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Summary Report

Second Research Coordination Meeting on Development of a Reference Database for Ion Beam Analysis

IAEA Headquarters, Vienna, Austria
18 – 21 June 2007

Prepared by

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July 2007

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Second Research Coordination Meeting on Development of a Reference Database for Ion Beam Analysis

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Abstract

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Highlights of the 2^{nd} Research Coordination Meeting (RCM) are given with respect to the progress achieved in the first 1½ years of the Co-ordinated Research Project (CRP) on Development of a Reference Database for Ion Beam Analysis. Participants presented the results of their work to date, and identified and assigned key tasks required to ensure that the final output of the CRP is achieved. In addition, a number of lively and productive discussions took place concerning technical issues such as accelerator energy calibration, error reporting, accuracy of the existing IBANDL and EXFOR datasets for IBA, and procedures for producing recommended cross-section data. The main conclusions as well as lists of actions and tasks are presented in this report.

July 2007

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1. Introduction

The Coordinated Research Project (CRP) "Development of a Reference Database for Ion Beam Analysis" was initiated by the IAEA after consultation with the ion beam analysis (IBA) community with the aim to produce a nuclear reaction cross-section database containing recommended data of relevance to the IBA community. Initially, the total duration of the CRP was set for three years. The 1st research coordination meeting (RCM) assembled participants in order to define the scope of the CRP and identify priority reactions for compilation, assessment and evaluation, including measurement or re-measurement where necessary. This second RCM was scheduled at that time in order to assess progress at the half-way mark and define actions necessary to meet the goals of the CRP. During the second RCM all of the participants presented summaries of their work for comment and discussion by all participants, which has resulted in the development of a continued coordinated research plan.

Lively and productive discussions took place concerning technical issues such as accelerator energy calibration, error reporting, accuracy of the existing IBANDL and EXFOR datasets for IBA, and procedures for producing recommended cross-section data. In addition, a preliminary program was presented that allows R33 data to be extracted from EXFOR; furthermore, the steps necessary to arrive at full compliance with the R33 format were identified.

At the 1st RCM (21 – 23 November 2005) participants decided that strong emphasis should first be given to elastic reactions of protons and alphas with light elements, since these reactions are widely used and nuclear theory exists which enables valid evaluations to be made. A secondary emphasis was placed on deuteron-induced nuclear reactions such as $^{16}O(d,p_n)^{17}O$ since application of the underlying nuclear reaction theory for evaluation purposes is substantially complicated by the large number of reaction channels that need to be accounted for. The results presented at this RCM reflect this choice, with the majority of assessments and evaluations being performed for (α,α) and (p,p) scattering reactions.

A second activity within the CRP concerns the development of the IBANDL database and harmonisation of experimental data in IBANDL and EXFOR. This work was ongoing even before the CRP (see report INDC(NDS)-0481, January 2006, of the 1st RCM,) and substantial progress has been made in developing a computer code for format conversion and data transfer between these two databases, opening the possibility of automation in the future.

Participants' progress reports are included in this report, along with a synopsis of the conclusions reached and the tasks and deadlines agreed to by the participants.

2. Meeting Summary

Opening

The meeting was opened by the Head of the Nuclear Data Section (NDS), A. Nichols, who welcomed the participants to Vienna and looked forward to a successful meeting. He thanked the Technical Officer, O. Schwerer, who will retire later this year, for his efforts to run the CRP smoothly, and introduced NDS staff member Daniel Abriola who will take over the CRP after this meeting. D. Abriola briefly introduced himself to RCM participants.

O. Schwerer gave a brief introduction to the objectives of this RCM, and nominated A. Gurbich as chairman and I. Vickridge as rapporteur, both of whom were elected unanimously. A. Gurbich took over the chair. The agenda was adopted without change.

A. Nichols gave an introduction to the possible structure of the final CRP report to be published by the IAEA.

Progress reports

All participants presented progress reports on their measurements as well as on their assessment tasks which had been assigned at the 1st RCM (see Appendix C). An assessment report by CRP member E. Rauhala, who could not attend the meeting, had been received just before the meeting and was distributed. All reports were followed by brief discussions.

O. Schwerer pointed out that the assessment reports received prior to the meeting had been compared with EXFOR. Many works which were until recently not available in EXFOR and/or IBANDL have recently been added to EXFOR. A summary of this comparison was sent to the participants and had been placed on the CRP web page in March. The table given therein also lists cases of differences between IBANDL and EXFOR for the same work (e.g., discrepancies in the numerical values, different number of angles, etc.).

A. Gurbich reported on the progress of the evaluations (see Appendix C).

Digitizing data

Participants use various software for digitizing, such as *Datathief*.
S. Dunaeva demonstrated her digitizing program, which has been successfully used at NDS for EXFOR compilation for several years, and agreed to digitize any upcoming data for this CRP.

Assessments: Task for all

Participants agreed to finalize assessments for all reactions assigned to them at the 1st RCM. In particular, to include all data available in the literature and, if not yet done, to upload those data to IBANDL, and correct any mistakes and gaps in IBANDL.

Whenever work is added to IBANDL, all data should be included, in particular data at all angles (also forward angles) since they are needed for the evaluation, and, as far as feasible also data which are outside the energy range of immediate interest to IBA. The assessments should follow a template format to be sent by M. Mayer. The assessments should analyse the data situation and clearly emphasize gaps and inconsistencies in the available experimental data. The deadline for this task has been set for 31 December 2007.

Dunaeva and Schwerer pointed out that for some data given in IBANDL, the actual experiment could not be traced. Wherever possible, every effort should be made to identify and include a reference to the original experiment.

Benchmark experiments

Several discussions concerned the role of benchmark experiments that consist of measuring charged-particle spectra from thick targets. Whilst it should be possible in principle to derive cross-sections from such experiments, it was reported that even using advanced inversion techniques (simulated annealing with nuclear data furnace), the derived cross-sections were inferior to those obtained from thin targets. Nevertheless, thick target benchmark experiments provide a convincing test of the overall validity of the measured cross-sections for IBA. Such validation depends on the availability of tested simulation codes and valid stopping powers. Within this CRP, it is recommended to use the SIMNRA or Data Furnace simulation code and SRIM-2003 stopping powers to simulate particle spectra that correspond to a given cross-section. In cases where there is no evaluated data, an attempt will be made to recommend cross-sections based on the assessments of the participants. In these cases, one legitimate approach is to generate recommended cross sections by adjusting measured cross-sections to reproduce benchmark experiments.

Recommended and evaluated data in IBANDL

Recommended and evaluated data are also included in IBANDL and should be clearly identified. To this end, a new field should be added to R33 format to flag such data.

Concerning the presentation of recommended data in the final database, it is envisaged to present them in a suitable way within the IBANDL interface.

Energy calibration of accelerators

The importance of accurate energy calibration of accelerators was emphasized and, after discussion, it was agreed to use the primary calibration points of Al(p,γ) 991.86 ± 0.03 keV and the Li-7(p,n) threshold at 1880.6 keV. Participants are urged to use other points as cited in Marion, Rev. Mod. Phys. 38, 1966, p. 660.

The participants recognized that e.g. the Mg(p,p) 1483 keV resonance (well known to better than 2 keV and Al(p,p′γ) (1664.4 ± 0.2 and 1683.6 ± 0.1 keV) are particularly useful. However, the difficulty of accurate calibration at higher energies was recognized.

Choice of reactions for evaluations and recommended data

One of the objectives of the CRP is the identification of the most pressing reactions for assessment and evaluation for IBA. After some discussion it was decided that this list consists of those reactions already assigned for assessment at the 1^{st} RCM. The choice of reactions for evaluation is made on the basis of relevance to IBA, the feasibility of development of appropriate nuclear reaction theory, and available manpower. These factors have guided the choice of reactions for evaluation throughout the CRP. Where evaluation is not feasible, participants felt that it was nevertheless important to produce recommended data that reflect our best estimate of the cross-sections based on existing experimental data.

Participants decided that it would be useful to extend the list of the reactions assigned at the 1^{st} RCM to include K(p,p), S(α,α), Cl(p,p), (α,α) for which literature data are either non-existent or sparse. These reactions have been assigned to participants as further optional tasks.

EXFOR to R33 conversion

Recent progress by NDS in implementing R33 as an EXFOR output was presented and discussed. It was pointed out that R33 includes some information not normally included in EXFOR and contains cross-sections only referred to in the laboratory frame. In order to produce complete R33 files from EXFOR, it is necessary to identify appropriate product nucleus levels, calculate associated Q values, and perform centre of mass to lab transformation when necessary. The participants expressed their appreciation for the progress already achieved.

Relation IBANDL - EXFOR

After discussion of the relationship between EXFOR and IBANDL, it was recognized that data should be ideally compiled in one authoritative database, but that the convenient interface of IBANDL and the focus of the data have been significant contributing factors to its adoption by the IBA community. In view of this, it appears desirable to maintain IBANDL in its present form. Inclusion of new EXFOR data into IBANDL may be done by manual selection of data chosen from an automatically generated preselection. In the longer term, it is envisaged that automatic filtering alone may suffice and ultimately it may be possible to respond to IBANDL requests directly on the fly from EXFOR.

Structure of final report

After extensive discussions the meeting decided to structure the final report such that various chapters are drafted by individual CRP members. The distribution of chapters is listed in Section 3.3. Reports on measurements are to be submitted to Bogdanovic by 1 September 2008 so that the chapter on measurements can be written. The deadline for submitting the draft chapters of the final report to all members is 1 January 2009.

Third RCM

The 3rd RCM is envisaged to take place in the first quarter of 2009.

Request of CRP-extension by one year for validation of data

Although the participants expect to produce a set of recommended cross-sections based on existing experimental data and cross-sections measured in the framework of the CRP, it has become apparent that benchmark experiments play a much greater role for the validation of the recommended cross-sections than initially foreseen. An extensive set of benchmark experiments with thick targets followed by spectral simulation will add substantial value to the recommended database with incorporation of the results in the recommended data sets that constitute the final output of the CRP. These considerations led to the proposal for an extension of the CRP by one year.

Proposal of a follow-up CRP on PIGE data for IBA

The results achieved so far have shown that great progress in the problem of nuclear cross-section data for IBA can be achieved by coordinated efforts in a CRP framework.

A significant number of particle-induced gamma-ray emission (PIGE) cross-section data, which fall outside the scope of the present CRP, have been uploaded to IBANDL by members of the IBA community other than participants of the CRP. The IBA community has shown by this action that there is an overwhelming need for the compilation, assessment and evaluation of PIGE data which would require the constitution of a new CRP. This proposed new CRP could benefit from the experience of those present members with appropriate PIGE expertise, that would be reinforced by participation of new members chosen for their specific PIGE expertise.

3. Action lists

3.1. Table of special Actions

Action	**Subject**
All concerned	Submit (provisional) assessment on those reactions where no report has been produced yet.
Dunaeva	On request of participants, digitize data for inclusion in IBANDL and EXFOR.
Dunaeva	Check and, if necessary, redigitize data which were taken from SigmaBase and NRABase.
Kokkoris	Decide whether he can do measurement of S(α,α) in addition.
Mayer	Provide CM-to-Lab calculator as a tool for SigmaCalc users; also calculator for Rutherford cross-sections if possible.
Gurbich	In addition to elemental data, make data for main isotope available in SigmaCalc.
Zerkin	Continue development of EXFOR – R33 converter with high priority.
Gurbich and Zerkin	Implement automatic Q_0-value calculation and CM – Lab transformation for the EXFOR to R33 conversion.
Gurbich and Zerkin	Define and implement a strategy to identify excited states of product nucleus corresponding to outgoing particles in order to calculate the associated Q values.
All	Communicate to Zerkin feedback concerning the EXFOR to R33 converter.
Vickridge	Implement R33 format upgrade for gamma production data.
Mayer	Provide an example of a recommended data set for a reaction suitable for an “averaging” approach to participants.

3.2. Assignment of recommended data

(after selection of appropriate approach, depending on reaction)

Proposed approaches (more options may arise in the course of the work):

- "Averaging"
- Adjust cross-sections based on results of simulation of benchmark experiments

Deadline: 1 September 2008

Vickridge	^{13}C(d,p), ^{15}N(d,α)
Bogdanovic	O(d,p), (d,α)
Kokkoris	B reactions, S reactions, S(,p,p) optional, ^{14}N reactions
Mayer	Selected from: Be(p,p), (α,α), Be,B,C,O,D(^{3}He,x)
Chiari	^{6,7}Li, ^{19}F (p,p), Na(p,p)
Shi	^{4}He (p,p) up to 5 MeV
Ramos	N(α,α)
Jeynes	Cl(p,p), (α,α)

3.3. Assignment of chapters for final report

Deadline for submission of draft chapters: 1 January 2009
Submission of measurements to Bogdanovic: 1 September 2008

Introduction	Vickridge
Compilation	Gurbich, NDS
Assessments	Mayer
Measurements	Bogdanovic
Elaboration of recommended data	*to be decided*
Evaluations	Gurbich
Description of databases (in general, and about attached CD):	
EXFOR	NDS
IBANDL, R33 format	Gurbich, Vickridge
SigmaCalc	Gurbich

3.4. List of basic tasks and assessment tasks (as updated at the 2nd RCM, June 2007)

Name	Basic tasks	Assessment tasks
Bogdanovic-Radovic	**Year 1:** 1. Determine energy and angular ranges where new measurements are most urgently needed. 2. Preparation of target and scattering chamber for the experiment. 3. Detector calibration by measuring scattering chamber and detector solid angles. 4. Measure the **N(p,p)** non-Rutherford elastic scattering cross-section **up to 5 MeV** and provide results to IBANDL. **Year 2:** 1. Measure the **O(p,p)** and **Al(p,p)** non-Rutherford elastic scattering cross-section **up to 5 MeV** and provide results to IBANDL. 2. Measure the **N(α,α)** and **Si(α,α)** non-Rutherford elastic scattering cross-section **between 2 and 8 MeV** and provide results to IBANDL.	nat C (p,p) 3.5 to 5 MeV, (α,α) up to 8 MeV
Chiari	**Year 1:** Install and test the multiple-detector scattering chamber. **Year 2:** Measure **N(p,p)** elastic scattering cross-section at energies **up to 6 MeV** as function of scattering angle. **Year 3:** Measure **C(p,p)** elastic scattering cross-section in energy range **3 - 6 MeV** as a function of scattering angle. Measure **F(p,p)** and **Li(p,p)** elastic scattering cross-sections at energies **up to 6 MeV** as a function of scattering angle.	^{23}Na(p,p) ^{19}F, ^{7}Li, ^{6}Li
Gurbich	**Year 1:** 1. Search literature and include 20 additional works in IBANDL database. 2. **Evaluate** differential cross-sections for elastic scattering of **alphas on O and Si**, based on critical assessment of existing experimental data and on nuclear model calculations, and supply the results in tabular form to NDS. 3. **Measure** the differential cross-section of **(d,p) and (d,α)** reactions on **Al**, as well as the thick-target **gamma-ray yield on Al**, in the energy range **1 to 2 MeV**, and include the new data in IBANDL. **Year 2:** 1. Continue support for IBANDL database by adding new data sets from literature or supplied by authors and by including improvements of database structure. 2. Evaluate differential cross-sections for elastic scattering of protons on N, based on critical assessment of existing experimental data and on nuclear model calculations, and supply the results in tabular form to NDS. 3. Measure the differential cross-section of (d,p) and (d,α) reactions on N in the energy range from 1 to 2 MeV with an energy step of 20 keV, and include the new data in IBANDL. **Year 3:** 1. Continue support for IBANDL database by adding new data sets from literature or supplied by authors and by including improvements of internal structure of database.	nat C, nat O (d,p) (d,α)

Gurbich	2. Extend evaluation of differential cross-sections for elastic scattering of protons on N to energy range 3.5 – 5 MeV. 3. Evaluate differential cross-sections for elastic scattering of protons on B-10, B-11 and F. **4. Extend evaluation of C(p,p) to 4.5 MeV (added at RCM2)**	nat C, nat O (d,p) (d,α)
Jeynes	**Year 1:** Measure and evaluate Mg(p,p). Experiment up to 4 MeV at 2 angles as a benchmark. **Year 2:** Measure and evaluate Si(α,α**).** Experiment at 2 angles. Extract cs from bulk target data using Bayesian Inference. Evaluate stopping cs using Sb implanted ref. Standard from IRMM Geel. Measure Ti(α,α**), V**(α,α**)** and ^{14}N(α,α**)** up to 6 MeV at 2 angles from bulk targets using BI. **Year 3:** Measure Ti(p,p**), V**(p,p) and ^{14}N (p,p) to 4 MeV at 2 angles from bulk targets using BI.	
Kokkoris	**Year 1:** Measure **^{10,11}B(d,p) and (d,α)** reactions (on natural and enriched targets) at 8 angles from **900 to 2000 keV.** **Year 2:** Measure **^{14}N(d,p), (d,α), (d,d).** **Year 3:** Measure **^{19}F(d,p), (d,α), ^{6}Li(d,p),(d,α).**	^{10,11}B, ^{6}Li, ^{7}Li (d,p) (p,α) (d,α), ^{14}N, ^{19}F(d,p), (d,α), nat S(NRA)
Lopes Ramos	**Year 1:** 1. Obtain appropriate samples and perform detailed compositional analysis by PIXE and RBS. 2. Measure **N(p,p)** elastic cross-section by thin film technique in energy range **500 - 2500 keV** at scattering angles **130 - 160 degrees** in 10 deg. steps. 3. Develop and validate "bulk sample method" for proton elastic scattering cross-section measurements. 4. Apply bulk sample method to measurement of **Li(p,p)** elastic scattering cross section. **Year 2:** 1. Perform reproducibility tests for ^{14}N(p,p$_0$) ^{14}N cross-sections measured during the first year using thin films. 2. Application of the previously developed algorithm to the determination of ^{14}N(p,p$_0$) ^{14}N cross-sections using a bulk nitride sample and comparison of results with the thin film measurements of the first year. 3. Benchmarking of evaluated/measured (p,p) cross-sections in the 500 – 2500 keV range for C, N and Si using standard bulk samples. **Year 3:** 1. Perform reproducibility tests for the Li(p,p) cross sections measured during the first and second year. 2. Finalize the benchmarking of evaluated/measured N(p,p) and C(p,p) cross-sections in the energy range 500-2500 keV.	nat N (p,p) (α,α)

Mayer	**Year 1: Identify** most important cross-sections for **incident p, d, He-3 and alpha particles** for backscattering, elastic recoil analysis, and nuclear reactions. **Year 2: Analysis and synthesis** of assessments from participants, and preparation of manuscript for submission to international journal. **Year 3: Assessment** of the existing data (experimental and theoretical) for incident ^{3}**He, alphas and heavier ions.**	B (p,p) and (α,α) Be (p,p) and (α,α) Be, B, nat C, nat O, D (^{3}He,charged particle)
Rauhala	**Year 1:** Measure **O(α,α)** at **7-9 MeV** over wide angular region. **Year 2:** Measure **D(p,p)** at **0.5-1 and 2-4 MeV** at several angles > 100 deg. in cooperation with Vickridge and Mayer. **Year 3:** Measure nuclear reactions of ^{3}**He + d** system.	D (p,p) B (p,p) and (α,α)
Shi	**Year 1:** 1. Measurement of the differential elastic scattering cross-section of **alphas incident on D and T** in the energy range **3 - 8 MeV** at scattering angle of **30 degrees.** 2. Measurement of the differential elastic scattering cross-section of **protons incident on D and T** in the energy range **1 - 3 MeV** at scattering angles of **151 and 165 degrees.** 3. Provide results to IAEA Nuclear Data Section in tabular form for inclusion in IBANDL database. **Year 2:** Measurement of the differential elastic scattering cross-section of **alphas incident on D and T** in the energy range **3 - 8 MeV** at scattering angle of **20 and 40 degrees.**	D,T (α,α), (p,p)
Vickridge	**Year 1: Identification of most important reactions** based on needs for NRA and feasibility of measurements, and identification of optimal energy and angular ranges, with input from 1st RCM. Preparation of **trial targets** and tests of target stability under the beam. Evaluation of interferences from parasite reactions. **Year 2: Measurement** of cross sections for **deuteron-induced reactions on** ^{13}**C**, and inclusion of results in IBANDL. Preparation of thin ^{15}N films for measurements in Year 3. Measure **D(p,p)** at **1-2 MeV** at several angles > 100 deg. in cooperation with Rauhala and Mayer. **Year 3:** Measurement of cross-sections for **deuteron-induced reactions on** ^{15}**N**, and inclusion of results in IBANDL.	^{13}C, ^{15}N (p,p) (α,α) (d,p) (p,α) (d,α)

Appendix A

International Atomic Energy Agency
Second Research Co-ordination Meeting on

Development of a Reference Database for Ion Beam Analysis

IAEA Headquarters, Vienna, Austria

18-21 June 2007
Meeting Room ACV U1U 6400

AGENDA (draft)

Monday 18 June

08:30 – 09:20	Registration (IAEA Registration Desk, Gate 1)
09:30 – 10:15	Opening Session Opening (A. Nichols) Introduction: Objectives of this RCM (O. Schwerer) Election of Chairman and Rapporteur Discussion and Adoption of the Agenda (Chairman) Explanation of Technical Report: scope, format, authorship, etc. (A. Nichols)
10:15 – 11:00	Coffee break and Administrative Matters
11:15 – 12:35	Progress Reports on Measurements (15 mins per presentation + 5 mins discussion) Bogdanovic Radovic Chiari Gurbich Jeynes
12:35 – 14:00	LUNCH
14:00 – 15:20	Progress Reports on Measurements (cont'd) Kokkoris Lopes Ramos Wahl Shi Vickridge
15:20 – 15:50	Coffee break
15:50 – 17:30	Progress Reports on Assessments (15 mins per presentation + 5 mins discussion) Bogdanovic Radovic Chiari Gurbich Kokkoris Lopes Ramos Wahl
Evening	Social event to be announced

Tuesday 19 June

09:00 – 10:00	Progress Reports on Assessments (cont'd) Mayer Shi Vickridge
10:00 – 10:40	Progress Reports on Evaluations Gurbich Jeynes
10:40 – 11:10	Coffee break
11:00 – 12:30	Review of Tasks from RCM-1
	New Task List
	Results of assessments: How to deal with gaps and inconsistencies
12:30 – 14:00	LUNCH
14:00 – 15:30	List of reactions for final database
	IBANDL Status Report (Gurbich)
	EXFOR/IBANDL comparison, completeness (S. Dunaeva)
15:30 – 16:00	Coffee break
16:00 – 17:30	General discussion

Wednesday 20 June

09:00 – 10:30	Format questions; experimental data
	r33 format Conversion EXFOR -> r33, plotting (V. Zerkin)
10:30 – 11:00	Coffee break
11:00 – 12:30	Formats for evaluated data SigmaCalc, tabulated data, ENDF-6
	Recommended data: elaboration and presentation
12:30 – 14:00	LUNCH
14:00 – 17:30	Discussion of structure of the final CRP report (Technical Report) Assignment of chapters to authors

Thursday 21 June

09:00 – 12:30	CRP paper for IBA-18 (September 2007, Hyderabad) (A. Gurbich)
	Time frame for rest of CRP Deadlines for tasks Date of 3rd RCM (also deadline for draft of final report) Deadline for preparation of final database
	Summarize results of RCM Review of tasks and conclusions
12:30	Closing of the meeting

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"Development of a Reference Database for Ion Beam Analysis"
IAEA Headquarters, Vienna, Austria
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Development of a Reference Database for Ion Beam Analysis

2nd RCM, IAEA, Vienna

18 – 21 June 2007

Introductory Remarks (O. Schwerer)

CRP objectives

- Overall objective:
  - **Create** nuclear cross-section **database** for IBA containing reliable and usable data that will be made available freely to user community
- Specific objectives:
  - **Identify** most important reactions for IBA
  - **Search** literature and existing databases and **convert** relevant data to format used in IBA simulation programs
  - **Compare** data from different sources and perform **measurements** when data are lacking or discrepant
  - Apply model calculations to **evaluate** cross sections
  - **Incorporate** all measured and evaluated data into new database and them make available to community

Expected output

- Database (Web and CD-ROM)
- IAEA technical document

Objectives of this RCM

- Review progress
  - Measurements (-> IBANDL)
  - Assessments
  - Evaluations (-> SigmaCalc)
- “Identify most important reactions”

Objectives of this RCM (cont.)

