.34	n_0, p_1			(9.60)	(56RO1A, 55MA1C, 61DI1A)
2.55	p_1			(9.79)	(55ST1A, 56RO1A)
2.92	n_0, p_0, p_1			10.12	(55MA1C, 55ST1A, 56RO1A)
3.05	α_0		3, 4⁻; 0	10.24	(73JO13)
					(73JO13)





$^{18}_{9}F$ (continued)

Firestone

7336 *2*, 1⁻, Γ=16 *2* keV, *[KL]*, %IT=?, %p=?, T=1
- γ_{4226} ***3109.9*** *22* ($\dagger_\gamma$27.8 *11*)
- γ_{3134} ***4201.6*** *20* ($\dagger_\gamma$14.8 *9*)
- γ_{3062} ***4273.7*** *20* ($\dagger_\gamma$1.9 *9*)
- γ_{2101} ***5234.6*** *20* ($\dagger_\gamma$33.3 *19*)
- γ_{1081} ***6254.3*** *20* ($\dagger_\gamma$100 *4*)
- γ_0 ***7334.4*** *20* ($\dagger_\gamma$7.4 *9*)

7406 *2*, 1⁺, Γ=14.6 *14* keV, *[L]*, %p=100

7447 *10*, Γ=140 keV, *[M]*, %p=?, %α=?

7454 *2*, 1⁻, Γ=6 keV, *[L]*, %p=100

7478 *2*, (2), Γ=12 *3* keV, *[KLM]*, %IT=?, %p=?, %α=?
- γ_{937} ***6539.5*** *20* ($\dagger_\gamma$100)

7485 *2*(?), (1⁻), Γ=32 keV, *[L]*, %p=100

7506 *2*, 4⁻, Γ=12 *2* keV, *[LM]*, %p=?, %α=?

7763 *4*, Γ=70 keV, *[L]*, %p=100

7878 *3*, ≥2, Γ=20 keV, *[LM]*, %p=?, %α=?

7899 *2*, (2⁻), Γ=38 keV, *[CM]*, %p=?, %α=?

7941 *12*, (1⁺), Γ=112 keV, *[CM]*, %p=?, %α=?

8064 *6*, ≥4, Γ=60 keV, *[LM]*, %p=?, %α=?

8115 *8*, Γ=96 keV, *[L]*, %p=100

8209 *2*, 2⁻, Γ=52 keV, *[LM]*, %p=?, %α=?

8238 *2*, 4⁺, Γ=20 keV, *[L]*, %p=100

9207 *15*, 3,4⁻, *[H]*, %p=?, %α=?, T=0

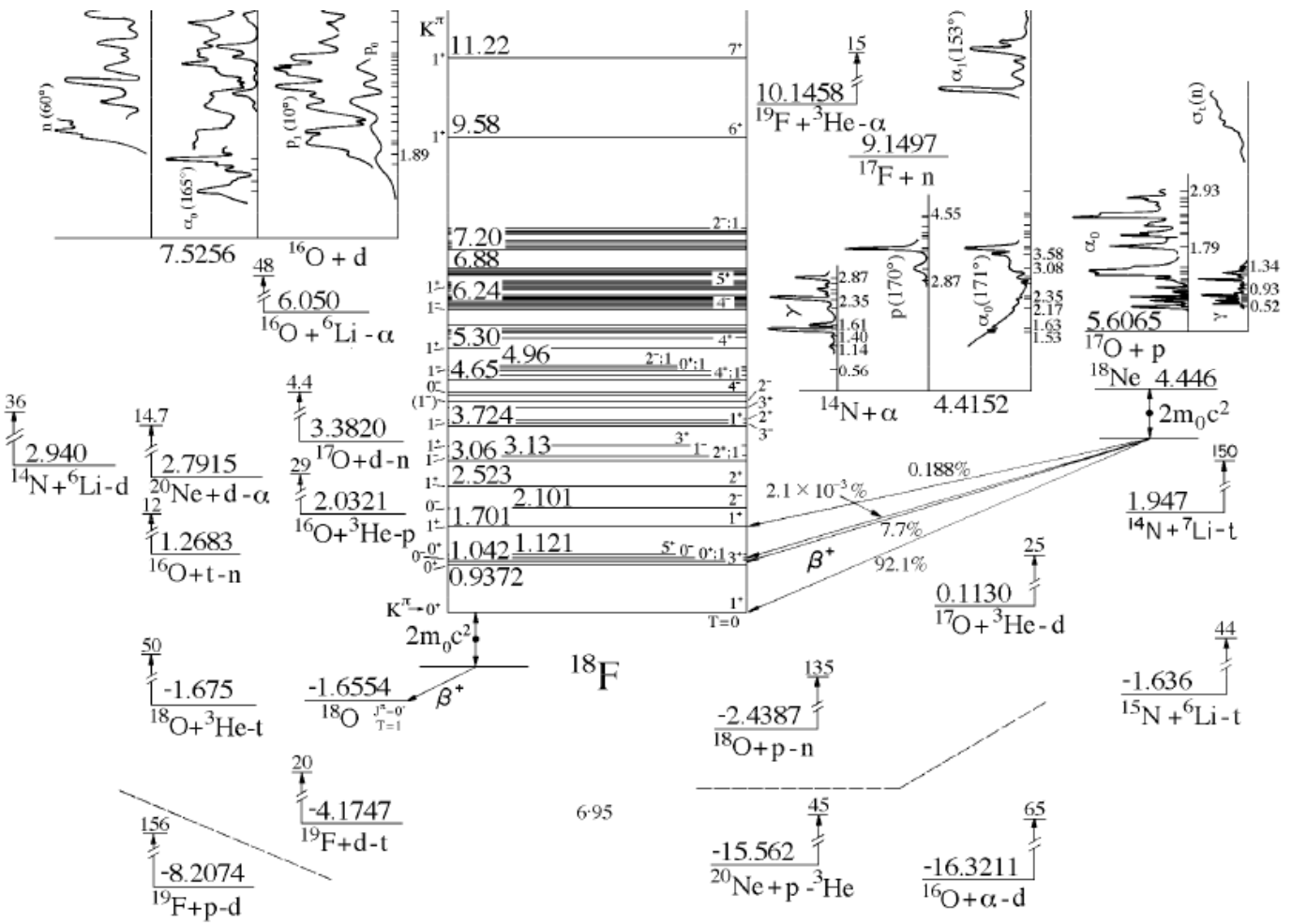
9500, 2,3⁺, *[H]*, %n=?, %α=?, T=0

9580 *20*, 6⁺, *[DEF]*, %α=?

10580 *50*, *[F]*

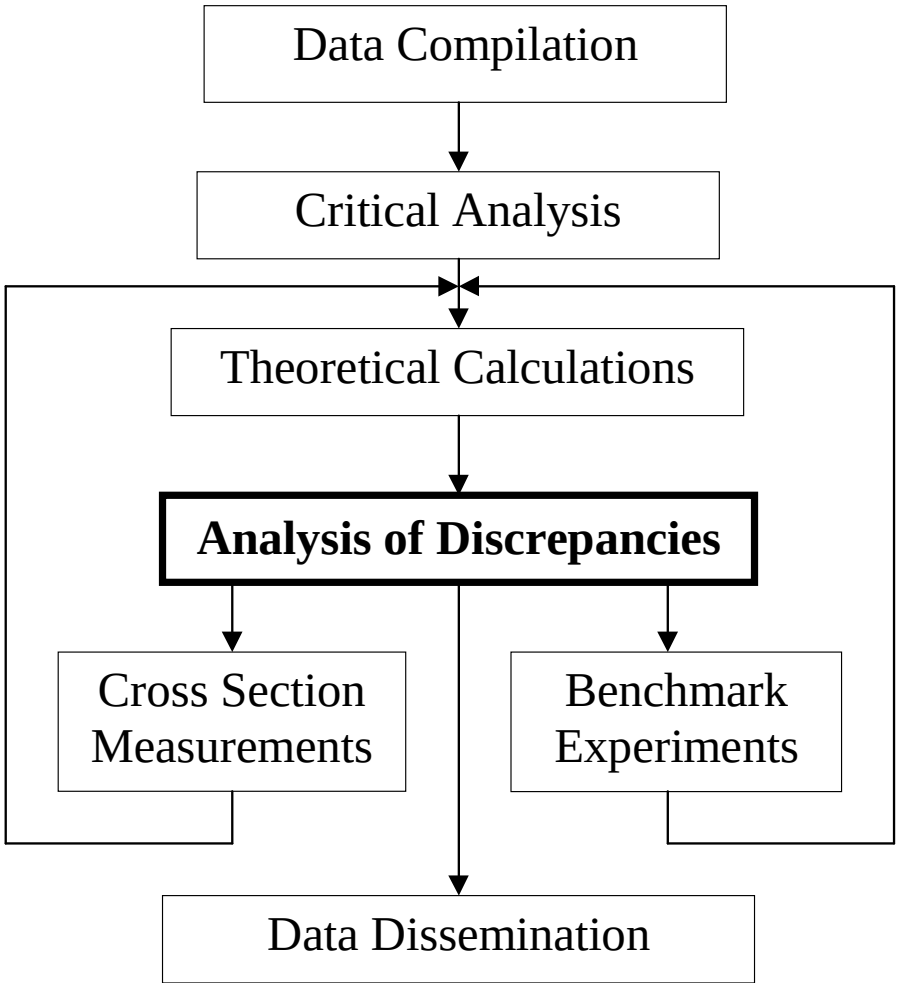
11220 *30*, 7⁺, *[DEF]*, %α=?

13830, 4⁻,5⁺, Γ=60 keV, *[H]*, %α=?

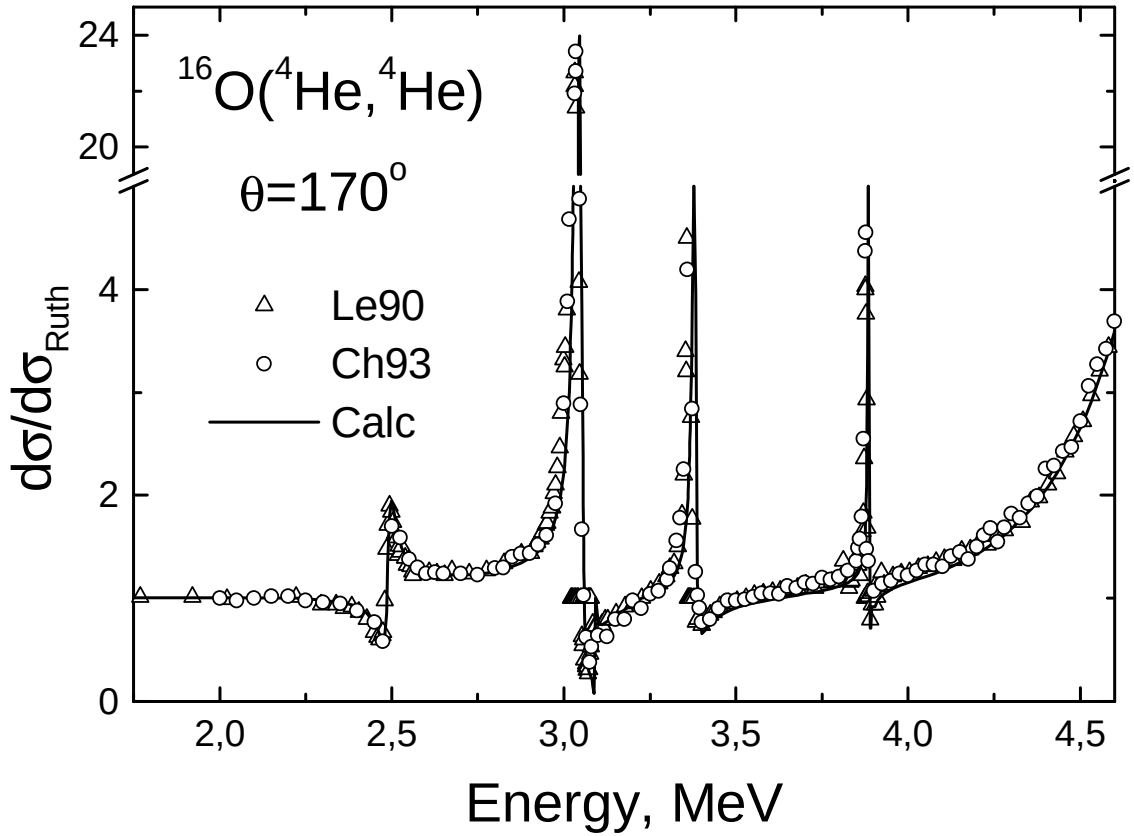

18F
11.22
9.58
7.20
6.88
6.24
5.30
4.96
4.65
3.724
3.06
3.13
2.523
2.101
1.701
1.042
1.121
0.9372
1.89
7.5256
16O + d
6.050
16O + 6Li - α
2.940
14N + 6Li-d
2.7915
20Ne + d - α
1.2683
16O + t - n
3.3820
17O + d - n
2.0321
16O + 3He - p
-1.675
18O + 3He-t
-1.6554
18O
-4.1747
19F + d - t
-8.2074
19F + p - d
10.1458
19F + 3He - α
9.1497
17F + n
4.4152
14N + α
5.6065
17O + p
18Ne 4.446
2m0c2
1.947
14N + 7Li - t
0.1130
17O + 3He - d
-2.4387
18O + p - n
-1.636
15N + 6Li - t
-15.562
20Ne + p - 3He
-16.3211
16O + α - d
0.188%
2.1 × 10-3 %
7.7%
92.1%
β+
6·95

36

Evaluation Scheme



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



38

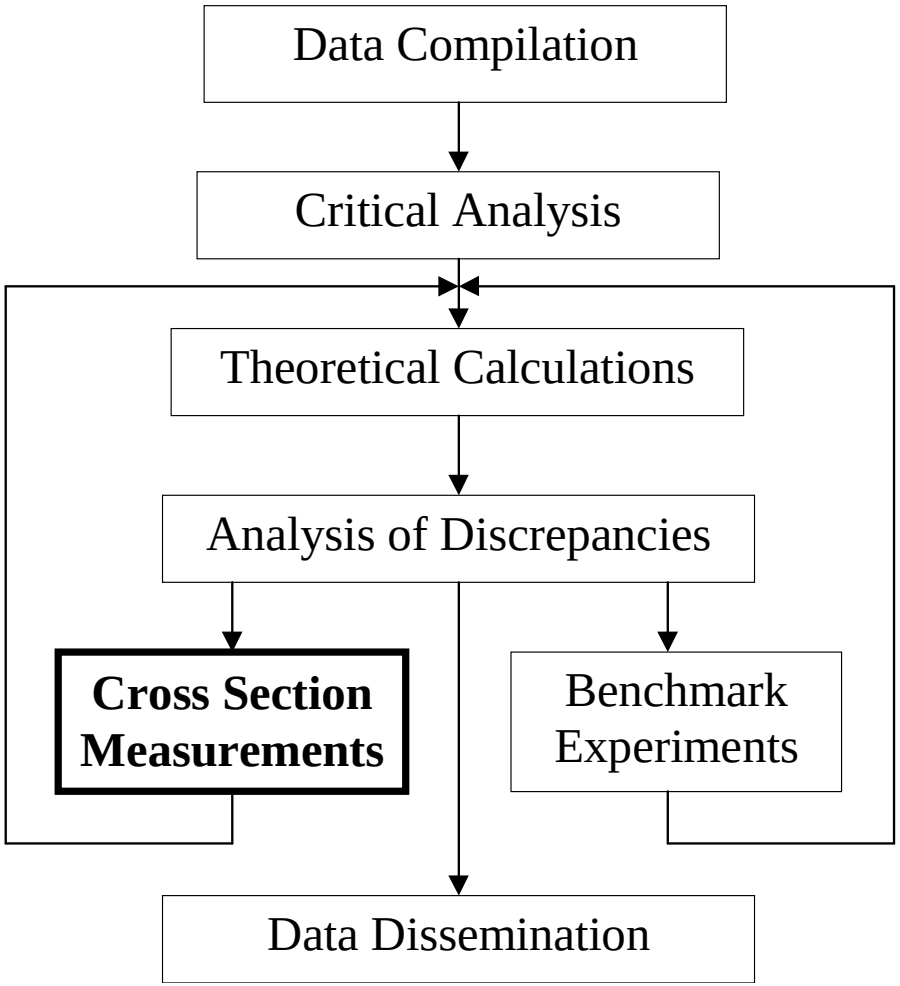
$^{16}O(\alpha,\alpha_0)^{16}O$

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)

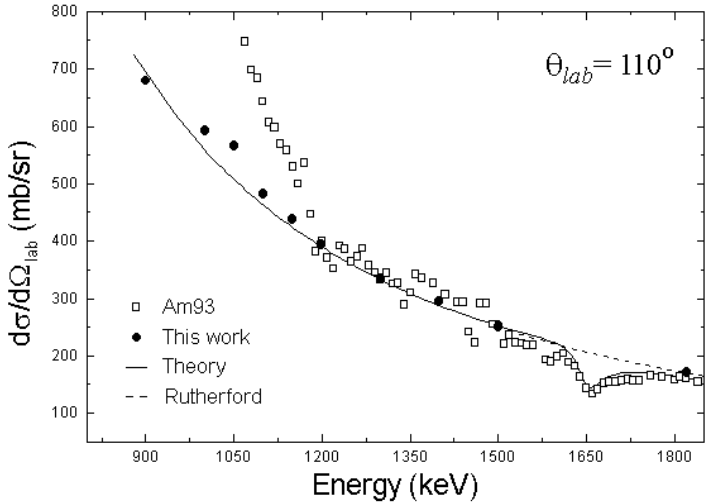
39

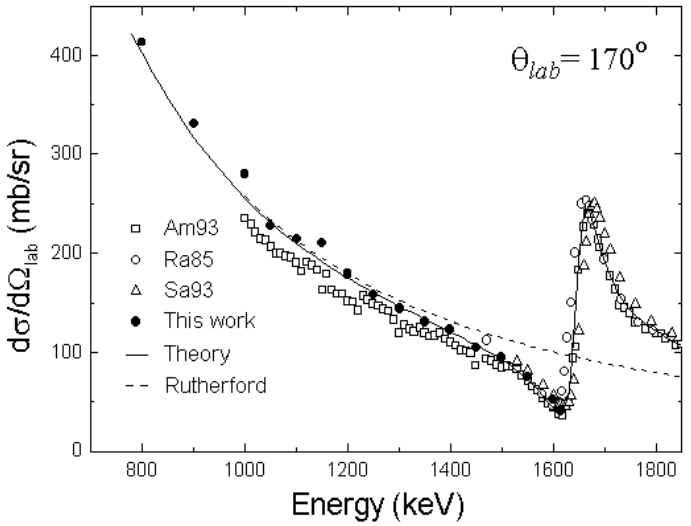
Evaluation Scheme



40

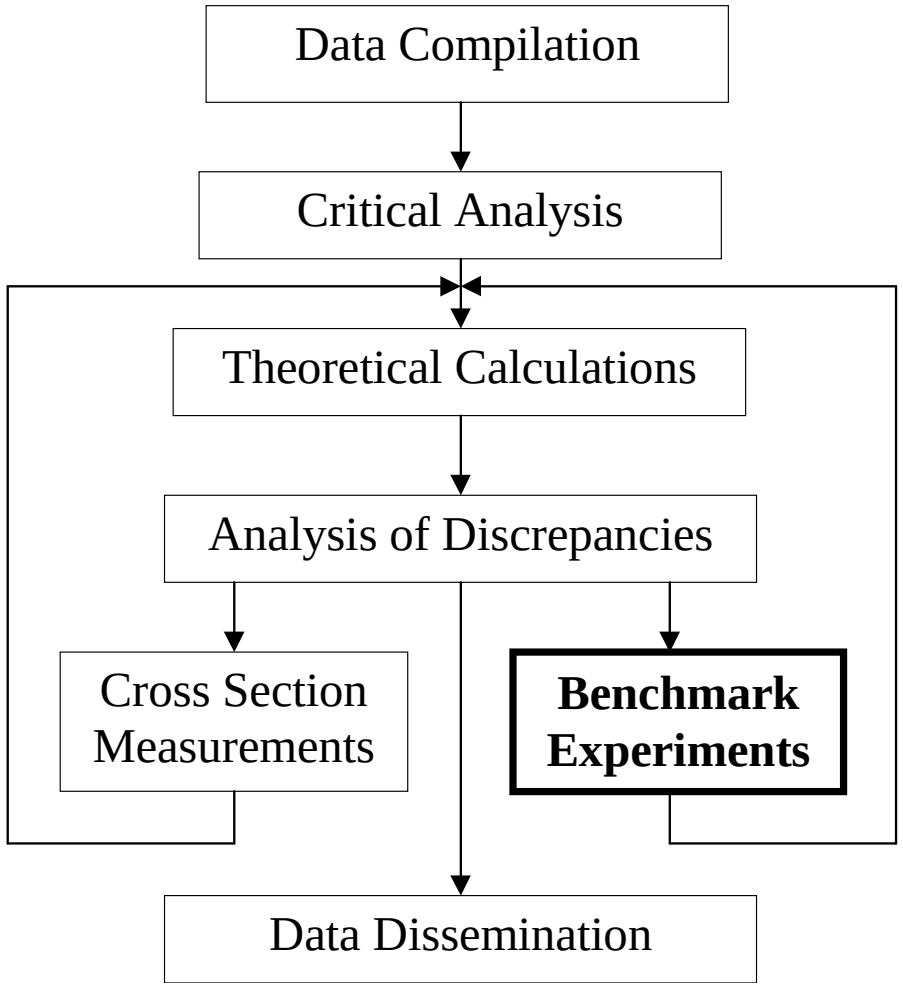
Additional experiment to resolve a problem with $^{28}Si(p,p_0)^{28}Si$ cross-section





41

Evaluation Scheme



42

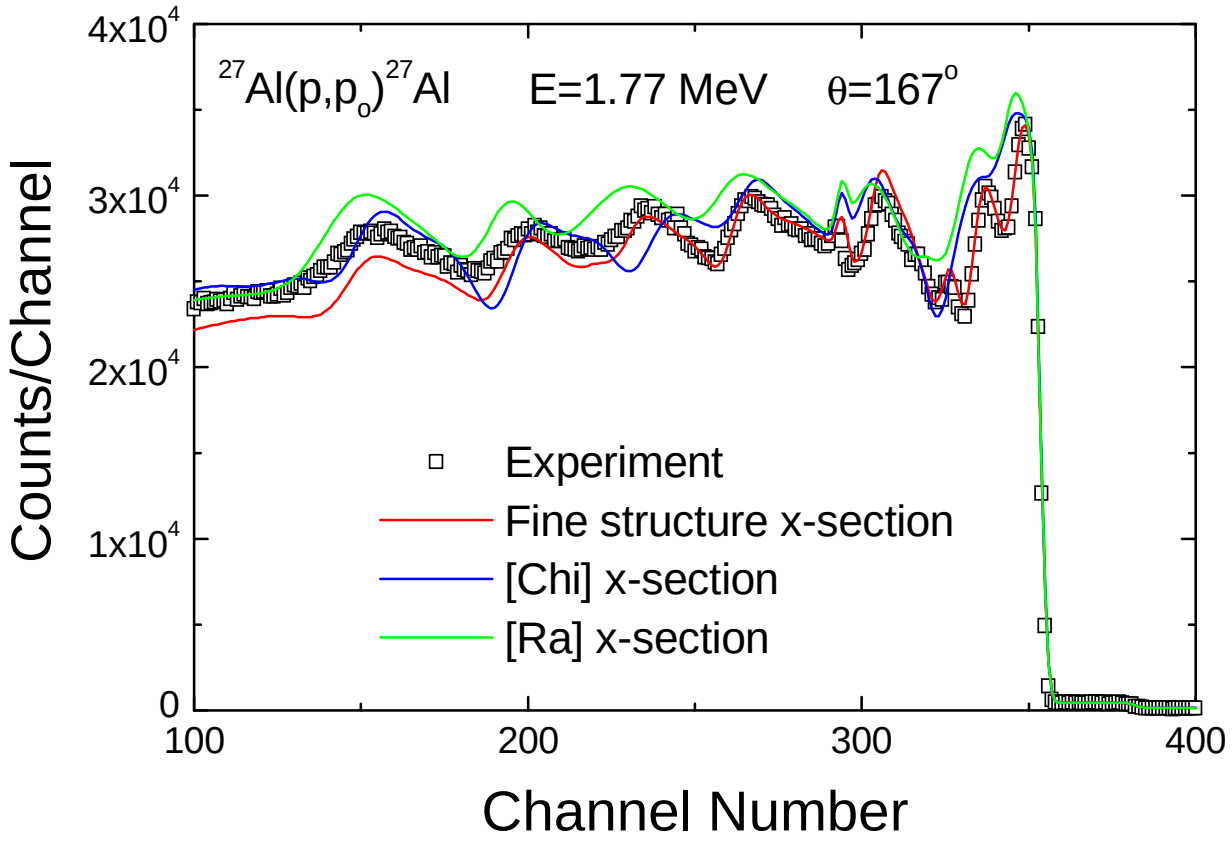
Benchmarks

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.

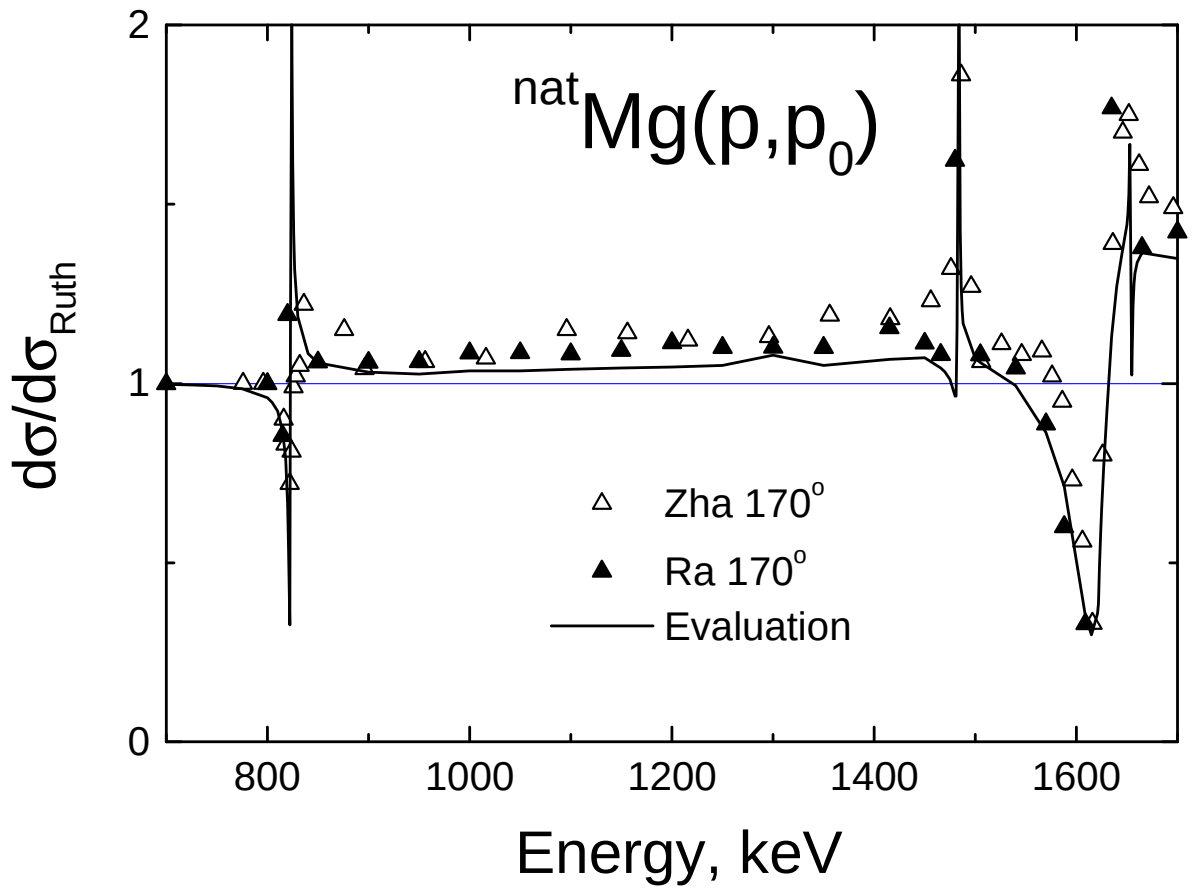
This is an extension of the definition taken from reactor physics where microscopic neutron data are verified by comparison of calculated integral reactor characteristics such as e.g. neutron flux with results of direct measurements.