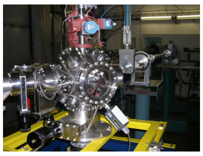
- Form of final CRP results
  - Evaluations (SigmaCalc)
  - Recommended data
- Structure of final CRP report (IAEA publication)

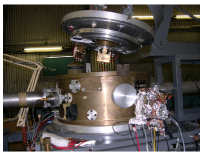
Objectives of this RCM (cont.)

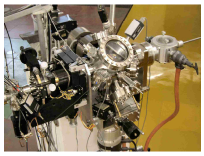
- Overall time scale for rest of CRP
- Summary of this RCM
  - New task list with deadlines

CRP: Development of a Reference Database for Ion Beam Analysis

Measurements of differential cross sections for elastic scattering of ^{1}H and ^{4}He ions from selected light elements







Iva Bogdanović Radović
Laboratory for ion beam interactions
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CRP: Development of a Reference Database for Ion Beam Analysis

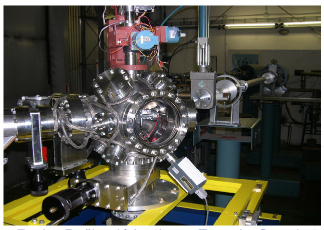
Differential cross sections for elastic scattering of H ions from nitrogen, aluminum and oxygen

- protons and alphas from the 6.0 MV Tandem Van de Graaff accelerator at the Ruđer Bošković Institute in Zagreb

- energy calibration of analyzing 90° magnet was made using narrow resonances $^{27}Al(p,\gamma)^{28}Si$ at 991.88 keV and neutron threshold reaction $^{7}Li(p,n)^{7}Be$ at 1880.6 keV

- secondary calibration points $^{16}O(p,p)^{16}O$ at 3.47 MeV and $^{12}C(p,p)^{12}C$ at 4.808 MeV were used to check calibration

- energy spread of the beam - 0.1%



Target for N measurements

- AlNO film (150 nm) on vitreous graphite substrate (provided by A.R.L. Ramos)

- 6 nm thick Au layer was evaporated onto the target

- energy interval: 2.4 to 5 MeV, with minimum step of 10 keV near the resonances and 25 keV elsewhere, measurement steps were adjusted to N(p,p)N resonances

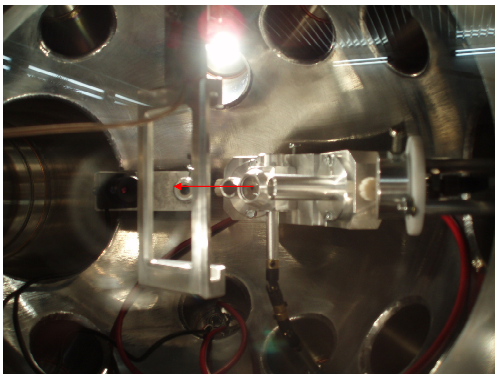
-three surface barrier detectors positioned at 120°, 150° and 165°, 2.5 msr solid angle

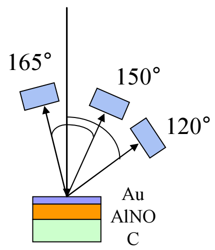
- ΔE in Au and AlNO layer - stopping power data from SRIM 2003

- energy loss of protons in the Au layer varied between 0.5 and 0.3 keV and in the AlN between 5.5 and 3.2 keV for the minimum and maximum projectile energy, respectively

Experimental

TOF-ERDA beam line

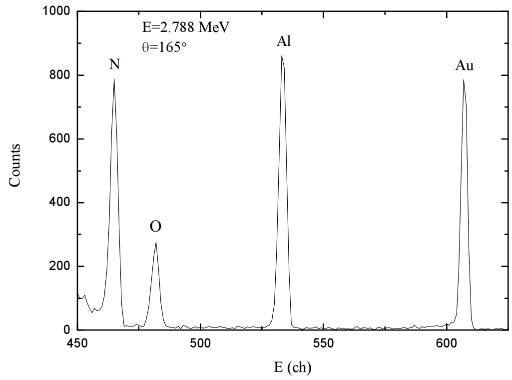




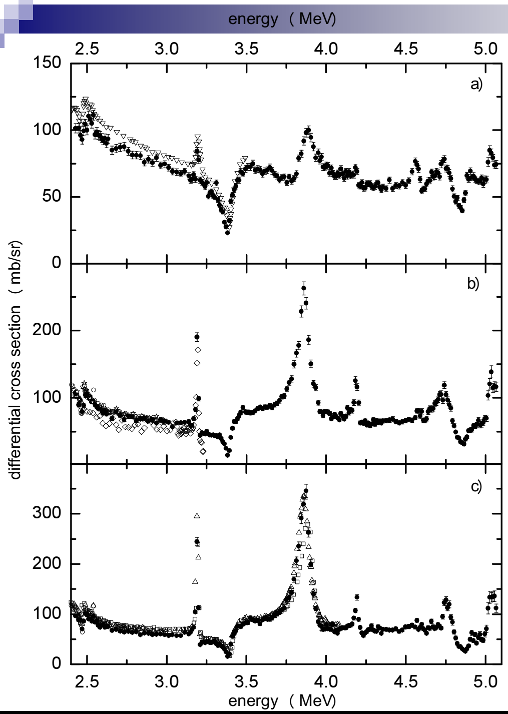
- measurement with 2 MeV He beam to determine N_N,N_{Al}, N_O and N_{Au} (at/cm²)

$$\frac{d\sigma_x}{d\Omega}\left(E-\Delta E_{Au}-\frac{\Delta E_{AlNO}}{2},\theta\right)=\frac{A_x}{A_{Au}}\frac{N_{Au}}{N_x}\frac{d\sigma_{Au}}{d\Omega}\left(E-\frac{\Delta E_{Au}}{2},\theta\right) \qquad x = N,O,Al$$

N(p,p)N



Backscattering spectrum of 2.8 MeV protons from 150 nm thick AlNO film

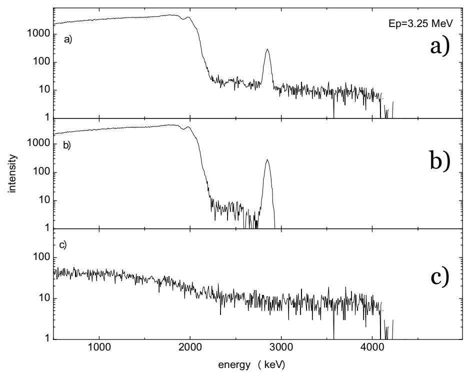


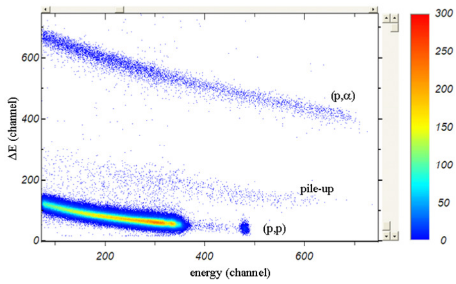
Differential cross sections for elastic backscattering of protons from nitrogen for: a) 120°, b) 150° and c) 165°.

- • - present measurements
- ∇- Bolmgren et al., Phys. Rev. 105 (1957) 210
- □ - Bashkin et al., Phys.Rev. 114 (1959) 1552
- Δ – Olness, et al., Phys.Rev. 112 (1958) 475
- ☆- Ferguson et al., Phys. Rev. 115 (1959) 1655
- ○ – Lambert et al., Phys. Let. 24B (1967) 287
- ◊ - Jiang et al., Surf. Interface Anal. 37 (2005) 374

Benchmark experiment

- thick BN target covered with 8 nm Au
- to separate N(p,p)N spectrum from the background coming from $^{10}B(p,\alpha)\,^{10}B$, $^{11}B(p,\alpha)\,^{11}B$ as well as possible pile-up contribution





ΔE-E telescope

ΔE 15.9 μm Si
E – 300 μm Si

Θ = 150°

a) all
b) (p,p)
c) (p,a)

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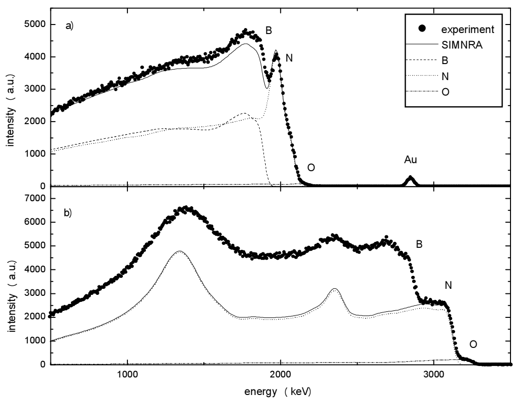
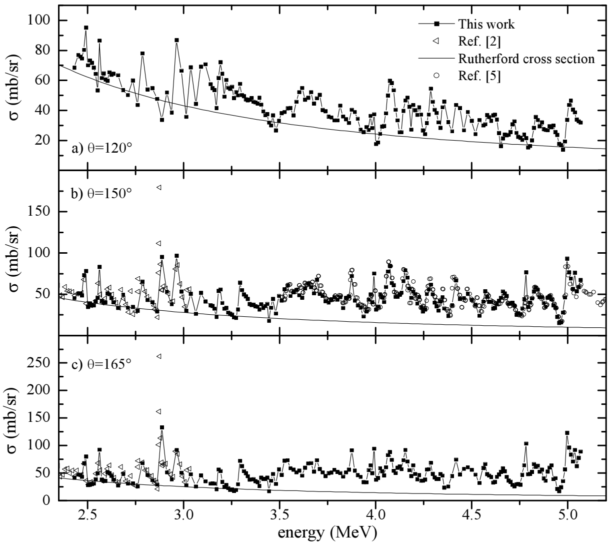
Benchmark experiment



Comparison between experimental and simulated spectra of BN target at 150° and two proton energies: a) 3.24 and b) 4.50 MeV. Solid line (SIMNRA simulation), circles – experimental data.

Al(p,p)Al



- Energy dependence of backscattering cross section for H from Al for (a) θ = 120°, (b) θ = 150° and (c) θ = 165°.

● - present measurements
◁ - M. Chiari et al.,Nucl. Instr. and Meth. B174 (2001) 259
O- R. V. Elliott and H. Spear, Nucl. Phys. 84 (1966) 209 data for 140°

The solid lines represent the Rutherford cross sections.

Z. Siketić, I. Bogdanović Radović, N. Skukan, M. Jakšić and Ana Rita Lopes Ramos , Nucl. Instr. and Meth B , 2007, in press

Ruđer Bošković Institute, Zagreb

Al(p,p)Al

The most detailed, high resolution measurements were done by Nelson et al. , Phys. Rev. C29 (1984) 1656, Phys. Rev. C30 (1984) 755. They have measured differential cross sections in the energy range from 0.92 to 3.05 MeV with an overall resolution of 350 to 400 eV for several scattering angles.

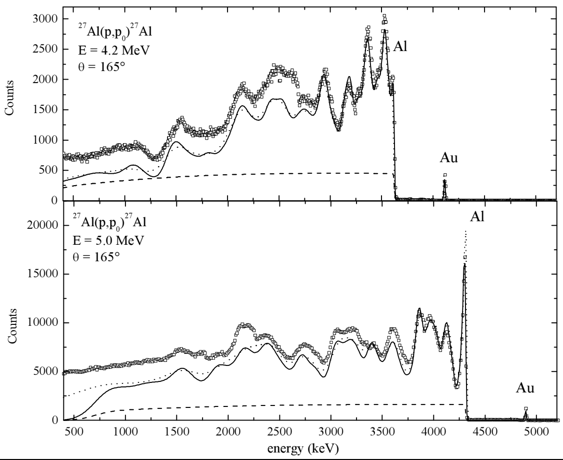
- energy resolution of our accelerator, target thickness as well as used energy steps are too wide to cover in all details the complex resonant structure of Al(p,p)Al scattering

Gurbich and his co-authors (A. F. Gurbich, N. P. Barradas, C. Jeynes, E. Wendler: NIMB 190 (2002) 237) have shown that in the case of complicated resonant structure spectra can be adequately simulated only if the excitation function is known in every detail (Nelson measurements).

Benchmark experiment

- 4.2 and 5.0 MeV protons on thick pure Al target covered with 9 nm Au

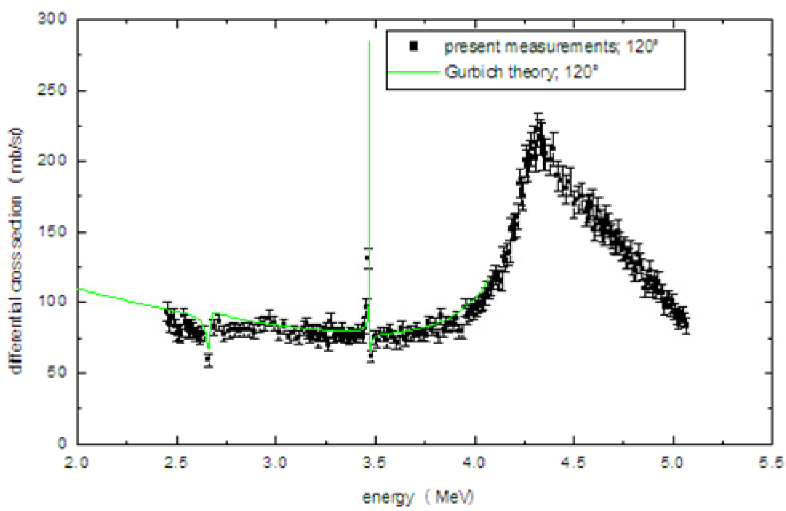
- to examine if Al excitation function measured in present work and incorporated into SIMNRA and NDF can simulate the experimentally obtained Al thick target yield



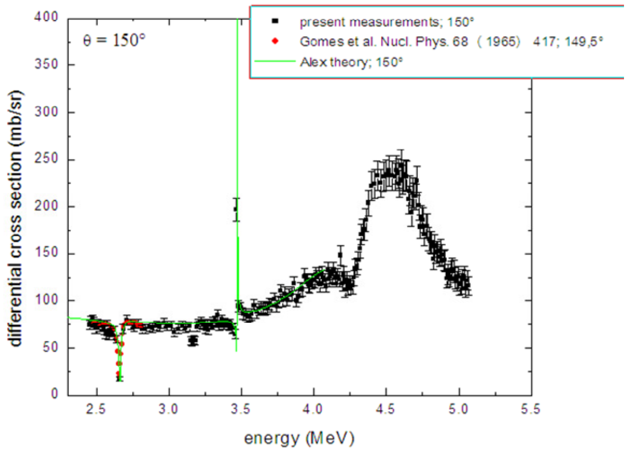
Disagreement caused by:

-unknown contribution coming from $^{27}Al(p,p1)$, $^{27}Al(p,p2)$, $^{27}Al(p,\alpha_0)$, and $^{27}Al(p,\alpha_1)$ reactions
-improper knowledge of fine resonant structure
-in the low energy part multiple and slit scattering

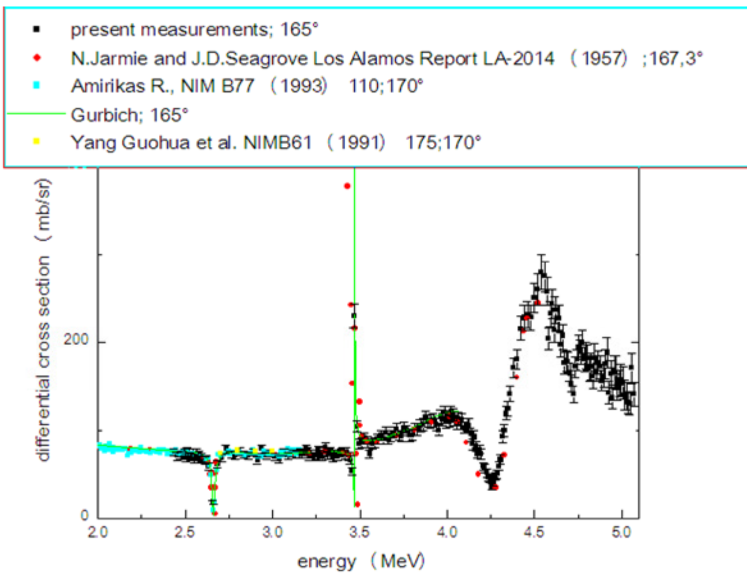
O(p,p)O 120°



O(p,p)O 150°



O(p,p)O 165°



Sources of errors

- the statistical errors of the counting rates of peak areas for backscattered protons and error of determining N_x/N_{Au} ratio
- errors of the detector angular settings were estimated to be negligible

- uncertainties due to dead time, solid angle and improper charge measurement are eliminated with the normalization to backscattering protons from gold

- it is evident that in the case of sharp resonance structure even a few keV energy shift may result in a dramatic change in the cross section, largest experimental error arose from the energy spread of the proton beam (0.1% of incident energy)

Differential cross sections for elastic scattering of He ions from nitrogen

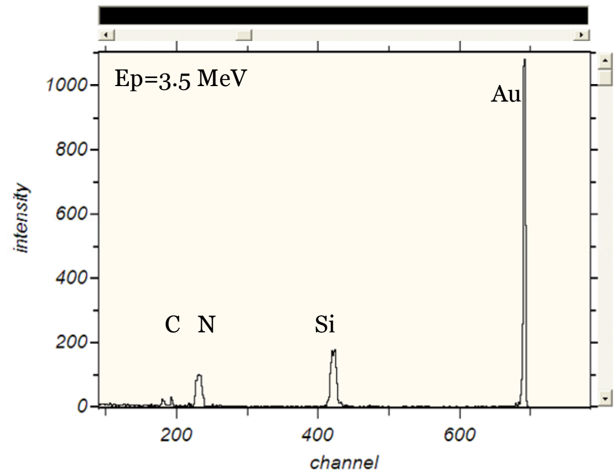
- For energies 2.5 – 8 MeV
- Three scattering angles 120°, 150° and 165°

-Target:

1. AlNO on thick carbon ΔE – from 57 keV (2.5 MeV) to 33 keV (6 MeV)
2. Thin melamine ($C_3H_6N_6$) target on 20 μg/cm² C – unstable
3. Si_3N_4 100 nm thick + 6 nm Au

Stable under beam irradiation

Ruđer Bošković Institute, Zagreb, Croatia



Backscattering of 3.5 MeV protons from 100 nm Si3N4 target

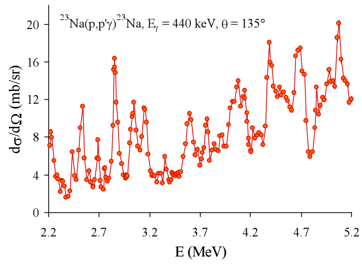
Status of IBA CRP experimental activity in Florence: Nov.2005 – Jun.2007

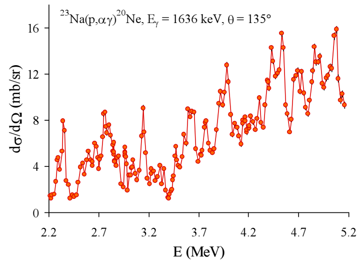
Massimo Chiari (I.N.F.N Florence)

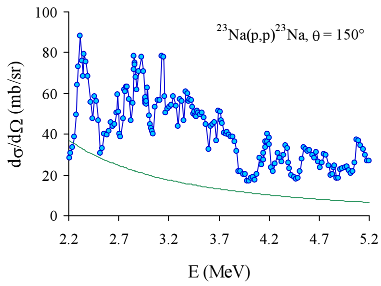
Scattering chamber installation

- The multi-detector scattering chamber has not been installed yet.
- Beam optics calculation for the scattering chamber beamline have been completed.
- Crucial equipments for the beamline (i.e. remote controlled, high power 4-sectors slit) have to be purchased.

p+Na cross-section data: elastic scattering & γ-ray emission

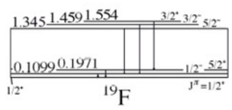


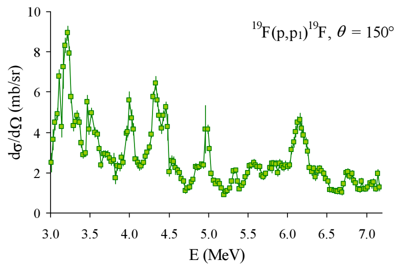


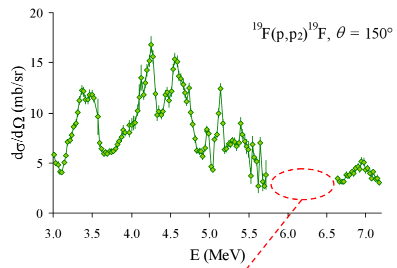


Abstract submitted to IBA2007

p+^{19}F inelastic scattering cross-section data



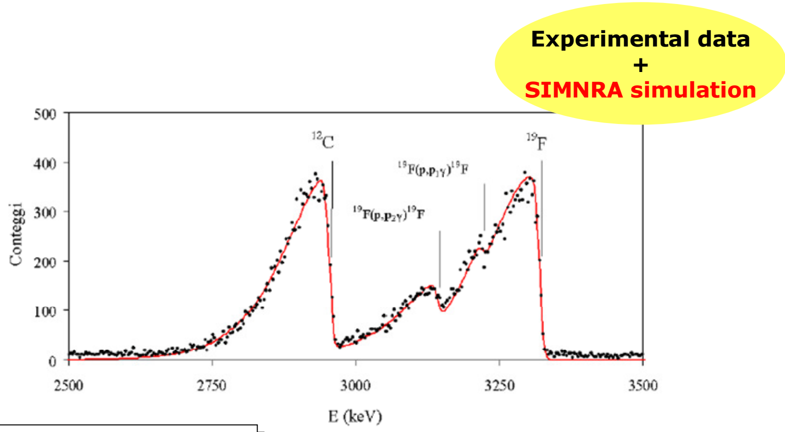




Peak overlapping with p+^{16}O elastic scattering peak

DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS
Research Co-ordination Meeting, Vienna, 18-21 June 2007

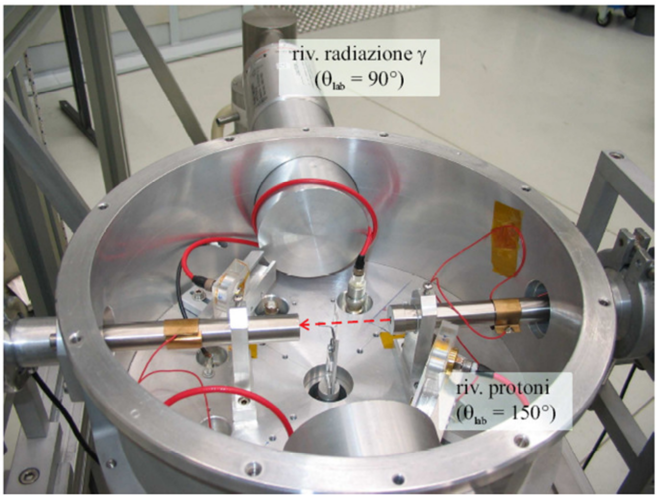
PESA for C,N,O determination in particulate matter samples



4.05 MeV proton energy
150° scattering angle
650 μg/cm² Teflon (CF_2) filter

DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS
Research Co-ordination Meeting, Vienna, 18-21 June 2007

"Small" IBA scattering chamber



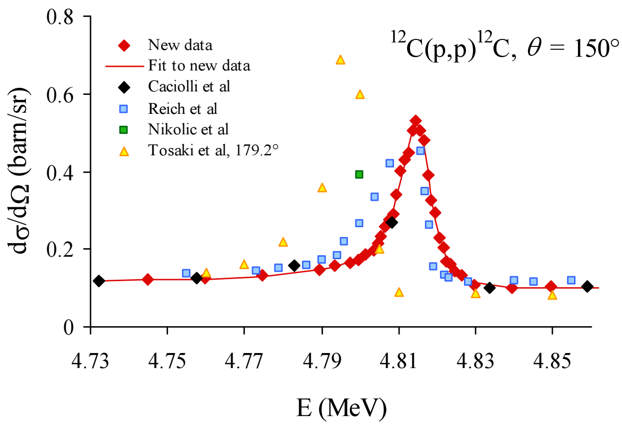
DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS
Research Co-ordination Meeting, Vienna, 18-21 June 2007

4.808 MeV resonance in $^{12}C(p,p)^{12}C$ cross-section

13 μg/cm² self-supporting C target
(ΔE = 1 keV)

	E_p(keV)	Γ_{CM}(keV)
$^{12}C(p,p)^{12}C$	4808±10	11.0±0.5

4815±2 fit
±5 energy calibration



Cross-section data

Statistical uncertainty: 1.5% - 2%

Normalisation factor uncertainty: 2.5%

DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS
Research Co-ordination Meeting, Vienna, 18-21 June 2007

Performed and foreseen diff. cross-section measurements

- ✓ Proton elastic and inelastic scattering on ^{19}F (E_p = 2.5 – 3.3 MeV, θ = 150°).
- ✓ 2.3 MeV γ-ray emission induced by proton on ^{14}N (E_p = 3.5 – 5.0 MeV, θ = 135°).
- ? Proton elastic scattering on N (E_p > 3 MeV, θ = 150° + one angle more, target: Au on 55 μg/cm² Si_3N_4).

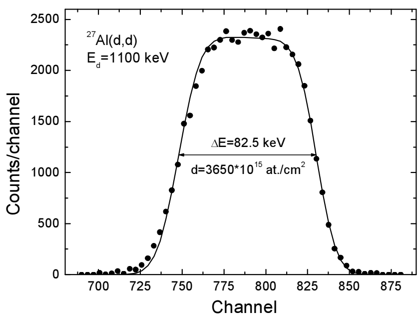
DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS
Research Co-ordination Meeting, Vienna, 18-21 June 2007

Measurements of the $^{27}Al(d,\alpha)^{25}Mg$ excitation functions

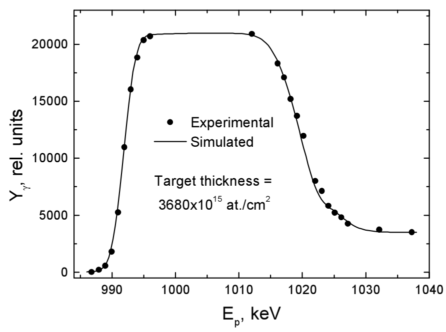
A. Gurbich
Institute of Physics and Power Engineering
Obninsk, Russia

Determination of the target thickness

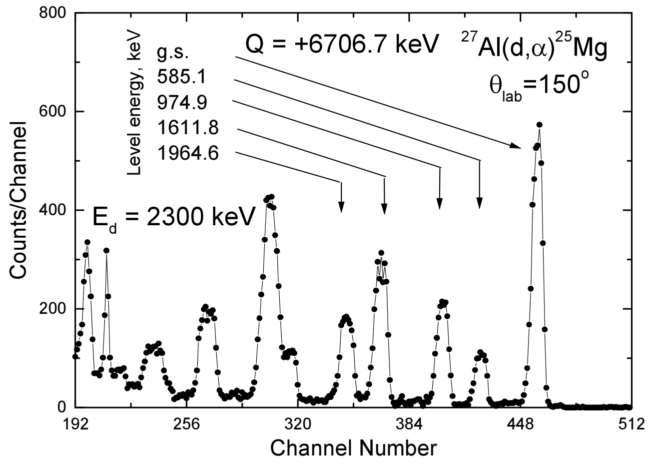
RBS



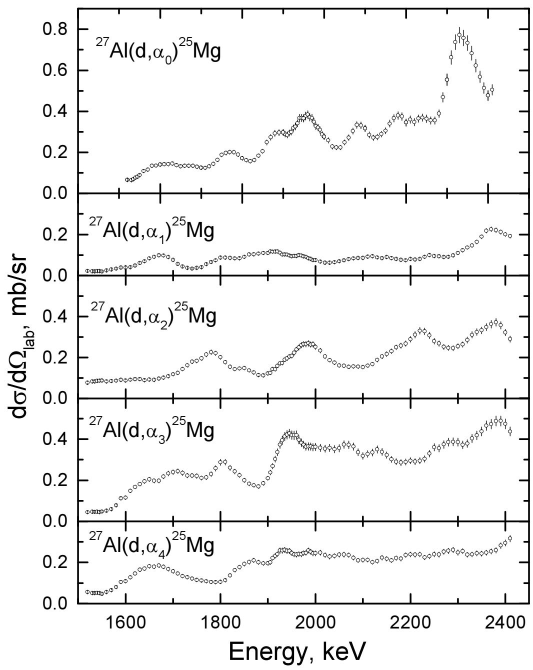
PIGE



A typical spectrum of α-particles for $^{27}Al(d,\alpha)^{25}Mg$ reaction



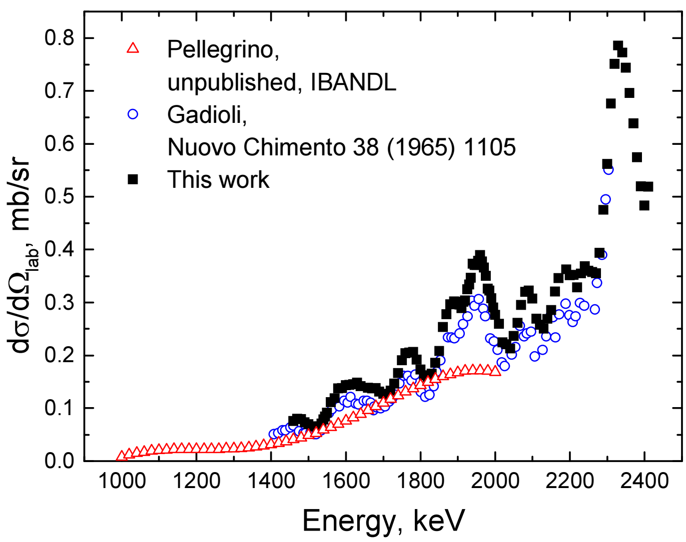
The excitation functions for $^{27}Al(d,\alpha)^{25}Mg$ reaction



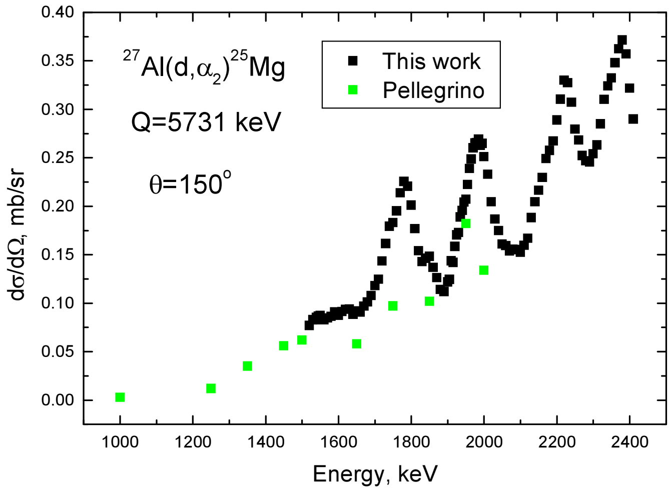
Uncertainty Budget

Source	Uncertainty	Comment
Current integration	2%	Calibrated with a precise amperemeter
Solid angle	2.5%	Direct geometrical measurement
Target thickness	2%	Two independent measurements by PIGE and RBS agree within 0.8%
Statistics	1-3%	1σ
Total	<4.5%	
Beam energy	0.2%	Calibration by the ^{27}Al(p,γ) resonance at 991.9 keV and the ^{7}Li(p,n) reaction threshold at 1880.4 keV
Detector angle	±1°	

The comparison of the present results with other data for $^{27}Al(d,\alpha_0)^{25}Mg$

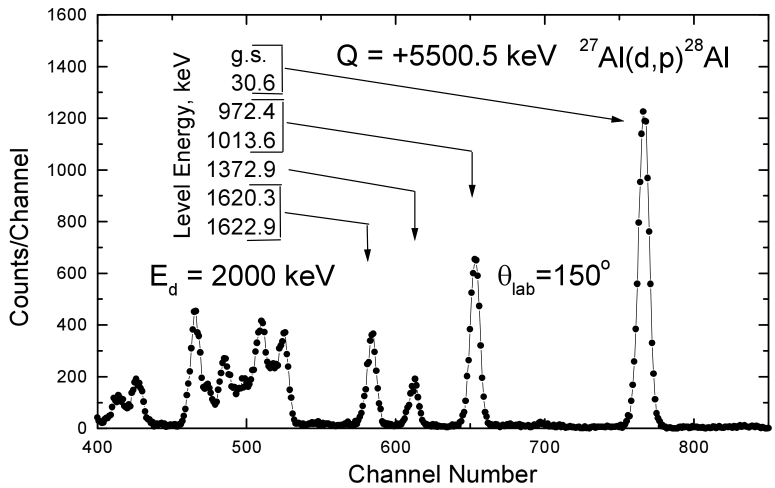


The comparison of the present results with Pellegrino's data for $^{27}Al(d,\alpha_2)^{25}Mg$

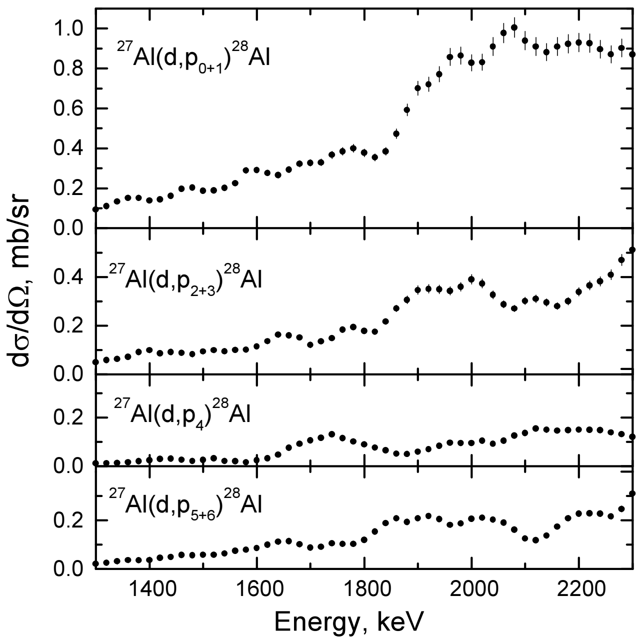


Measurements of the $^{27}Al(d,p)^{28}Al$ excitation functions

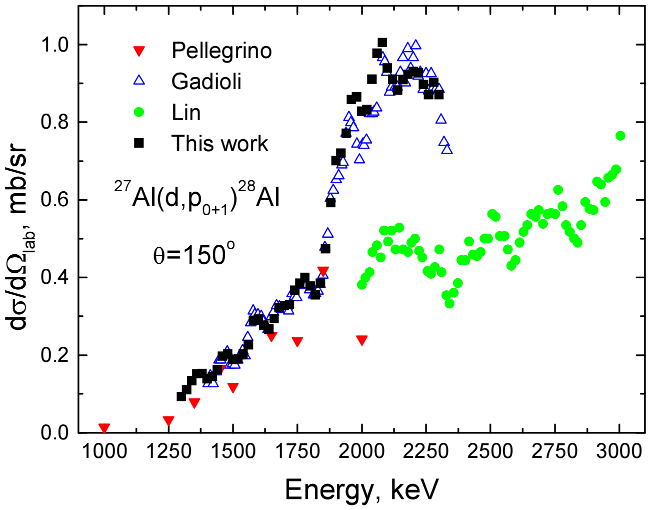
A typical spectrum of protons for the $^{27}Al(d,p)^{28}Al$ reaction



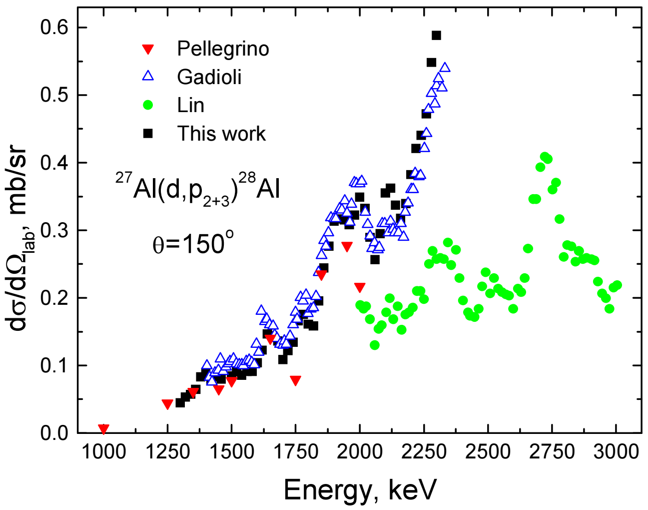
The excitation functions for $^{27}Al(d,p)^{28}Al$ reaction



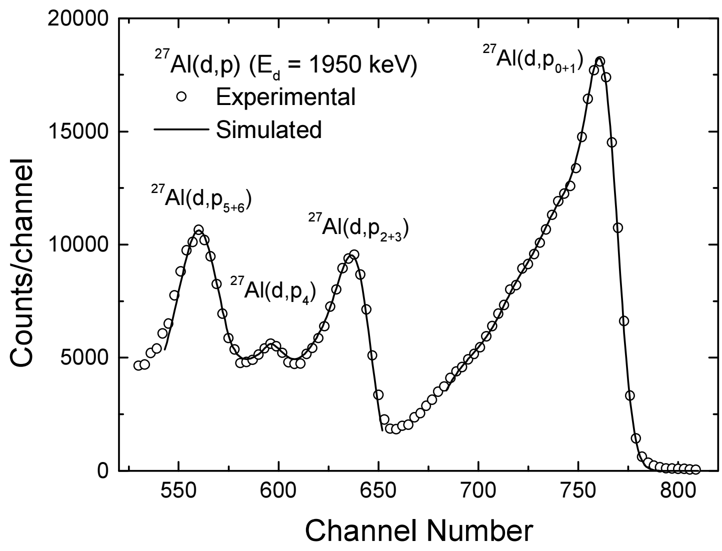
The comparison of the present results with other data for $^{27}Al(d,p_{0+1})^{28}Al$



The comparison of the present results with other data for $^{27}Al(d,p_{2+3})^{28}Al$

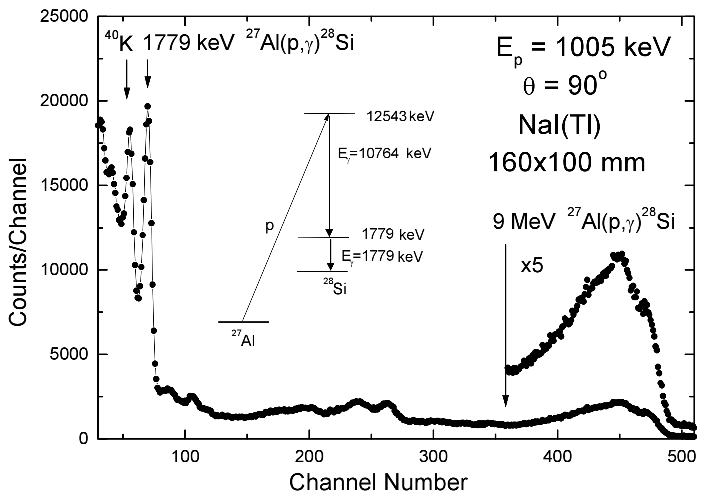


Benchmark



Measurements of the $^{27}Al(p,\gamma)^{28}Si$ thick target yield

A typical pulse-height spectrum for γ-rays emitted in p + ^{27}Al reaction

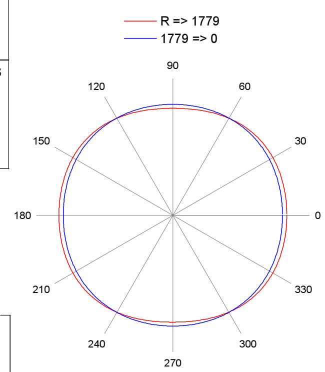


Characteristics of the gamma rays emitted in the decay of the ^{27}Al resonance level excited at E_p=991.9 keV

Transition (level energies in MeV)	Gamma-ray energies, keV	Gamma-ray intensities (%)	Coefficient A_2	Coefficient A_4
R→1778.9	10764	94.0±9.4 [Azuma et al] 94.1±9.4 [Scott & Lusby] 94.8±1.5 [Anttila et al.] 95 [Meyer et al.]	0.051±0.005	-0.032±0.005
1778.9→g.s.	1778.9	77±7.7 [Azuma et al.] 72.4±3.6 [Scott & Lusby] 76.6±1.5 [Anttila et al.] 75 [Meyer et al.]	0.000±0.003	-0.016±0.003

R.E.Azuma et al. Can. J. Phys. 44 (1966) 3075
H.L.Scot, T.F.Lusby, NIM 131 (1975) 517
A.Anttila et al. NIM 147 (1977) 501
M.A.Meyer et al. Nucl. Phys. A250 (1975) 235

$$W(\theta) = 1 + A_2 P_2(\cos\theta) + A_4 P_4(\cos\theta)$$

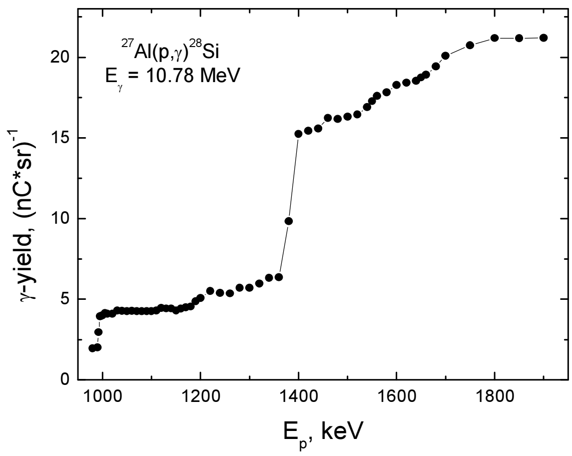


Characteristics of the gamma source used in the work

Major radionuclide	Initial radioactivity according to certificate, kBk	Uncertainty of the acivity, %, (p=0.95)	Half-decay	Radioactivity on the day of the measurement, kBk	Gamma-ray energy, keV	Gamma-ray intensity, %
^{88}Y	276.0 on 01.12.2003	1.7	106.65 d	0.358	898 1836 2734	93.7±0.3 99.2±0.3 0.71±0.07

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{I_2}{I_1}\frac{N_1}{N_2} M(\theta)$$

The p + ^{27}Al γ-ray yield for E_γ=9-11 MeV



Measurements of the ^{14}N(d,α)^{12}C excitation functions

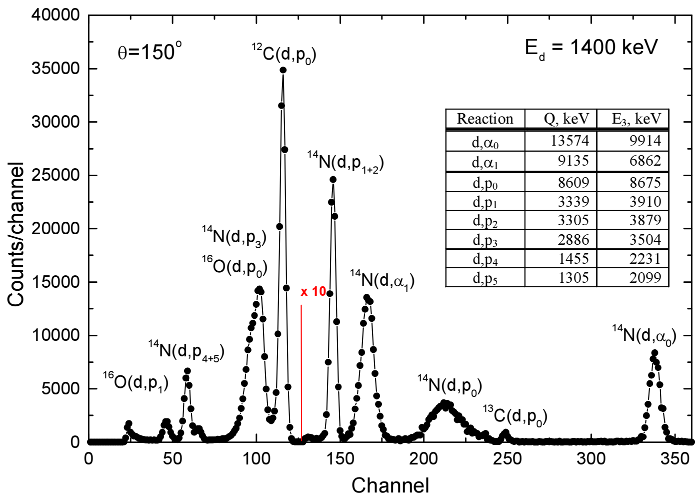
Experimental details

Target: $C_5H_5N_5$ (~1.4×10^{18} cm^{-2}) evaporated on the silver backing 0.3 mg/cm^2 thick.

Normalization: at 972 keV against Davies J.A., Jackman T.E., Plattner, H., Bubb I. Absolute calibration of ^{14}N(d,α) and ^{14}N(d,p) reactions for surface adsorption studies. // Nucl. Instr. and Meth. 218 (1983) 141.