43

The benchmark demonstrated the significance of the cross section fine structure

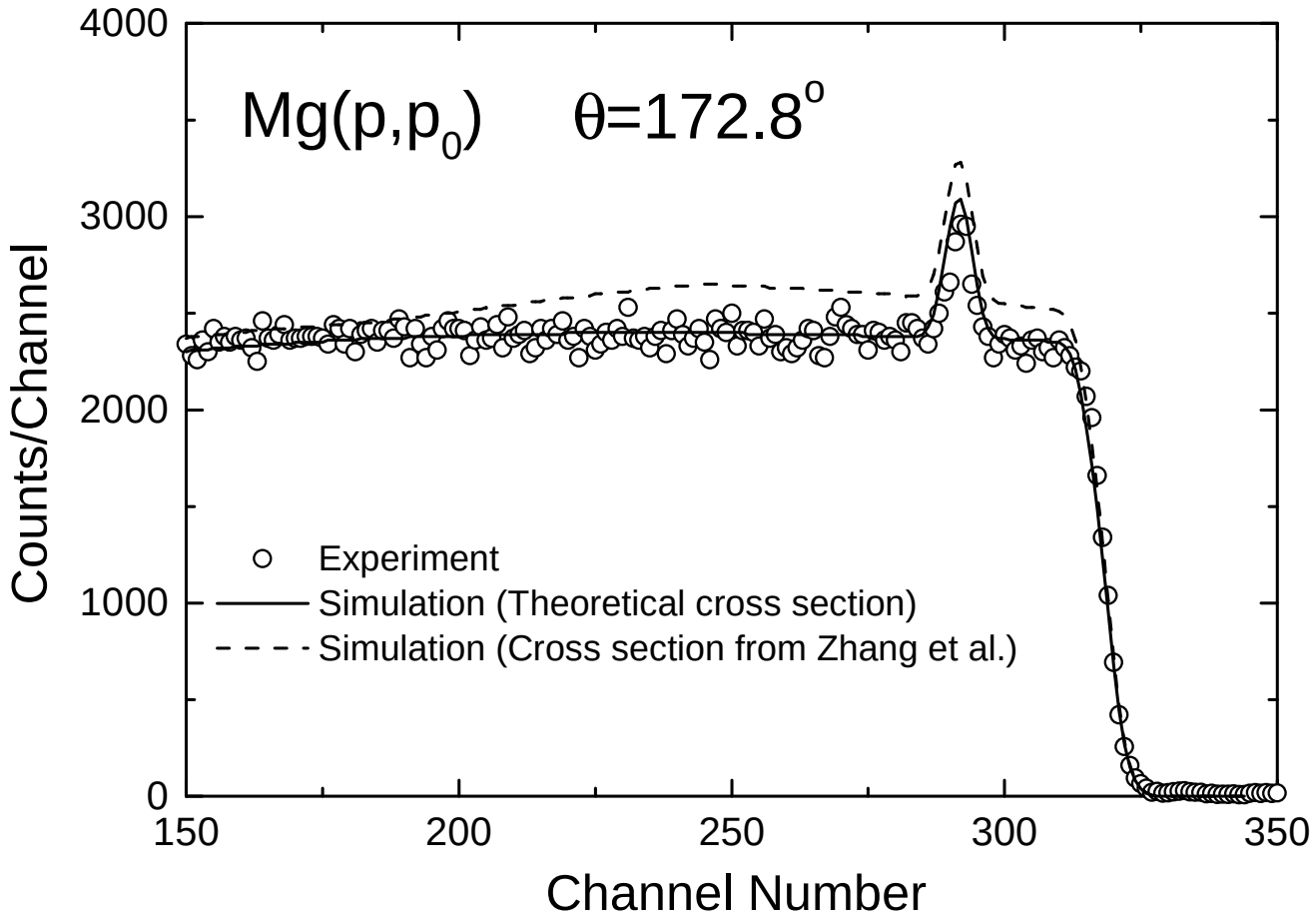


The deviation of the cross section for Mg(p,p$_0$) from Rutherford above 800 keV

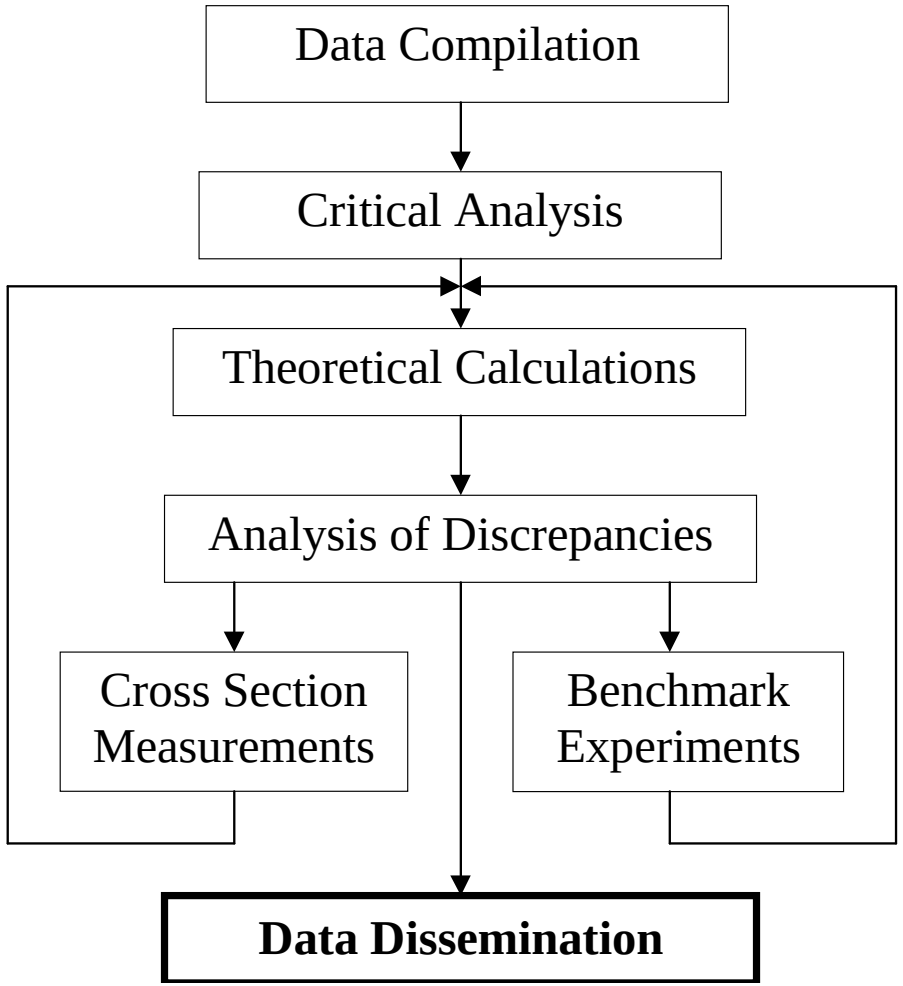


45

The benchmark for $Mg(p,p_0)$

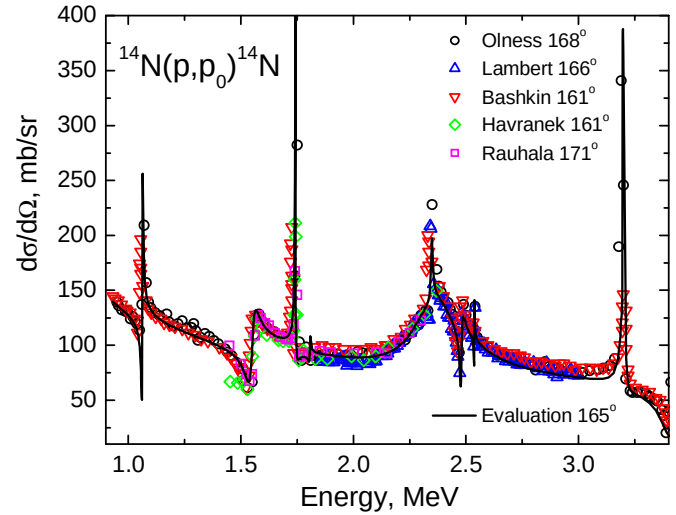


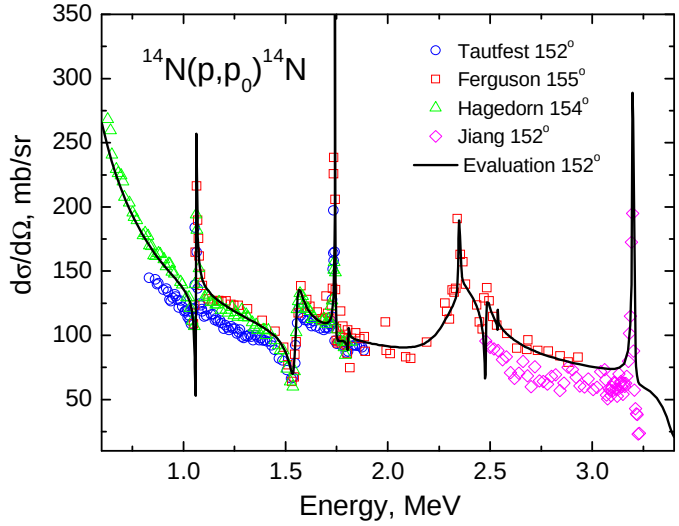
Evaluation Scheme

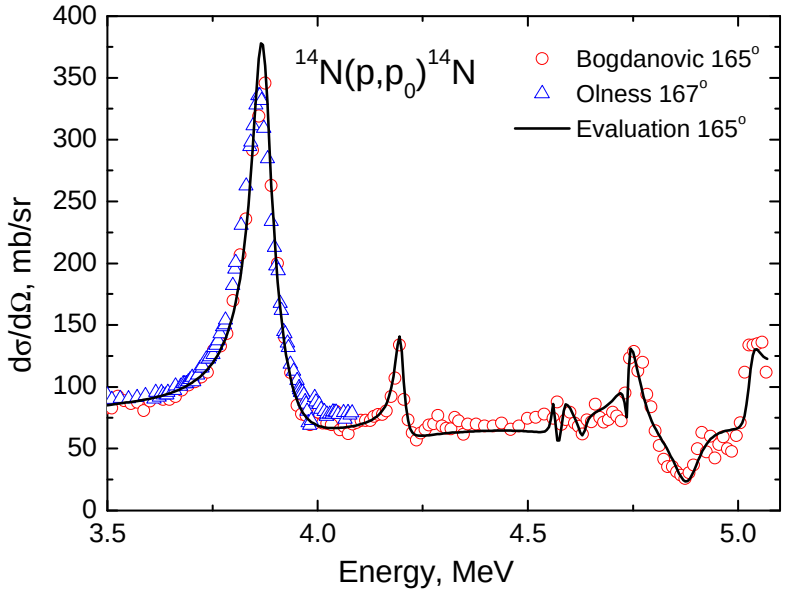


47

Evaluation of the $^{14}N(p,p_0)^{14}N$ cross-section

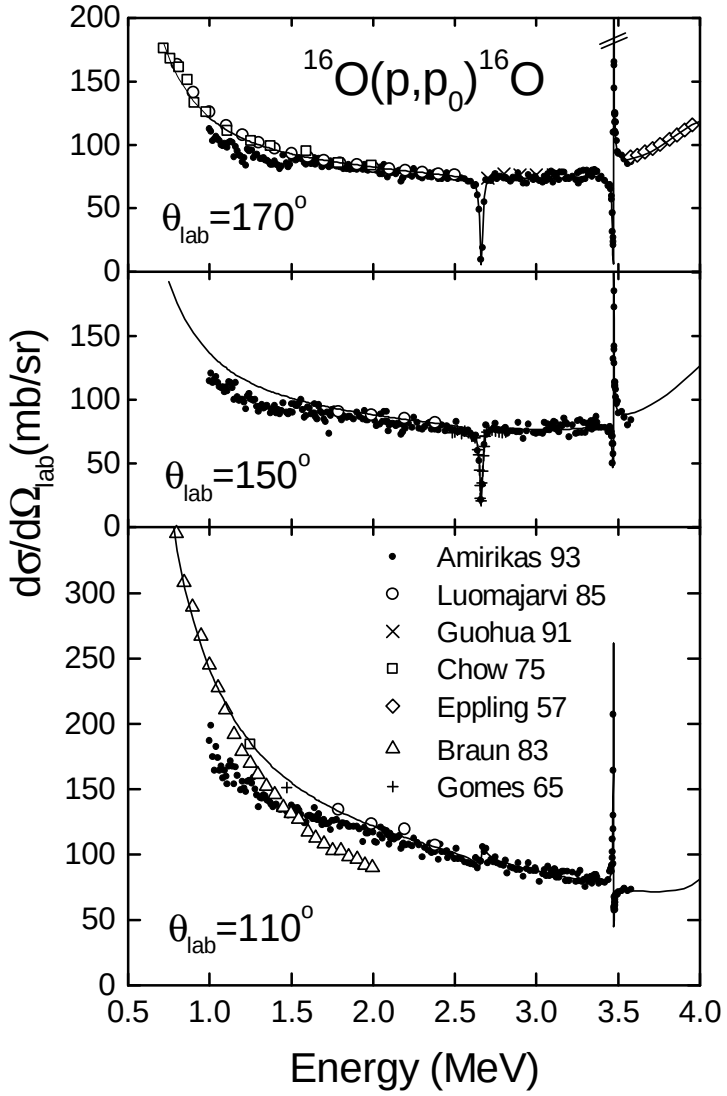






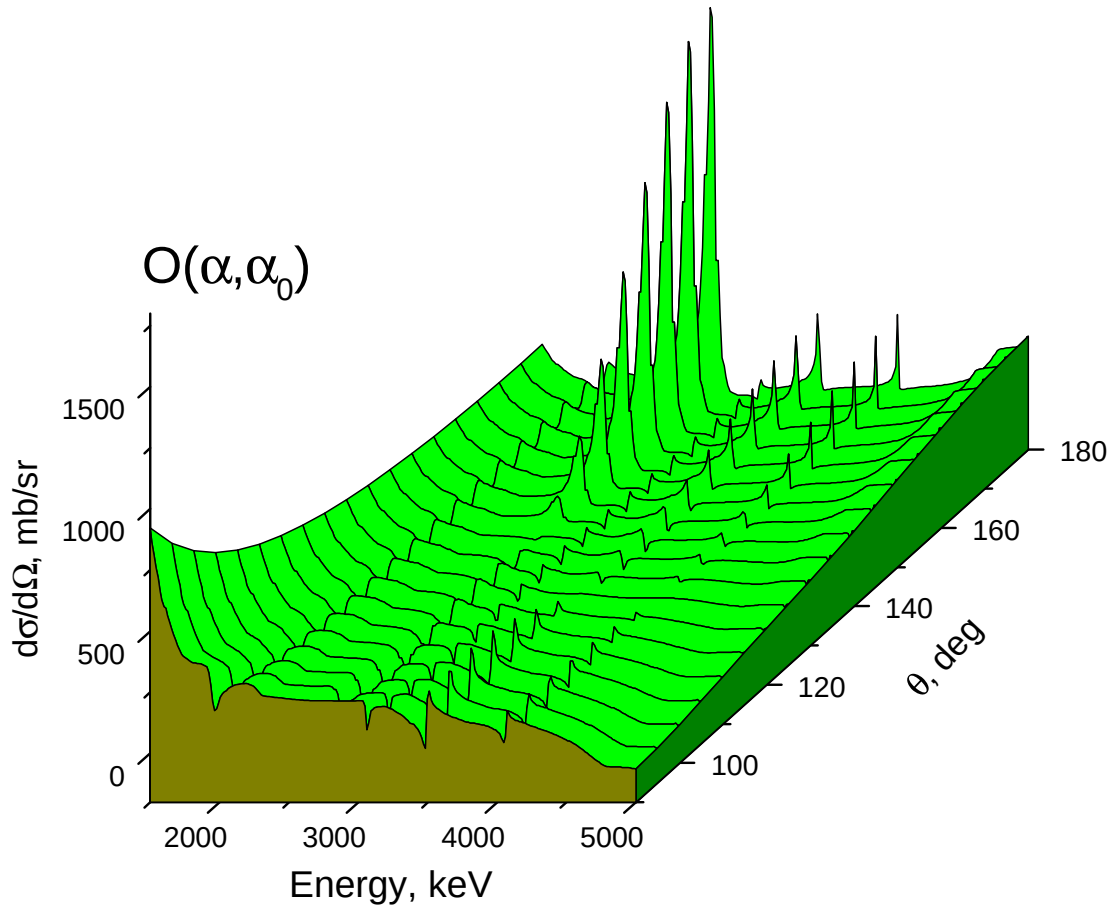
48

Evaluation of the proton elastic scattering from oxygen



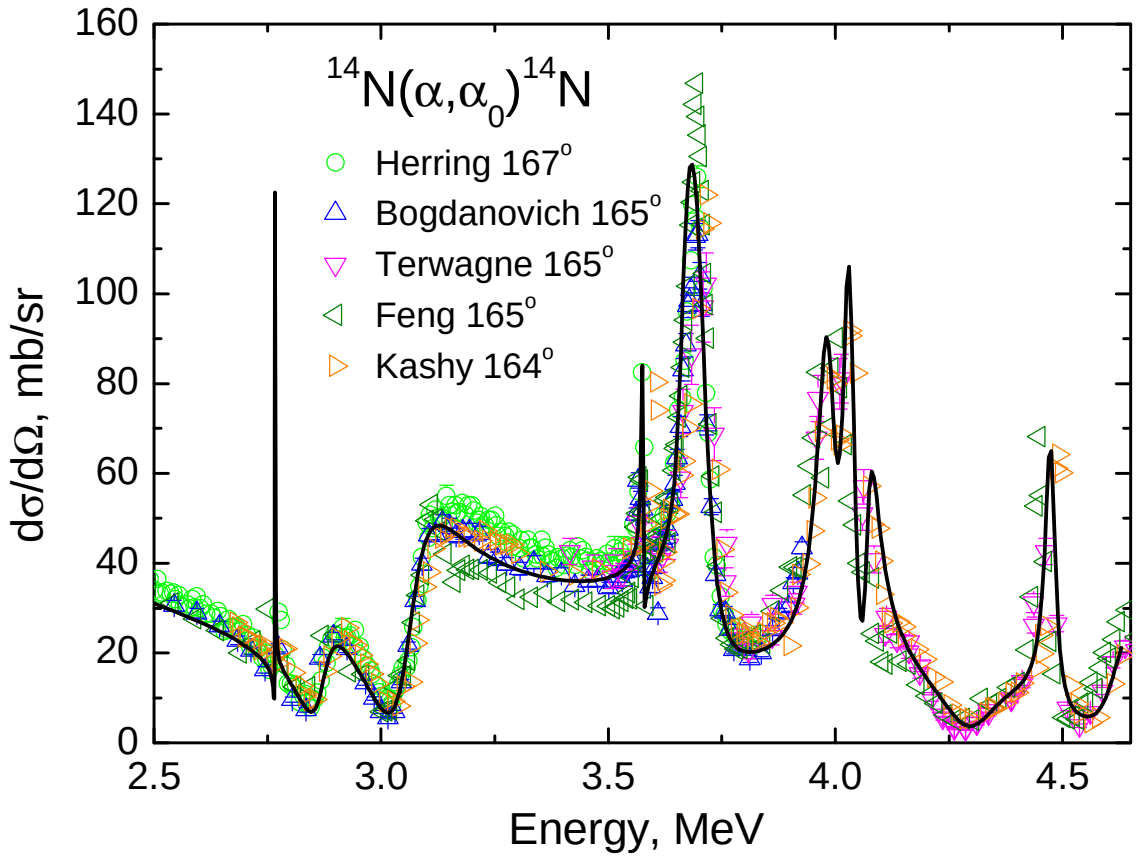
49

The evaluated cross section for alpha elastic scattering from oxygen



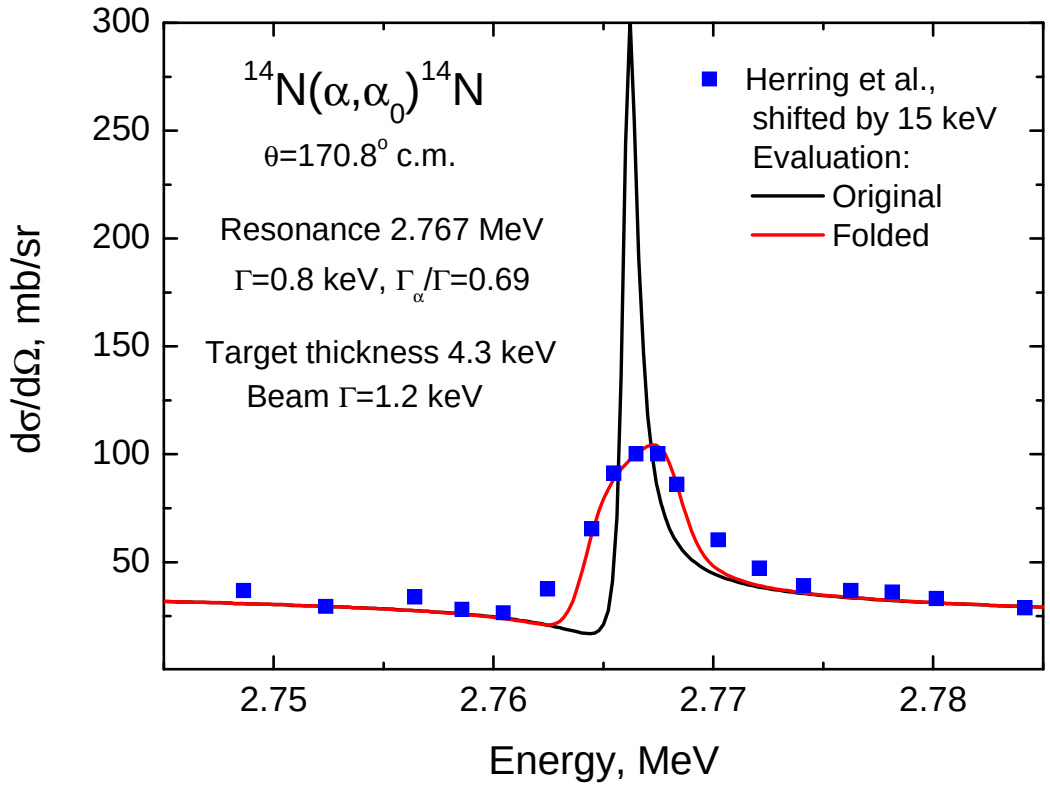
50

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



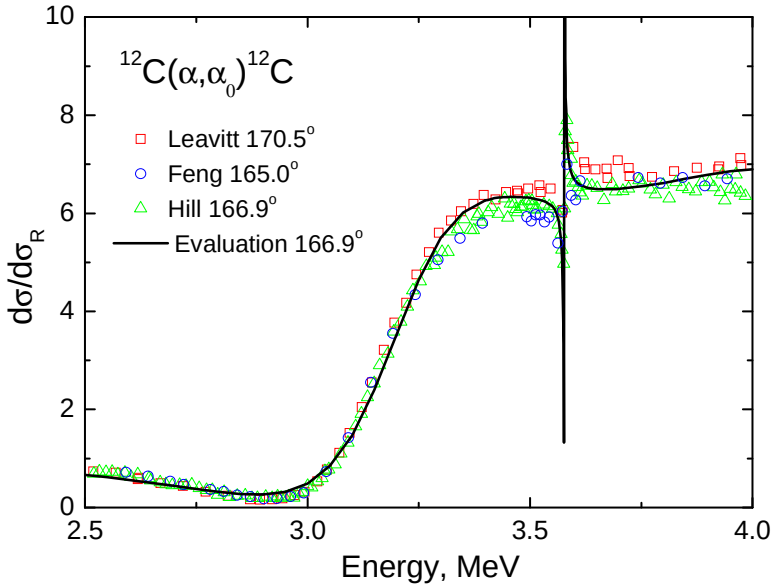
51

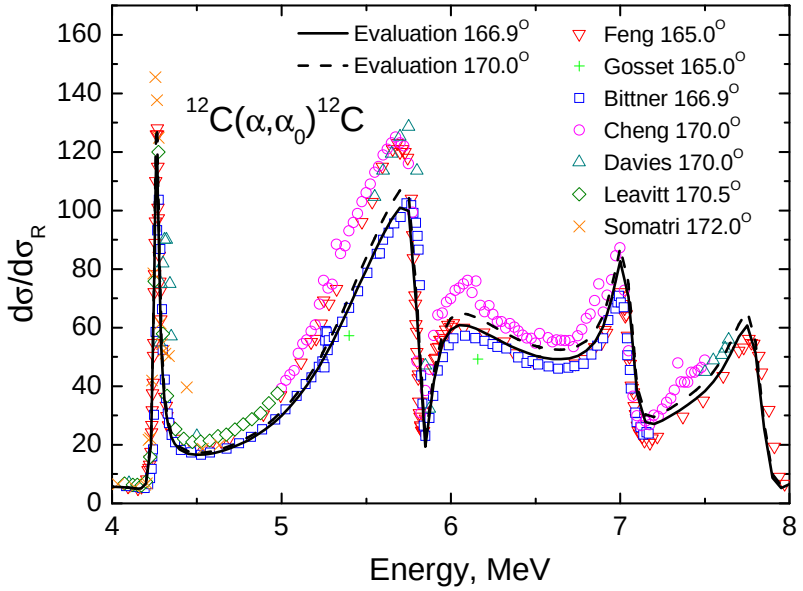
$^{14}N(\alpha,\alpha_0)^{14}N$ narrow resonance



52

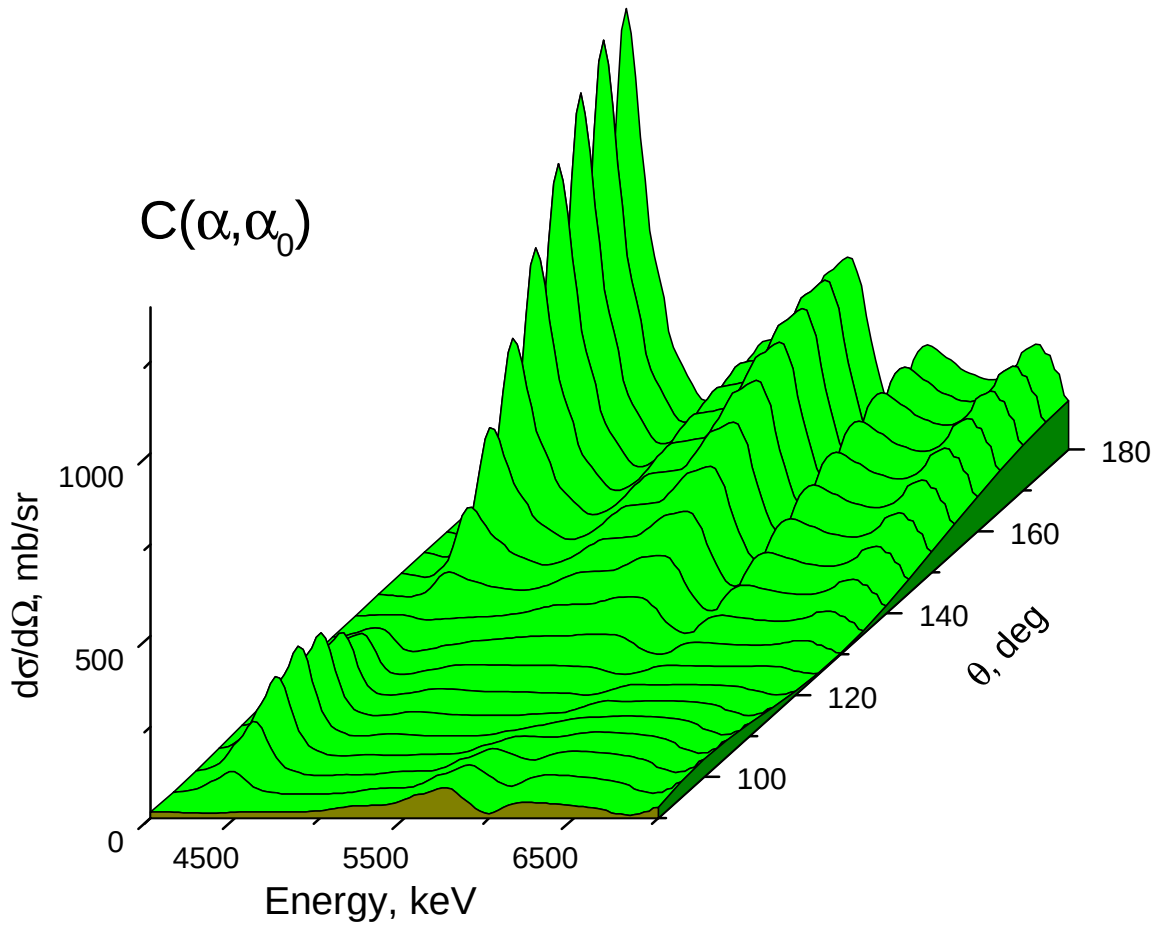
Evaluation of the $^{12}C(\alpha,\alpha_0)^{12}C$ cross-section





53

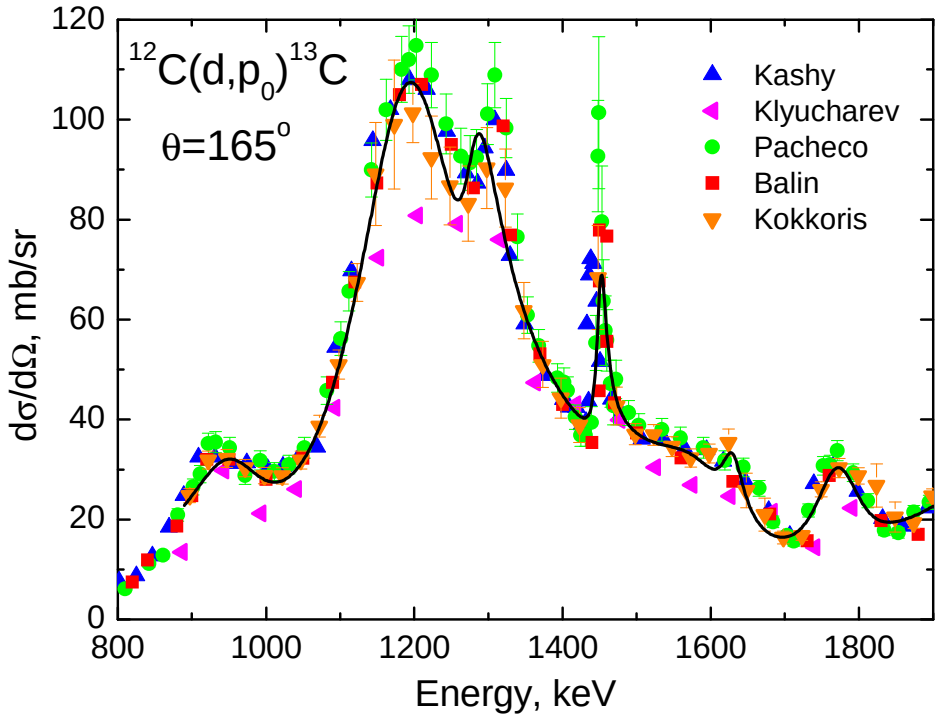
The evaluated cross section for alpha elastic scattering from carbon