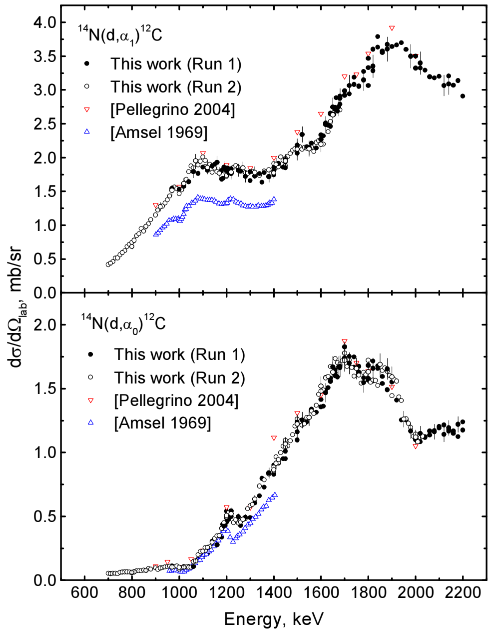
Typical d + ^{14}N spectrum

(12 μm aluminum filtering foil, low bias voltage)



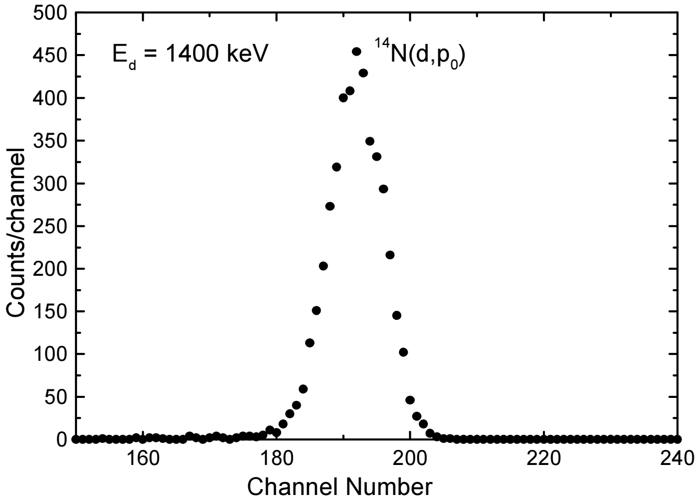
Reaction	Q, keV	E_3, keV
d,α_0	13574	9914
d,α_1	9135	6862
d,p_0	8609	8675
d,p_1	3339	3910
d,p_2	3305	3879
d,p_3	2886	3504
d,p_4	1455	2231
d,p_5	1305	2099

The excitation functions for the $^{14}N(d,\alpha)^{12}C$ reaction

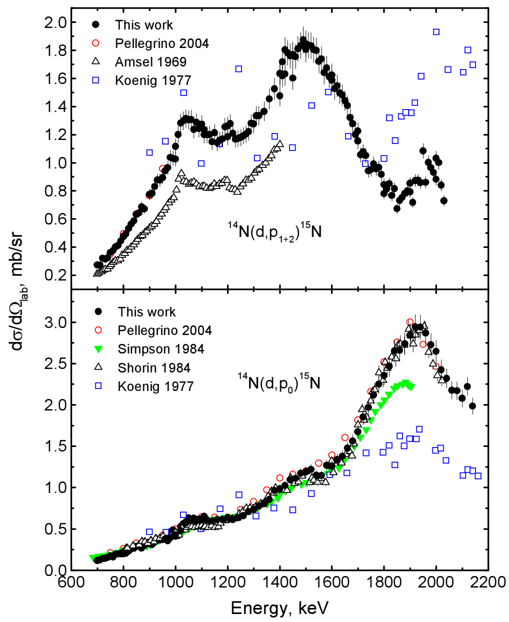


Measurements of the $^{14}N(d,p)^{15}N$ excitation functions

Typical d + ^{14}N spectrum (300 μm aluminum filtering foil)



The excitation functions for the $^{14}N(d,p)^{15}N$ reaction



$^{nat}Mg(p,p)^{nat}Mg$ cross-sections: benchmark experiment

Chris Jeynes and Alex Gurbich

University of Surrey Ion Beam Centre, Guildford

Institute for Physics and Power Engineering, Obninsk

IAEA CRP on elastic scattering cross-sections for IBA

18-21 June 2007, Wien

Contents

- Mg(p,p)Mg
- C(p,p)C example: C implant in Si
- CuInAlSe/glass example: Na(p,p)Na???
- SigmaCalc O(a,a)O: bad at top of range?
- Si(a,a)Si??
- H in GaN ERD: interference?

DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf

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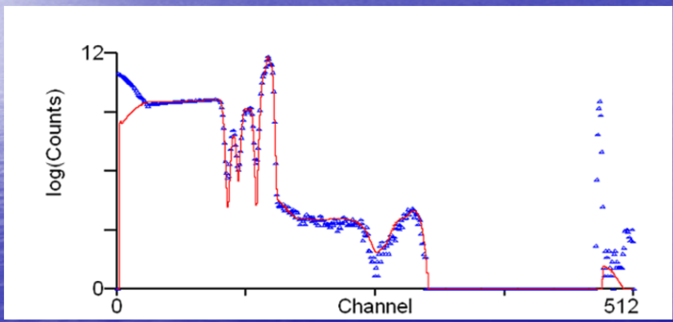
Mg(p,p)Mg: measurement conditions

- Bulk Mg sample
- Multilayer Au/Mg/Au/Mg/Au/C sample



DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf

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Mg(p,p)Mg: high precision measurements

Table 1: Fitted offset for the Au/Mg ML sample
(with fixed gain and (246, 100)TFU dead layer

Samples	Terminal	Beam	Offset (keV)	
saumg.spc	kV	keV	Adetector	Bdetector
31	335	706.75	5.6	0.6
32	335	706.75	5.4	0.3
33	400	840	4.2	0.9
34	450	942.5	5.9	1.7
35	550	1147.5	5.5	1.2
36	650	1352.5	5.7	1.4
37	725	1506	5.1	1.5
38	725	1506	5.1	1.5
39	845	1752	4.8	2.3
41	400	840	5.1	1.2
average			5.2	1.3
stdev			0.5	0.6

Electronic gain determined for whole data set using PHD correction (Lennard):

Gain uncertainty <0.1%

Offset uncertainty ~600eV

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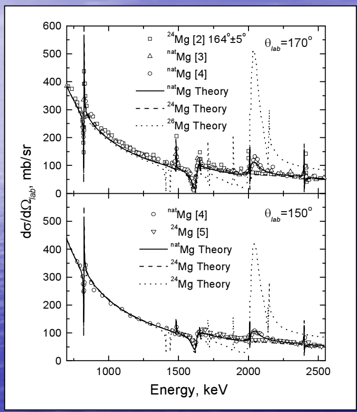
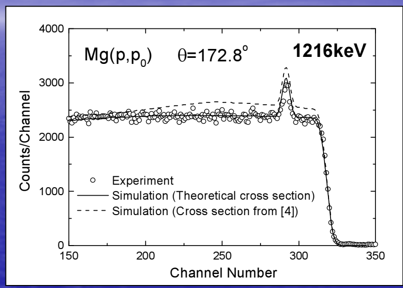
Mg(p,p)Mg: data, theory & benchmark





DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf

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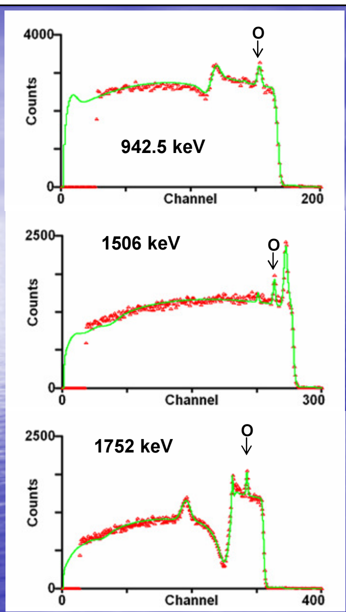

Mg(p,p)Mg, benchmark

942keV: shows resonance at 823keV

1506keV: shows resonance at 1483keV

1752keV: shows resonances at 1483keV and 1650keV

(68TFU C & 800TFU MgO on surface)

DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf

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Mg(p,p)Mg, benchmark (multilayer sample)

Table 2: Pileup corrected data quantified by comparison with simulation

Thickness given in thin film units (TFU: 10^{15}atoms/cm^2). Detectors A and B have scattering angles 172.8^0 and 148.2^0

	Energy	**Au**		**Mg**		**O**		**Mg/Au**	**Au**	**Mg**	**O**
Detector:		A	B	A	B	A	B		A/B	A/B	A/B
Spectrum	**keV**	TFU	TFU	TFU	TFU	TFU	TFU	TFU			
1	**706.75**	276	269	974	944	376	389	959	1.025	1.032	0.967
2	**706.75**	279	270	967	974	407	397	962	1.034	0.993	1.027
3	**840**	278	269	965	944	376	369	950	1.036	1.022	1.018
4	**942.5**	282	269	972	925	338	353	939	1.049	1.051	0.958
5	**1147.5**	283	271	998	933	309	311	949	1.042	1.070	0.993
6	**1352.5**	285	272	960	929	321	311	922	1.047	1.033	1.033
7	**1506**	285	275	953	910	320	294	907	1.035	1.047	1.091
8	**1506**	288	274	936	923	312	294	901	1.050	1.014	1.060
9	**1752**	279	272	1005	984	304	303	983	1.025	1.021	1.004
10	**840**	280	270	954	931	380	366	933	1.035	1.024	1.038
Average counting											
statistics uncertainty		0.3%	0.2%	1.1%	0.7%	2.3%	1.3%	1.4%	0.4%	1.3%	2.7%
Average		281	271	968	940	344	339	940	1.038	1.031	1.019
Standard deviation		1.3%	0.8%	2.1%	2.5%	10.7%	11.9%	2.7%	0.9%	2.1%	4.0%

DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf

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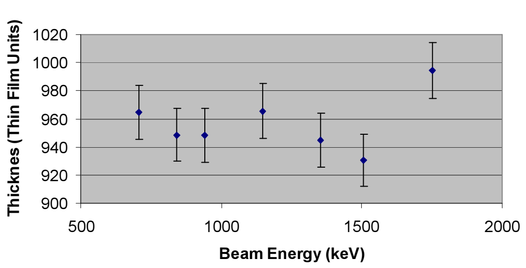
Mg(p,p)Mg, multilayer sample conclusions

Figure 6: Variation of Apparent Mg content



DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf

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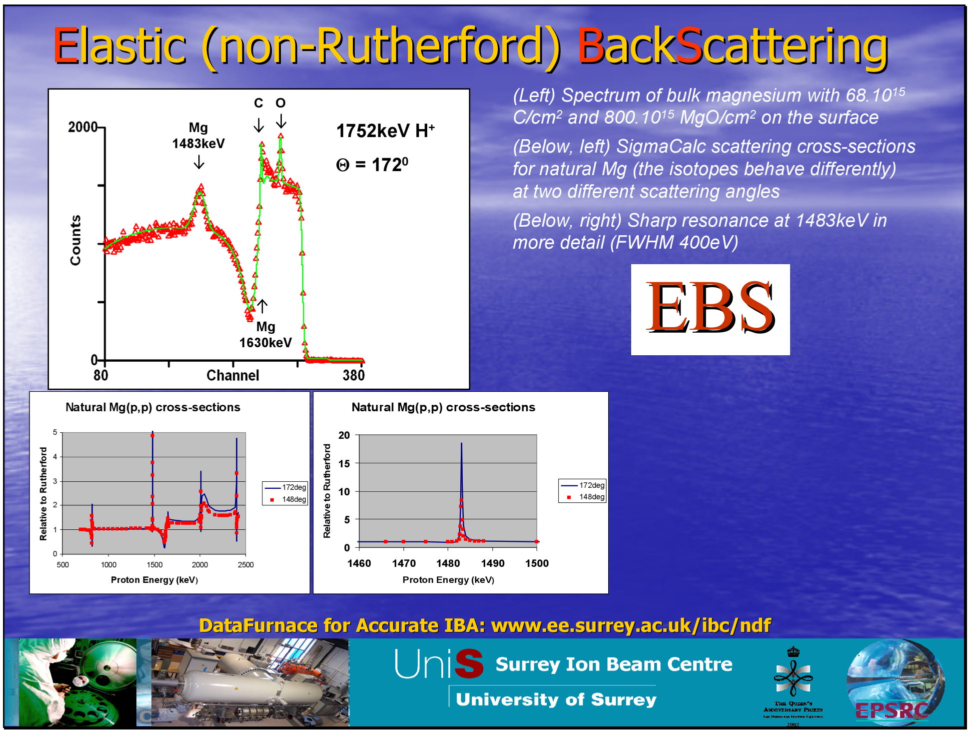
Elastic (non-Rutherford) BackScattering
(Left) Spectrum of bulk magnesium with 68.10[15] C/cm[2] and 800.10[15] MgO/cm[2] on the surface
(Below, left) SigmaCalc scattering cross-sections for natural Mg (the isotopes behave differently) at two different scattering angles
(Below, right) Sharp resonance at 1483keV in more detail (FWHM 400eV)
EBS
1752keV H+
Θ = 172°
Mg 1483keV
C
O
Mg 1630keV
Counts
Channel
2000
0
80
380
Natural Mg(p,p) cross-sections
Relative to Rutherford
Proton Energy (keV)
172deg
148deg
DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf
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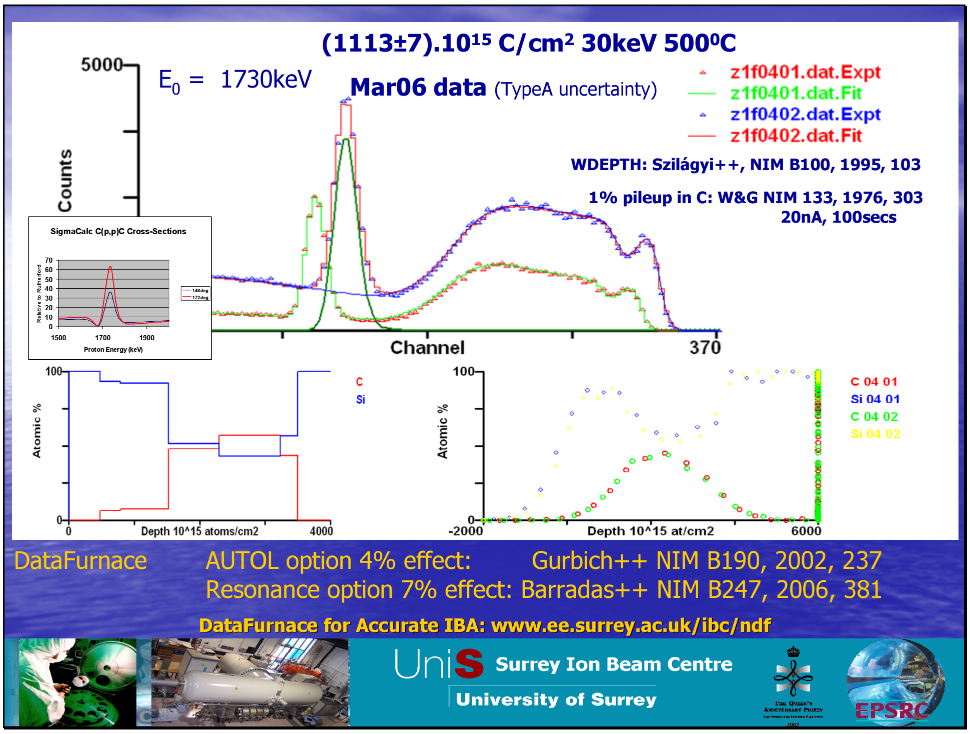
(1113±7).10[15] C/cm[2] 30keV 500°C
E0 = 1730keV
Mar06 data (TypeA uncertainty)
z1f0401.dat.Expt
z1f0401.dat.Fit
z1f0402.dat.Expt
z1f0402.dat.Fit
WDEPTH: Szilágyi++, NIM B100, 1995, 103
1% pileup in C: W&G NIM 133, 1976, 303
20nA, 100secs
Counts
5000
Channel
370
SigmaCalc C(p,p)C Cross-Sections
Proton Energy (keV)
Atomic %
Depth 10^15 atoms/cm2
C
Si
Depth 10^15 at/cm2
C 04 01
Si 04 01
C 04 02
Si 04 02
DataFurnace AUTOL option 4% effect: Gurbich++ NIM B190, 2002, 237
Resonance option 7% effect: Barradas++ NIM B247, 2006, 381
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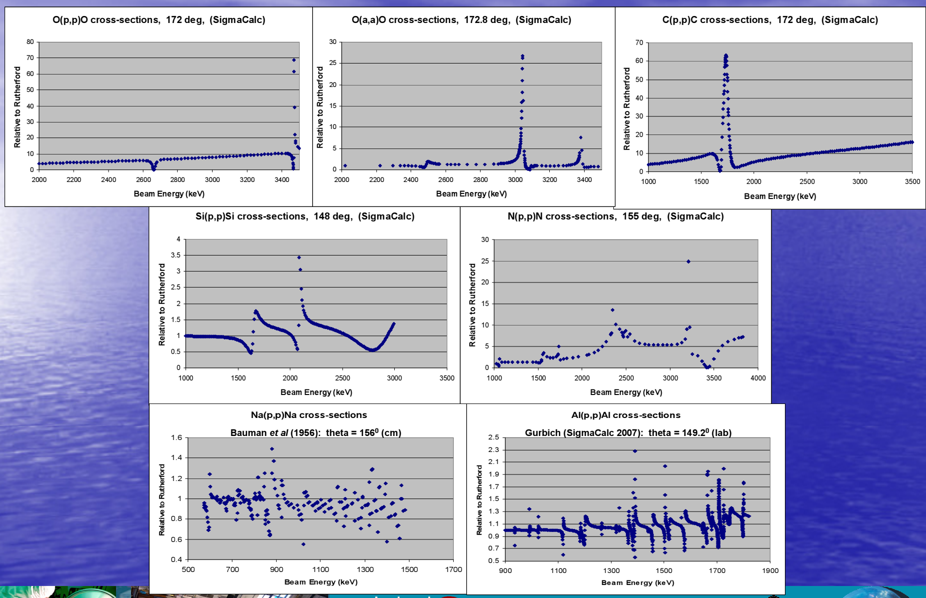
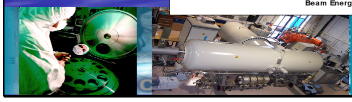
EBS cross-sections





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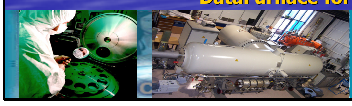
Contents

- The Inverse Problem in IBA (RBS/EBS/ERD/NRA) and Simulated Annealing (DataFurnace code)
- Accurate Thin Film Depth Profiling in IBA
- PIXE + particle scattering spectroscopies for depth profiling
- Example 1: Pb glass standard – sanity check
- Example 2: CuInAl thin films (photovoltaics)
- Conclusions

DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf



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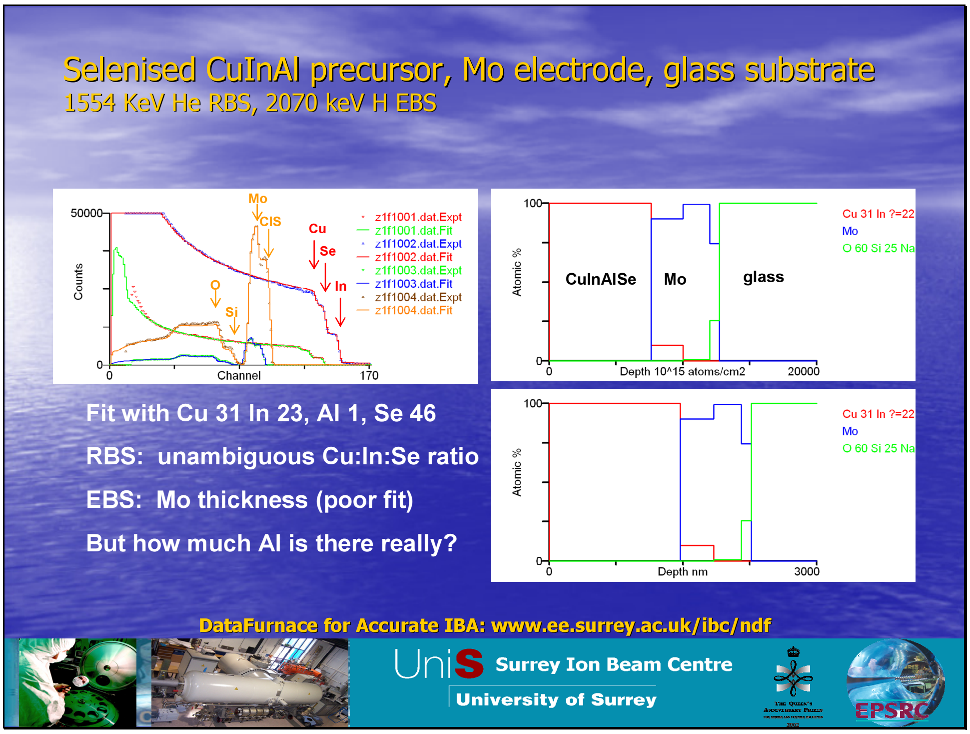

Selenised CuInAl precursor, Mo electrode, glass substrate
1554 KeV He RBS, 2070 keV H EBS
50000
Counts
Channel
0
170
Mo
CIS
Cu
Se
In
O
Si
z1f1001.dat.Expt
z1f1001.dat.Fit
z1f1002.dat.Expt
z1f1002.dat.Fit
z1f1003.dat.Expt
z1f1003.dat.Fit
z1f1004.dat.Expt
z1f1004.dat.Fit
100
Atomic %
CuInAlSe
Mo
glass
Depth 10^15 atoms/cm2
20000
Cu 31 In ?=22
Mo
O 60 Si 25 Na
Depth nm
3000
Fit with Cu 31 In 23, Al 1, Se 46
RBS: unambiguous Cu:In:Se ratio
EBS: Mo thickness (poor fit)
But how much Al is there really?
DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf
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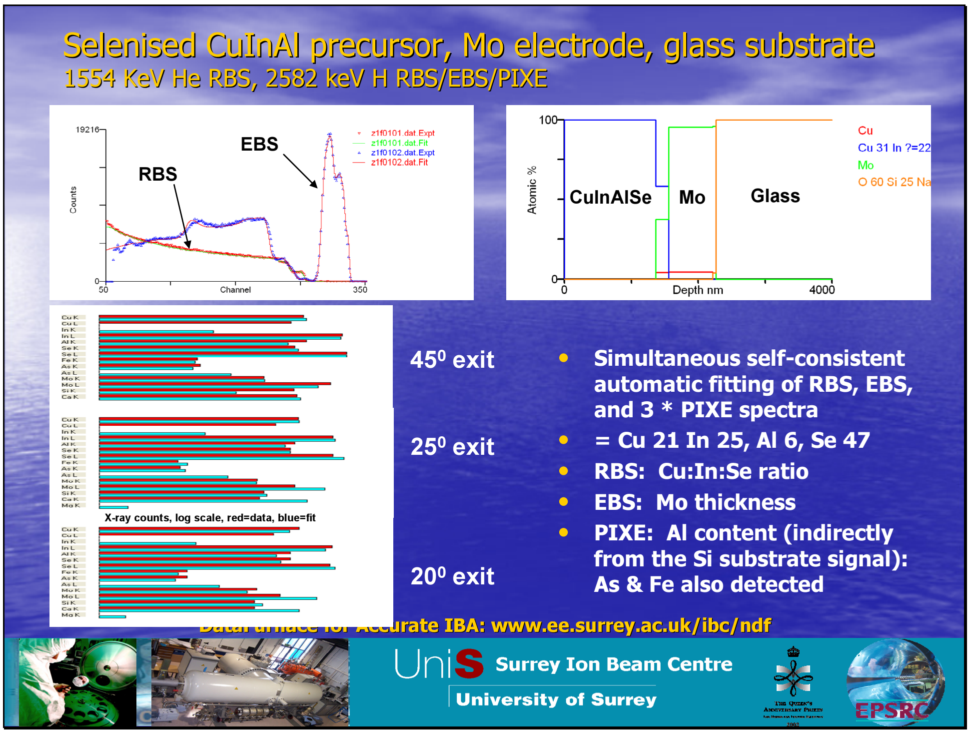

Selenised CuInAl precursor, Mo electrode, glass substrate
1554 KeV He RBS, 2582 keV H RBS/EBS/PIXE
19216
Counts
Channel
50
350
RBS
EBS
z1f0101.dat.Expt
z1f0101.dat.Fit
z1f0102.dat.Expt
z1f0102.dat.Fit
100
Atomic %
CuInAlSe
Mo
Glass
Depth nm
4000
Cu
Cu 31 In ?=22
Mo
O 60 Si 25 Na
X-ray counts, log scale, red=data, blue=fit
45⁰ exit
25⁰ exit
20⁰ exit
Simultaneous self-consistent automatic fitting of RBS, EBS, and 3 * PIXE spectra
= Cu 21 In 25, Al 6, Se 47
RBS: Cu:In:Se ratio
EBS: Mo thickness
PIXE: Al content (indirectly from the Si substrate signal): As & Fe also detected
DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf
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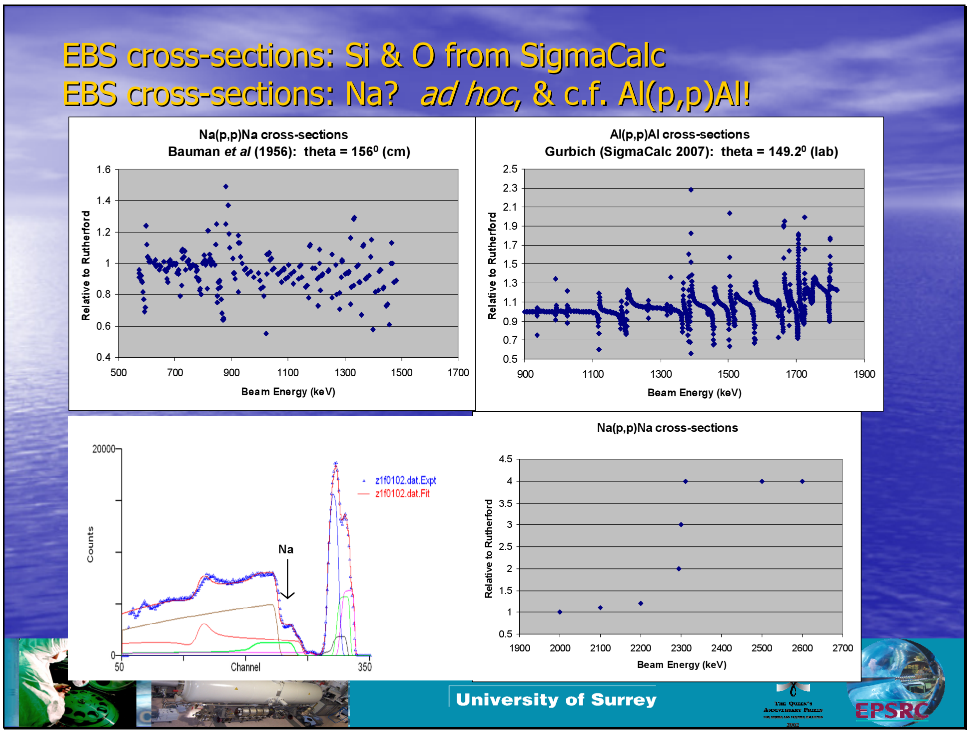
EBS cross-sections: Si & O from SigmaCalc
EBS cross-sections: Na? ad hoc, & c.f. Al(p,p)Al!
Na(p,p)Na cross-sections
Bauman et al (1956): theta = 156⁰ (cm)
Relative to Rutherford
Beam Energy (keV)
Al(p,p)Al cross-sections
Gurbich (SigmaCalc 2007): theta = 149.2⁰ (lab)
Relative to Rutherford
Beam Energy (keV)
z1f0102.dat.Expt
z1f0102.dat.Fit
Na
Counts
Channel
Na(p,p)Na cross-sections
Relative to Rutherford
Beam Energy (keV)
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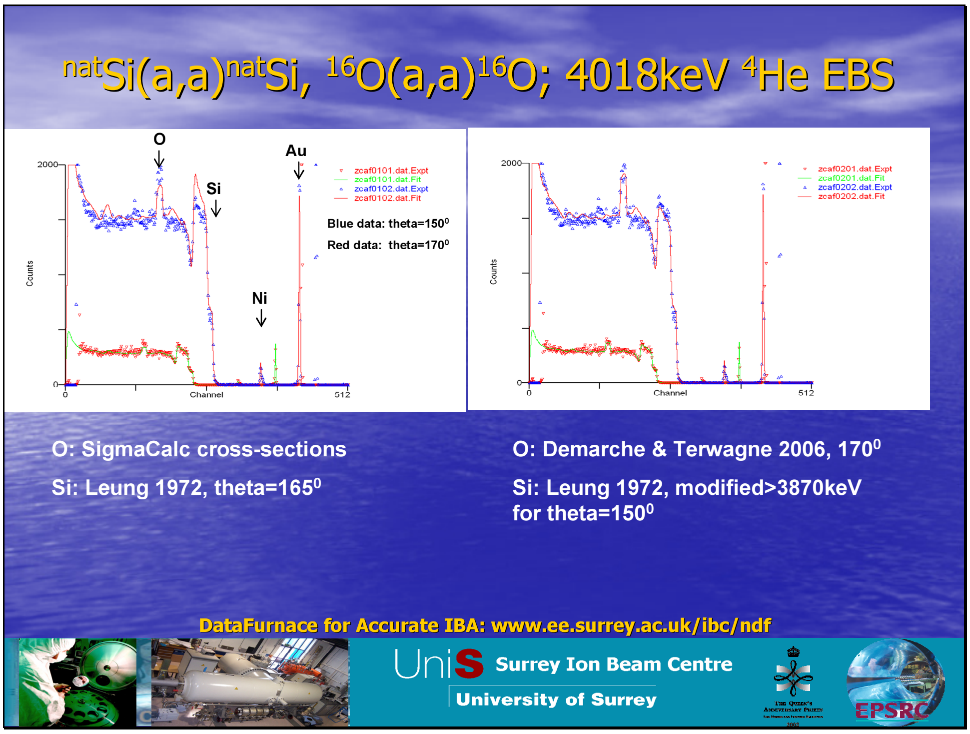
natSi(a,a)natSi, 16O(a,a)16O; 4018keV 4He EBS
O
Au
Si
Ni
zcaf0101.dat.Expt
zcaf0101.dat.Fit
zcaf0102.dat.Expt
zcaf0102.dat.Fit
Blue data: theta=150⁰
Red data: theta=170⁰
Counts
Channel
zcaf0201.dat.Expt
zcaf0201.dat.Fit
zcaf0202.dat.Expt
zcaf0202.dat.Fit
O: SigmaCalc cross-sections
Si: Leung 1972, theta=165⁰
O: Demarche & Terwagne 2006, 170⁰
Si: Leung 1972, modified>3870keV for theta=150⁰
DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf
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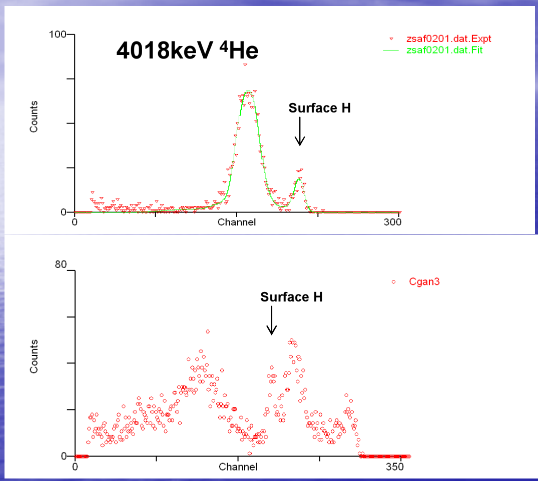
H in GaN: ERD interferences?



60keV H in Si ERD: 24um range foil, 30^0 scattering

60keV H in GaN: interference from ^{14}N(a,p)^{17}O??

Cross-sections only available for 135^0

DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf

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Conclusions

- Mg(p,p)Mg:
  - (i) High precision measurements 700keV - 1750keV with gain determined <0.1%;
  - (ii) SigmaCalc confirmed at 2.2% accuracy;
  - (iii) 1483keV resonance @400eV too narrow to determine directly: indirect thick film EBS works
- C(p,p)C example: C implant in Si determined at <1% precision with SigmaCalc using DEPTH, W&G pileup, NDF AUTOL, NDF resonance
- CuInAlSe/glass example: Na(p,p)Na needed!
- SigmaCalc O(a,a)O: bad at top of range
- SigmaCalc Si(a,a)Si needed
- 60keV H in GaN (He ERD): interference from ^{14}N(a,p)^{17}O (no Xsections at forward angle!)

DataFurnace for Accurate IBA: www.ee.surrey.ac.uk/ibc/ndf

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Report on the $^{10}B(d,\alpha)$, $^{10}B(d,p)$ and $^{32}S(d,p)$ Reactions at Detector Angles between 135 and 170 degrees for the Energy Range $E_{d,Lab}$=900-2600 keV

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[1] Department of Physics, National Technical University of Athens, Zografou Campus 157 80, Athens, Greece
[2] Department of Chemistry, Aristotle University, GR-54006, Thessaloniki, Greece
[3] Institute of Nuclear Physics, TANDEM Accelerator, N.C.S.R. 'Demokritos', Aghia Paraskevi 153 10, Athens, Greece

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TOPICS:

1. EXPERIMENTAL SETUP AND PROCEDURE
2. ANALYSIS AND DISCUSSION
3. CONCLUSIONS
4. CURRENT SITUATION / FUTURE PERSPECTIVES

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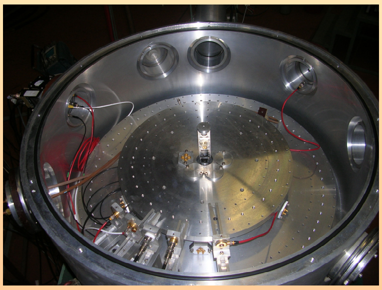
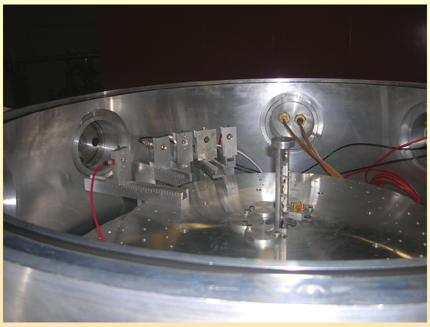
EXPERIMENTAL SETUP:

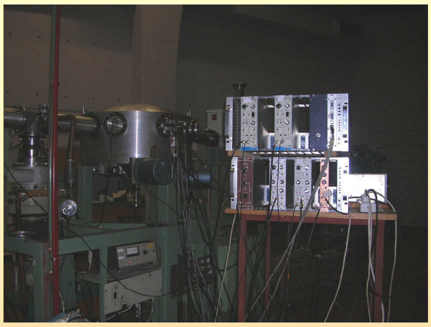
5.5 MV HV Tandem Accelerator, N.C.S.R. 'Demokritos'

Motor driven goniometer
Great angular accuracy (0.01 deg.)



*** A.Pakou et al. , Phys. Rev. Lett. 90 (2003)**





- 4 single SSB, associated with standard NIM electronics. Upgrading is scheduled.
- The current setup allows for target cooling with water or methanol through a closed circuit during acquisition
- Voltage suppression up to 1000 V on the collimator, target and/or faraday cup.
- Orthogonal slits (4.5 x 10 mm^2) in front of the detectors + 50 μm kapton absorber foils

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EXPERIMENTAL PROCEDURE:

(a) Preparation/testing of the targets (B on Ta and S on C + Ta flash).

(b) Spectra acquisition at variable charge, depending on statistics for both reactions.

(c) Determination of the solid angle using an uncalibrated Am-Pu-Cm α-source + RBS spectra. Uncertainty in Q*Ω < 2.5(4.3)% due to voltage suppression and effective faraday cup (tested with Al and Au foils in the past).

(d) Peak analysis using two different algorithms to account for the bias error (σ Yield(exp) <1% using Spectr and Origin).

(e) Error evaluation: 1. Monitoring of the changes in the foil thickness (A in at/cm^2) by sputtering and accuracy in the energy due to carbon buildup (despite the two liquid nitrogen traps).

(f) Measurements with slits and absorber foils.

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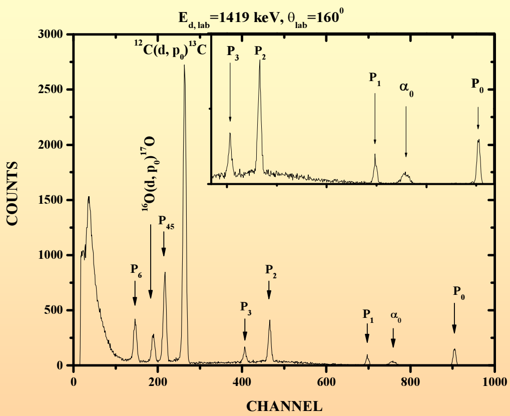
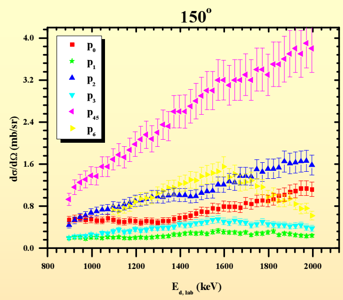
ANALYSIS AND DISCUSSION:

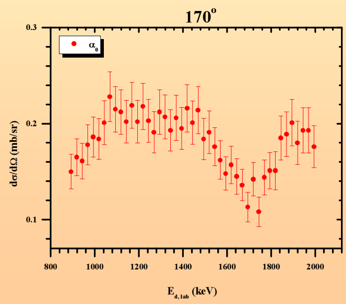
Reaction	Q-value (keV)	$E_{x,lab,max}$ (keV)	Excitation energy range (keV)
$^{10}B(d,\alpha)^{8}Be$ (2α)	17820 (17914)	11285	25936-26852 ($^{12}C^*$)
$^{10}B(d,p)^{11}B$	9229	9223	25936-26852 ($^{12}C^*$)
$^{32}S(d,p)^{33}S$	6417	8295	13348-14007 ($^{34}Cl^*$)

- The excitation energy range reported, is important for the study of the influence of the resonance mechanism.
- CIRE (GANIL) has been used for 2 or 3-body kinematics.
- If absorber foils are not used, then thick SSB detectors are required (> 500 μm)
- ^{10}B enriched targets (94%) on Ta backings, d = 10.2±1.0 μg/cm^2,
- ^{32}S (95.02% on natural S) evaporated (TiS_2) on machine carbon foils + Ta flash for protection.

RESULTS FOR d+^{10}B:



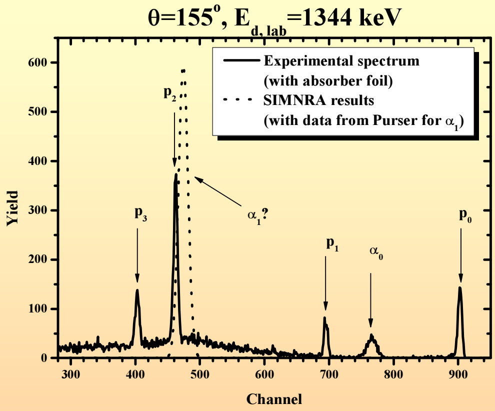




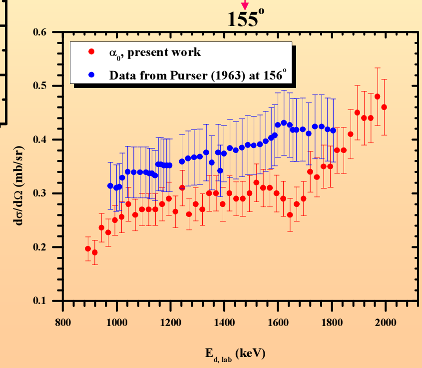
More than ~2000 differential cross section values have been determined for 8 different detector angles (at 5° intervals), in beam energy steps of ~25 keV (900-2000 keV).

Results already at IBANDL, submitted to NIM.

INTERESTING POINTS – PROBLEMS:

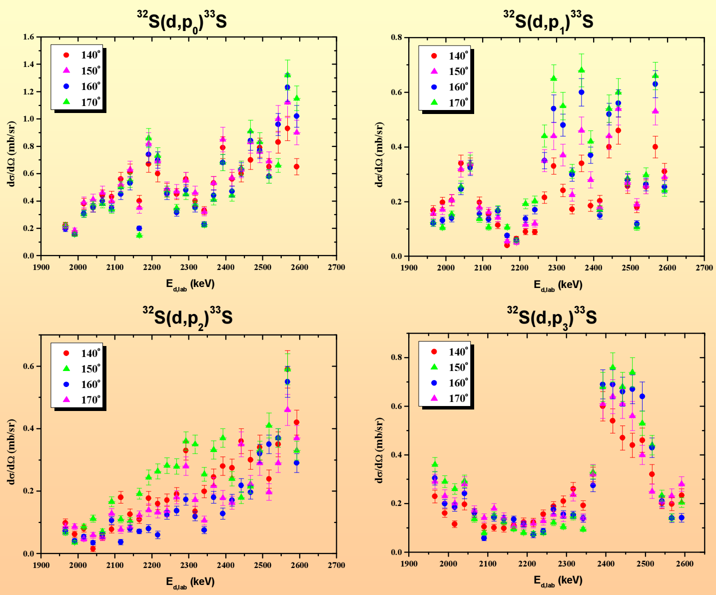


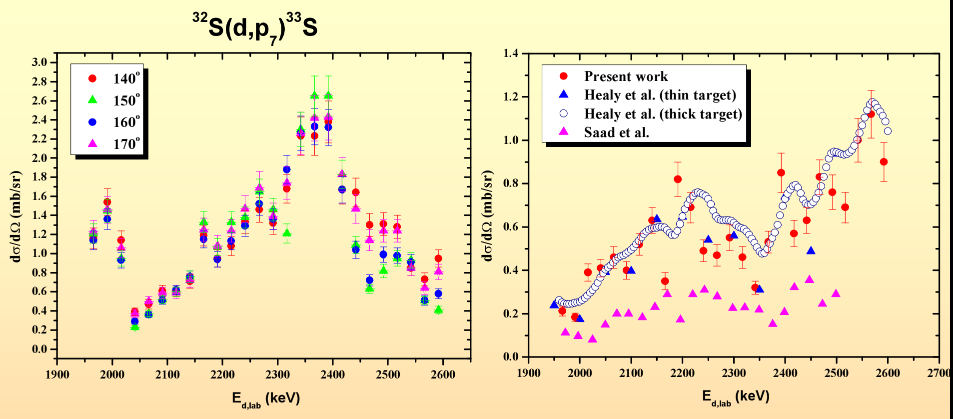
Thick target smears out the resonance structure



α_1 does not exist! A note should be made at IBANDL

RESULTS FOR d+^{32}S:





INTERESTING POINTS – PROBLEMS:

- Very strong and unknown resonance structure (^{34}Cl level scheme is missing!)
- Disagreement with Healy et al. NIM B (1998) data from thick target yield deconvolution, very good agreement with digitized data from publication!
- More than ~500 new data points at IBANDL, $p_{4,5,6}$ pending…
- Submitted to ECAART 2007

NATIONAL TECHNICAL UNIVERSITY OF ATHENS
DEPARTMENT OF PHYSICS

CURRENT SITUATION / FUTURE PERSPECTIVES:

(a) Many open questions: Angular distribution at forward angles?

(b) What is the maximum analyzing depth? All the (d,p) and (d,α) reactions in light elements also need to be studied. Study of ^{14}N, ^{11}B (submitted to ECAART 2007), in progress using the same technique.

(c) Time-consuming studies affect quick quantification of the results.

(d) In the next phase we will proceed to (p,α) reaction studies.

(e) $^{12}C(d,p_{1,2,3})$ already published…

(f) Completing analysis in d+^{11}B, while d+^{14}N is still pending – expected around 9/2007.

(g) Fluorine and lithium measurements scheduled after 10/2007 due to accelerator upgrade. Targets are still not available. We will proceed through test evaporations on machine carbon stripper foils.

MEASUREMENT OF PROTON ELASTIC SCATTERING CROSS SECTIONS FOR N AND Li

A.R. Ramos, N.P. Barradas, E. Alves

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Tasks Performed

- Measurement of (p,p) elastic scattering cross sections for nitrogen and lithium in the 500-2500 keV energy range.

➢(p,p) cross sections for N measured using the standard ”thin film” technique. Measurement span the 500-2500 keV energy range and scattering angles 160º, 150º, 130º and 110º.

➢(p,p) cross sections for Li measured using a bulk sample – “*point by point technique*” -. Measurement span the 500-2500 keV energy range and scattering angles 160º and 150º.

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Samples

• Thin film (**for N**): C/AlN/Au

Au determined from ^{4}He-RBS by means of the formula:

$$A = \sigma \times \Omega \times Q \times Nt$$

ΩxQ determined using Si(Sb) implanted sample (EC Institute for Reference Materials and Measurements).

Al and N determined from He-RBS using NDF.

• Bulk samples (**for Li**): LiF(Ar)/Au ...(+ LiCl + LiNbO3)

Au determined as described above.

Other elements determined from He-RBS using NDF.

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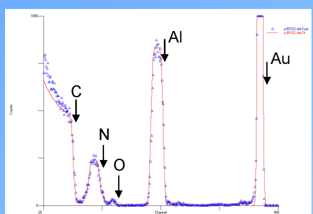
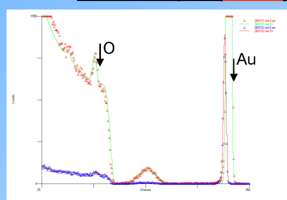
Samples

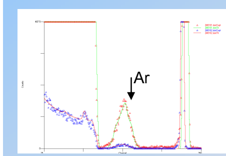
Thin film (**for N**): C/AlN/Au



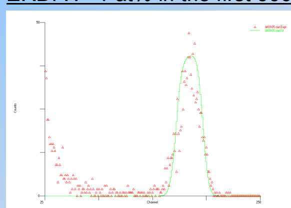
$$\sigma_N = \frac{A_N}{A_{Au}} \times \frac{(Nt)_{Au}}{(Nt)_N} \times \sigma_{Au}$$

Bulk sample (**for Li**): LiF(Ar)/Au





ERD: H~ 1 at% in the first 300 nm



$$H_0 = \frac{\sigma(E_0)\Omega Q \xi}{[\varepsilon_0]\cos\theta_1}$$

(top surface layer)

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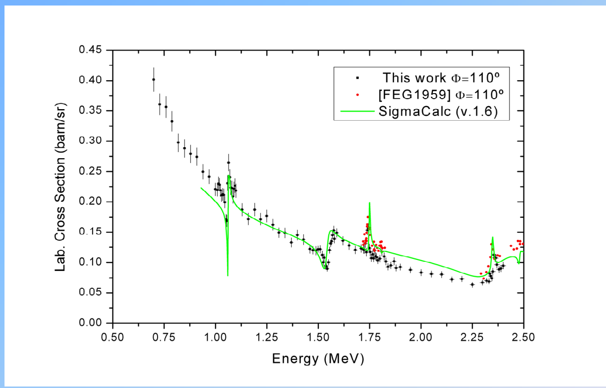
Measurement of $^{14}N(p,p_0)^{14}N$

$\Phi = 110^o$



[FEG1959] A.J. Ferguson, R.L. Clarke and H.E. Gove, Phys. Rev. 115 (1959) 1655.