Most useful reactions with deuterons

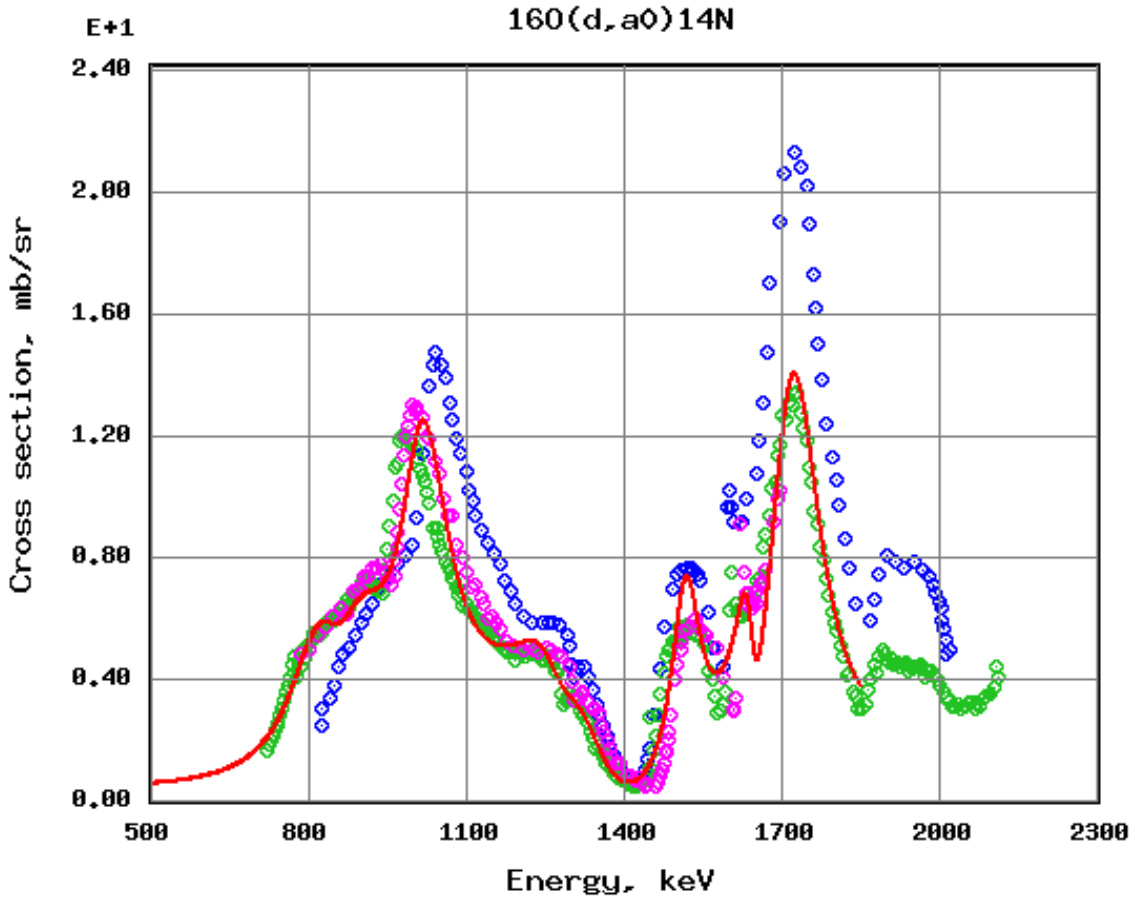
$^{2}H(d,p)^{3}H$	Q = 4.03 MeV
$^{12}C(d,p)^{13}C$	Q = 2.72 MeV
$^{14}N(d,p)^{15}N$	Q = 8.62 MeV (p_0)
$^{14}N(d,\alpha)^{12}C$	Q = 13.57 MeV (α_0)
$^{16}O(d,p)^{17}O$	Q = 1.92 MeV (p_0)
$^{16}O(d,\alpha)^{14}N$	Q = 3.11 MeV
$^{27}Al(d,p)^{28}Al$	Q = 5.50 MeV (p_0)
$^{27}Al(d,\alpha)^{25}Mg$	Q = 6.71 MeV (α_0)
$^{28}Si(d,p)^{29}Si$	Q = 6.25 MeV

Evaluation of the $^{12}C(d,p_0)^{13}C$ cross-section



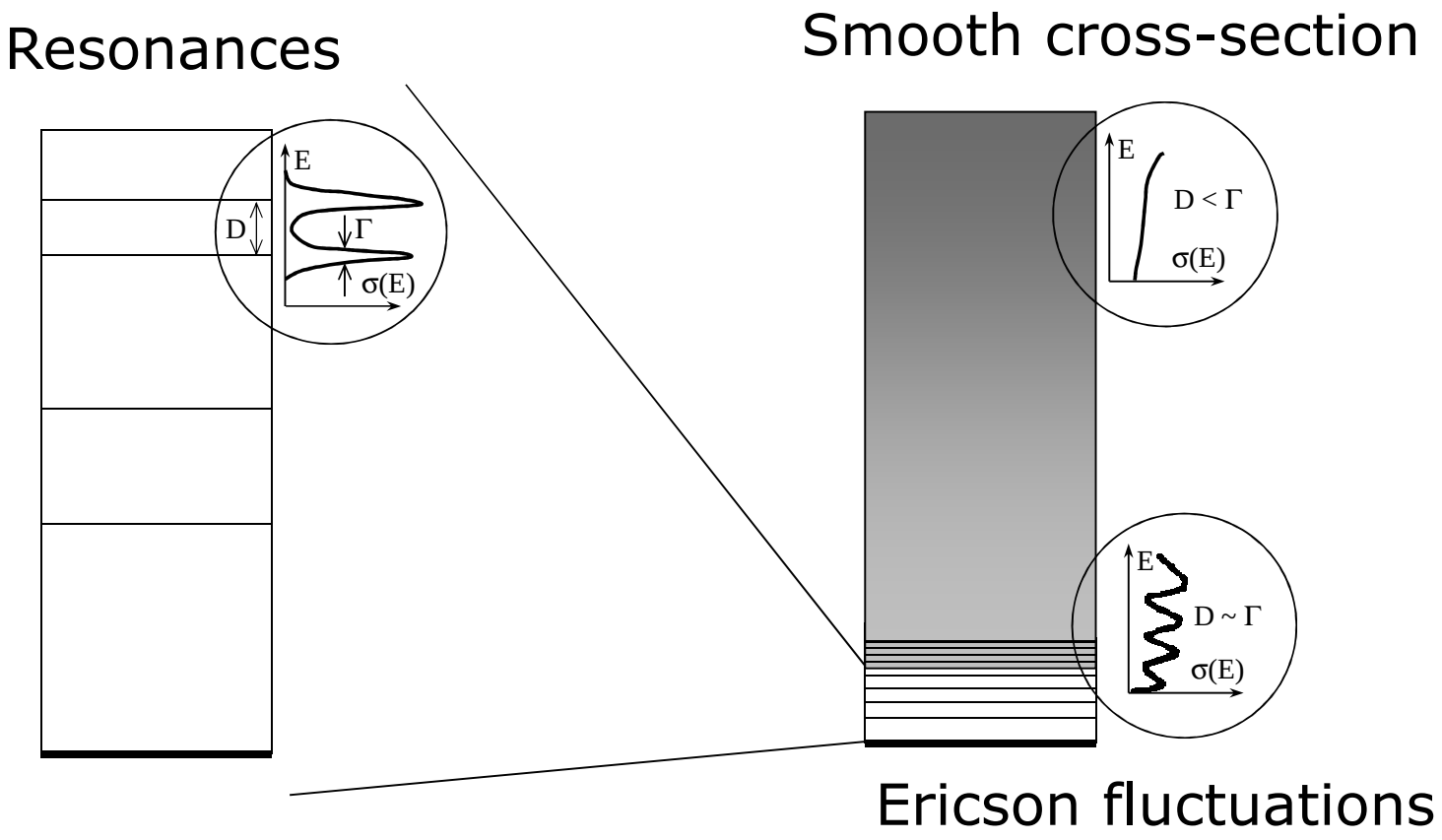
56

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



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

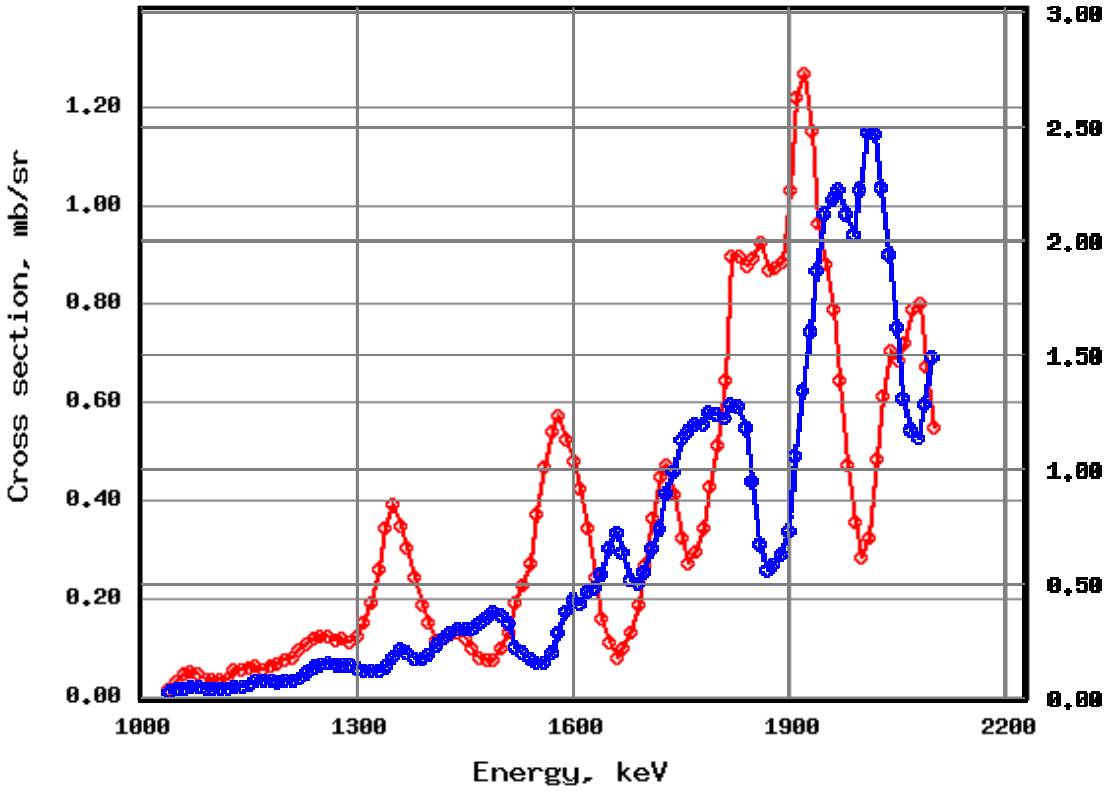
Three regions in the compound nucleus excitation and corresponding cross-section behavior



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

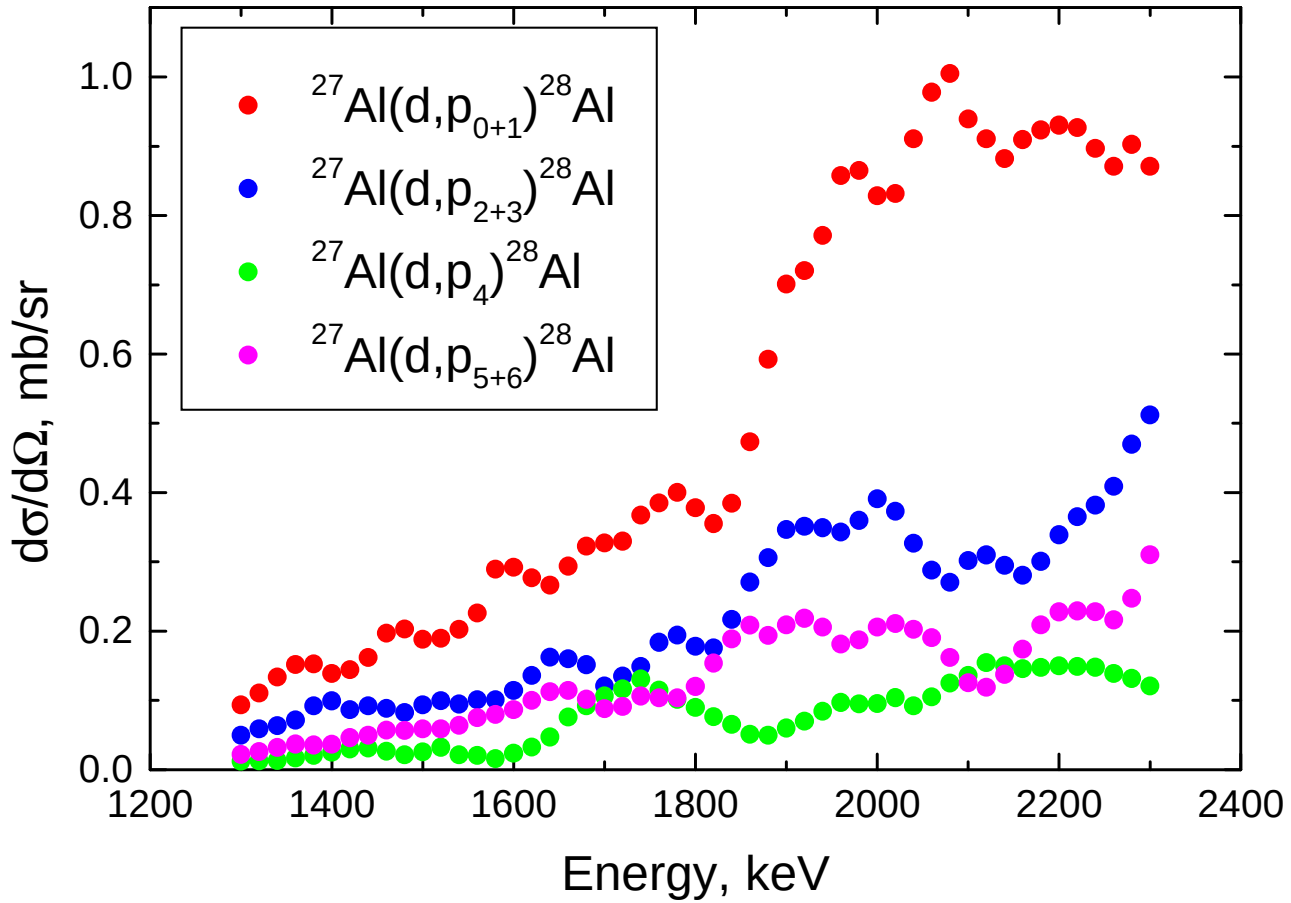
$^{28}Si(d,p_0)^{29}Si$

$^{28}Si(d,p_1)^{29}Si$



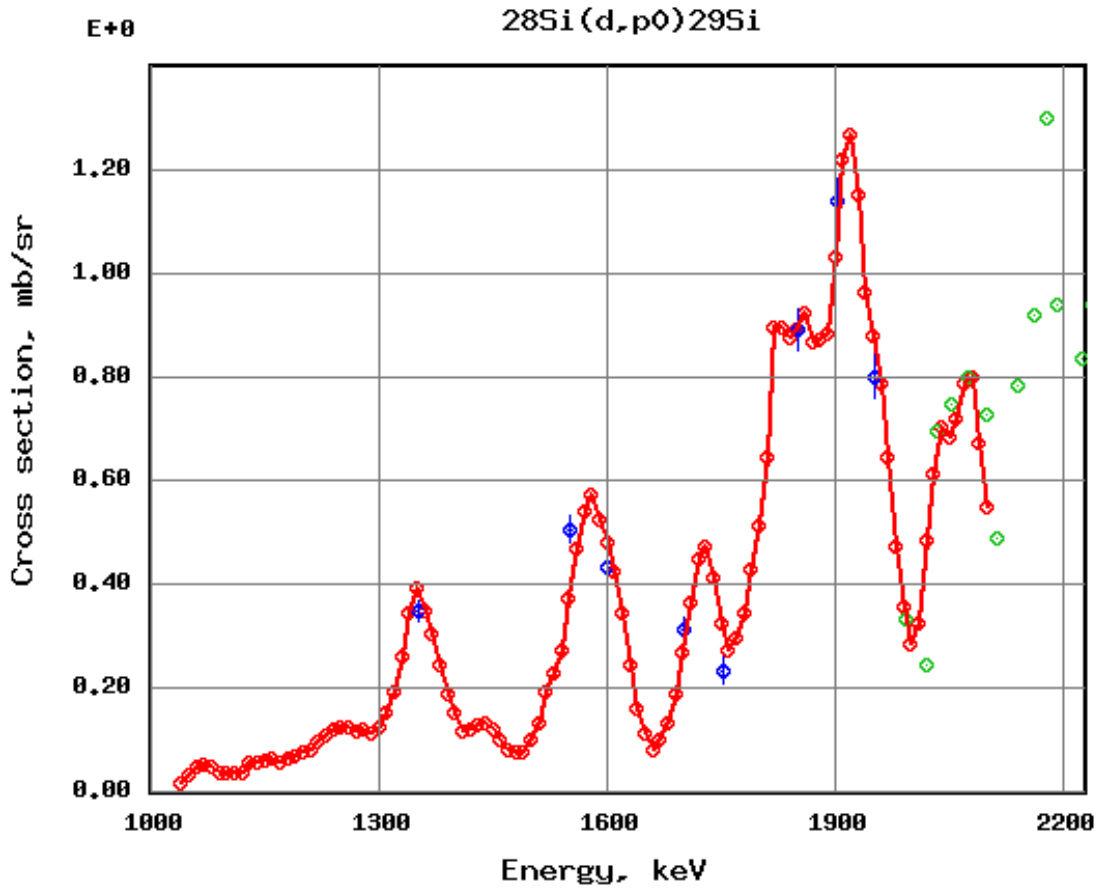
59

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



60

"Recommended" cross-section for $^{28}Si(d,p_0)^{29}Si$ at 150°



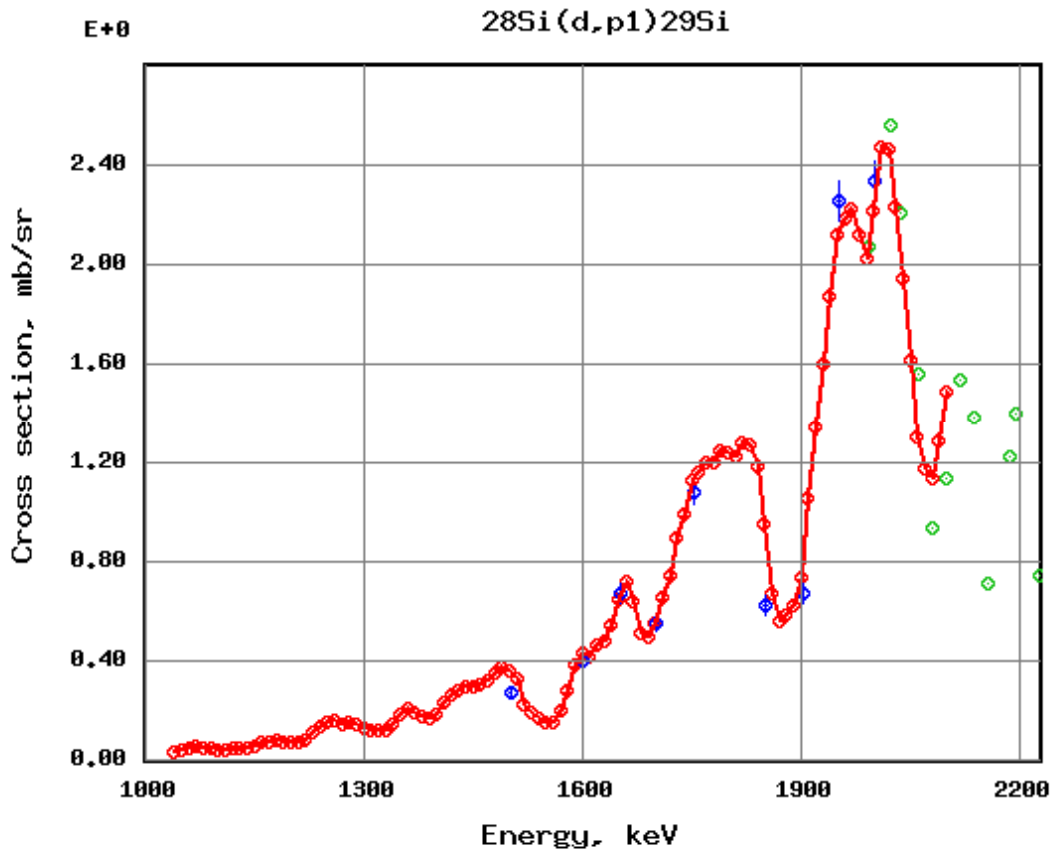
Theta=150.00 Recommended - A.F.Gurbich, S.L.Molodtsov, Nucl.Instr.& Meth. B226 (2004) 637

Theta=150.00 M. Kokkoris et al.

Theta=150.00 C.C.Hsu et al. Physical Review C v.7 (1973) 1425

61

"Recommended" cross-section for $^{28}Si(d,p_1)^{29}Si$ at 150°



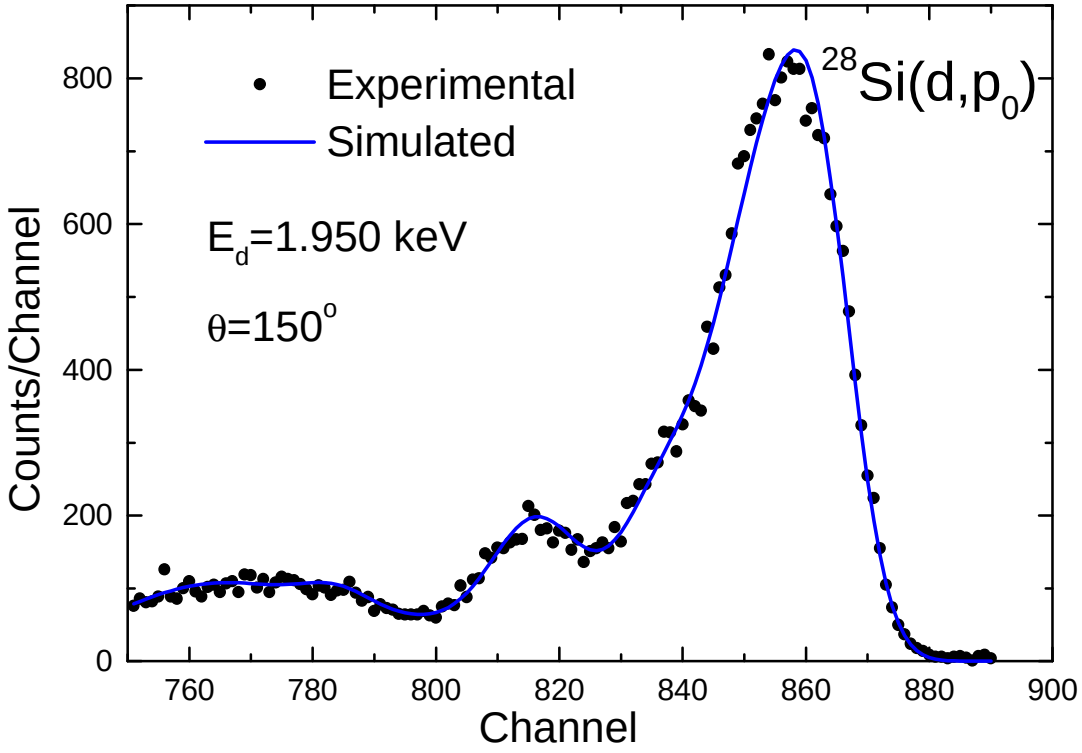
Theta=150.00 Recommended - A.F.Gurbich, S.L.Molodtsov, Nucl.Instr.& Meth. B226 (2004) 637

Theta=150.00 M. Kokkoris et al.

Theta=150.00 C.C.Hsu et al. Physical Review C v.7 (1973) 1425

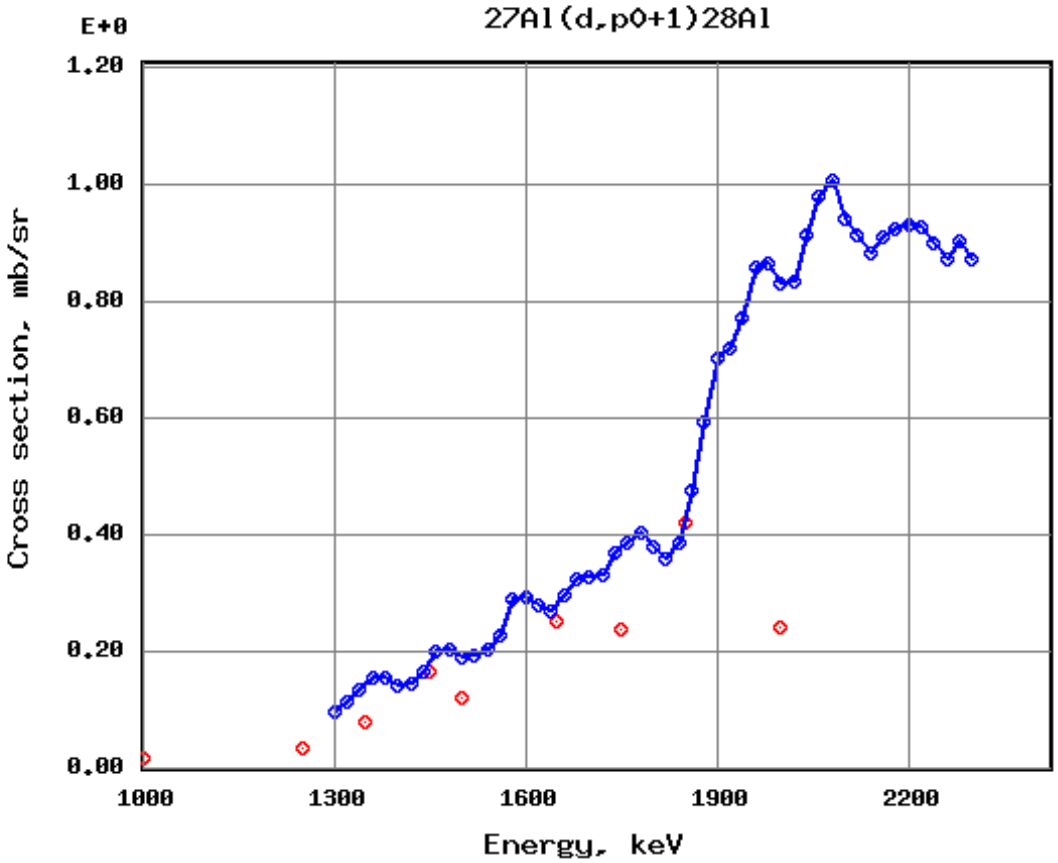
62

Benchmark for the $^{28}Si(d,p_0)^{29}Si$ cross-section



63

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

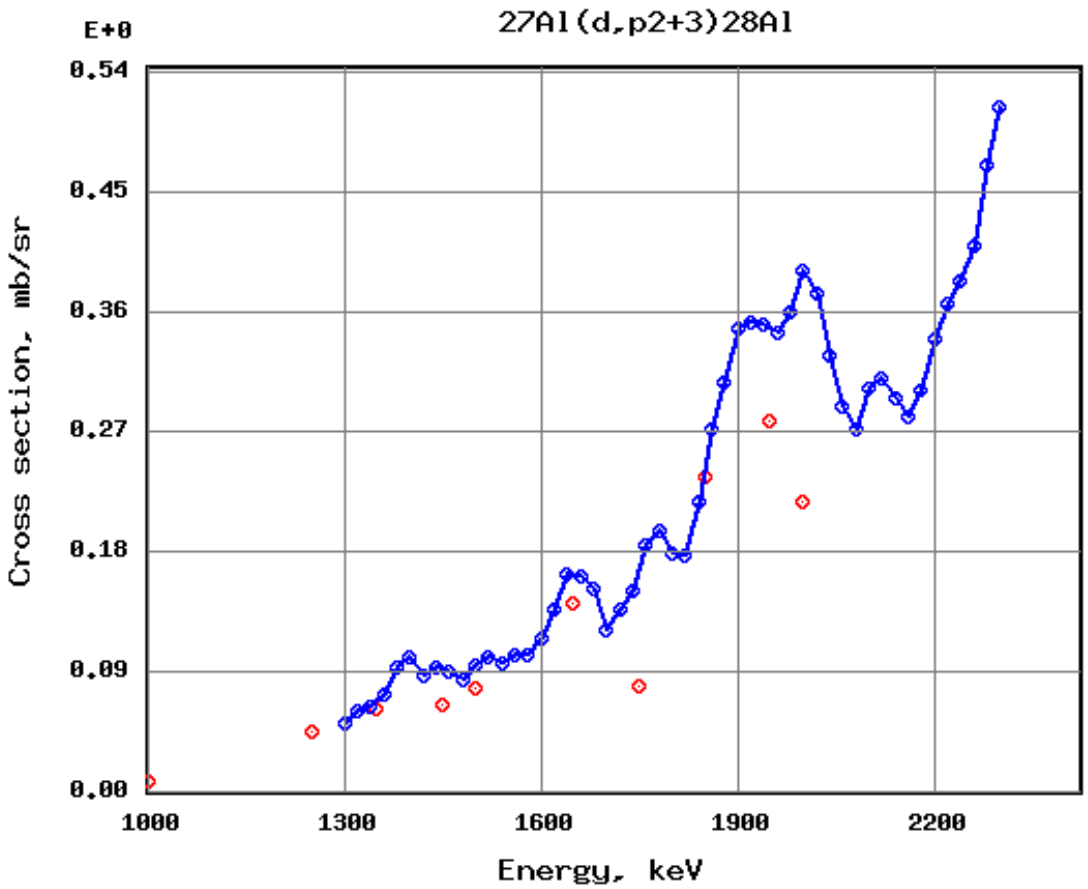


Theta=150.00 S. Pellegrino et al., Nucl. Instr. and Meth. B 266 (2008) 2268

Theta=150.00 Recommended - A.F.Gurbich, S.L.Molodtsov, Nucl. Instr. & Meth. B266 (2008) 3535