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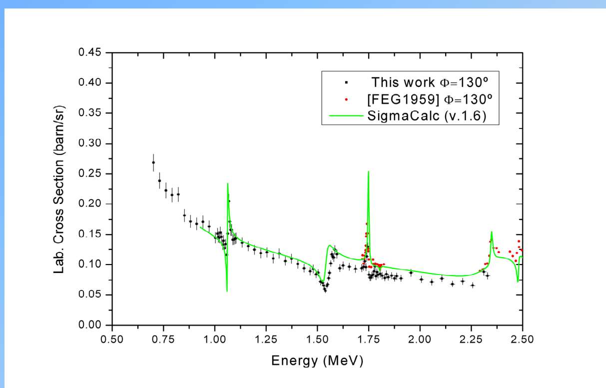
Measurement of $^{14}N(p,p_0)^{14}N$

$\Phi = 130^o$



[FEG1959] A.J. Ferguson, R.L. Clarke and H.E. Gove, Phys. Rev. 115 (1959) 1655.

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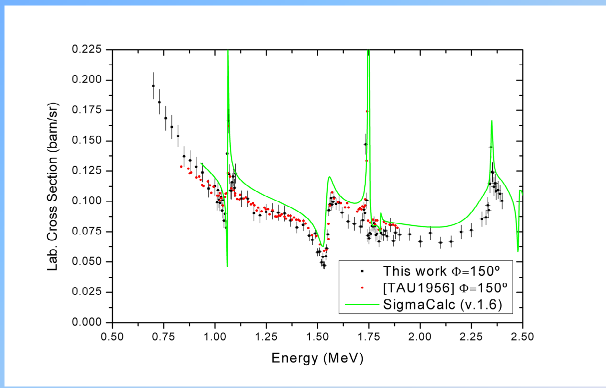
Measurement of $^{14}N(p,p_0)^{14}N$

$\Phi = 150^o$



[TAU1956] G.W. Tautfest, S. Rubin, Phys. Rev. 103 (1956) 196.

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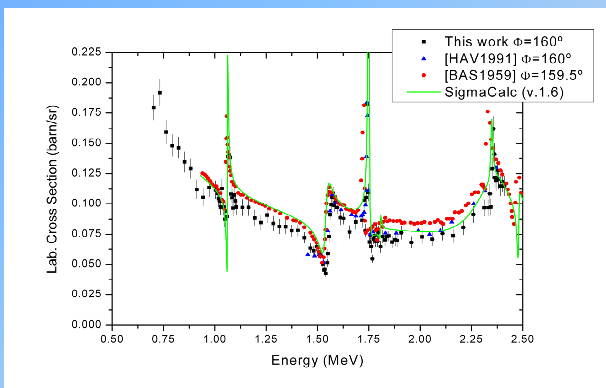
Measurement of $^{14}N(p,p_0)^{14}N$

$\Phi = 160^o$



[HAV1991] V. Havranek, V. Hnatowic, J. Kvitek, Czech. J. Phys. 41 (1991) 921.

[BAS1959] S. Bashkin, R.R. Carlson, R.A. Douglas, Phys. Rev. 114 (1959) 1552.

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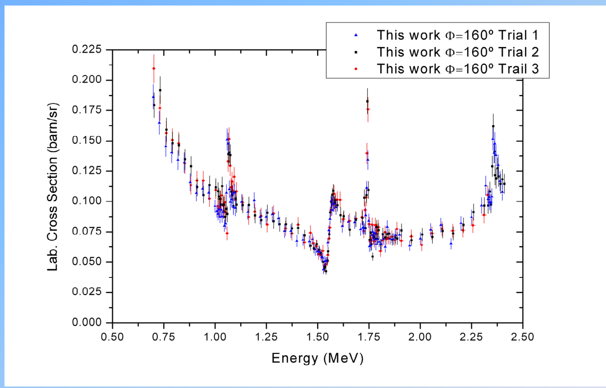
Measurement of $^{14}N(p,p_0)^{14}N$

Φ = 160º - Repeat



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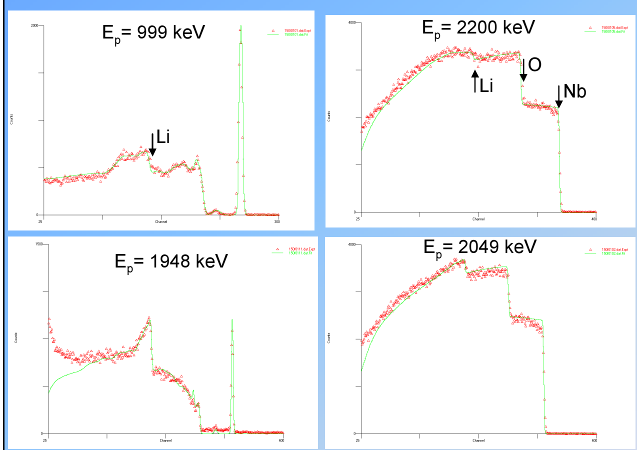
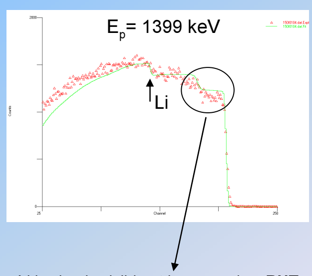
Li(p,p)Li Measurement

Examples for Φ = 150º

LiF　　LiNbO3　　LiCl





Li is clearly visible at low energies. **BUT**, LiCl is hygroscopic and the pellet surface is rough.

At% H and O?

Experimental setup does not allow the proton measurements and ERD to be performed without breaking vacuum.

Results pertaining to this sample are merely indicative.

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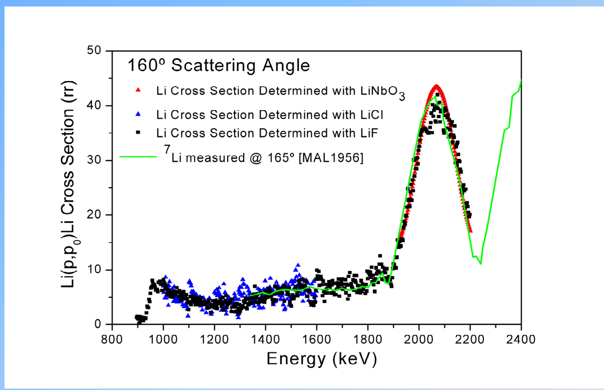
Li(p,p)Li Measurement

Φ = 160º



[MAL1956] P.R. Malmberg, Phys. Rev. 101 (1956) 114.

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Further Work

- Re-Measurement of the $^{14}N(p,p_0)^{14}N$ cross section @ Φ=140º.

- Verification of the Li cross section with other thick targets.

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BENCHMARKING OF PROTON ELASTIC SCATTERING CROSS SECTIONS FOR N, C AND Si

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Tasks Performed

- Benchmarking of evaluated/measured (p,p) cross-sections in the 500-2500 keV energy range for carbon, nitrogen and silicon using bulk samples.

➢Measured (p,p) cross sections for N assessed using Bayesian inference applied to “thin film” spectra.

➢Evaluated (p,p) cross sections for C assessed using Bayesian inference applied to bulk spectra.

➢Evaluated (p,p) cross sections for Si assessed using bulk sample spectra by transforming the yield at each channel into a cross section value – *“point by point technique”* -.

Samples

• Thin film (for N and C): C/AlN/Au

Au determined from ^{4}He-RBS by means of the formula:

$$A = \sigma \times \Omega \times Q \times Nt$$

ΩxQ determined using Si(Sb) implanted sample (EC Institute for Reference Materials and Measurements).

Al and N determined from He-RBS using NDF.

• Bulk samples (for Si): Si(W)

W determined as described above for Au.

• Bulk samples (for N): C/TiN/Au

Au determined as described above.

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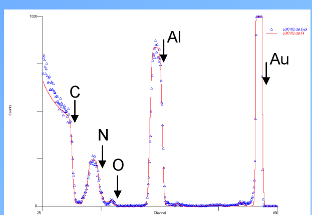
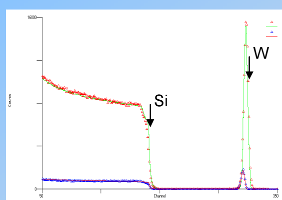
Samples

C/AlN/Au for N and C:

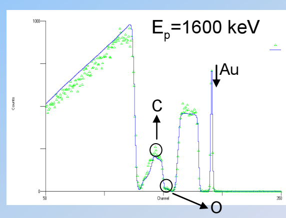
- AlN thin film for N
- C substrate for C

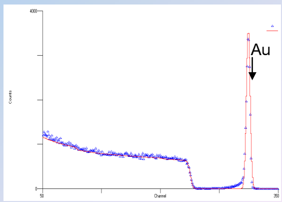


Bulk sample (for Si): Si(W)



Bulk sample (for N): C/TiN/Au





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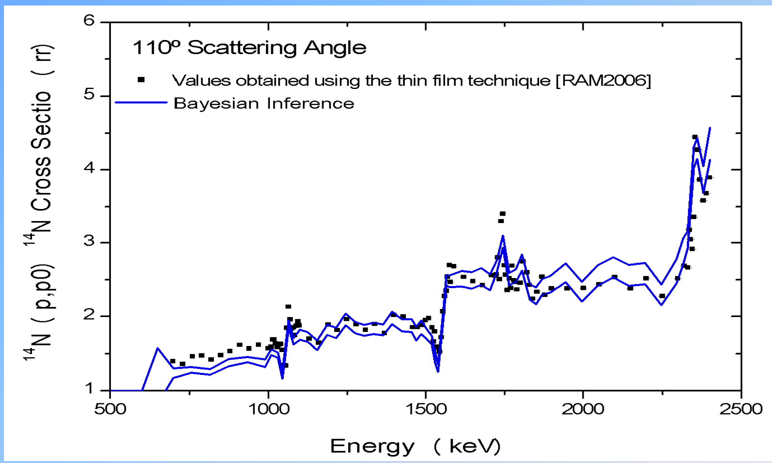
N(p,p)N assessment using Bayesian inference applied to “thin film” spectra



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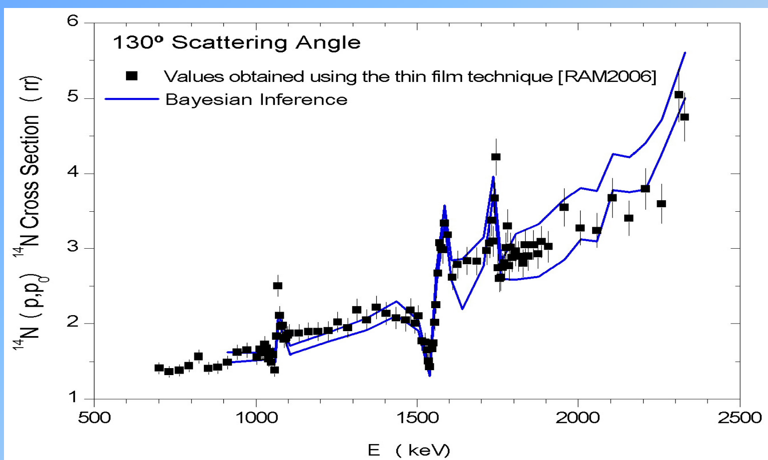
N(p,p)N assessment using Bayesian inference applied to “thin film” spectra



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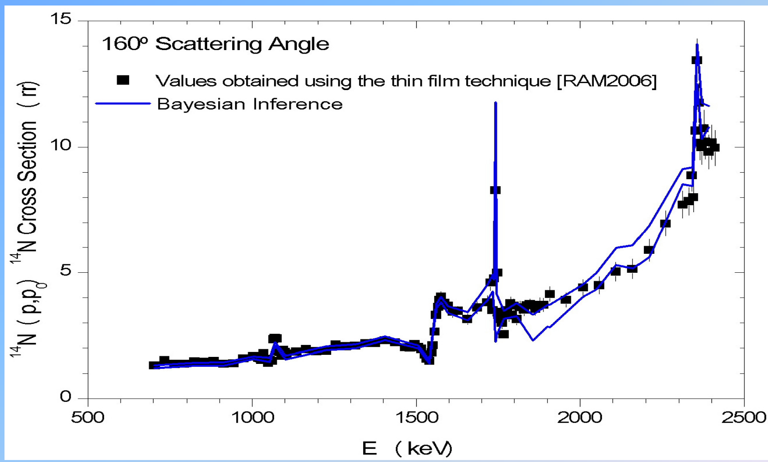

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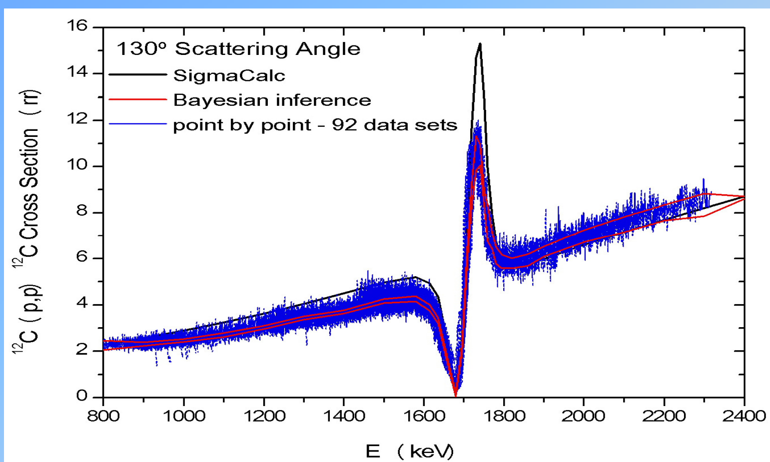
C(p,p)C assessment using Bayesian inference applied to bulk spectra



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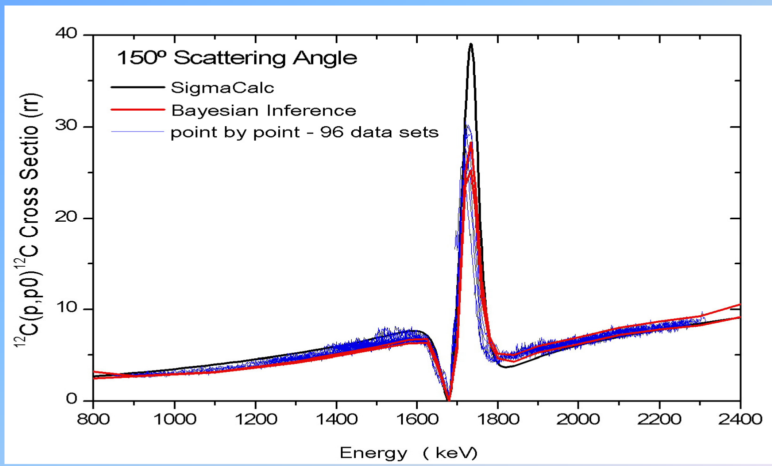
C(p,p)C assessment using Bayesian inference applied to bulk spectra



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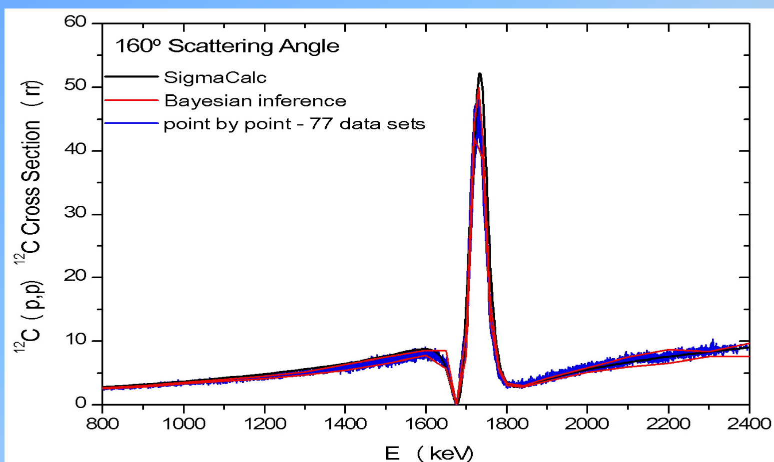
C(p,p)C assessment using Bayesian inference applied to bulk spectra



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Sources of error - Experimental

- Wrong scattering angle originating in the positioning system?

✓Measures taken: verification of 2 points in the scale: 0º and 10º - verification shows positioning to be correct within +-1º

- Wrong scattering angle originating in operator error?

✓C(p,p)C discrepancies found at 2 different scattering angles (130º and 150º).

✓C(p,p)C for 150º reproduced in different sample, measured during a different beam time.

- Wrong normalization to Au?

✓Areal density of Au determined using a standard sample and verified by fit/simulation of several spectra.

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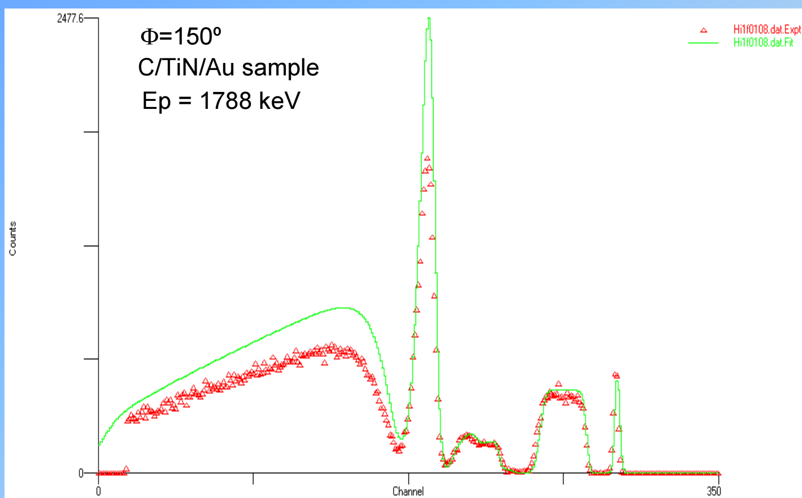
Sources of error - Experimental



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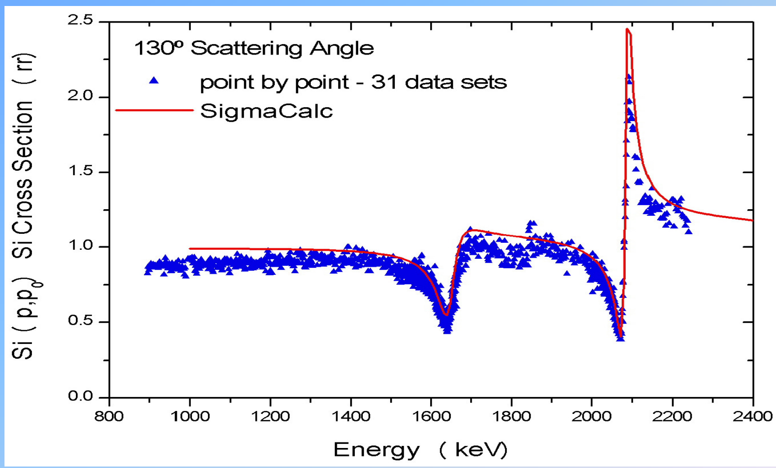
Si(p,p)Si assessment using a point by point technique



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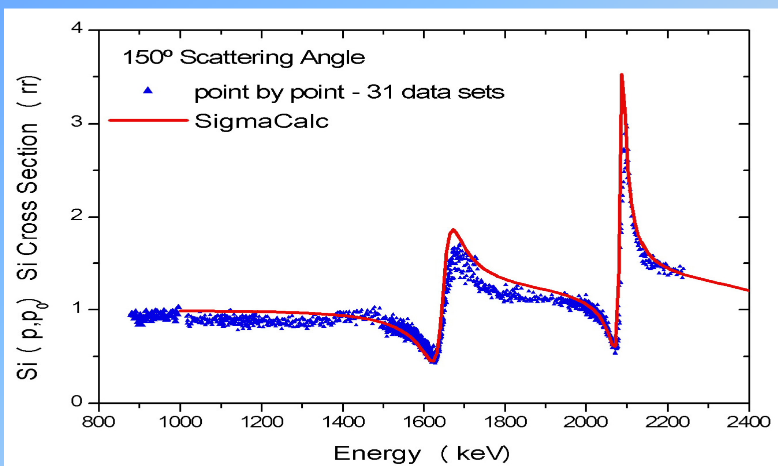
Si(p,p)Si assessment using a point by point technique



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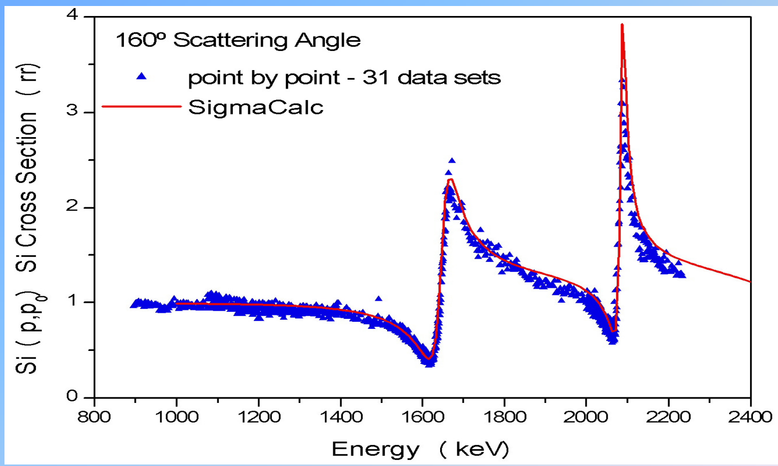
Si(p,p)Si assessment using a point by point technique



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Further Work

- Re-Measurement of the $C(p,p_0)C$ cross section @ Φ=150º (simultaneous N cross section re-measurement @ Φ=150º).
- Verification of the N cross sections with a thick (thicker) target.

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Cross section measurements for analysis of D and T in thicker films

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一、Scientific Background

二、Experimental technique

- The targets
- Experimental system
- The measurement of recoil cross section

三、Experimental Results

一、Scientific Background

- Accurate knowledge of the concentration of hydrogen and its isotopes in materials is important in a wide range of application. The elastic recoil detection analysis(ERDA) and Proton backscattering (PBS) are important analytical methods for their concentration determination.

  For samples containing multiple hydrogen isotopes with several μm's thickness, it may be necessary to perform high energy ERDA in order to achieve good

mass resolution and to analysis relative thick sample. But for the sample with much thicker samples or the bulk materials, it may also become necessary to employ proton backscattering technique to achieve large depth detection and relative good sensitivity for D,T.

In either case, accurate knowledge of the elastic scattering cross-sections for the incident beam interaction with the hydrogen isotopes or materials of interest is required.

- In previous works, some cross-sections for the interaction of $^4He^{2+}$ beams with hydrogen isotopes (*1-3.05 and 9-11 MeV for $^2H(\alpha,\alpha)^2H$, and 0.5-2.5 and 9-11 MeV for $^3H(\alpha,\alpha)^3H$*), and for the interaction of proton with D and T at some energy range (*2-2.78MeV for $^2H(p,p)^2H$ at 151^o and 2.74-3.49 MeV for $^3H(p,p)^3H$ at 163.2^o*), have been measured although there are some unresolved discrepancies for different data sources. However, very little data exist for proton incident on D,T in the energy range 1-3 MeV and

at assured angles, and No data for He ions on D,T in the energy range 3-8MeV in the literature are found.

- In order to make high accurate He- ERD analysis of D and T in the films with a thickness of less than 4 um under the condition of confined energy of accelerator, as well as the measurement of D and T concentration and depth profiles in the thick films or bulk materials by PBS technology， in this project we will perform the measurement of the cross-sections in energy range of interest:

(1) Helium on D and T in the energy range 3 –7.6 MeV at a recoil angle of 30°.

(2) Proton incident on D and T in the energy range 1-3 MeV at 165° , respectively .

二、Experimental technique

2.1 The targets

- TiT_x (TiD_x) targets are prepared by thermal sorption of tritium or deuterium on Ti films.

- In order to measure the cross section for ERD, the Ti films of $2.8\times10^{17}/cm^2$(50nm) with an overlayer Pd of 2nm(Pd/TiD_x) are deposited on the quartz substrates.

  Here Pd was used to improve absorption activity of Ti and obtain a high concentration of D in the Ti. It is found in previous experiment that T or D was located entirely in the Ti film and that virtually no T or D migrated into the quartz.

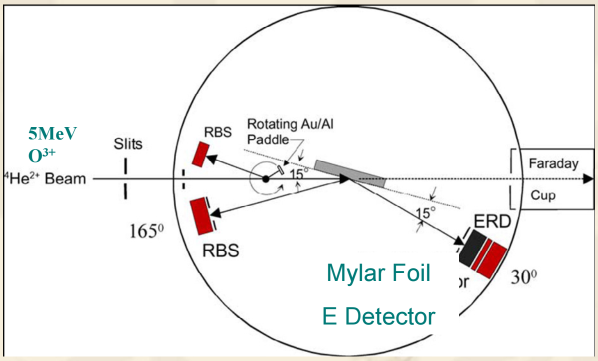
- For the measurement of PBS cross section, a multilayer compound film Pd/TiD(T)x (100 nm) /Al was employed. Here the Al foil(7um) was used to support Ti film but maintain a very low background . Pd overlayer is not only used to serve as an internal ion dose reference, and also to act as a protection against oxygenization.

- The chosen film thickness is a compromise between minimizing the energy lose in traversing the film and having a definite amount of D or T.

2.2 Experimental system

- A NEC 9SDH-2 ×3 MV tandem accelerator are used in this experiment, which can provide well collimated beam of He and H. The beam is incident on the target through a defining aperture of Φ0.6 mm.

- Two Au/Si surface barrier detectors are used to allow simultaneous collection of ERD and RBS spectra, thus avoiding the need to depend on the absolute charge collection. ERD detector is fixed at the recoil angle of 30^0. The aperture in front of the detector had dimension 2×3



Schematic of experimental system for ERD and RBS measurement

mm, which results in an angular resolution of 1.4^0. The RBS detector is placed at 165^0 and it subtended a solid angle of 1.25 msr

- For measurement of PBS cross section, the Au/Si detector is placed at 151^0 and 165^0 , respectively.
- The accelerator energy is calibrated by using both nuclear resonance reactions of $^{27}Al(p,\gamma)^{28}Si$ at 992 keV, $^{19}F(p,\alpha\gamma)^{28}O$ at 872 keV and ^{241}Am source.

2.3 The measurement of recoil cross section

- Cross-sections for the $^2H(\alpha,\alpha)^2H$ and $^3H(\alpha,\alpha)^3H$ ERD interactions can be determined by

$$\frac{d\sigma(E)}{d\Omega} = \frac{A(E)\cos\theta_1}{N\Omega Q_\alpha} \qquad (1)$$

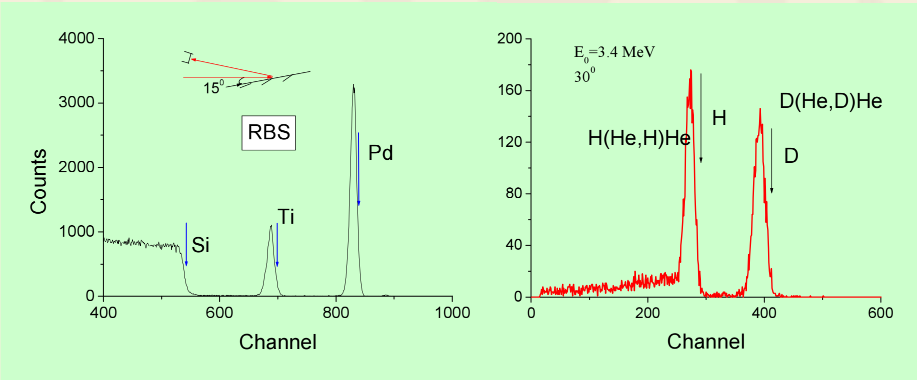
$D(^3He,\alpha)p$ absolute accuracy of for c.m.s energies < 500 keV.

T(d, α)n reaction with a quoted accuracy of 2%

where A(E) is the integrated area under the peak, θ_1 the angle of the target normal relative to the incident beam(up-stream), N the area density of the recoil product, Ω the solid angle subtended by the detector and Q is the total number of He ions incident on the target.

For the hydride film used in experiment, besides A(E) (possible multiple scattering effect), hydrogen isotope concentration N is also a difficult parameter accurately to be determined in order to achieve ideal precision.

- $\frac{\cos\theta_1}{N\Omega Q}$ in above equation can be obtained by simultaneous solving ERD and RBS spectra of He ions as well as 5 MeV O^{3+} imping on the sample.



RBS (a) and ERD(b)Spectra for 3.4 MeV He ions incident at 15^0 to the surface of the Pd/TiD/SiO_2 films

- Thus,

$$\left(\frac{d\sigma}{d\Omega}\right)^{\alpha}_{D}(E)=\frac{A^{\alpha}_{D}(E)A^{O}_{Ni}(E_0)\left(\frac{d\sigma}{d\Omega}\right)^{\alpha}_{Ni,Ruth}(E_0)}{A^{O}_{D}(E)A^{\alpha}_{Ni}(E_0)\left(\frac{d\sigma}{d\Omega}\right)^{O}_{Ni,Ruth}(E_0)}\left(\frac{d\sigma}{d\Omega}\right)^{O}_{D,Ruth}(E)$$

where $E = E_0 - \Delta E_{Pd}$, E_0 is the incident He(or O) ion energy, ΔE_{Pd} is the energy loss of ion in the Pd film. In this way, the accuracy of the recoil cross sections measured here is only limited by the following uncertainties:

A(E), the statistical uncertainty, is typically ±3%;

and $\left(\frac{d\sigma}{d\Omega}\right)$. Because thickness of target is very thin(15 nm), main error for $\left(\frac{d\sigma}{d\Omega}\right)$ is $\left(\frac{d\sigma}{d\Omega}\right)^{o}_{D,Ruth}(E)$

The total error associated with the cross sections measured is not larger than 7%

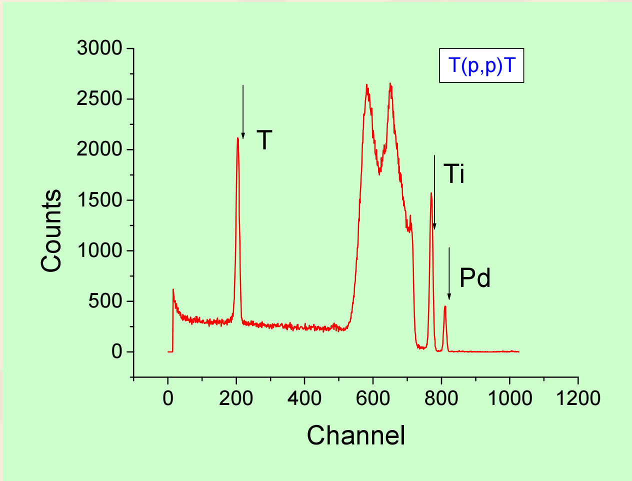
2.4 The measurement of proton elastic scattering cross sections

- By using Pd/TiD(T)x compound film, the elastic scattering cross-sections of D or T can be calculated from:

$$\sigma_{D(orT)}(E) = \sigma_{Pd,Ruth}(E_0)\frac{A_{D(orT)}(Nt)_{Pd}}{A_{Pd}(Nt)_{D(T)}} \quad (3)$$

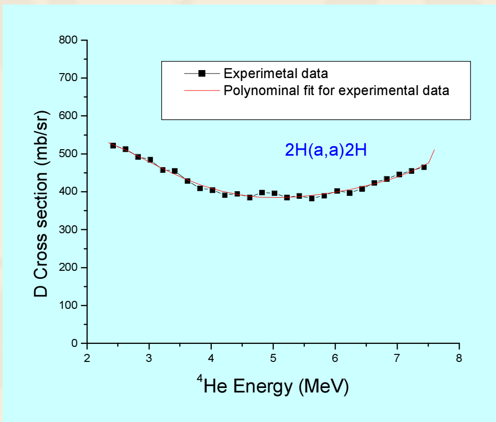
- where $\sigma_{Pd,Ruth}$ is the calculate proton Rutherford scattering cross section of Pd. The ratio $(Nt)_{Pd}/(Nt)_{D(T)}$ (N=atom density, t=layer thickness) is determined using the areal density value for $(Nt)_{D(T)}$ from ERD measurements(±5%). and $(Nt)_{Pd}$ measuring by proton backscattering. The signal peak area ratios $A_{Pd}/A_{D(T)}$ is determined from the measured spectra.

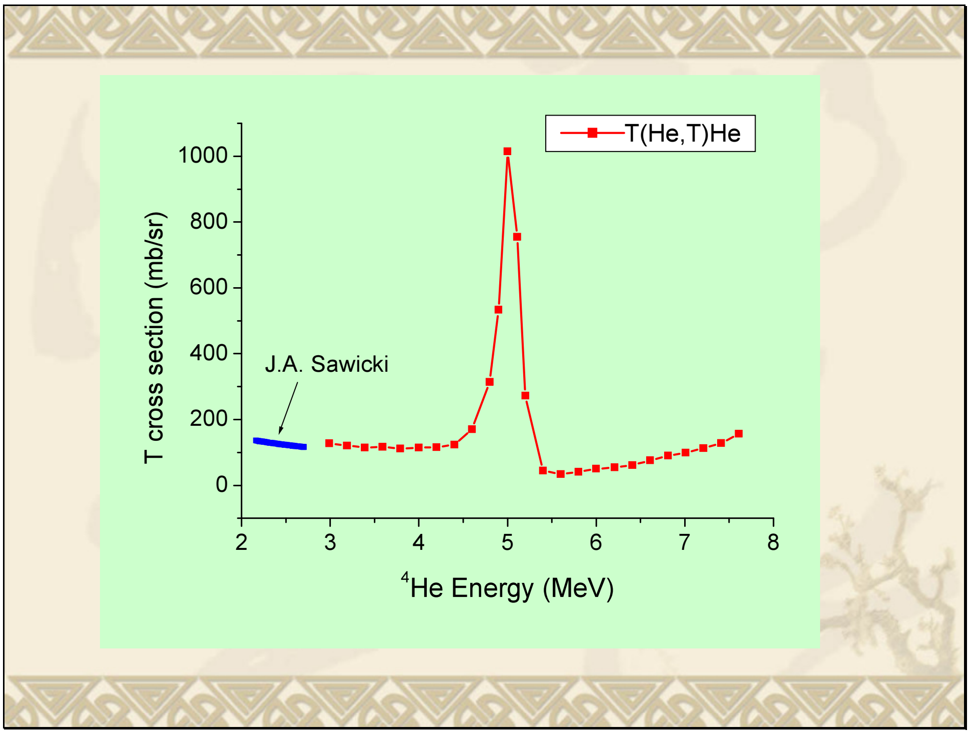
- The total estimated errors for the cross sections measured is less than 8%

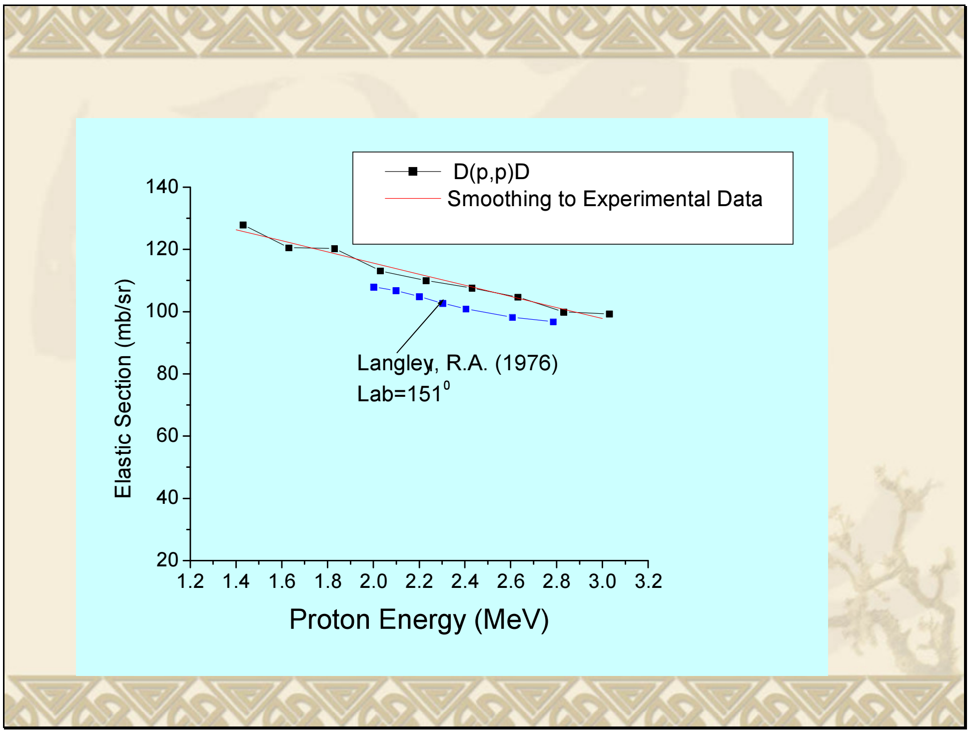


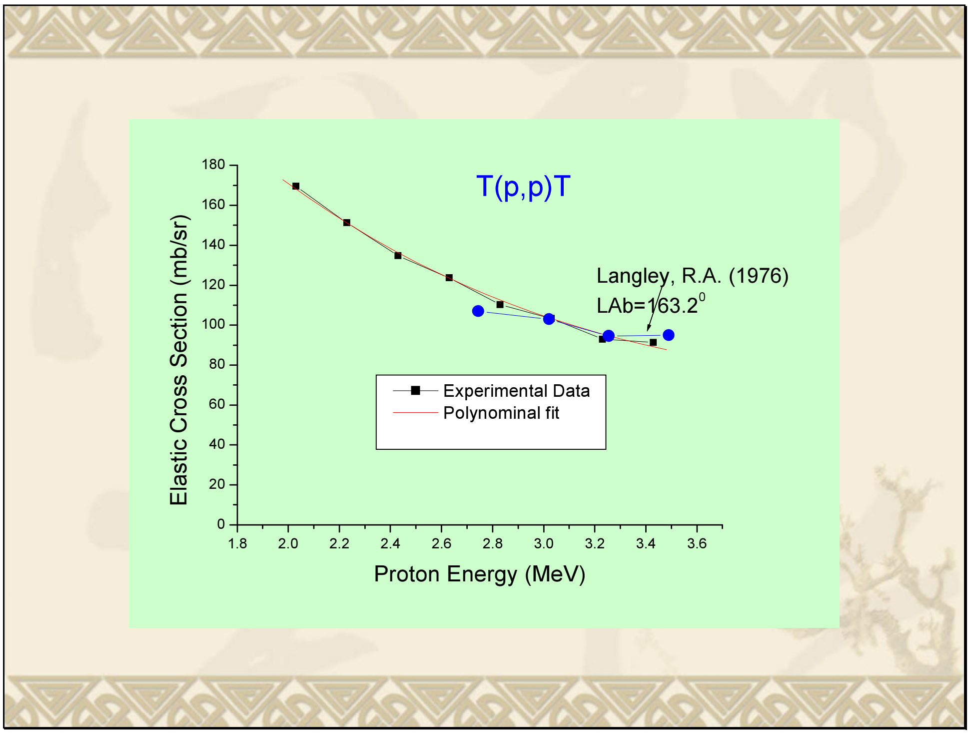
The PBS spectrum of Pd/TiD/Al hybrid film using 2.2MeV proton at 165⁰

三、Experimental Results




T(He,T)He
1000
800
600
400
200
0
T cross section (mb/sr)
J.A. Sawicki
2
3
4
5
6
7
8
4He Energy (MeV)


D(p,p)D
Smoothing to Experimental Data
140
120
100
80
60
40
20
Elastic Section (mb/sr)
Langley, R.A. (1976)
Lab=151°
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
Proton Energy (MeV)



T(p,p)T
Langley, R.A. (1976)
LAb=163.2^0
Experimental Data
Polynominal fit
Elastic Cross Section (mb/sr)
Proton Energy (MeV)
180
160
140
120
100
80
60
40
20
0
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6

Preparation and characterisation of a ^{13}C target for $^{13}C(d,p)$ cross section measurements

Objective : make a robust and stable target containing a known quantity of ^{13}C

Ian Vickridge, Marie D'Angelo, Catherine Deville
Institut des NanoSciences de Paris

D. Ledu
Centre de Spéctrometire de Masse et de Spectroscopie Nucléaire, Orsay

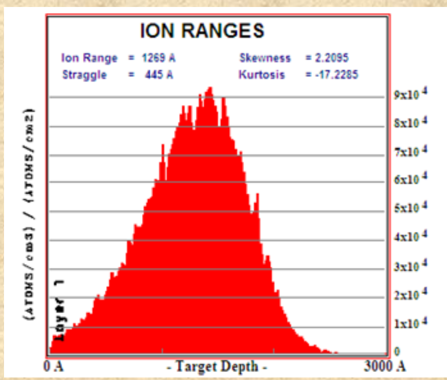
Solution Chosen

Ion Implantation of $^{13}C^{+}$ into Si (40keV)

Methane gas source enriched (10%) in 13C
Isotope separator SIDONIE
(Centre de Spectrométrie de Masse et Spectroscopie Nucléaire, Orsay)

Dose measurement and homogeniety are 'reputed reliable'

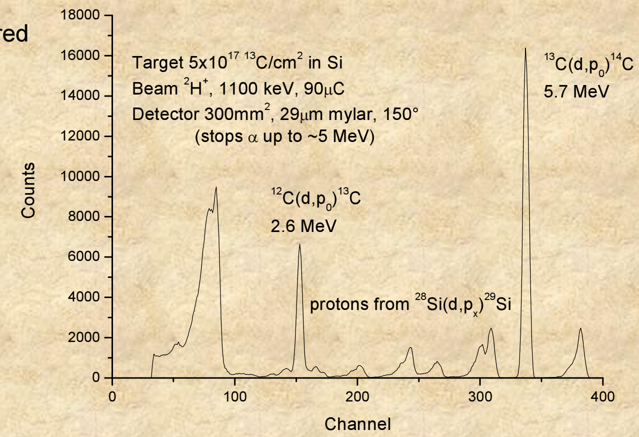
Possible problem :
contamination of beam with $^{12}CH^{+}$



Typical spectrum

Four implant doses prepared

5×10^{16}
1×10^{17}
5×10^{17}
1×10^{18}



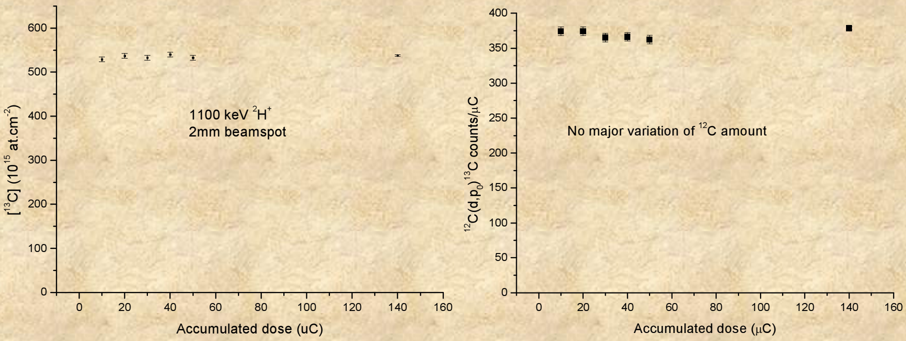
Obviously can estimate ^{12}C too if cross section is OK

Target Stability

^{13}C determined by $^{13}C(d,p_0)^{14}C$ using a 'marginal' ^{13}C reference.

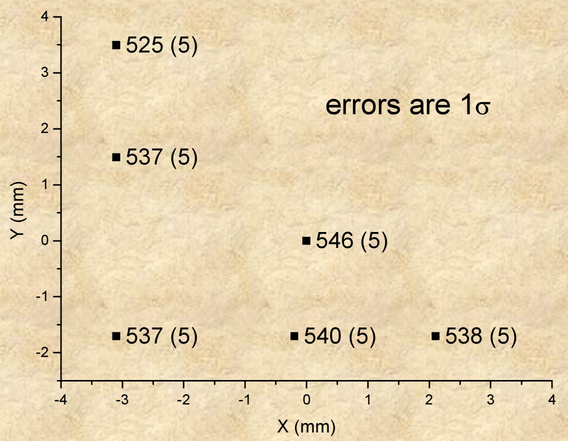
DLC plasma deposited 13C film on Si
5.4×10^{18} ^{13}C cm^{-2} measured by RBS
Film is not homogeneous

Nominal 5×10^{17} cm^{-2} implant



Target Uniformity

0.5 mm beamspot used

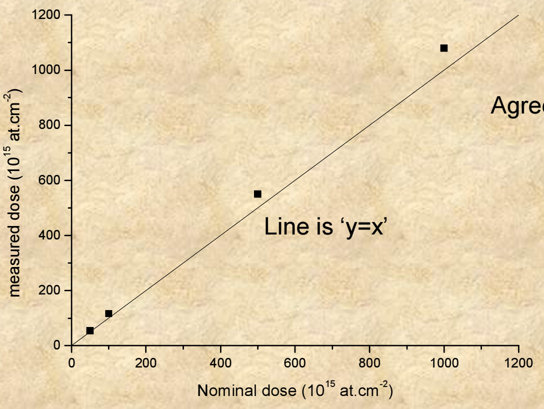


Mean = 537
σ=7

Dose linearity

^{13}C determined by $^{13}C(d,p_0)^{14}C$ using a 'marginal' ^{13}C reference.