64

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

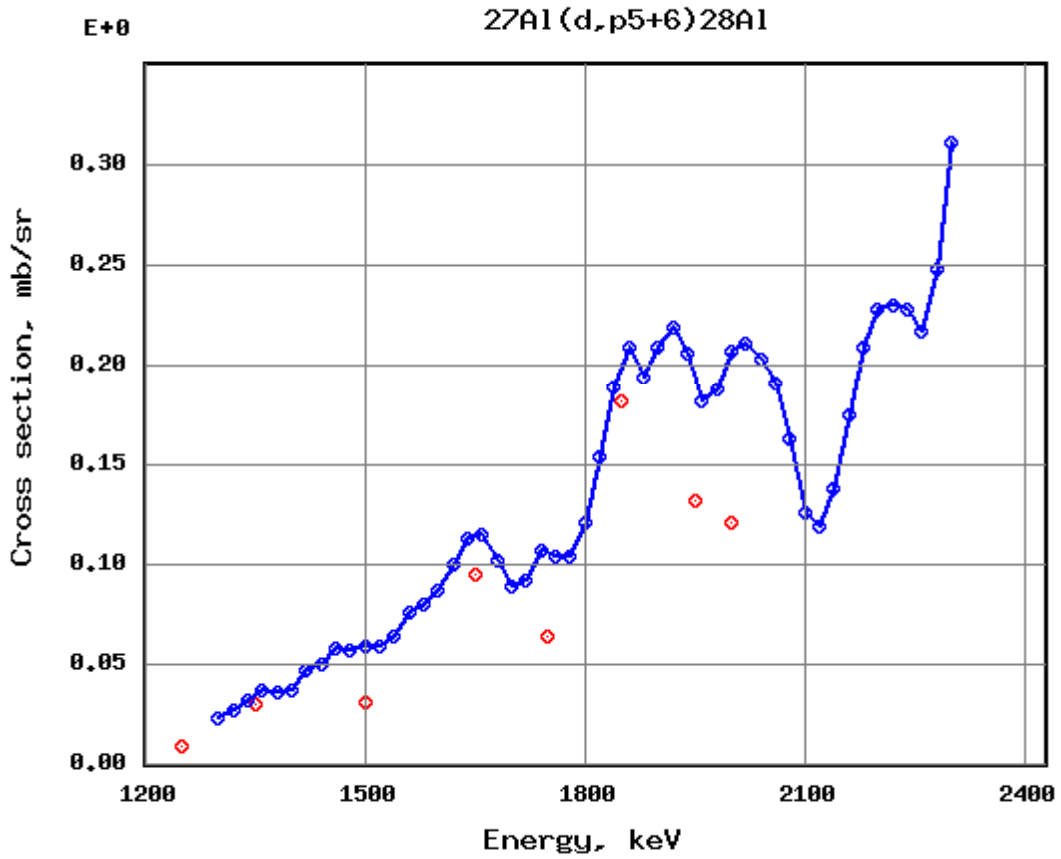


Theta=150.00 S. Pellegrino et al., Nucl. Instr. and Meth. B 266 (2008) 2268

Theta=150.00 Recommended - A.F.Gurbich, S.L.Molodtsov, Nucl. Instr. & Meth. B266 (2008) 3535

65

"Recommended" cross-section for $^{27}Al(d,p_{5+6})^{28}Al$ at 150°

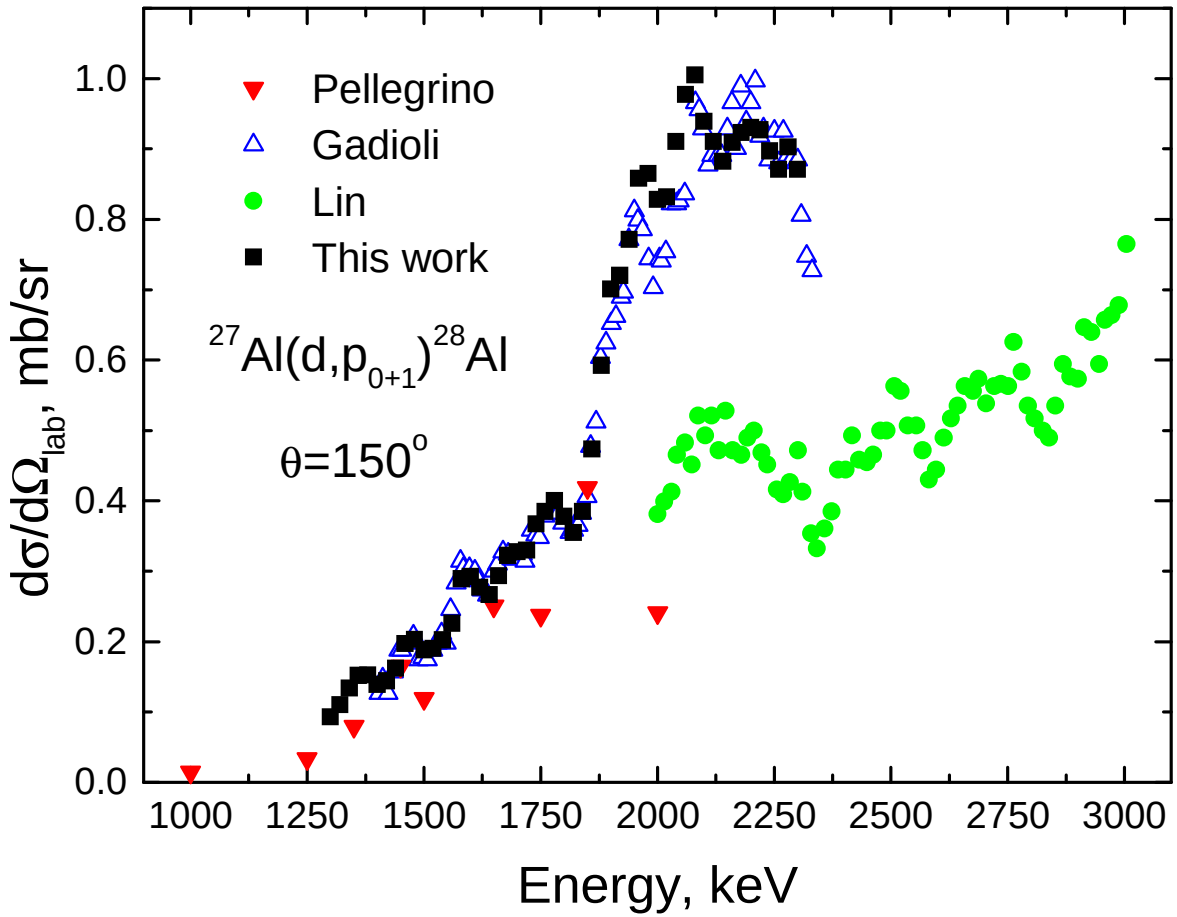


Theta=150.00 S. Pellegrino et al., Nucl. Instr. and Meth. B 266 (2008) 2268

Theta=150.00 Recommended - A.F.Gurbich, S.L.Molodtsov, Nucl. Instr. & Meth. B266 (2008) 3535

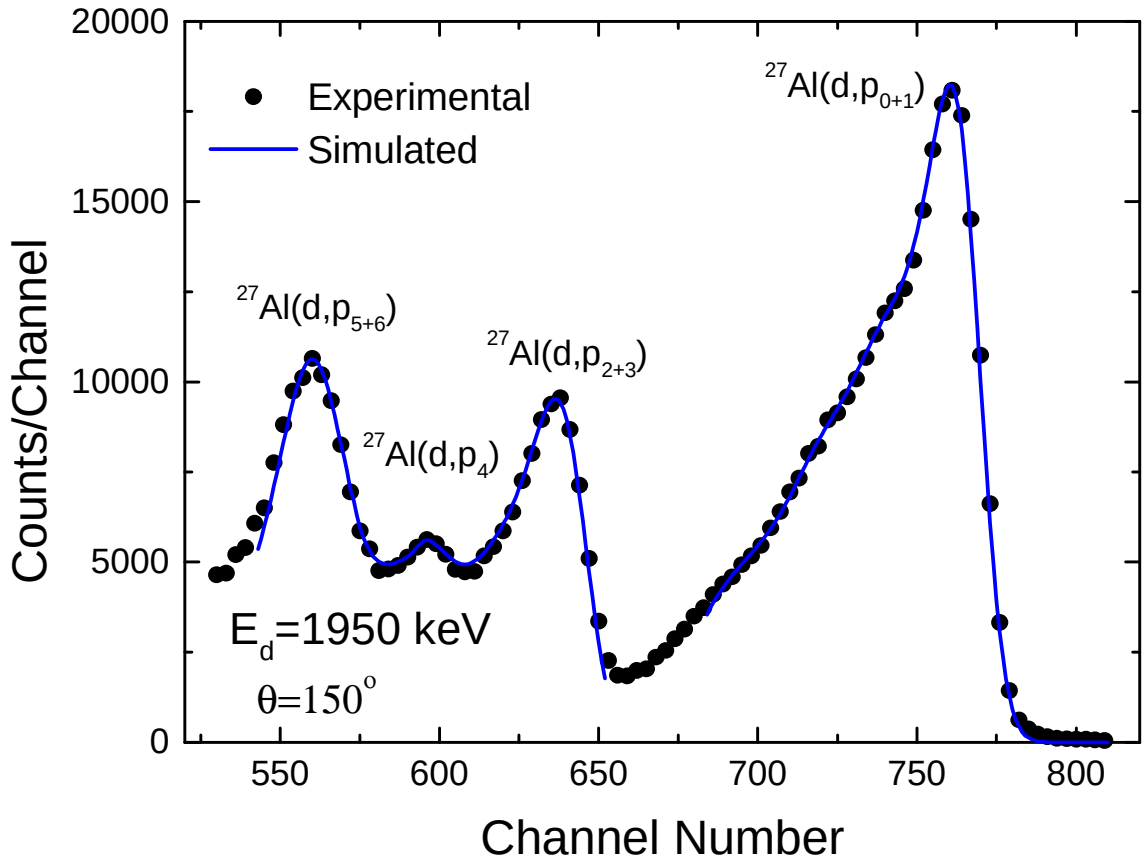
66

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



67

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

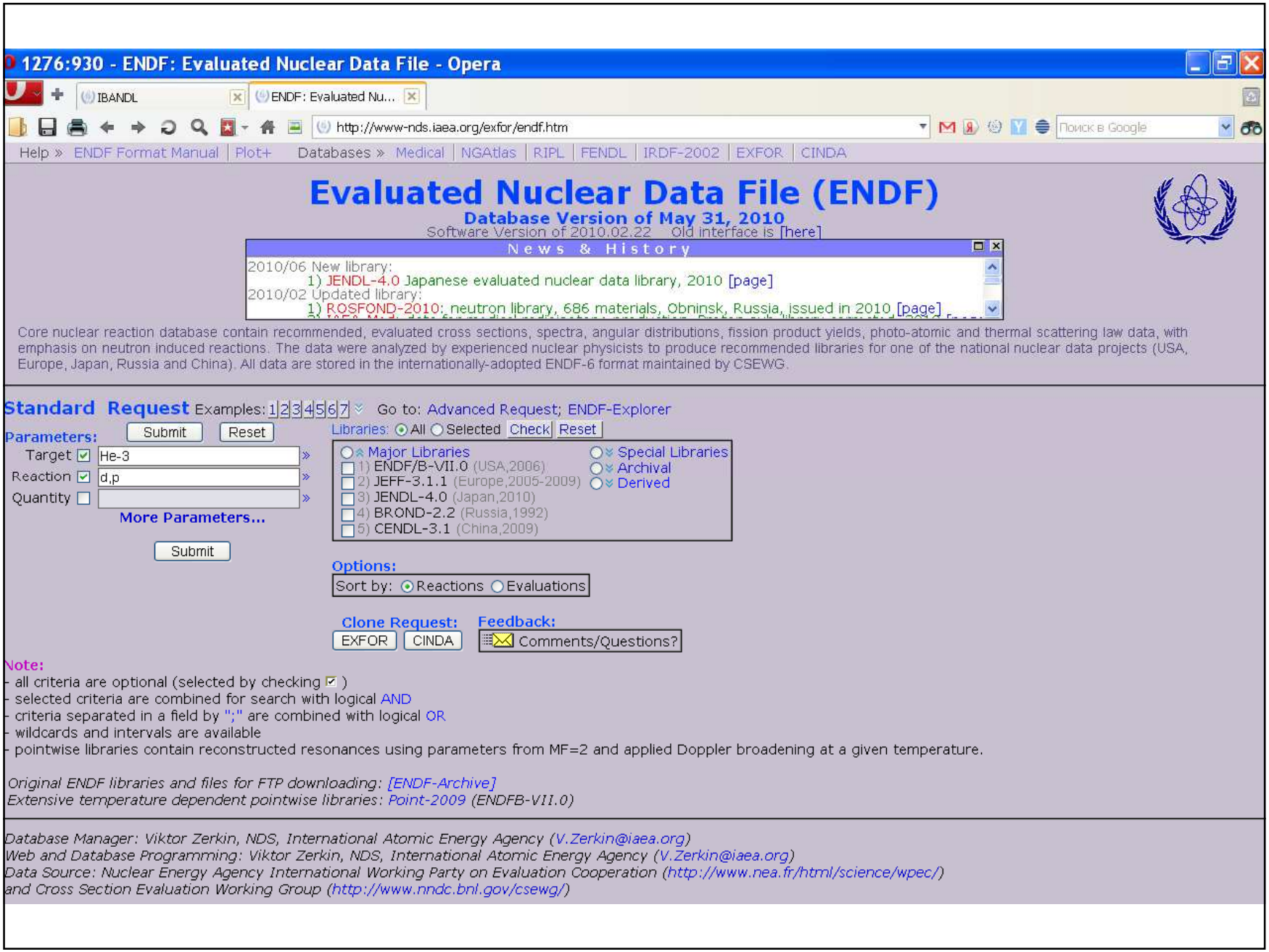


68

Most useful reactions with ^{3}He

$^{2}H(^{3}He,p)^{4}He$	Q = 18.35 MeV
$^{2}H(^{3}He,\alpha)^{1}H$	Q = 18.35 MeV
$^{9}Be(^{3}He,p_0)^{11}B$	Q = 10.32 MeV (p_0)
$^{12}C(^{3}He,p)^{14}N$	Q = 4.78 MeV (p_0)

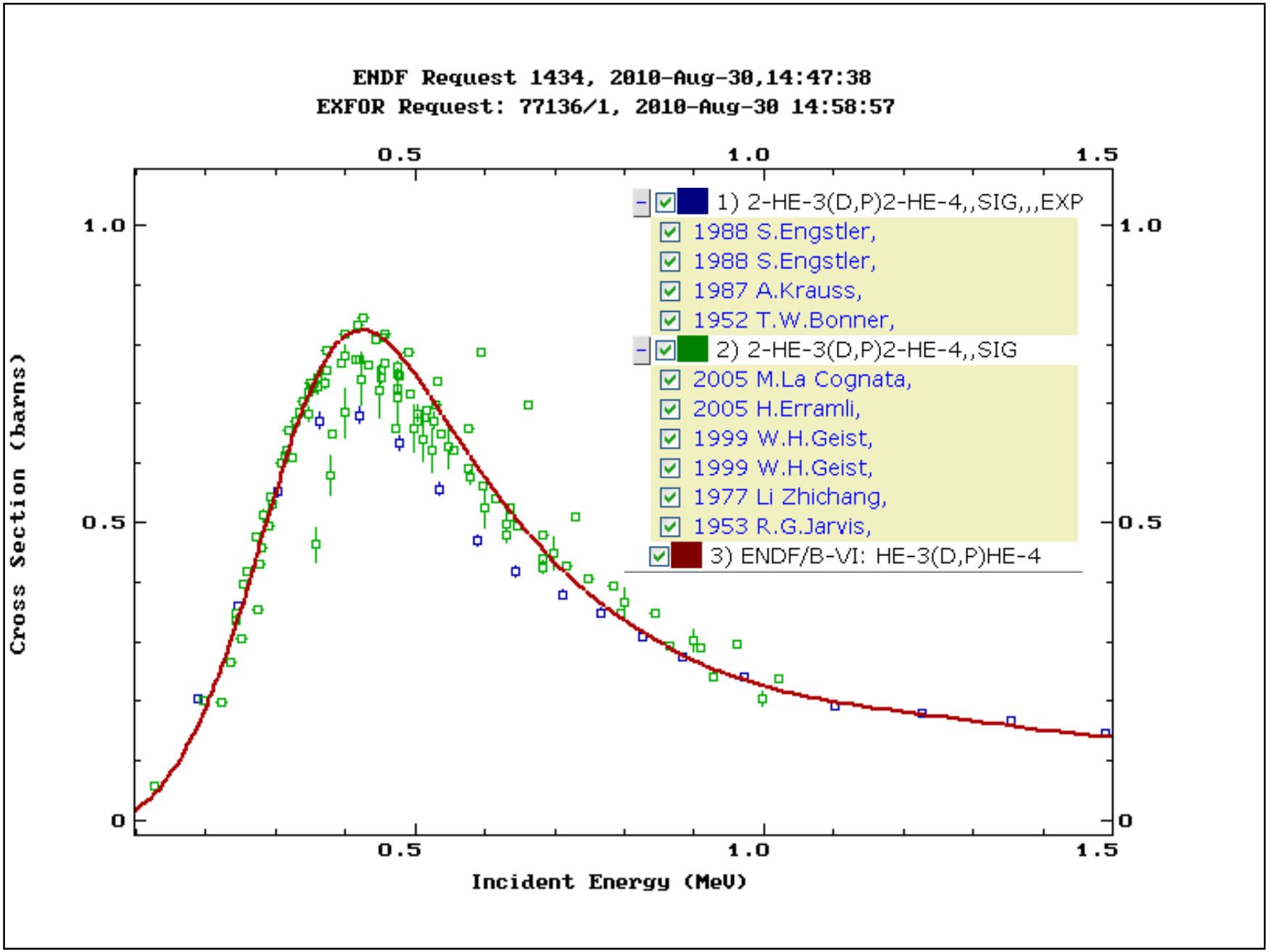
69


1276:930 - ENDF: Evaluated Nuclear Data File - Opera
IBANDL
ENDF: Evaluated Nu...
http://www-nds.iaea.org/exfor/endf.htm
Help » ENDF Format Manual | Plot+ Databases » Medical | NGAtlas | RIPL | FENDL | IRDF-2002 | EXFOR | CINDA
Evaluated Nuclear Data File (ENDF)
Database Version of May 31, 2010
Software Version of 2010.02.22 Old interface is [here]
News & History
2010/06 New library:
1) JENDL-4.0 Japanese evaluated nuclear data library, 2010 [page]
2010/02 Updated library:
1) ROSFOND-2010: neutron library, 686 materials, Obninsk, Russia, issued in 2010 [page]
Core nuclear reaction database contain recommended, evaluated cross sections, spectra, angular distributions, fission product yields, photo-atomic and thermal scattering law data, with emphasis on neutron induced reactions. The data were analyzed by experienced nuclear physicists to produce recommended libraries for one of the national nuclear data projects (USA, Europe, Japan, Russia and China). All data are stored in the internationally-adopted ENDF-6 format maintained by CSEWG.
Standard Request Examples: 1 2 3 4 5 6 7 Go to: Advanced Request; ENDF-Explorer
Parameters:
Submit
Reset
Target He-3
Reaction d,p
Quantity
More Parameters...
Submit
Libraries: All Selected Check Reset
Major Libraries
1) ENDF/B-VII.0 (USA,2006)
2) JEFF-3.1.1 (Europe,2005-2009)
3) JENDL-4.0 (Japan,2010)
4) BROND-2.2 (Russia,1992)
5) CENDL-3.1 (China,2009)
Special Libraries
Archival
Derived
Options:
Sort by: Reactions Evaluations
Clone Request:
EXFOR CINDA
Feedback:
Comments/Questions?
Note:
- all criteria are optional (selected by checking)
- selected criteria are combined for search with logical AND
- criteria separated in a field by ";" are combined with logical OR
- wildcards and intervals are available
- pointwise libraries contain reconstructed resonances using parameters from MF=2 and applied Doppler broadening at a given temperature.
Original ENDF libraries and files for FTP downloading: [ENDF-Archive]
Extensive temperature dependent pointwise libraries: Point-2009 (ENDFB-VII.0)
Database Manager: Viktor Zerkin, NDS, International Atomic Energy Agency (V.Zerkin@iaea.org)
Web and Database Programming: Viktor Zerkin, NDS, International Atomic Energy Agency (V.Zerkin@iaea.org)
Data Source: Nuclear Energy Agency International Working Party on Evaluation Cooperation (http://www.nea.fr/html/science/wpec/)
and Cross Section Evaluation Working Group (http://www.nndc.bnl.gov/csewg/)

ENDF Section Summary

Evaluation		
Library	ENDF/B-VI	
Material	MAT=225 ZA=2003 2-HE-3	
Sub-Library	NSUB=10020 (D)	
Lab	LLNL	
Author(s)	R. M. WHITE & D. A. RESLER	
Date(s)	ENDATE=19910613 RDATE= DDATE=DIST-SEP91 EDATE=EVAL-MAY91	
Sections	2	
Section		
File	MF3	Cross sections
Section	MT103 (D,P)	Production of a proton, plus a residual. Sum of MT=600-649, if they are present.
Reaction-code	HE-3(D,P)HE-4,SIG	
Lines	287	
Parameters	QM=1.83532e+7 QI=1.83532e+7 LR=0	
Product(s)	H-1, HE-4	

Tabulated Data:		
Points: 847		
Energy (eV)		
Min 1187.5	Max 3e+07	Reset
From 1187.5	To 3e+07	Get data: Submit
Calculation of Cross Section for a Single Energy:		
Energy (eV) = 1.8e+6		Calculate
Cross Section (b) = 0.11587687		

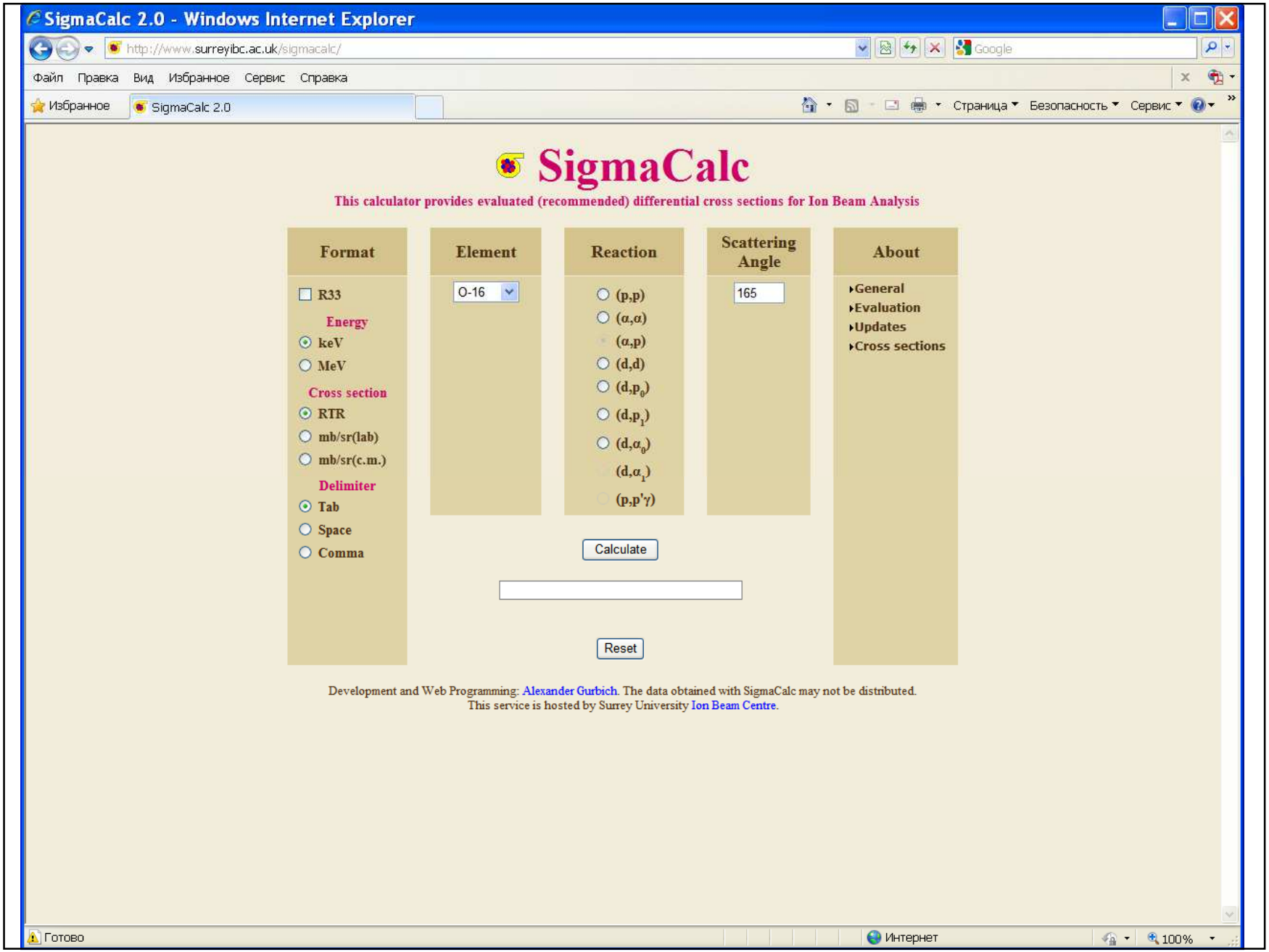

ENDF Request 1434, 2010-Aug-30,14:47:38
EXFOR Request: 77136/1, 2010-Aug-30 14:58:57
Cross Section (barns)
Incident Energy (MeV)
0
0.5
1.0
1.5
1) 2-HE-3(D,P)2-HE-4,,SIG,,,EXP
1988 S.Engstler,
1988 S.Engstler,
1987 A.Krauss,
1952 T.W.Bonner,
2) 2-HE-3(D,P)2-HE-4,,SIG
2005 M.La Cognata,
2005 H.Erramli,
1999 W.H.Geist,
1999 W.H.Geist,
1977 Li Zhichang,
1953 R.G.Jarvis,
3) ENDF/B-VI: HE-3(D,P)HE-4

Most useful reactions with protons

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

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

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


SigmaCalc 2.0 - Windows Internet Explorer
http://www.surreyibc.ac.uk/sigmacalc/
Google
Файл Правка Вид Избранное Сервис Справка
Избранное
SigmaCalc 2.0
Страница Безопасность Сервис
SigmaCalc
This calculator provides evaluated (recommended) differential cross sections for Ion Beam Analysis
Format
R33
Energy
keV
MeV
Cross section
RTR
mb/sr(lab)
mb/sr(c.m.)
Delimiter
Tab
Space
Comma
Element
O-16
Reaction
(p,p)
(α,α)
(α,p)
(d,d)
(d,p0)
(d,p1)
(d,α0)
(d,α1)
(p,p'γ)
Scattering Angle
165
About
General
Evaluation
Updates
Cross sections
Calculate
Reset
Development and Web Programming: Alexander Gurbich. The data obtained with SigmaCalc may not be distributed.
This service is hosted by Surrey University Ion Beam Centre.
Готово
Интернет
100%

SigmaCalc 2.0 => Results - Windows Internet Explorer

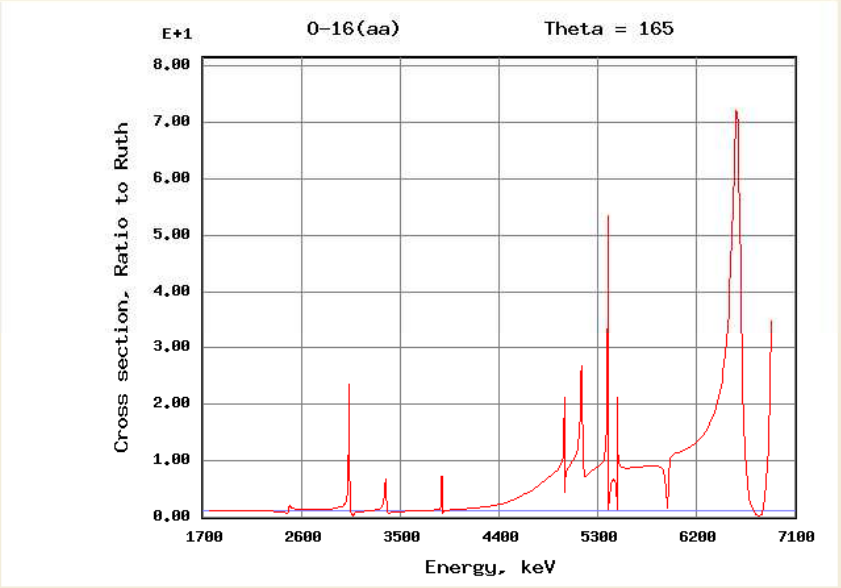
http://www.ionbeamcentre.co.uk/cgi-bin/sc/select_run.pl

Файл Правка Вид Избранное Сервис Справка

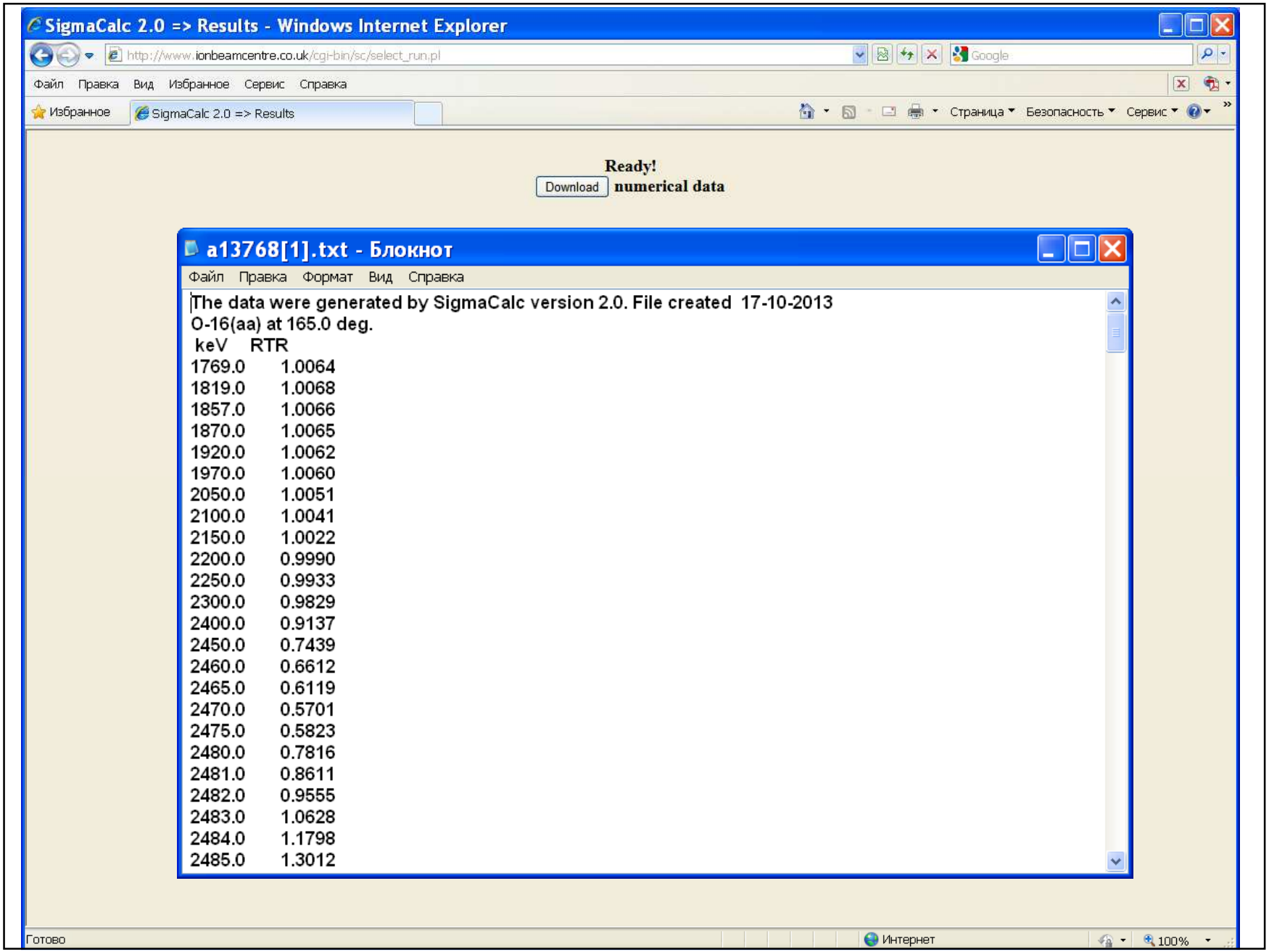
Избранное | SigmaCalc 2.0 => Results | Страница | Безопасность | Сервис

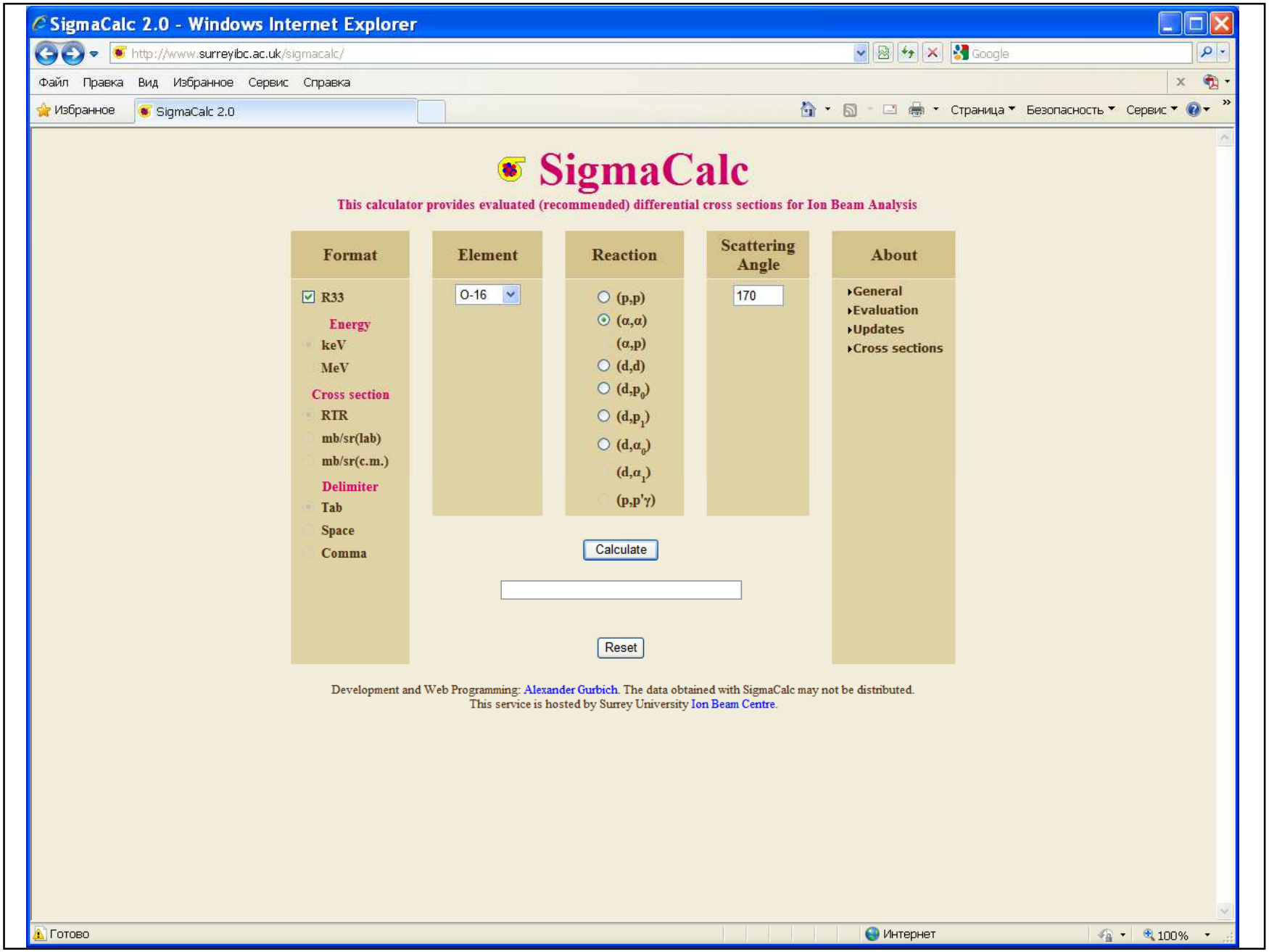
Ready!

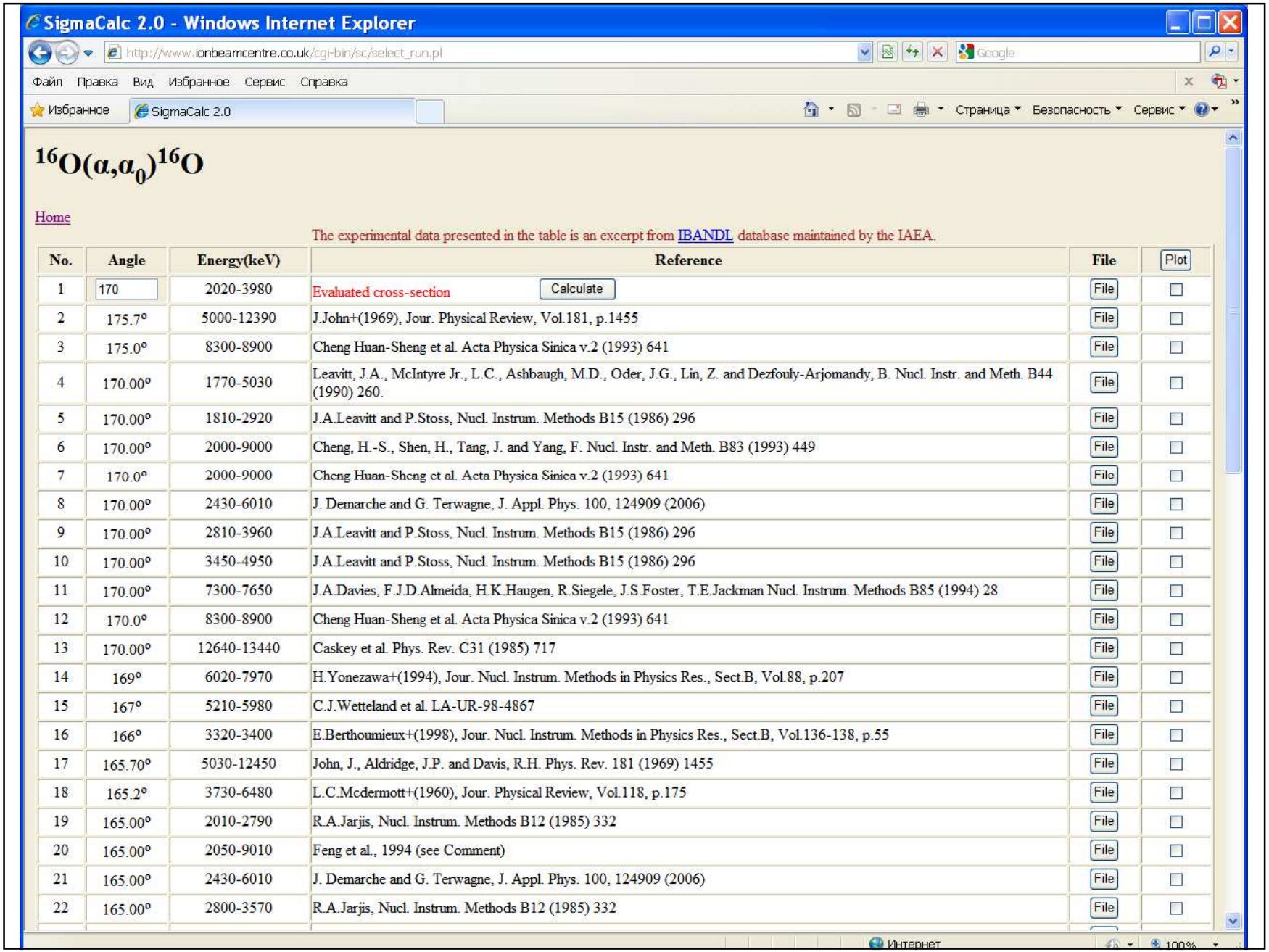
Download **numerical data**



Готово | Интернет | 100%


SigmaCalc 2.0 => Results - Windows Internet Explorer
http://www.ionbeamcentre.co.uk/cgi-bin/sc/select_run.pl
Google
Файл Правка Вид Избранное Сервис Справка
Избранное
SigmaCalc 2.0 => Results
Страница Безопасность Сервис
Ready!
Download
numerical data
a13768[1].txt - Блокнот
Файл Правка Формат Вид Справка
The data were generated by SigmaCalc version 2.0. File created 17-10-2013
O-16(aa) at 165.0 deg.
keV RTR
1769.0 1.0064
1819.0 1.0068
1857.0 1.0066
1870.0 1.0065
1920.0 1.0062
1970.0 1.0060
2050.0 1.0051
2100.0 1.0041
2150.0 1.0022
2200.0 0.9990
2250.0 0.9933
2300.0 0.9829
2400.0 0.9137
2450.0 0.7439
2460.0 0.6612
2465.0 0.6119
2470.0 0.5701
2475.0 0.5823
2480.0 0.7816
2481.0 0.8611
2482.0 0.9555
2483.0 1.0628
2484.0 1.1798
2485.0 1.3012
Готово
Интернет
100%


SigmaCalc 2.0 - Windows Internet Explorer
http://www.surreyibc.ac.uk/sigmacalc/
Google
Файл Правка Вид Избранное Сервис Справка
Избранное
SigmaCalc 2.0
Страница Безопасность Сервис
SigmaCalc
This calculator provides evaluated (recommended) differential cross sections for Ion Beam Analysis
Format
R33
Energy
keV
MeV
Cross section
RTR
mb/sr(lab)
mb/sr(c.m.)
Delimiter
Tab
Space
Comma
Element
O-16
Reaction
(p,p)
(α,α)
(α,p)
(d,d)
(d,p0)
(d,p1)
(d,α0)
(d,α1)
(p,p'γ)
Scattering Angle
170
About
General
Evaluation
Updates
Cross sections
Calculate
Reset
Development and Web Programming: Alexander Gurbich. The data obtained with SigmaCalc may not be distributed.
This service is hosted by Surrey University Ion Beam Centre.
Готово
Интернет
100%



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

Home

The experimental data presented in the table is an excerpt from IBANDL database maintained by the IAEA.

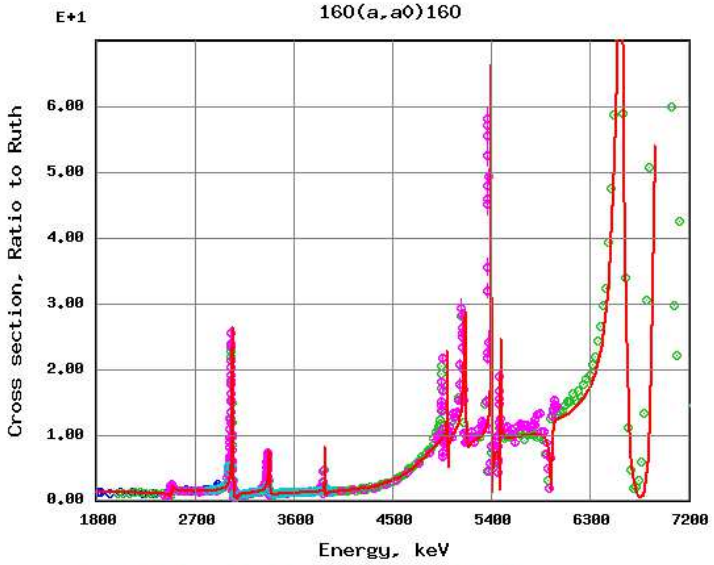
No.	Angle	Energy(keV)	Reference	File	Plot
1	170	2020-3980	Evaluated cross-section Calculate	File	☐
2	175.7°	5000-12390	J.John+(1969), Jour. Physical Review, Vol.181, p.1455	File	☐
3	175.0°	8300-8900	Cheng Huan-Sheng et al. Acta Physica Sinica v.2 (1993) 641	File	☐
4	170.00°	1770-5030	Leavitt, J.A., McIntyre Jr., L.C., Ashbaugh, M.D., Oder, J.G., Lin, Z. and Dezfouly-Arjomandy, B. Nucl. Instr. and Meth. B44 (1990) 260.	File	☐
5	170.00°	1810-2920	J.A.Leavitt and P.Stoss, Nucl. Instrum. Methods B15 (1986) 296	File	☐
6	170.00°	2000-9000	Cheng, H.-S., Shen, H., Tang, J. and Yang, F. Nucl. Instr. and Meth. B83 (1993) 449	File	☐
7	170.0°	2000-9000	Cheng Huan-Sheng et al. Acta Physica Sinica v.2 (1993) 641	File	☐
8	170.00°	2430-6010	J. Demarche and G. Terwagne, J. Appl. Phys. 100, 124909 (2006)	File	☐
9	170.00°	2810-3960	J.A.Leavitt and P.Stoss, Nucl. Instrum. Methods B15 (1986) 296	File	☐
10	170.00°	3450-4950	J.A.Leavitt and P.Stoss, Nucl. Instrum. Methods B15 (1986) 296	File	☐
11	170.00°	7300-7650	J.A.Davies, F.J.D.Almeida, H.K.Haugen, R.Siegele, J.S.Foster, T.E.Jackman Nucl. Instrum. Methods B85 (1994) 28	File	☐
12	170.0°	8300-8900	Cheng Huan-Sheng et al. Acta Physica Sinica v.2 (1993) 641	File	☐
13	170.00°	12640-13440	Caskey et al. Phys. Rev. C31 (1985) 717	File	☐
14	169°	6020-7970	H.Yonezawa+(1994), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.88, p.207	File	☐
15	167°	5210-5980	C.J.Wetteland et al. LA-UR-98-4867	File	☐
16	166°	3320-3400	E.Berthoumieux+(1998), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.136-138, p.55	File	☐
17	165.70°	5030-12450	John, J., Aldridge, J.P. and Davis, R.H. Phys. Rev. 181 (1969) 1455	File	☐
18	165.2°	3730-6480	L.C.Mcdermott+(1960), Jour. Physical Review, Vol.118, p.175	File	☐
19	165.00°	2010-2790	R.A.Jarjis, Nucl. Instrum. Methods B12 (1985) 332	File	☐
20	165.00°	2050-9010	Feng et al., 1994 (see Comment)	File	☐
21	165.00°	2430-6010	J. Demarche and G. Terwagne, J. Appl. Phys. 100, 124909 (2006)	File	☐
22	165.00°	2800-3570	R.A.Jarjis, Nucl. Instrum. Methods B12 (1985) 332	File	☐

http://www.ionbeamcentre.co.uk/cgi-bin/sc/draw4.pl - Windows Internet Explorer

http://www.ionbeamcentre.co.uk/cgi-bin/sc/draw4.pl

Файл Правка Вид Избранное Сервис Справка

Избранное http://www.ionbeamcentre.co.uk/cgi-bin/sc/...



Theta=170.0 SigmaCalc 2.0. File created 17-10-2013

Theta=170.00 J.A.Leavitt and P.Stoss, Nucl. Instrum. Methods B15 (1986) 296

Theta=170.00 Cheng, H.-S., Shen, H., Tang, J. and Yang, F. Nucl. Instr. and Meth. B83 (1993) 449

Theta=170.00 J. Demarche and G. Terwagne, J. Appl. Phys. 100, 124909 (2006)

Theta=170.00 J.A.Leavitt and P.Stoss, Nucl. Instrum. Methods B15 (1986) 296

Theta=170.00 J.A.Davies, F.J.D.Almeida, H.K.Haugen, R.Siegele, J.S.Foster, T.E.Jackman Nucl. Instrum. Methods B85 (1994) 28

Original

Home

Интернет 100%

APPENDIX
12

PARTICLE-GAMMA DATA

Handbook of Modern Ion Beam Materials Analysis

Compiled by

J-P. Hirvonen

Technical Research Centre of Finland, Espoo, Finland

R. Lappalainen

University of Helsinki, Helsinki, Finland

CONTENTS

PROMPT GAMMA-RAY SPECTROSCOPY AND ITS USE IN ELEMENTAL ANALYSIS

G. DECONNINCK, G. DEMORTIER, F. BODART
Laboratoire d'analyses par réactions nucléaires (LARN),
Facultés Universitaires de Namur,
Namur, Belgium

ABSTRACT. Elemental analysis by nuclear techniques has developed considerably over the last twenty-five years. In this review we considere the analysis of the great majority of chemical elements by irradiation of the sample (solid or liquid) with charged particles, and detection, during such irradiation, of the gamma photons characteristic of each element. A succinct account of the physical phenomena peculiar to prompt photon detection, as compared with activation methods where delayed activity is measured, is followed by a brief description of the experimental apparatus needed for this type of analysis. A large section is devoted to a critical study of recent applications to the analysis of metals, semiconductors and electrical insulators. A set of tables provides the information necessary for selecting the nuclear reaction to be used for a specific analysis.

Atomic Energy Review
Supplement No.2 (1981)

81

Table 1. Prompt γ-ray energies

E_γ (MeV)	Reaction	E_γ (MeV)	Reaction	E_γ (MeV)	Reaction
	Proton induced reactions				
0·099	$^{195}Pt(p,p')^{195}Pt$	0·476	$^{60}Ni(p,\gamma)^{61}Cu$	1·273	$^{29}Si(p,p')^{29}Si$
0·100	$^{182}W(p,p')^{182}W$	0·477	$^{7}Li(p,p')^{7}Li$	1·292	$^{52}Cr(p,\gamma)^{53}Mn$
0·110	$^{19}F(p,p')^{19}F$	0·496	$^{16}O(p,\gamma)^{17}F$	1·318	$^{65}Cu(p,\gamma)^{66}Zn$
0·110	$^{18}O(p,\gamma)^{19}F$	0·555	$^{104}Pd(p,p')^{104}Pd$	1·342	$^{25}Mg(p,\gamma)^{26}Al$
0·111	$^{184}W(p,p')^{184}W$	0·560	$^{76}Se(p,p')^{76}Se$	1·368	$^{23}Na(p,\gamma)^{24}Mg$
0·122	$^{186}W(p,p')^{186}W$	0·568	$^{37}Cl(p,\alpha)^{34}S$	1·368	$^{24}Mg(p,p')^{24}Mg$
0·123	$^{56}Fe(p,p')^{56}Fe$	0·574	$^{68}Zn(p,\gamma)^{69}Ga$	1·368	$^{27}Al(p,\alpha)^{24}Mg$
0·126	$^{54}Cr(p,\gamma)^{55}Mn$	0·586	$^{25}Mg(p,p')^{25}Mg$	1·379	$^{56}Fe(p,p')^{56}Fe$
0·126	$^{55}Mn(p,p')^{55}Mn$	0·595	$^{55}Mn(p,p')^{55}Mn$	1·384	$^{28}Si(p,\gamma)^{29}P$
0·128	$^{56}Fe(p,\gamma)^{57}Co$	0·602	$^{37}Cl(p,\alpha)^{34}S$	1·39	$^{14}N(p,\gamma)^{15}O$
0·136	$^{57}Fe(p,p')^{57}Fe$	0·614	$^{78}Se(p,p')^{78}Se$	1·437	$^{9}Be(p,\gamma)^{10}B$
0·136	$^{181}Ta(p,p')^{181}Ta$	0·667	$^{80}Se(p,p')^{80}Se$	1·46	$^{29}Si(p,\gamma)^{30}P$
0·168	$^{66}Zn(p,\gamma)^{67}Ga$	0·697	$^{37}Cl(p,\alpha)^{34}S$	1·47	$^{14}N(p,\gamma)^{15}O$
0·170	$^{26}Mg(p,\gamma)^{27}Al$	0·709	$^{29}Si(p,\gamma)^{30}P$	1·54	$^{24}Mg(p,\gamma)^{25}Al$
0·170	$^{27}Al(p,p')^{27}Al$	0·717	$^{9}Be(p,\gamma)^{10}B$	1·634	$^{23}Na(p,\alpha)^{20}Ne$
0·176	$^{66}Zn(p,\gamma)^{67}Ga$	0·717	$^{10}B(p,p')^{10}B$	1·643	$^{28}Si(p,\gamma)^{29}P$
0·185	$^{67}Zn(p,\gamma)^{68}Ga$	0·75	$^{14}N(p,\gamma)^{15}O$	1·72	$^{28}Si(p,\gamma)^{29}P$
0·192	$^{197}Au(p,p')^{197}Au$	0·783	$^{50}Cr(p,p')^{50}Cr$	1·760	$^{56}Fe(p,p')^{56}Fe$
0·197	$^{19}F(p,p'\gamma)^{19}F$	0·797	$^{35}Cl(p,\gamma)^{36}Ar$	1·763	$^{34}S(p,\gamma)^{35}Cl$
0·197	$^{18}O(p,\gamma)^{19}F$	0·806	$^{32}S(p,\gamma)^{33}Cl$	1·763	$^{35}Cl(p,p')^{35}Cl$
0·200	$^{77}Se(p,p')^{77}Se$	0·809	$^{63}Cu(p,\gamma)^{64}Zn$	1·778	$^{27}Al(p,\gamma)^{28}Si$
0·202	$^{127}I(p,p')^{127}I$	0·830	$^{25}Mg(p,\gamma)^{26}Al$	1·778	$^{28}Si(p,p')^{28}Si$
0·211	$^{195}Pt(p,p')^{195}Pt$	0·834	$^{65}Cu(p,\gamma)^{66}Zn$	1·778	$^{31}P(p,\alpha)^{28}Si$
0·239	$^{77}Se(p,p')^{77}Se$	0·840	$^{56}Fe(p,p')^{56}Fe$	1·80	$^{24}Mg(p,\gamma)^{25}Al$
0·239	$^{195}Pt(p,p')^{195}Pt$	0·842	$^{33}S(p,p')^{33}S$	1·809	$^{26}Mg(p,p')^{26}Mg$
0·279	$^{197}Au(p,p')^{197}Au$	0·843	$^{26}Mg(p,\gamma)^{27}Al$	1·84	$^{25}Mg(p,\gamma)^{26}Al$
0·280	$^{105}Pd(p,p')^{105}Pd$	0·843	$^{27}Al(p,p')^{27}Al$	1·922	$^{56}Fe(p,p')^{56}Fe$
0·296	$^{103}Rh(p,p')^{103}Rh$	0·845	$^{24}Mg(p,\gamma)^{25}Al$	1·95	$^{28}Si(p,\gamma)^{29}P$
0·309	$^{109}Ag(p,p')^{109}Ag$	0·847	$^{55}Mn(p,\gamma)^{56}Fe$	1·972	$^{35}Cl(p,\gamma)^{36}Ar$
0·320	$^{68}Zn(p,\gamma)^{69}Ga$	0·871	$^{17}O(p,p')^{17}O$	1·982	$^{18}O(p,p')^{18}O$
0·320	$^{51}V(p,p')^{51}V$	0·874	$^{68}Zn(p,\gamma)^{69}Ga$	2·02	$^{33}S(p,\gamma)^{34}Cl$
0·325	$^{107}Ag(p,p')^{107}Ag$	0·913	$^{52}Cr(p,\gamma)^{53}Mn$	2·04	$^{24}Mg(p,\gamma)^{25}Al$
0·328	$^{194}Pt(p,p')^{194}Pt$	0·933	$^{56}Mn(p,n)^{56}Fe$	2·05	$^{32}S(p,\gamma)^{33}Cl$
0·354	$^{57}Fe(p,p')^{57}Fe$	0·945	$^{24}Mg(p,\gamma)^{25}Al$	2·127	$^{37}Cl(p,\alpha)^{34}S$
0·356	$^{196}Pt(p,p')^{196}Pt$	0·970	$^{60}Ni(p,\gamma)^{61}Cu$	2·144	$^{11}B(p,\gamma)^{12}C$
0·358	$^{103}Rh(p,p')^{103}Rh$	0·976	$^{25}Mg(p,p')^{25}Mg$	2·15	$^{9}Be(p,\gamma)^{10}B$
0·375	$^{110}Pd(p,p')^{110}Pd$	0·992	$^{63}Cu(p,\gamma)^{64}Zn$	2·168	$^{37}Cl(p,\gamma)^{38}Ar$
0·379	$^{52}Cr(p,\gamma)^{53}Mn$	0·998	$^{35}Cl(p,\gamma)^{36}Ar$	2·209	$^{35}Cl(p,\gamma)^{36}Ar$
0·390	$^{25}Mg(p,p')^{25}Mg$	1·013	$^{26}Mg(p,\gamma)^{27}Al$	2·237	$^{35}Cl(p,\alpha)^{32}S$
0·406	$^{198}Pt(p,p')^{198}Pt$	1·013	$^{27}Al(p,p')^{27}Al$	2·237	$^{31}P(p,\gamma)^{32}S$
0·413	$^{55}Mn(p,n)^{55}Fe$	1·023	$^{9}Be(p,\gamma)^{10}B$	2·237	$^{32}S(p,p')^{32}S$
0·414	$^{9}Be(p,\gamma)^{10}B$	1·035	$^{55}Mn(p,\gamma)^{56}Fe$	2·24	$^{24}Mg(p,\gamma)^{25}Al$
0·414	$^{109}Ag(p,p')^{109}Ag$	1·039	$^{65}Cu(p,\gamma)^{66}Zn$	2·28	$^{29}Si(p,\gamma)^{30}P$
0·418	$^{25}Mg(p,\gamma)^{26}Al$	1·078	$^{68}Zn(p,\gamma)^{69}Ga$	2·357	$^{12}C(p,\gamma)^{13}N$
0·425	$^{107}Ag(p,p')^{107}Ag$	1·14	$^{12}C(p,\gamma)^{13}N$	2·366	$^{12}C(p,\gamma)^{13}N$
0·429	$^{10}B(p,\alpha)^{7}Li$	1·220	$^{35}Cl(p,p')^{35}Cl$	2·38	$^{14}N(p,\gamma)^{15}O$
0·434	$^{108}Pd(p,p')^{108}Pd$	1·266	$^{31}P(p,p')^{31}P$	2·39	$^{13}C(p,\gamma)^{14}N$
0·439	$^{23}Na(p,p')^{23}Na$	1·266	$^{34}S(p,\alpha)^{31}P$	2·40	$^{9}Be(p,\gamma)^{10}B$
0·440	$^{77}Se(p,p')^{77}Se$	1·266	$^{56}Fe(p,p')^{56}Fe$	2·440	$^{31}P(p,\gamma)^{32}S$
0·452	$^{24}Mg(p,\gamma)^{25}Al$	1·266	$^{30}Si(p,\gamma)^{31}P$	2·59	$^{18}O(p,\gamma)^{19}F$

J.R. Bird, M.D. Scott, L.H. Russel, M.J. Kenny, Analysis using Ion Induced γ Rays. Aust. J. Phys., 31 (1978) 209.

82

Case studies

- $^{23}Na(p,p_1\gamma)^{23}Na$ (E_γ = 440 keV) for proton inelastic scattering – R-matrix + DWBA
- $^{52}Cr(p,\gamma)^{53}Mn$ (E_γ = 378 keV) for proton radiative capture – Houser-Feshbach statistical model

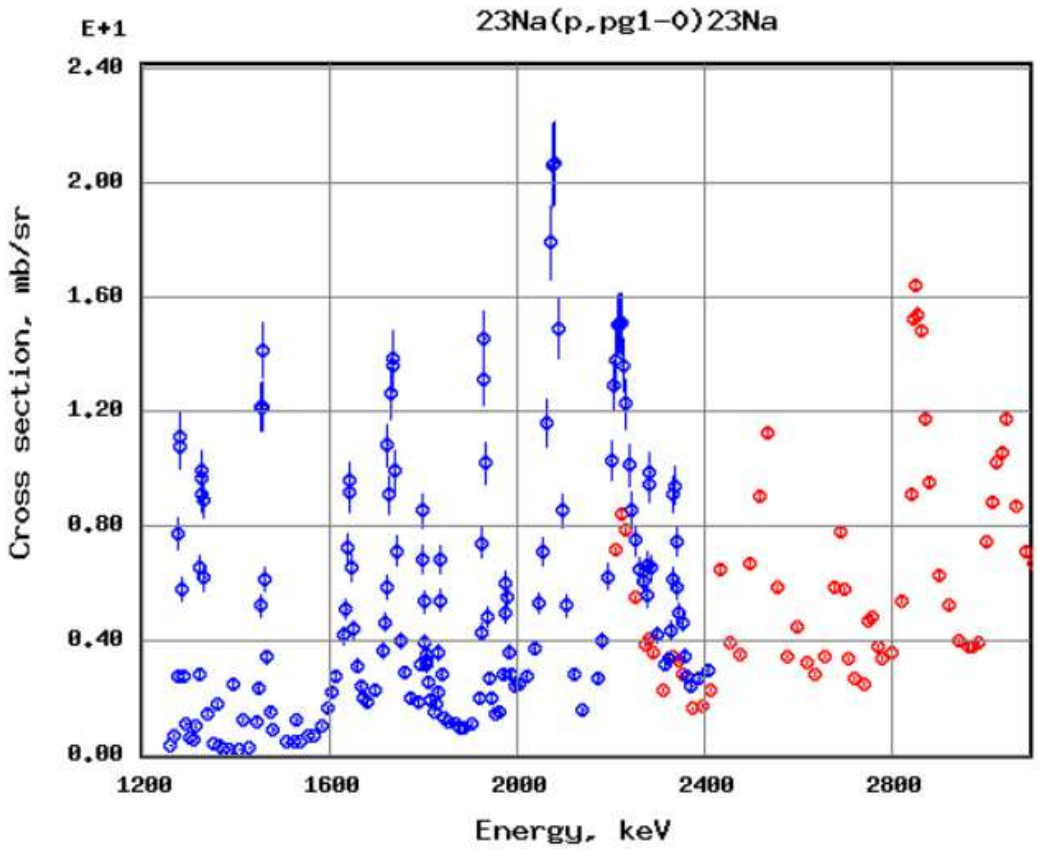
83

Experimental data available in IBANDL for the 440 keV γ-ray from $^{23}Na(p,p_1\gamma)^{23}Na$

$^{23}Na+p$

No.	Reaction	Angle	Energy(keV)	Reference	File	Plot
1	$^{23}Na(p,\gamma_{2+3})^{24}Mg$	90.0°	4000-12720	R.C. Bearse Nuclear Physics A v. 116 (1968) 682	File	☐
2	$^{23}Na(p,\gamma_{0})^{24}Mg$	90.0°	4000-12700	R.C. Bearse Nuclear Physics A v. 116 (1968) 682	File	☐
3	$^{23}Na(p,\gamma_{1})^{24}Mg$	90.0°	4010-12720	R.C. Bearse Nuclear Physics A v. 116 (1968) 682	File	☐
4	$^{23}Na(p,p\gamma_{1-0})^{23}Na$ E_γ=440 keV	135.00°	2210-5200	A. Caciolli et al., Nucl. Instr. and Meth. B 266 (2008) 1392	File	☐
5	$^{23}Na(p,p\gamma_{1-0})^{23}Na$ E_γ=440 keV	130°	1260-2410	R.Mateus et al. Nucl. Instr. & Meth. B219-220 (2004) 307	File	☐
6	$^{23}Na(p,p\gamma_{1-0})^{23}Na$ E_γ=440 keV	90°	850-2700	F.Bodart, G.Deconninck, G.Demortier, J. Radioanal. Chem. 35 (1977) 95	File	☐
7	$^{23}Na(p,\gamma)^{24}Mg$ E_γ=1368 keV	90°	490-1000	F.Bodart, G.Deconninck, G.Demortier, J. Radioanal. Chem. 35 (1977) 95	File	☐
8	$^{23}Na(p,\alpha\gamma)^{20}Ne$ E_γ=1634 keV	90°	1010-2700	F.Bodart, G.Deconninck, G.Demortier, J. Radioanal. Chem. 35 (1977) 95	File	☐

Experimental data available in IBANDL for the 440 keV γ-ray from $^{23}Na(p,p_1\gamma)^{23}Na$

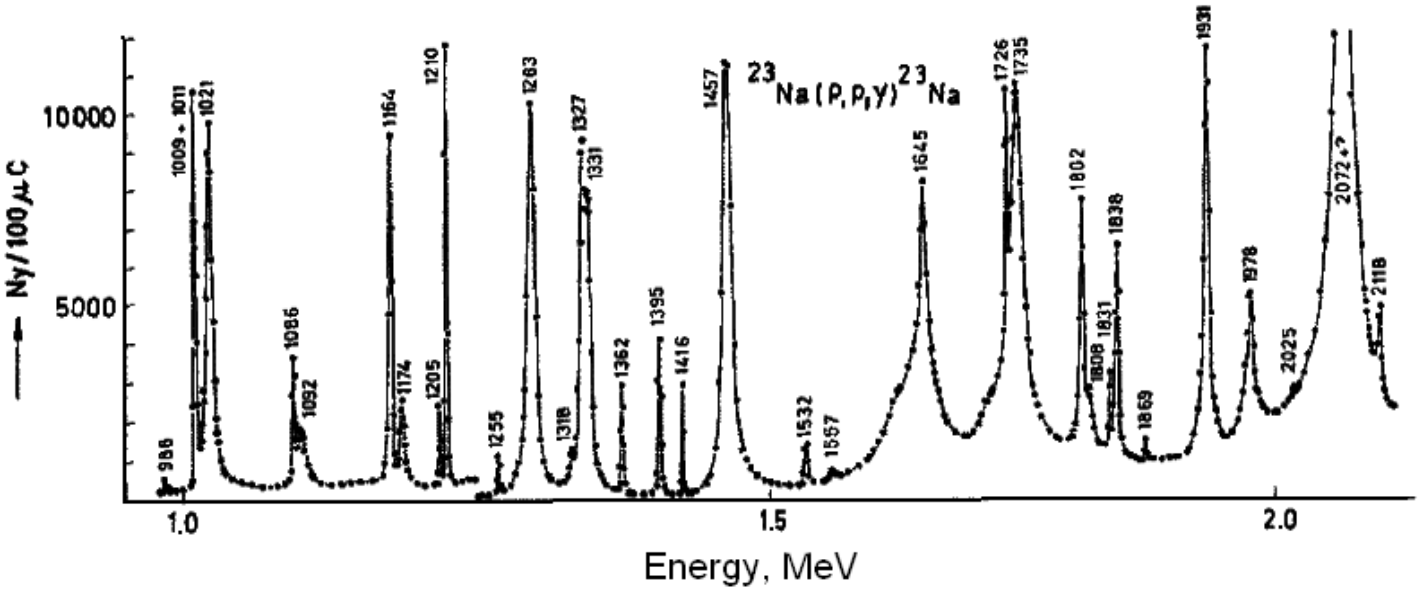


Theta=135.00 A. Caciolli et al., Nucl. Instr. and Meth. B 266 (2008) 1392

Theta=130 R.Mateus et al. Nucl. Instr. & Meth. B219-220 (2004) 307

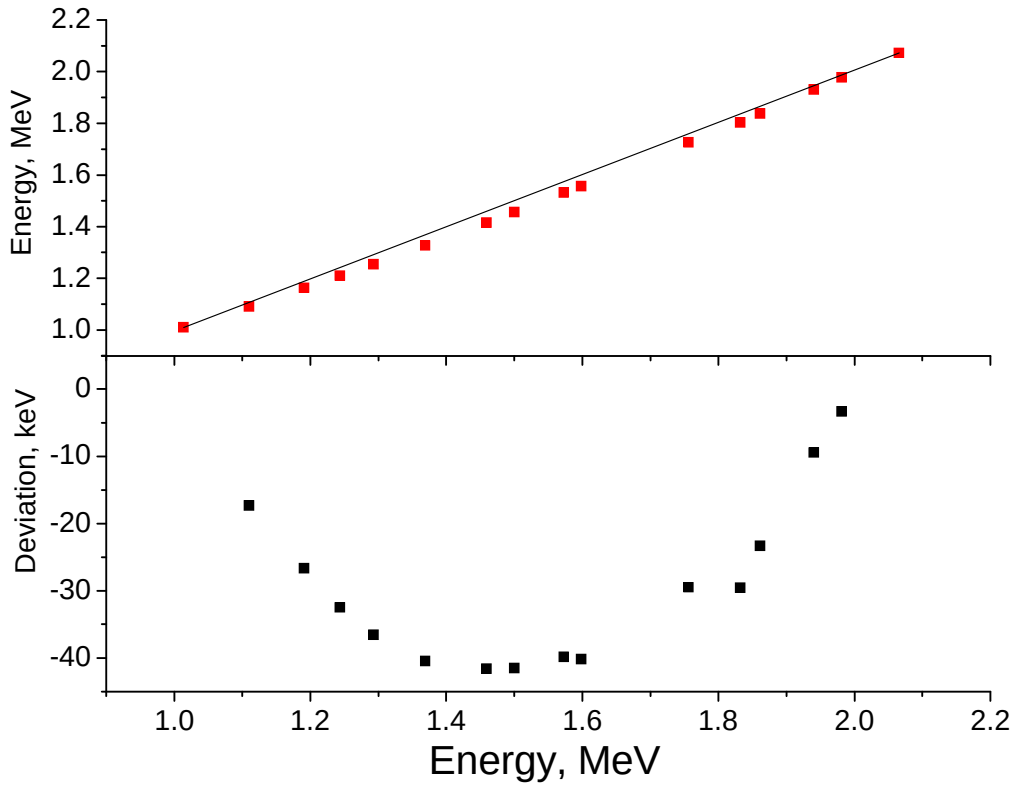
85

Experimental data by Meyer et al.



86

Non-linearity of the energy axis in the Meyer's et al. data



87

ADOPTED LEVELS, GAMMAS for ^{23}Na

Author: R.B. FIRESTONE

Citation: Nuclear Data Sheets 108, 1 (2007)

E_{level} (keV)	Jπ	E_γ (keV)	I_γ	γ mult.	Final level	
0	3/2+					
439.990 *9*	5/2+	439.986 *10*	100	M1+E2	0	3/2+
2076.011 *22*	7/2+	1635.96 *3* 2076.7 *5*	100.00 *14* 8.93 *14*	M1+E2 E2(+M3)	439.990 0	5/2+ 3/2+
2390.732 *13*	1/2+	1950.652 *21* 2390.599 *18*	52.1 *8* 100.0 *6*	E2	439.990 0	5/2+ 3/2+
2639.85 *4*	1/2-	2639.70 *5*	100		0	3/2+
2703.500 *25*	9/2+	627.48 *4* 2263.39 *3*	54.4 *9* 100.0 *9*	M1+E2 E2(+M3)	2076.011 439.990	7/2+ 5/2+
2982.060 *19*	3/2+	591.32 *4* 2541.92 *4* 2981.85 *4*	0.51 *17* 70.1 *3* 100.0 *3*	 M1+E2 M1(+E2)	2390.732 439.990 0	1/2+ 5/2+ 3/2+
3677.60 *4*	3/2-	695.53 *9* 1037.71 *9* 1286.83 *8* 3237.36 *8*	0.64 *13* 24.7 *6* 1.65 *13* 100.0 *8*	 M1+E2 E1(+M2)	2982.060 2639.85 2390.732 439.990	3/2+ 1/2- 1/2+ 5/2+

PHYSICAL REVIEW C VOLUME 36, NUMBER 3 SEPTEMBER 1987

Proton resonances in ^{24}Mg from $E_x = 12.7$ to 15.7 MeV

J. R. Vanhoy, E. G. Bilpuch, and C. R. Westerfeldt
Duke University, Durham, North Carolina 27706
and Triangle Universities Nuclear Laboratory, Duke Station, Durham, North Carolina 27706

G. E. Mitchell
North Carolina State University, Raleigh, North Carolina 27695
and Triangle Universities Nuclear Laboratory, Duke Station, Durham, North Carolina 27706
(Received 11 May 1987)

The ^{23}Na(p,p$_0$), (p,p$_1$), (p,α_0), and (p,α_1) differential cross sections were measured in the energy range $E_p = 1.08$–4.15 MeV with an overall resolution of 400 eV full width at half maximum. Resonance parameters were obtained for 94 levels with a multilevel, multichannel R-matrix code; parameters include resonance energy, total angular momentum, proton and alpha partial widths, and channel spin and orbital angular momentum mixing ratios. The observed proton and alpha resonance widths provide an upper limit for ^{12}C + ^{12}C reaction rates for an energy region where there are no direct measurements.

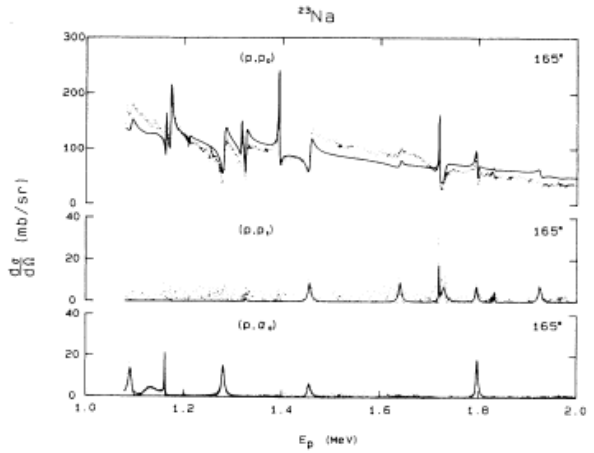


FIG. 1. ^{23}Na(p,p$_0$), (p,p$_1$), and (p,α_0) differential cross sections in the energy range $E_p = 1.08$–2.00 MeV. The solid line is the R-matrix fit to the data.

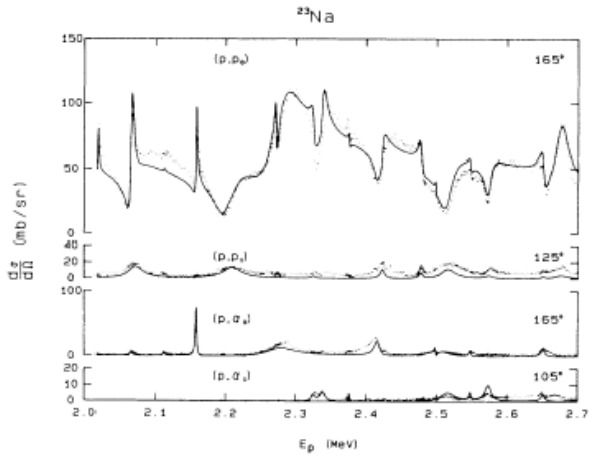
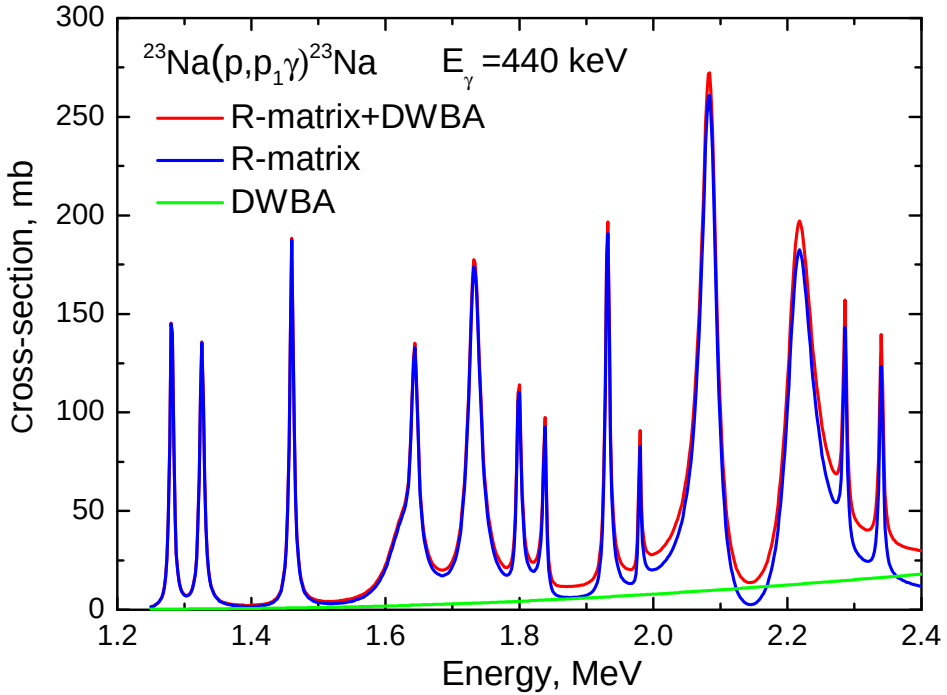


FIG. 2. ^{23}Na(p,p$_0$), (p,p$_1$), (p,α_0), and (p,α_1) differential cross sections in the energy range $E_p = 2.00$–2.70 MeV. The solid line is the R-matrix fit to the data.

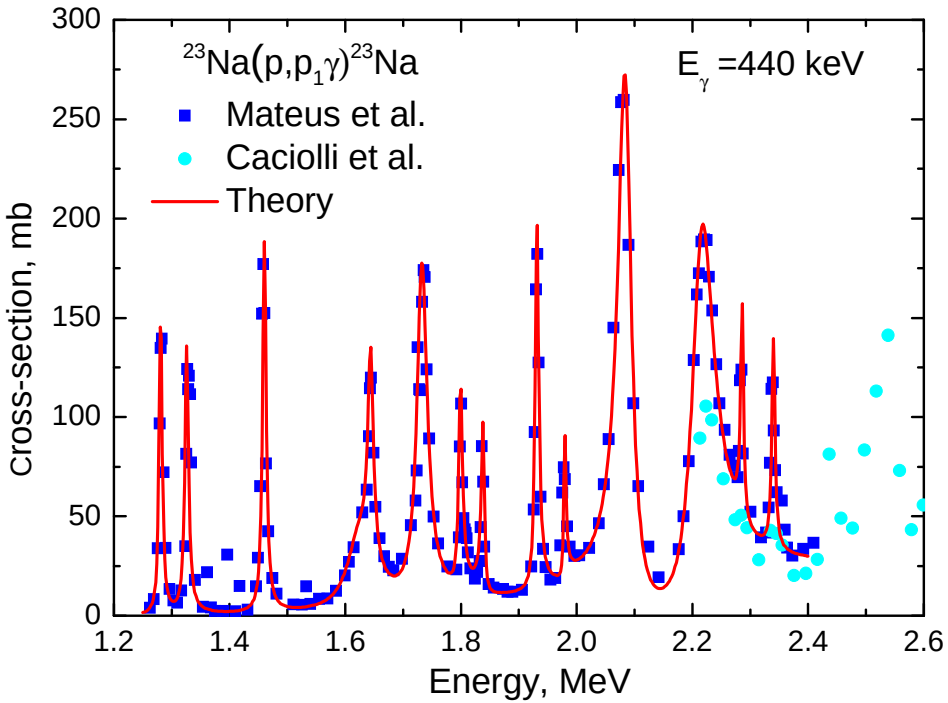
89

Contribution of the direct process



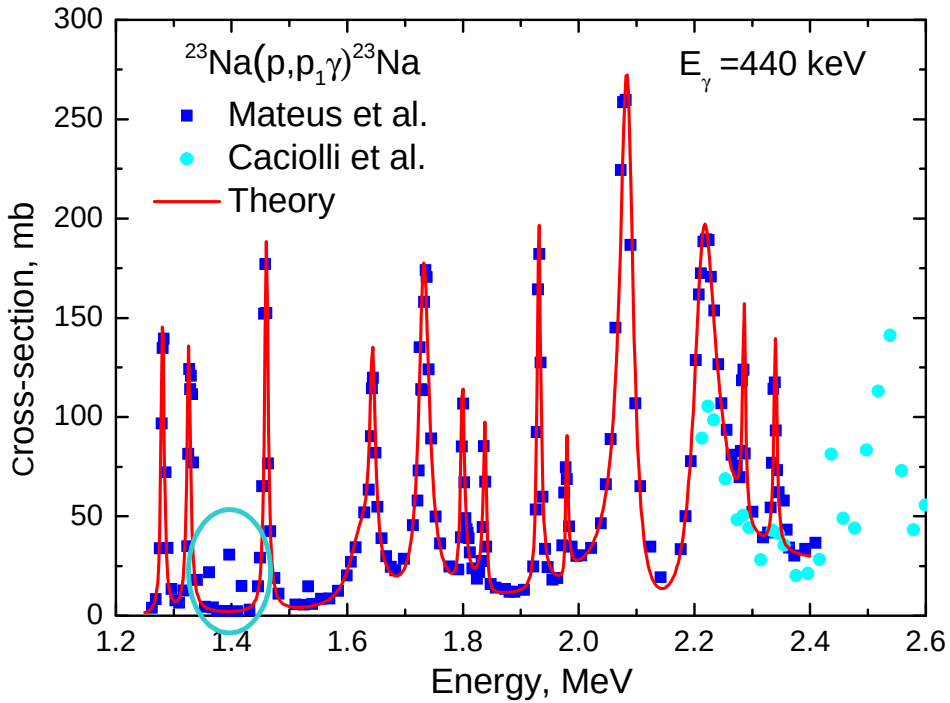
90

Comparison of theory and experiment



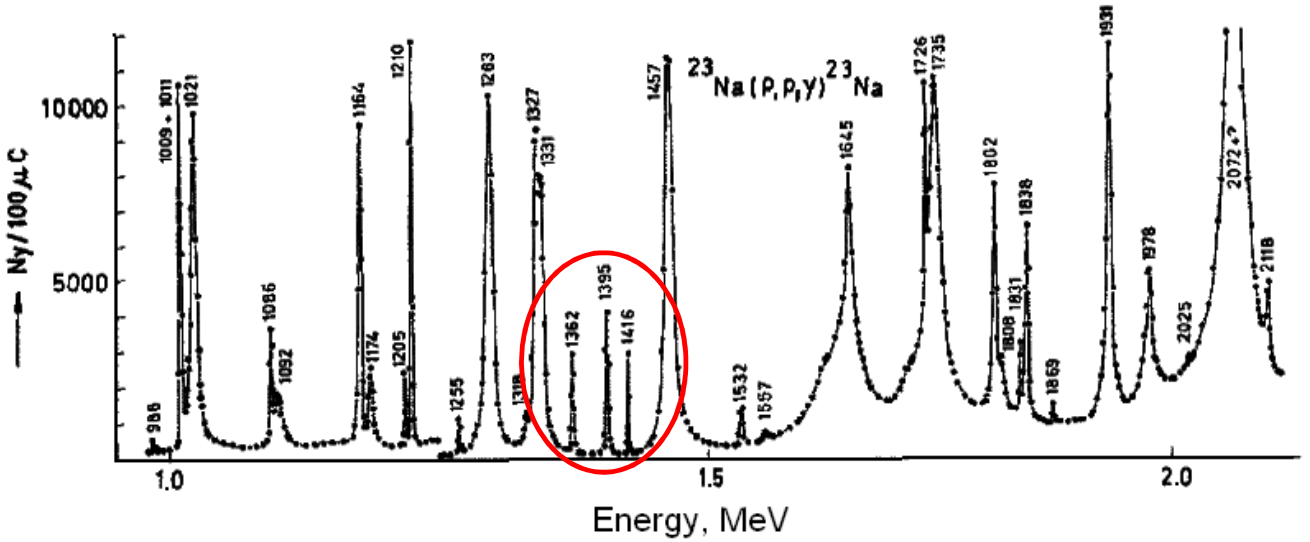
91

Comparison of theory and experiment



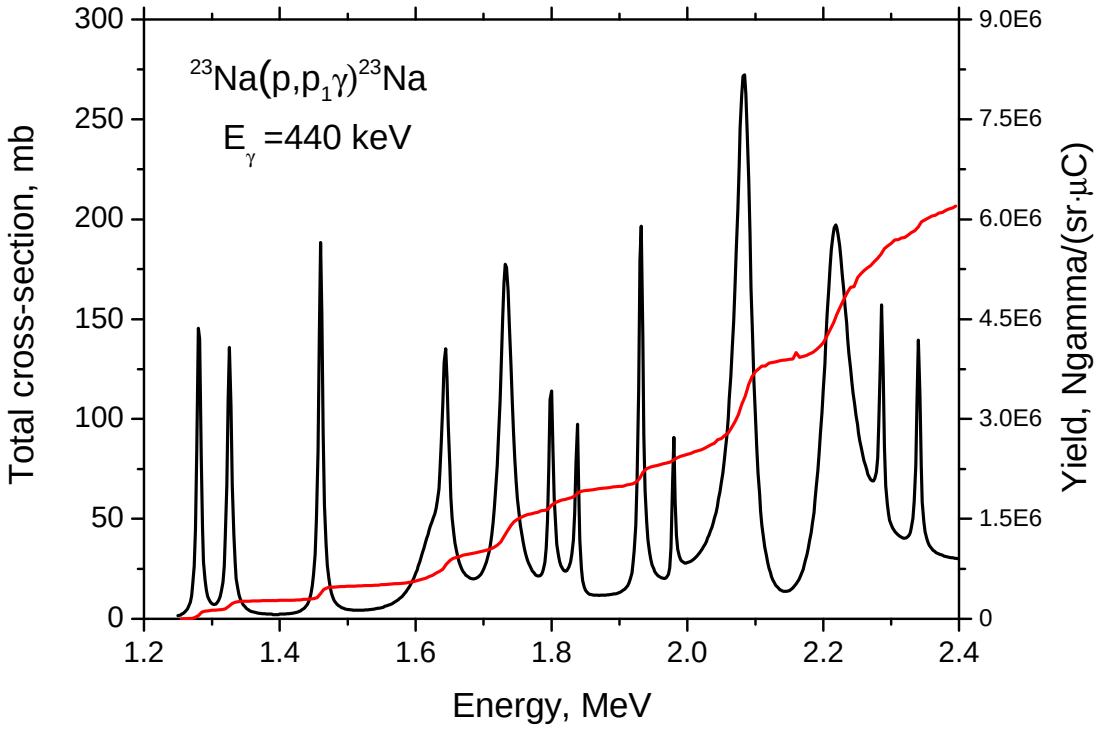
92

Experimental data by Meyer et al.



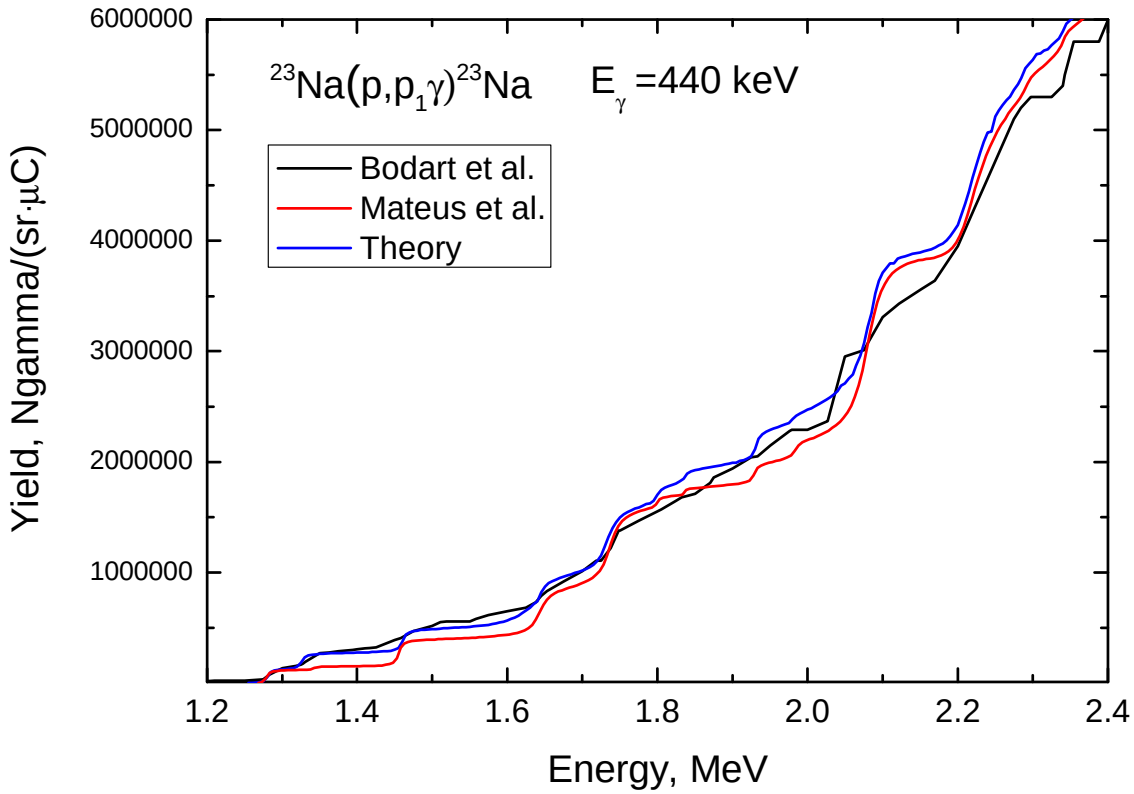
93

The evaluated cross-section and corresponding thick target yield for $^{23}Na(p,p_1\gamma)^{23}Na$



94

Thick target yield for E_γ=440 keV gammas from $^{23}Na(p,p_1\gamma)^{23}Na$ reaction



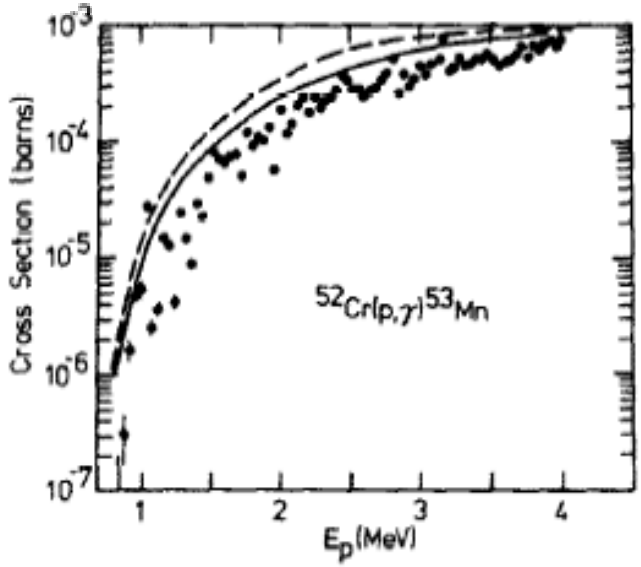
95

Nuclear Physics **A363** (1981) 233–241

CROSS-SECTION MEASUREMENTS AND THERMONUCLEAR REACTION RATES FOR $^{52}Cr(p, \gamma)^{53}Mn$ AND $^{54}Fe(p, \gamma)^{55}Co$ †

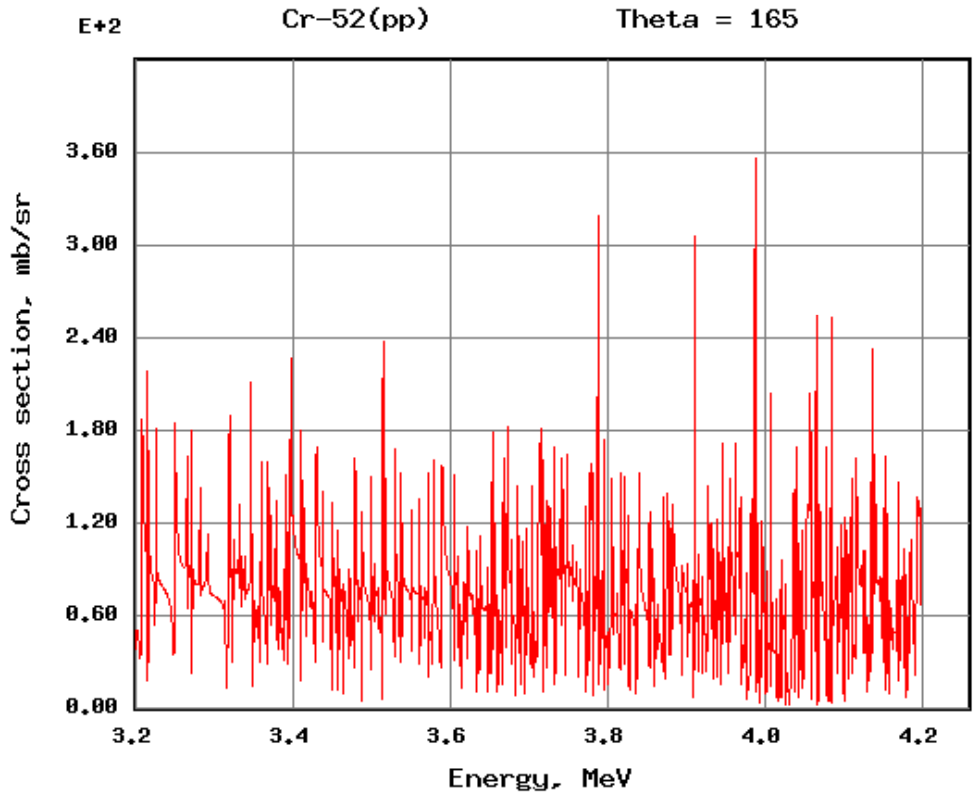
S. R. KENNETT, L. W. MITCHELL, M. R. ANDERSON and D. G. SARGOOD

School of Physics, University of Melbourne, Parkville, Victoria 3052, Australia



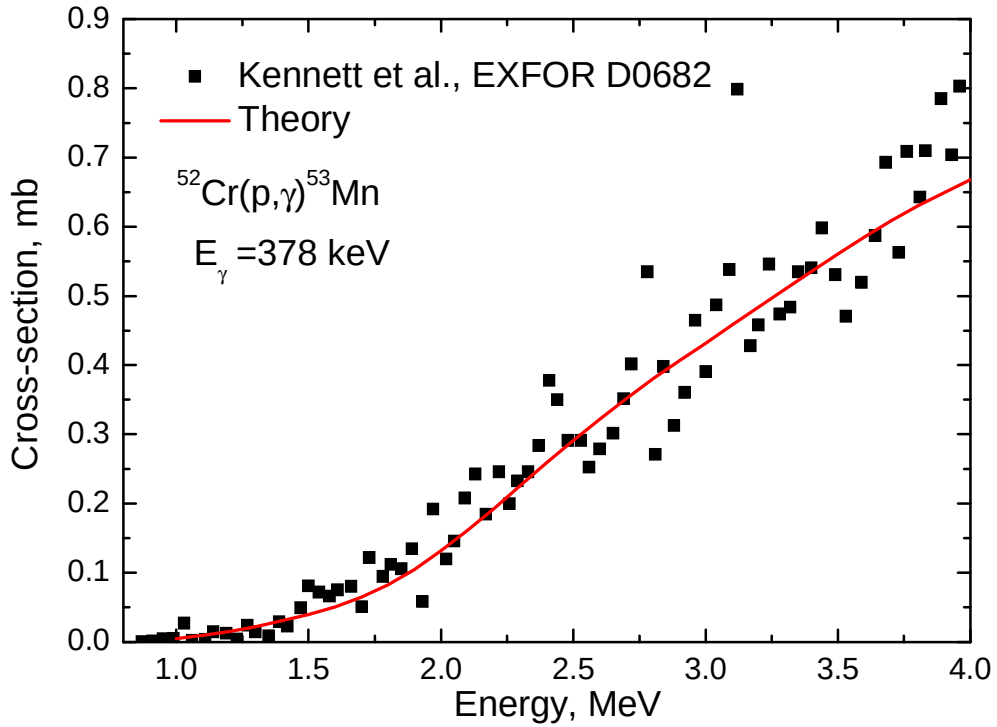
96

Evaluated cross-section for proton elastic scattering from ^{52}Cr



97

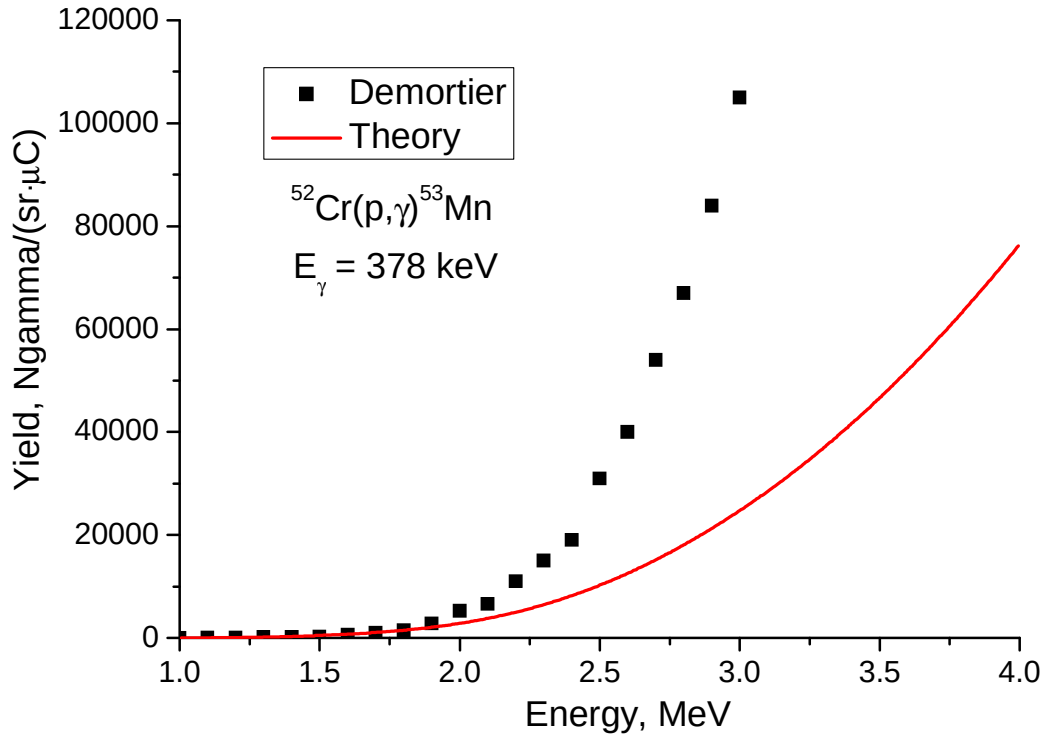
Evaluation of the cross-section for the $^{52}Cr(p,\gamma)^{53}Mn$ reaction



98

Gamma Ray Yield: Theory vs Experiment

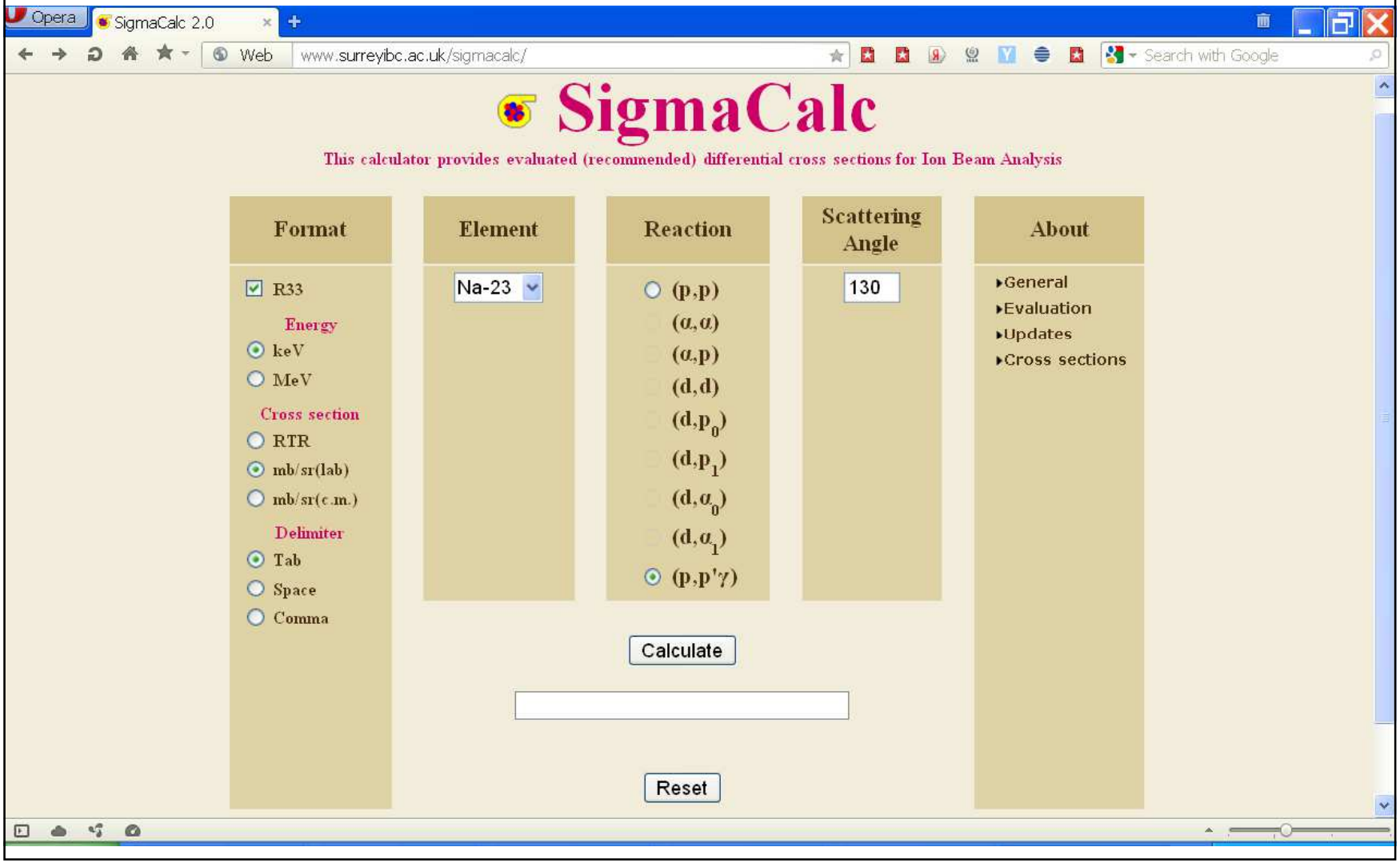
[G. Demortier, "Prompt gamma ray yield from proton bombardment of transition elements", J. Radional. Chem. 45 (1978) 459]



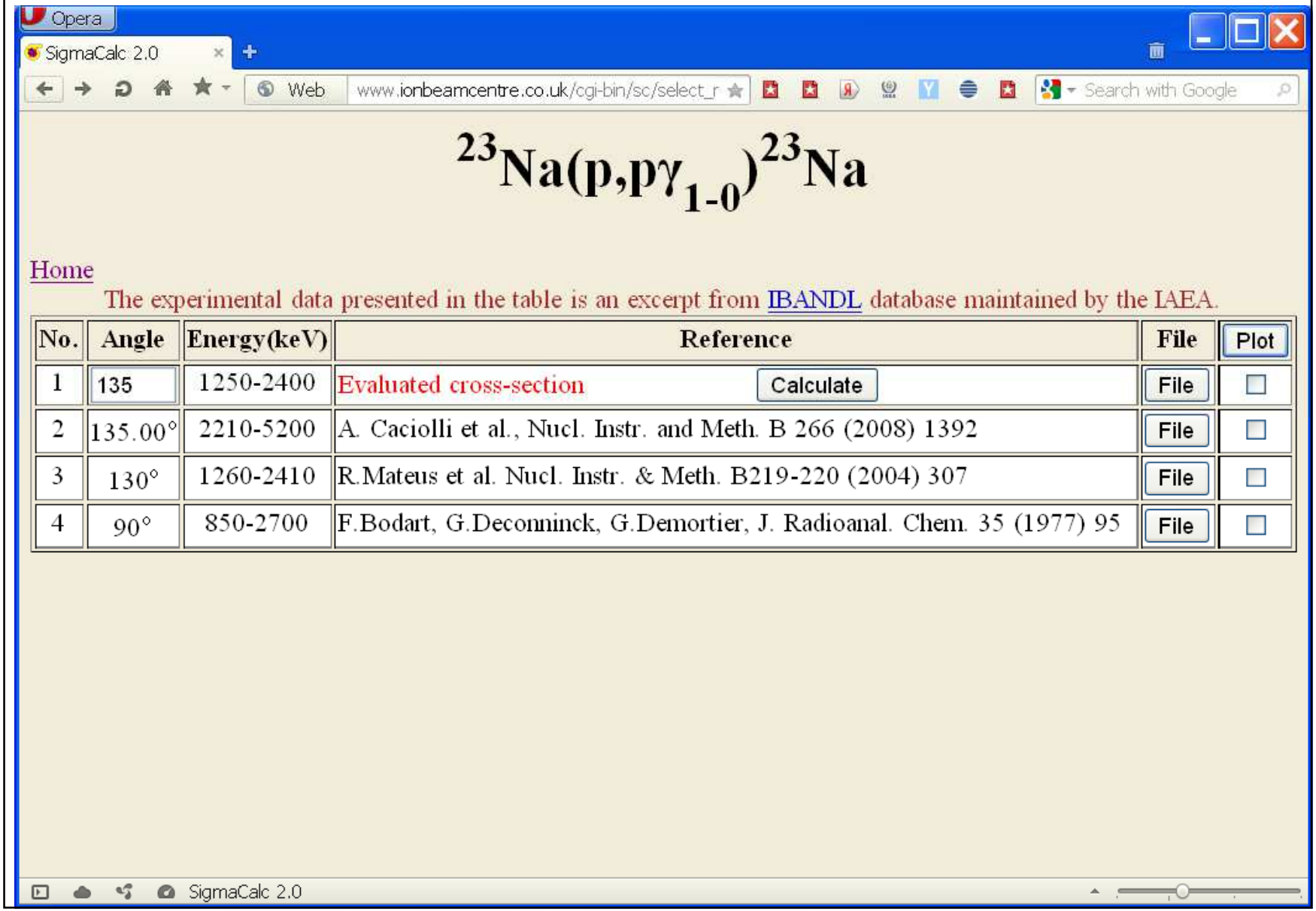
99

SigmaCalc 2.0

http://www.surreyibc.ac.uk/sigmacalc/

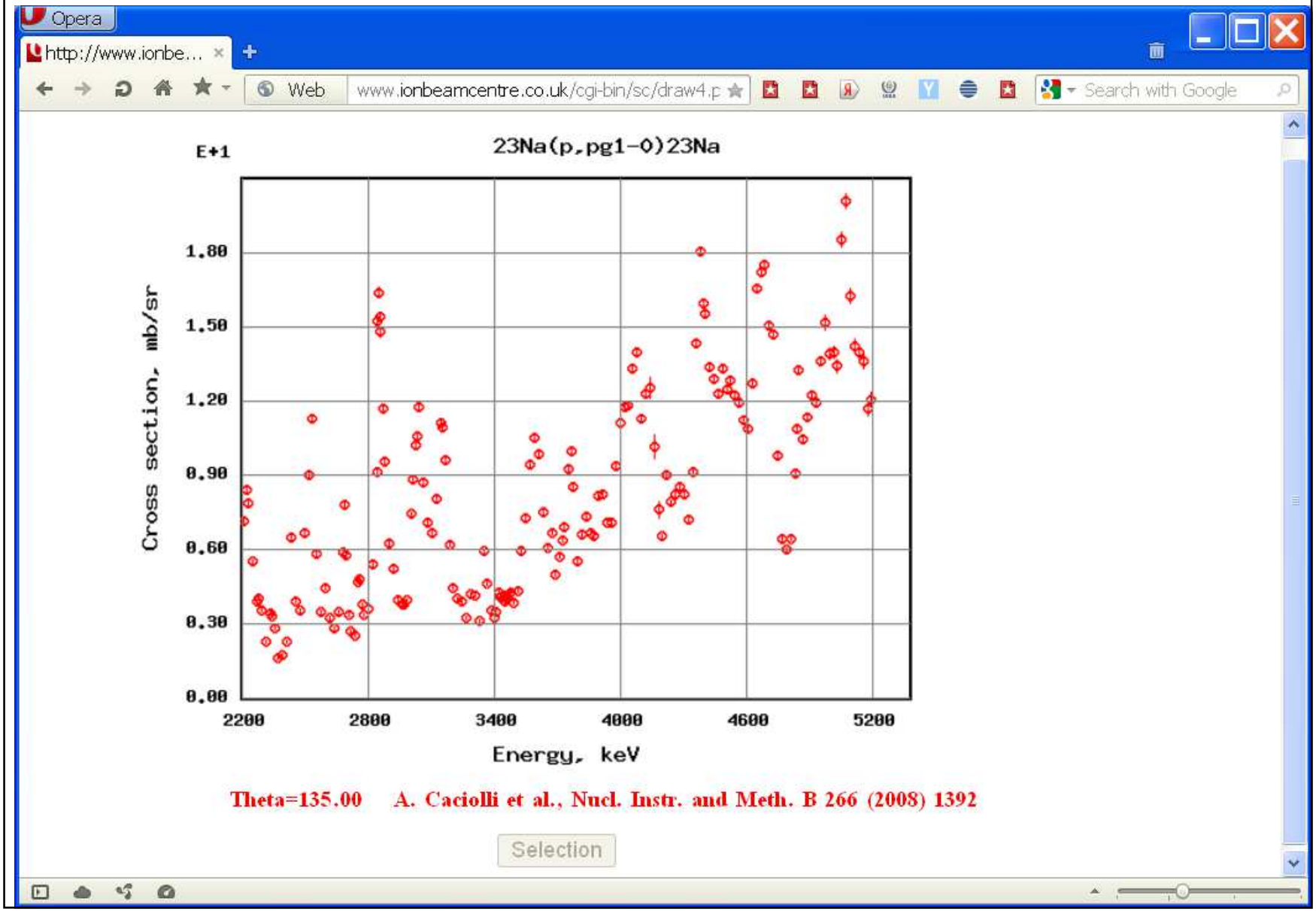


Presentation of PIGE data in different units

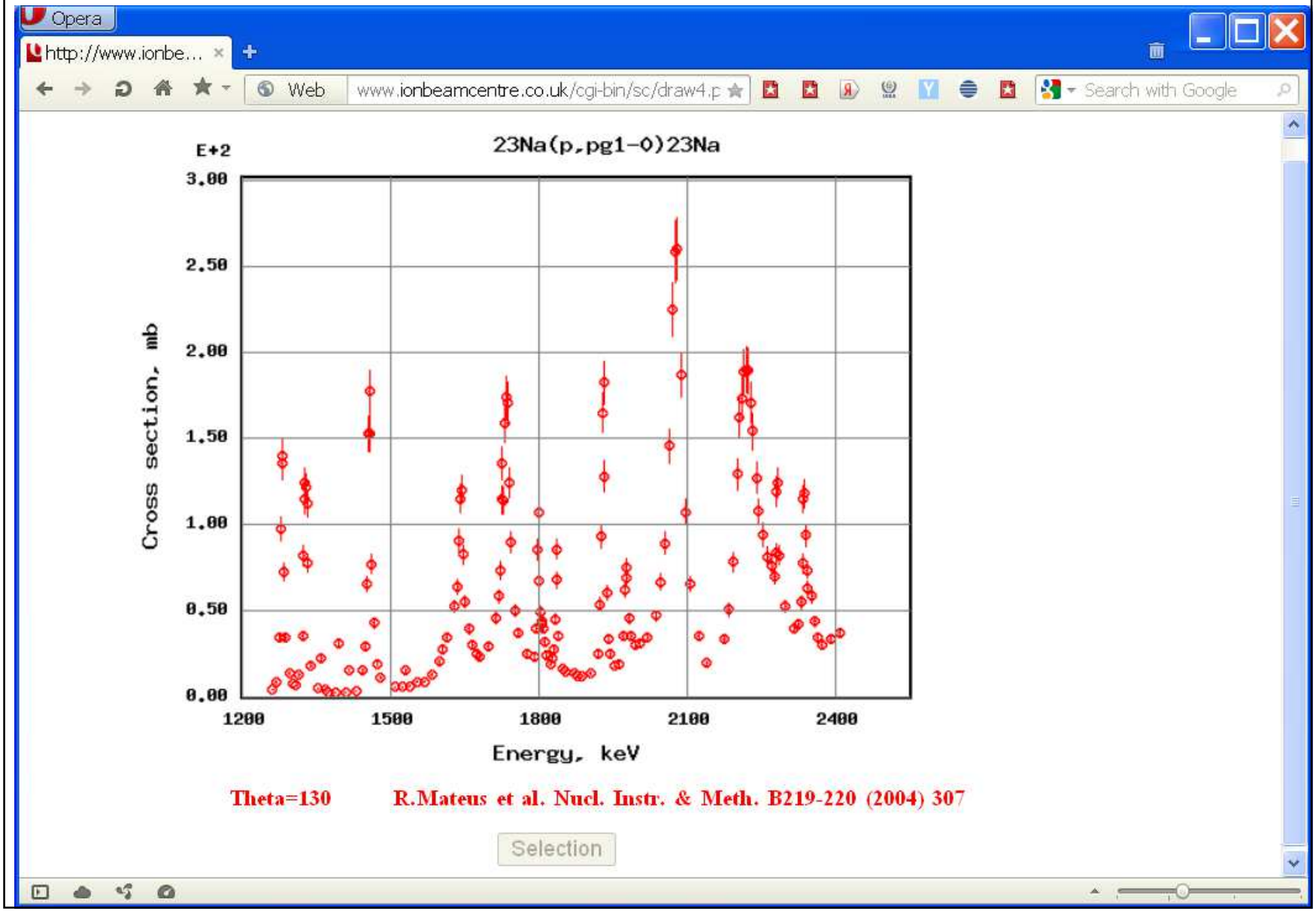


No.	Angle	Energy(keV)	Reference	File	Plot
1	135	1250-2400	Evaluated cross-section Calculate	File	☐
2	135.00°	2210-5200	A. Caciolli et al., Nucl. Instr. and Meth. B 266 (2008) 1392	File	☐
3	130°	1260-2410	R.Mateus et al. Nucl. Instr. & Meth. B219-220 (2004) 307	File	☐
4	90°	850-2700	F.Bodart, G.Deconninck, G.Demortier, J. Radioanal. Chem. 35 (1977) 95	File	☐

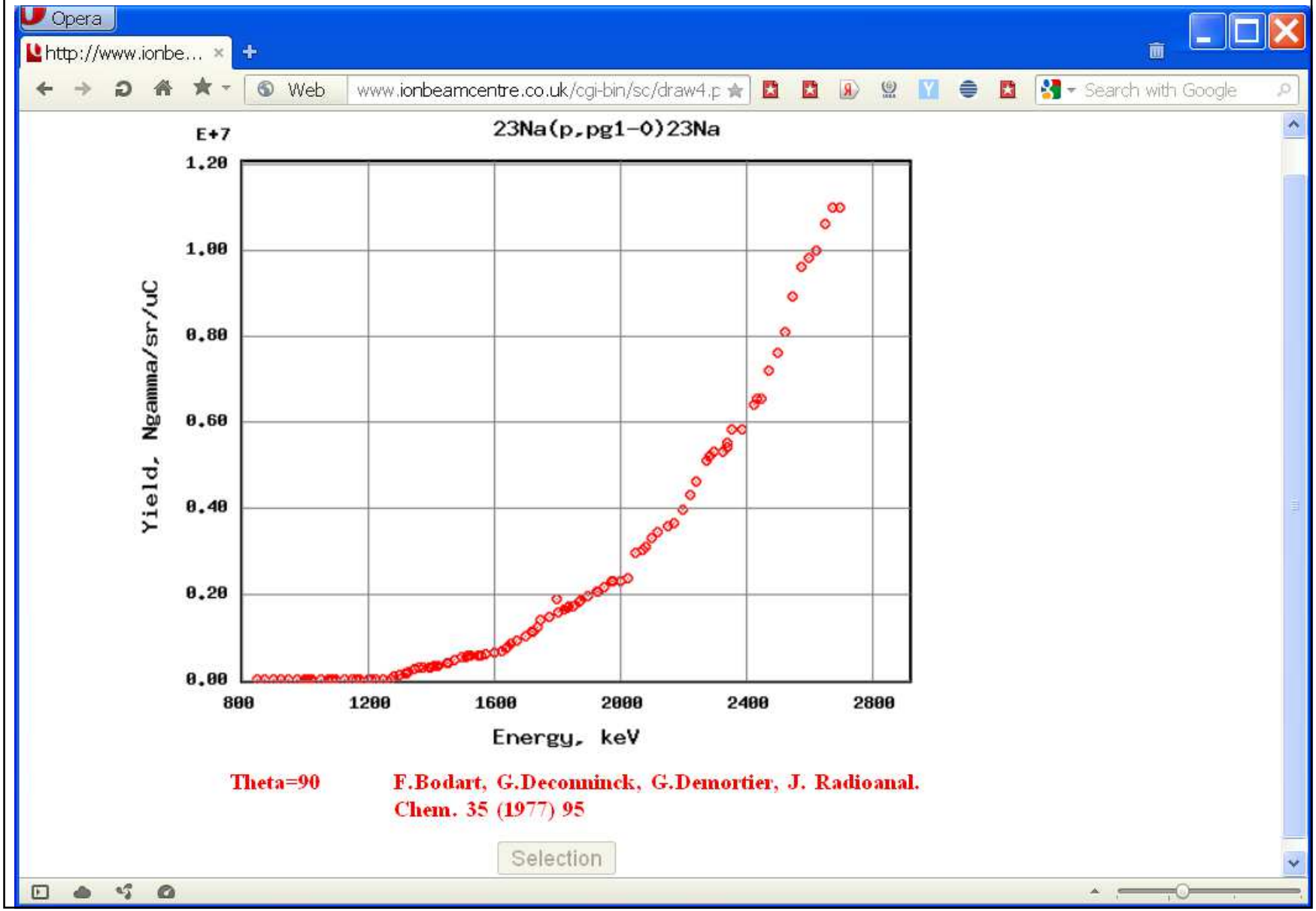
Differential cross-section

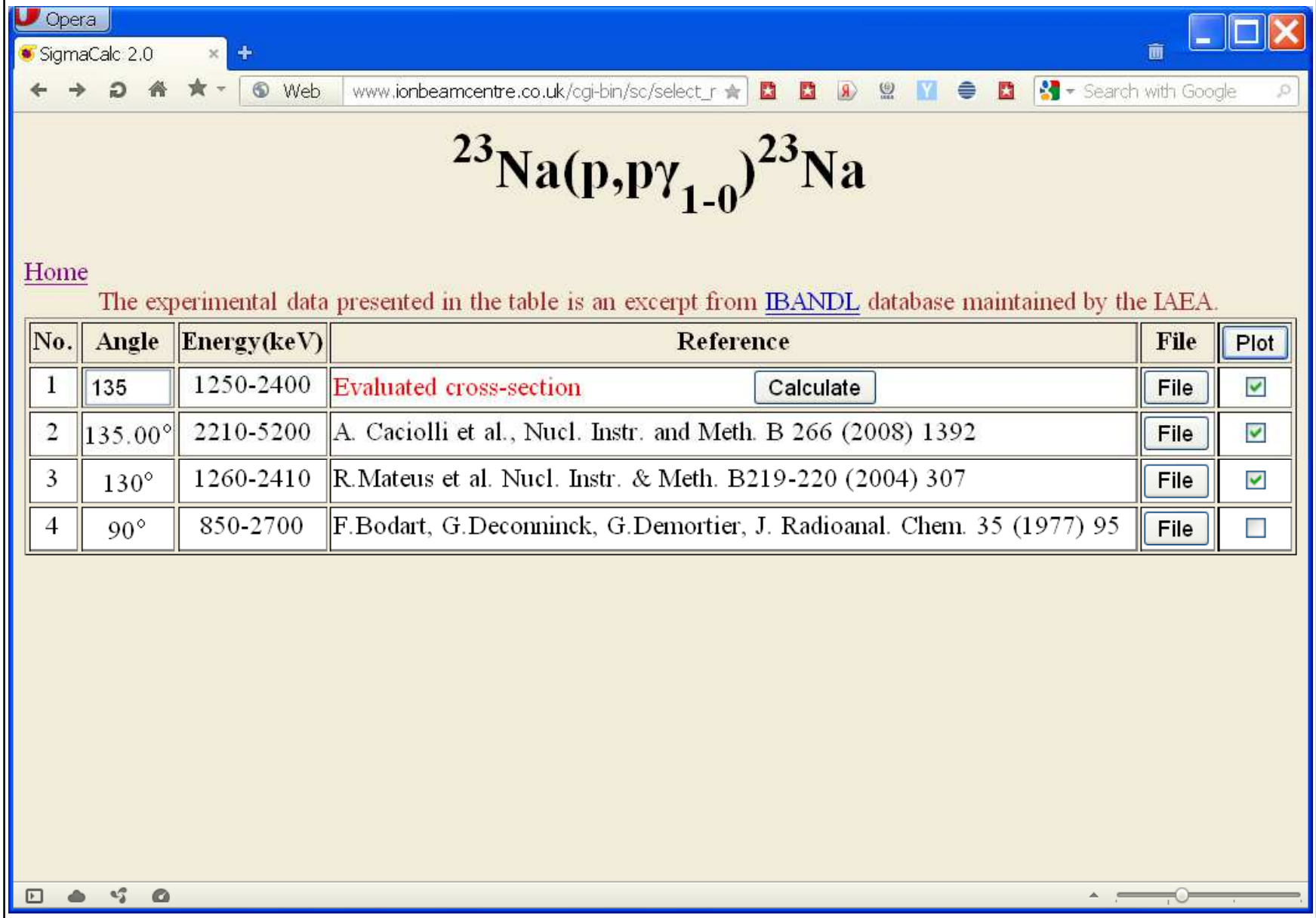


Total cross-section



Thick target yield



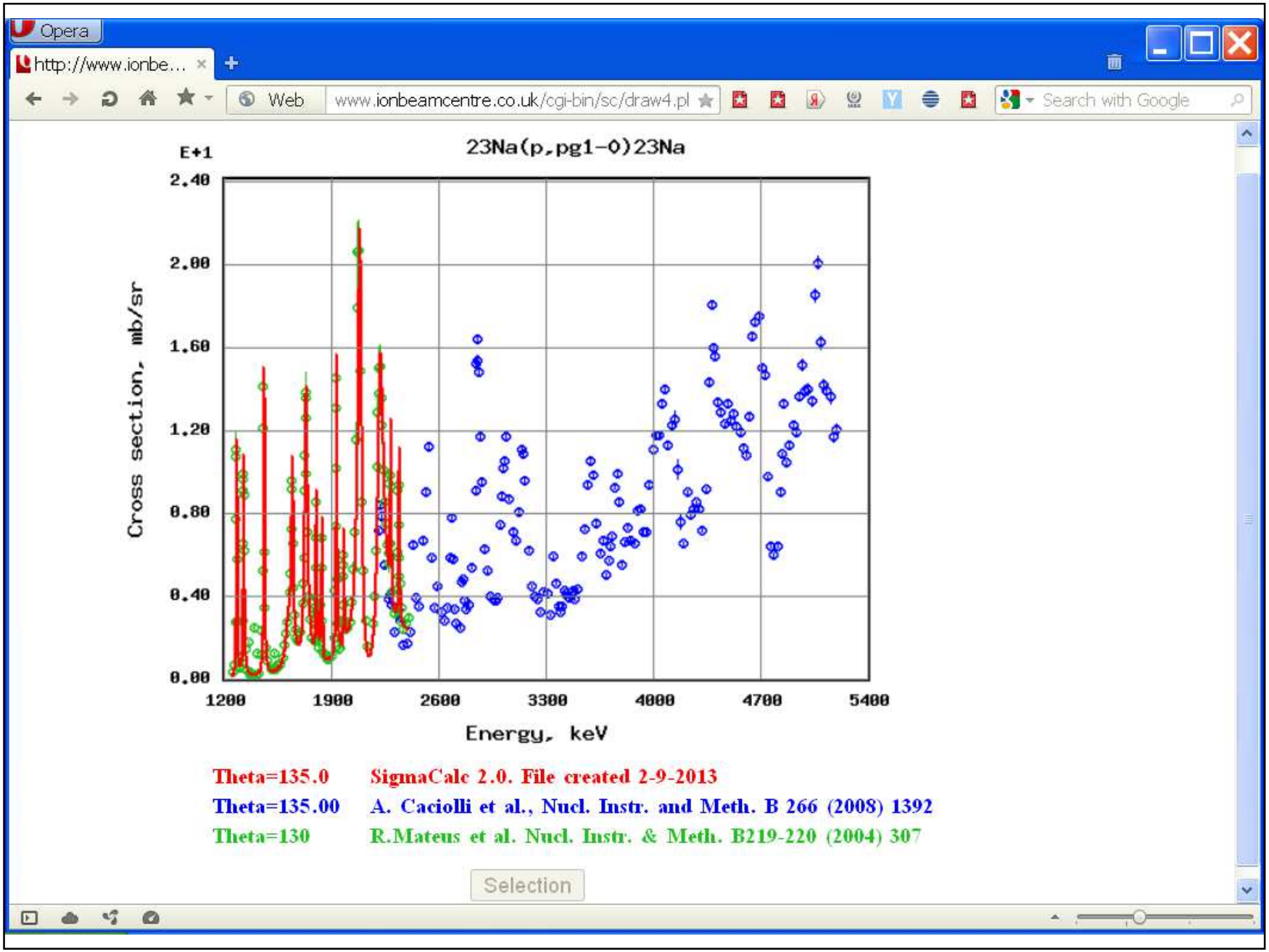


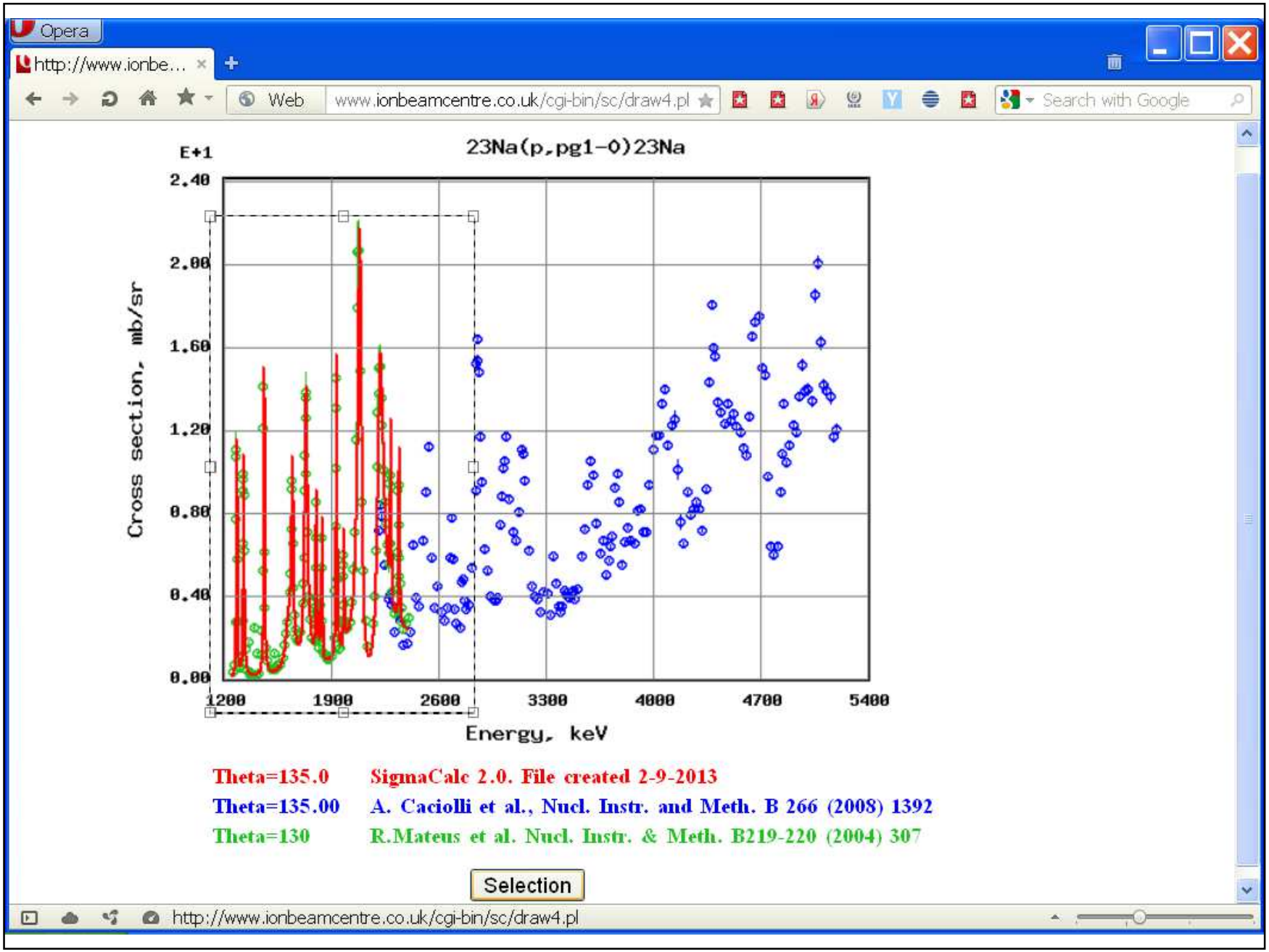
$^{23}Na(p,p\gamma_{1-0})^{23}Na$

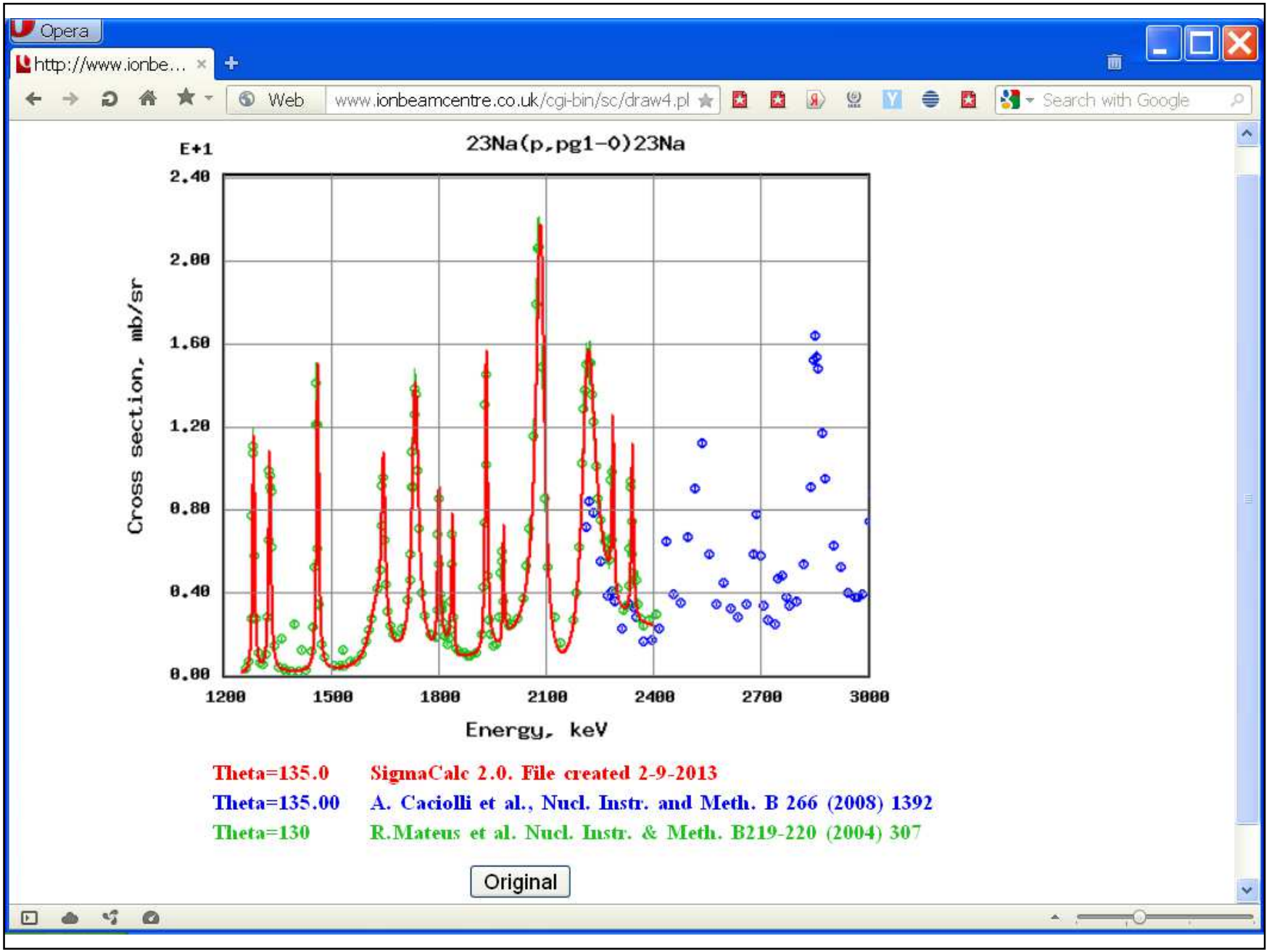
Home

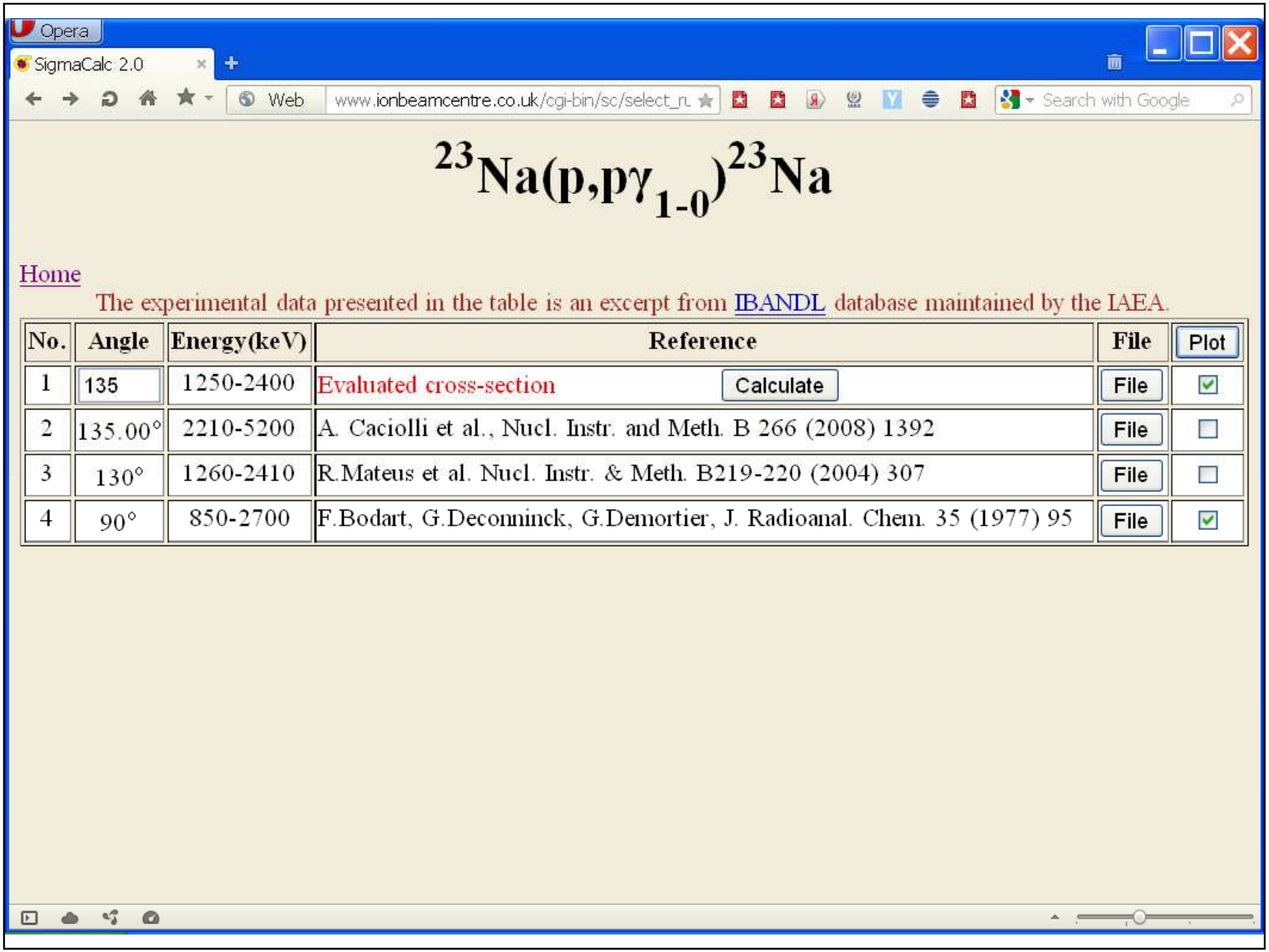
The experimental data presented in the table is an excerpt from IBANDL database maintained by the IAEA.

No.	Angle	Energy(keV)	Reference	File	Plot
1	135	1250-2400	Evaluated cross-section Calculate	File	☑
2	135.00°	2210-5200	A. Caciolli et al., Nucl. Instr. and Meth. B 266 (2008) 1392	File	☑
3	130°	1260-2410	R.Mateus et al. Nucl. Instr. & Meth. B219-220 (2004) 307	File	☑
4	90°	850-2700	F.Bodart, G.Deconninck, G.Demortier, J. Radioanal. Chem. 35 (1977) 95	File	☐


Opera
http://www.ionbe...
Web
www.ionbeamcentre.co.uk/cgi-bin/sc/draw4.pl
Search with Google
23Na(p,pg1-0)23Na
E+1
2.40
2.00
1.60
1.20
0.80
0.40
0.00
Cross section, mb/sr
1200
1900
2600
3300
4000
4700
5400
Energy, keV
Theta=135.0 SignaCalc 2.0. File created 2-9-2013
Theta=135.00 A. Caciolli et al., Nucl. Instr. and Meth. B 266 (2008) 1392
Theta=130 R.Mateus et al. Nucl. Instr. & Meth. B219-220 (2004) 307
Selection


Opera
http://www.ionbe...
Web
www.ionbeamcentre.co.uk/cgi-bin/sc/draw4.pl
Search with Google
23Na(p,pg1-0)23Na
E+1
2.40
2.00
1.60
1.20
0.80
0.40
0.00
Cross section, mb/sr
1200
1900
2600
3300
4000
4700
5400
Energy, keV
Theta=135.0 SignaCalc 2.0. File created 2-9-2013
Theta=135.00 A. Caciolli et al., Nucl. Instr. and Meth. B 266 (2008) 1392
Theta=130 R.Mateus et al. Nucl. Instr. & Meth. B219-220 (2004) 307
Selection
http://www.ionbeamcentre.co.uk/cgi-bin/sc/draw4.pl


Opera
http://www.ionbe...
Web
www.ionbeamcentre.co.uk/cgi-bin/sc/draw4.pl
Search with Google
23Na(p,pg1-0)23Na
E+1
2.40
2.00
1.60
1.20
0.80
0.40
0.00
Cross section, mb/sr
1200
1500
1800
2100
2400
2700
3000
Energy, keV
Theta=135.0 SignaCalc 2.0. File created 2-9-2013
Theta=135.00 A. Caciolli et al., Nucl. Instr. and Meth. B 266 (2008) 1392
Theta=130 R.Mateus et al. Nucl. Instr. & Meth. B219-220 (2004) 307
Original

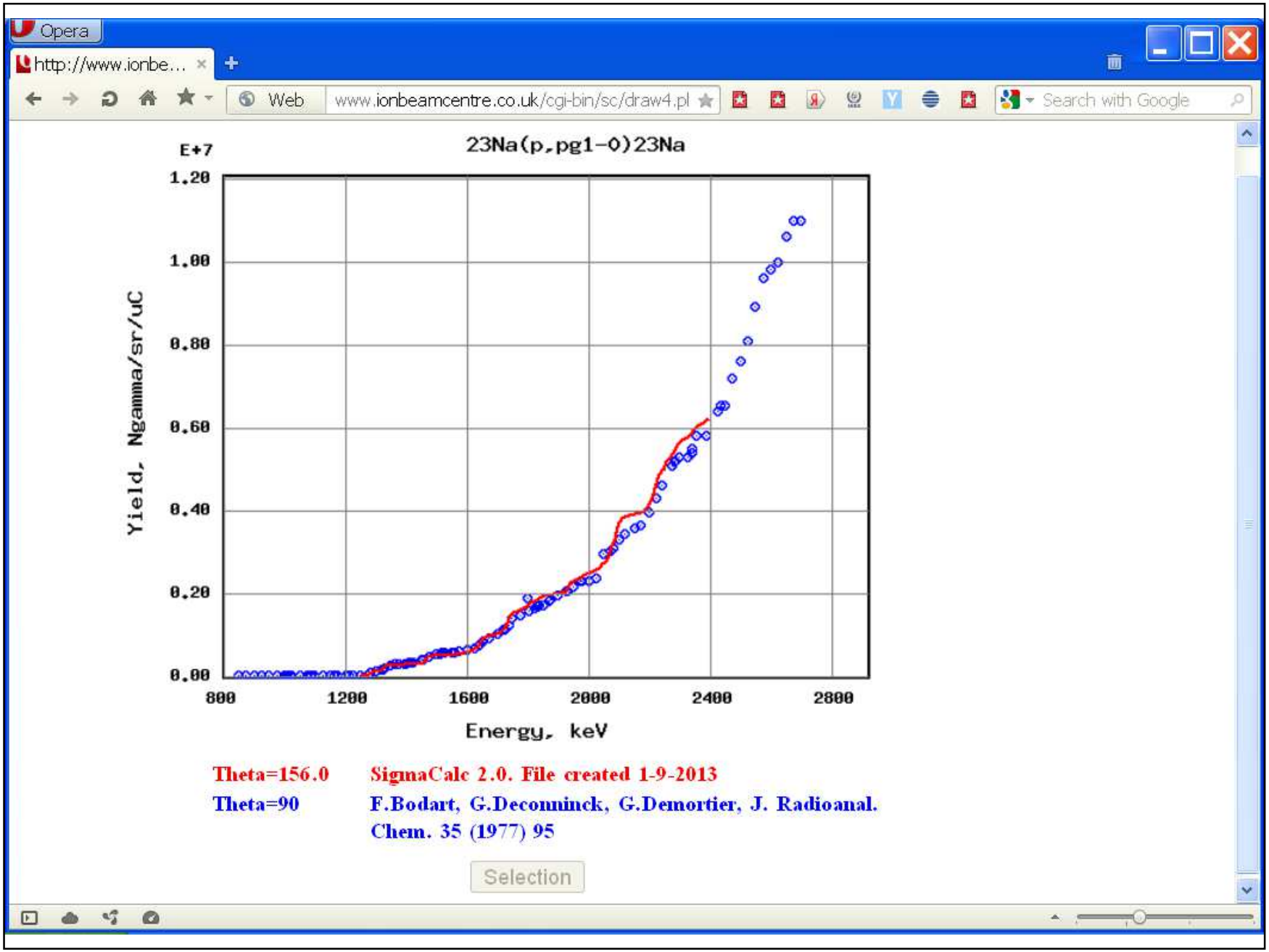


$^{23}Na(p,p\gamma_{1-0})^{23}Na$

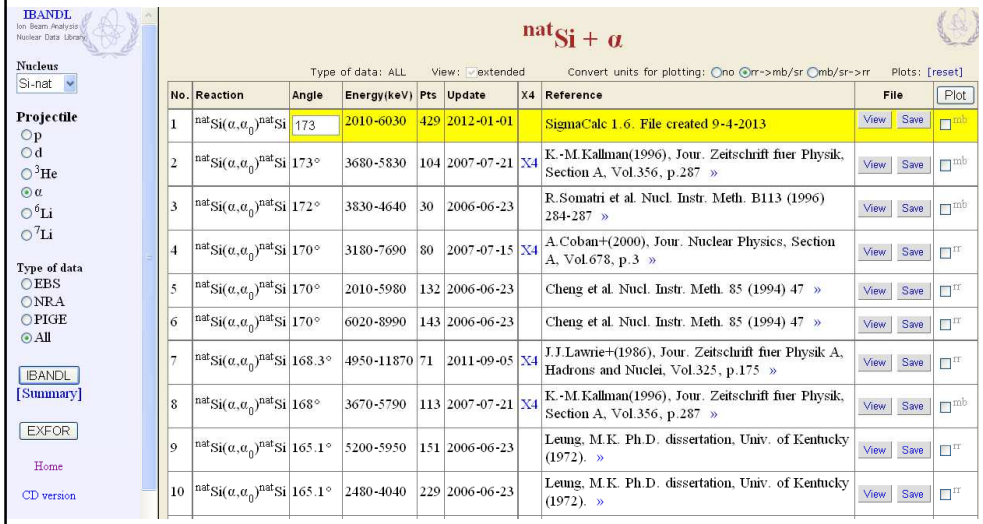
Home

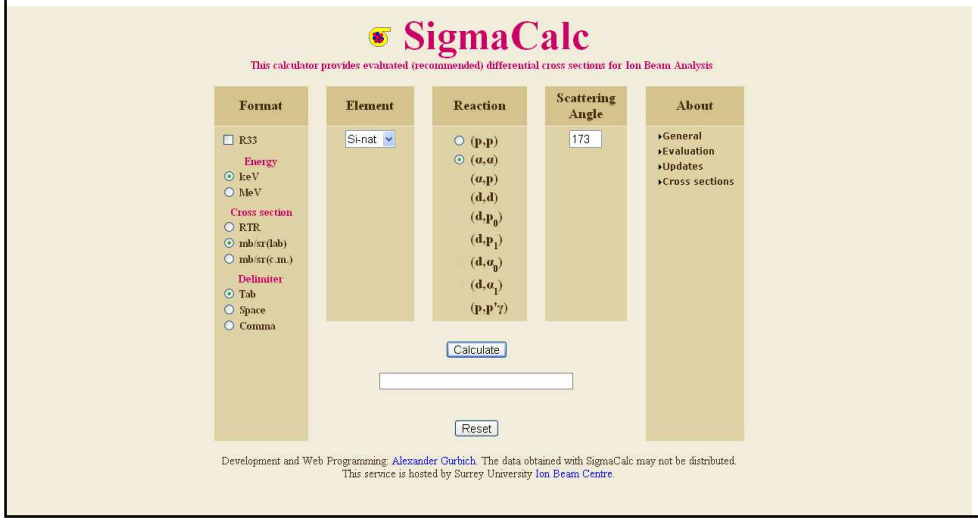
The experimental data presented in the table is an excerpt from IBANDL database maintained by the IAEA.

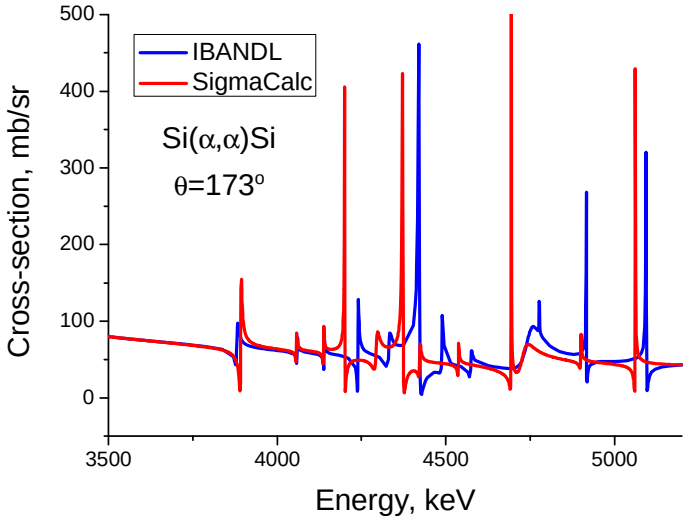
No.	Angle	Energy(keV)	Reference	File	Plot
1	135	1250-2400	Evaluated cross-section Calculate	File	☑
2	135.00°	2210-5200	A. Caciolli et al., Nucl. Instr. and Meth. B 266 (2008) 1392	File	☐
3	130°	1260-2410	R.Mateus et al. Nucl. Instr. & Meth. B219-220 (2004) 307	File	☐
4	90°	850-2700	F.Bodart, G.Deconninck, G.Demortier, J. Radioanal. Chem. 35 (1977) 95	File	☑


Opera
http://www.ionbe...
Web
www.ionbeamcentre.co.uk/cgi-bin/sc/draw4.pl
Search with Google
23Na(p,pg1-0)23Na
E+7
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Yield, Ngamma/sr/uC
800
1200
1600
2000
2400
2800
Energy, keV
Theta=156.0
Theta=90
SignaCalc 2.0. File created 1-9-2013
F.Bodart, G.Deconninck, G.Demortier, J. Radioanal. Chem. 35 (1977) 95
Selection

The contradiction between evaluated data in IBANDL and SigmaCalc







111

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

112