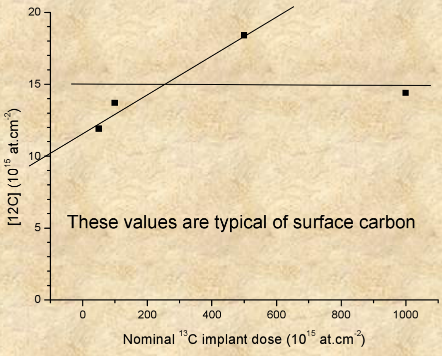
DLC plasma deposited 13C film on Si
5.4×10^{18} ^{13}C cm^{-2} measured by RBS
Film is not homogeneous

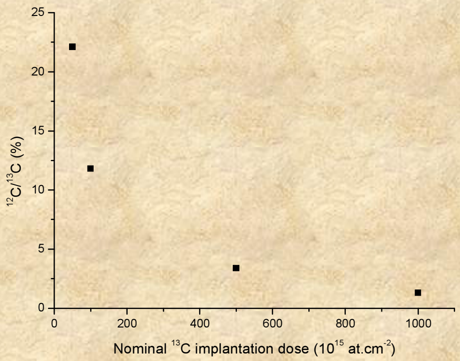


Agreement surprisingly good!

How much $^{12}CH^+$ in implantor mass 13 beam?

^{12}C determined using $^{12}C(d,p_0)^{13}C$ and $^{13}C(d,p_0)^{13}C$ cross sections from IBANDL (Lennard and 'Kokkoris tbp' for ^{12}C, Colaux et al for ^{13}C





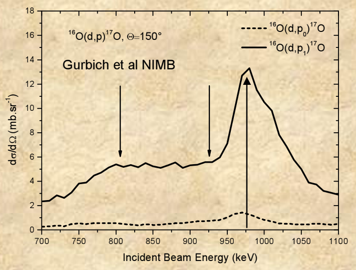
Probably less than 1%

How much 13C is in the implants?

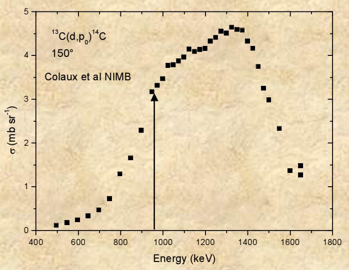
Nominal dose **5.0×10^{15} cm^{-2}**

From marginal reference **5.4×10^{15} cm^{-2}**

But using 'reliable' ^{16}O reference and IBANDL cross sections



σ = 13.3 mb sr^{-1}



σ = 3.3 mb sr^{-1}

=> 6.9×10^{15} cm^{-2}

Conclusions

- Target is stable and uniform.
- Absolute value remains uncertain

Next step : determine ^{13}C by RBS in channelling

Future measurement strategy : determine σ of $^{13}C(d,p_0)^{14}C$ precisely at a few energies and angles, and assume shape from Colaux et al between these values, scaled if necessary to agree with precise measurements.

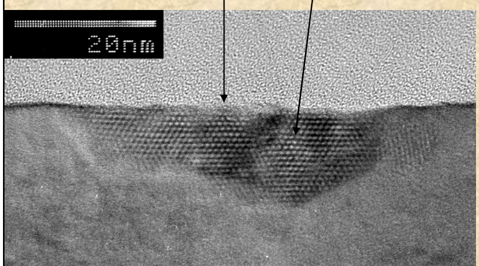
Comment : H_2^+ contamination in $^2H_+$ beam => current measurement errors

Why do this?

With G. Battistig, A. Pongracz, MFE-KFKI Budapest

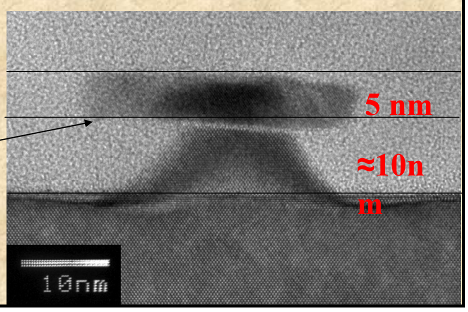
Epitaxial growth of SiC nanodots (3C) at the SiO_2/SiC interface with $^{(13)}C^{(18)}O$

CO



Quantitatively determine
growth kinetics
nucleation rate
=> Independance from surface ^{12}C

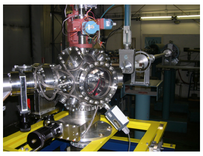
Formation of free-standing SiC platelets after post-oxidation, control of vertical inter-crystal spacing

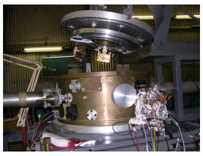
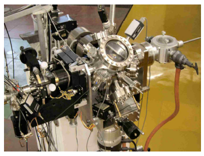


Photoluminescence
(quantum confinement effects)

CRP: Development of a Reference Database for Ion Beam Analysis

Data assessment of $^{12}C(p,p)^{12}C$ cross sections from 3.5 to 5 MeV
Data assessment of $^{12}C(\alpha,\alpha)^{12}C$ cross sections



Iva Bogdanović Radović
Laboratory for ion beam interactions
Division of experimental physics
Ruđer Bošković Institute
Zagreb, Croatia

Data assessment of $^{12}C(p,p)^{12}C$ cross sections from 3.5 to 5 MeV

IBANDL reports only two databases for $^{12}C(p,p)$ differential cross sections in the energy region from 3.5 – 5 MeV.

Tosaki data from original publication [1] were transferred to IBANDL without errors.

Second database reported in IBANDL is from Jackson et al.[2].
They reported cross sections from 400 keV up to 4360 keV for several c.m scattering angles 169.2°, 148.9°, 127.8° and 106.4° that corresponds to 168.2°, 146.3°, 123.8° and 101.7° laboratory angles. Differential cross sections are reported only in graphical for and in center-of-mass system. IBANDL reports only data for 168.2° from this reference.
Data for three other angles (146.3°, 123.8° and 101.7°) need to be digitized and transferred to IBANDL.

[1] M. Tosaki et al., Nucl. Instr. and Meth. B168 (2000) 543
[2] H.L. Jackson et al., Phys. Rev. 89 (1953) 365

Ruđer Bošković Institute, Zagreb, Croatia

Data assessment of 12C(p,p)12C cross sections from 3.5 to 5 MeV

-two other references are not mentioned in IBANDL, that report differential cross sections in the 3.5 – 5.0 MeV energy region

-First one is Reich et al. [3]. Authors report c.m. differential cross sections (barn/sr) at few different c.m. scattering angles. Only scattering angles larger than 100° are considered here. At the moment, data from [3] are not included to IBANDL. In the original publication they are presented only in the graphical form for following c.m. scattering angles: 125.2°, 140.5°, 131.2°, 137°, 149.3°, 164° that corresponds to 121°, 137.3°, 127.4°, 133.6°, 146.7°,162.6° laboratory angles respectively.

-[3] Reich et al., Phys. Rev. 104 (1956) 143

-Another recently published data set is from Cacciolli et al. Authors from [4] report about proton elastic scattering cross-sections on F, C and Li from 3 to 7 MeV for 150° scattering angle. Data are presented only in graphical form.

[4] A. Caciolli et al. Nucl. Instr. and Meth. B249 (2006) 95

Angle Lab	energy (keV)	Author	Comment
179.2°	4000-6000	M. Tosaki et al., Nucl. Instr. and Meth. B168 (2000) 543 Ref. [1]	Data in IBANDL are in agreement with data published in original publication
168.2°	400-4360	H.L. Jackson et al., Phys. Rev. 89 (1953) 365 Ref. [2]	Digitized data transferred to IBANDL
146.3°	400-4360	Ref. [2]	Need to be digitized Not included to IBANDL
123.8°	600-4360	Ref. [2]	Need to be digitized Not included to IBANDL
101.7°	600-4360	Ref. [2]	Need to be digitized Not included to IBANDL
121°	4100-5600	Reich et al., Phys. Rev. 104 (1956) 143 Ref. [3]	Need to be digitized Not included to IBANDL
137.3°	4100-5000	Ref. [3]	Need to be digitized Not included to IBANDL
127.4°	4600-5000	Ref. [3]	Need to be digitized Not included to IBANDL
133.6°	4600-5000	Ref. [3]	Need to be digitized Not included to IBANDL
146.7°	4100-5000	Ref. [3]	Need to be digitized Not included to IBANDL
162.6°	4800-5600	Ref. [3]	Need to be digitized Not included to IBANDL
150°	3000-7000	Caciolli et al. Ref. [4]	Not included to IBANDL

Data assessment of $^{12}C(\alpha,\alpha)^{12}C$ cross sections

Some discrepancies between original data and data published in IBANDL are detected.

-only part of data from original publications was digitized and transferred to IBANDL database. For instance, IBANDL contains data from C. Miller Jones at al.,Nucl. Phys.37 (1962)1 but only for 106,7° although original publication reports cross sections for three other laboratory angles 124°, 136° and 160°. As this is a case for several publications, all published data not included in IBANDL are marked red.
As they are published only in graphical form, it is necessarily to digitize them.

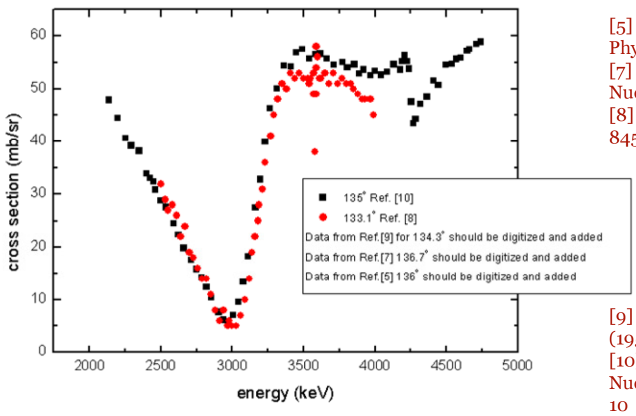
Angle Lab	energy (keV)	Author	Comment
170°	4100-7640	J.A. Davies et al.,Nucl. Instr. and Meth. B85 (1994) 28 Ref. [1]	In IBANDL CS at 5.5 MeV is missing and is given in original publication to be 493 mb/sr
172°	4035-4635	R. Somatri et al. Nucl. Instr. and Meth. B113 (1996) 284 Ref. [2]	The energies in original publication are for 5 keV lower than energies given in IBANDL
165°	1810-9052	Y. Feng et al., Nucl. Instr. and Meth. B86 (1994) 225 Ref. [3]	In original publication CS for 3543 keV is 5.95 instead of 5.92 in IBANDL
170.5°	1564-4976	J.A.Leavitt, Nucl. Instr. and Meth. B40/41 (1989) 776 Ref. [4]	Published data in agreement with IBANDL

106.7°	2500-4800	C. Miller Jones at al.,Nucl. Phys.37 (1962)1 Ref. [5]	Digitized data transferred to IBANDL
124°	2500-4800	Ref. [5]	Need to be digitized Not included to IBANDL, see Add.1
136°	2500-4800	Ref. [5]	Need to be digitized Not included to IBANDL, see Add.1
160°	2500-4800	Ref. [5]	Need to be digitized Not included to IBANDL, see Add.1
170°	5000-9000	H.-S. Cheng etal., Acta Phys. Sinica 43 (1994) 1569 Ref. [6]	Data published in IBANDL were not compared with original publication (not available)
149°	4000-13300	T.P.Marvin et al., Nucl.Phys.A180 (1972) 282 Ref. [7]	Digitized data transferred to IBANDL
143.9°	4000-13300	Ref. [7]	Need to be digitized Not included to IBANDL, see Add.2
136.7°	4000-13300	Ref. [7]	Need to be digitized Not included to IBANDL, see Add.2
125.1°	4000-13300	Ref. [7]	Need to be digitized Not included to IBANDL, see Add.2
113.9°	4000-13300	Ref. [7]	Need to be digitized Not included to IBANDL, see Add.2
106.8°	4000-13300	Ref. [7]	Need to be digitized Not included to IBANDL, see Add.2
104°	4000-13300	Ref. [7]	Need to be digitized Not included to IBANDL, see Add.2

104°	4000-13300	Ref. [7]	Need to be digitized Not included to IBANDL, see Add.2
166.6°	640-1170 1910-3980	R.W. Hill, Phys.Rev.90 (1953) 845 Ref. [8]	Digitized data available in IBANDL but from 640 –1170 keV and from 1910 -3980 keV, the part from 1170 to 1910 keV should be digitized and added to IBANDL
133.3°	2500-4000	Ref. [8]	Digitized data available in IBANDL
107,2°	2500-4000	Ref. [8]	Need to be digitized Not included to IBANDL, see Add.3
167°	3800-7600	J.W. Bittner et al., Phys. Rev. 96 (1954) 374 Ref. [9]	Digitized data available in IBANDL
134.3°	3800-7600	Ref. [9]	Need to be digitized Not included to IBANDL, see Add.4
125.2°	3800-7600	Ref. [9]	Need to be digitized Not included to IBANDL, see Add.4
104.8°	3800-7600	Ref. [9]	Need to be digitized Not included to IBANDL, see Add.4

Comparison of published data for different scattering angles

Data from [10] and [8] are in good agreement up to 3500 keV as can be seen from Fig. 1. For energies higher than 3500 keV discrepancy between this two data sets exist. Data from [9], [7] and [5] can give adittional information about cross-section behavior.



[5] C. Miller Jones at al., Nucl. Phys.37 (1962)1

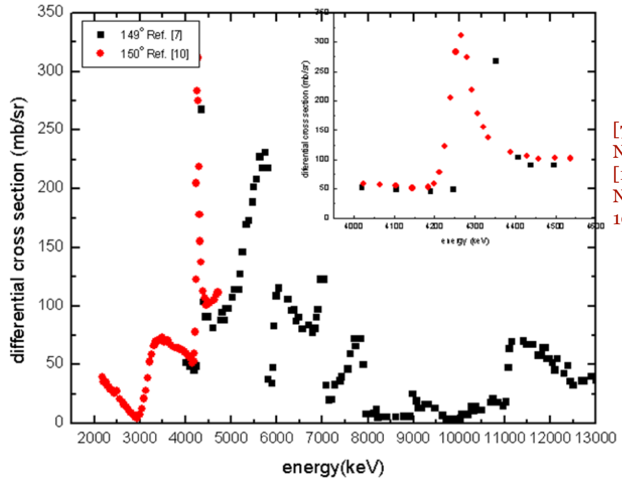
[7] T.P.Marvin et al., Nucl.Phys.A180 (1972) 282

[8] R.W. Hill, Phys.Rev.90 (1953) 845

[9] J.W. Bittner et al., Phys. Rev. 96 (1954) 374

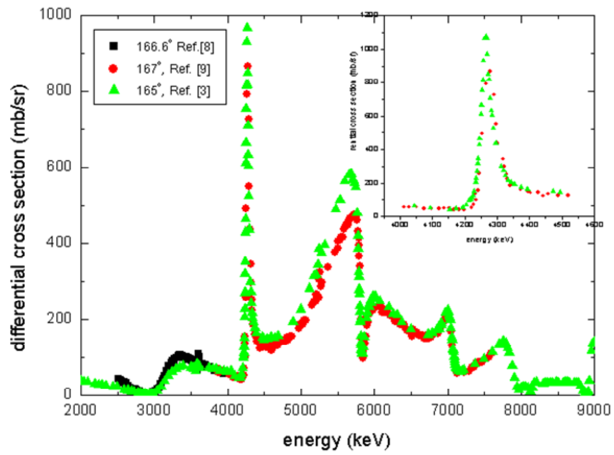
[10] I. Bogdanović Radović et al. , Nucl. Instr. and Meth. B190 (2002) 10

Around 150° there are data from [7] for 149° and data from [10] for 150°. Data overlap in the region where strong resonance exists. As can be seen from Fig.2 two sets of data differ in both, resonance position and intensity.



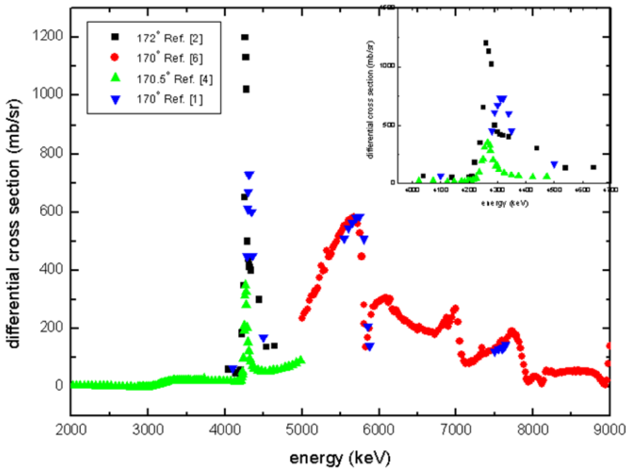
[7] T.P.Marvin et al., Nucl.Phys.A180 (1972) 282
[10] I. Bogdanović Radović et al. , Nucl. Instr. and Meth. B190 (2002) 10

Around 165° there are three databases available. Agreement between experimental points from [9] and [3] is good for ~ 4250 keV resonance, difference in resonance position between two data sets is about 10 keV as can be seen from Fig.3. Data also differ in the height of the resonance.



[3] Y. Feng et al., Nucl. Instr. and Meth. B86 (1994) 225
[8] R.W. Hill, Phys.Rev.90 (1953) 845
[9] J.W. Bittner et al., Phys. Rev. 96 (1954) 374

Around 170° there are four data sets available in IBANDL. For 4250 keV three data sets can be compared but as can be seen from the magnified part they all differ concerning resonance height. Two data sets [5] and [2] are in good agreement concerning resonance position.

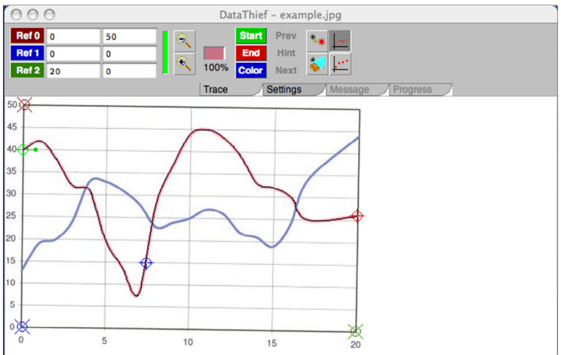


[1] J.A. Davies et al.,Nucl. Instr. and Meth. B85 (1994) 28
[2] R. Somatri et al., Nucl. Instr. and Meth. B113 (1996) 284
[4] J.A.Leavitt, Nucl. Instr. and Meth. B40/41 (1989) 776
[6] H.-S. Cheng et al., Acta Phys. Sinica 43 (1994) 1569

Data review on $^{23}Na(p,p)^{23}Na$, $^{19}F(p,p)\,^{19}F$, $^{6,7}Li(p,p)\,^{6,7}Li$ cross-sections

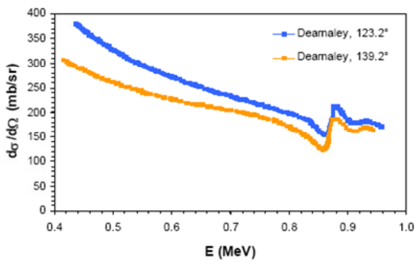
Massimo Chiari (I.N.F.N Florence)

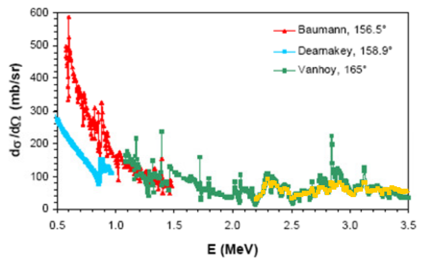
Reverse engineering data from plots: "Datathief" code



www.datathief.org

Data review on $^{23}Na(p,p)^{23}Na$ cross-section





Reference	Data source	θ_{lab}	E_p (MeV)	Target	Quoted uncertainties	Data presentation
[1]	IBANDL	156.5°	0.57-1.48	Metallic sodium evaporated onto Nylon films	-	Tabular
[2]	Original paper	123.2° 139.2° 158.9°	0.4-1.0	Na metal evaporated on a C backing	-	Graphical
[3]	Original paper	165°	1.08-3.50	1-3 μg/cm² Na evaporated on Au coated (1 μg/cm²) C foils (5 μg/cm²)	1-2% statistical	Graphical

Table 1: Available data in the literature on $^{23}Na(p,p_0)^{23}Na$ cross-sections.

[1] N.P. Baumann et al., Phys. Rev. 104 (1956) 376

[2] G. Deamaley, Philos. Mag. ser. 8, 1 (1956) 821

[3] J.R. Vanhoy et al., Phis. Rev. C vol. 39 (1987) 920

DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS

Research Co-ordination Meeting, Vienna, 18-21 June 2007

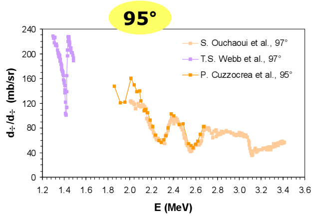
Data review on $^{19}F(p,p)^{19}F$ cross-section

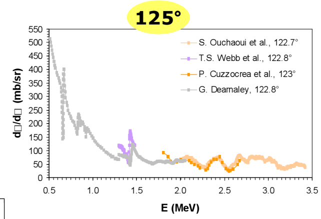
Reference	Data source	θ_{lab}	E_p (MeV)	Target	Quoted uncertainties	Data presentation	Notes
T.S. Webb et al., Phys. Rev. 99 (1955) 138	Original paper	122.8° 158.7°	0.55-1.80	Thick target LiF	6%	Graphical	Ratio to Rutherford
T.S. Webb et al., Phys. Rev. 99 (1955) 138	Original paper	97.0° 107.1° 133.8°	1.30-1.50	Thick target LiF	6%	Graphical	Ratio to Rutherford
G. Dearnaley, Philos. Mag. ser. 8, 1 (1956) 821	IBANDL, original paper	122.8° 138.8° 158.7°	0.50-2.06	LiF evaporated on to a C backing	10%	Tabular, graphical	
G.M. Lerner and J.B. Marion, Nucl. Instr. Meth. 69 (1969) 115	IBANDL	90°	1.36	0.03 to 0.1 mg/cm² LiF evaporated on a C foil	10% statistical and systematic	Tabular	223 ± 21 mb/sr
R. Caracciolo et al., Lettere al Nuovo Cimento 11 (1974) 33	Original paper	135° 145°	0.65-1.80	-	-	Graphical	Ratio to Rutherford
P. Cuzzocrea et al., Lettere al Nuovo Cimento 28 (1980) 515	EXFOR	95.0° 123.0° 137.0°	1.80-2.68	-	-	Tabular	Ratio to Rutherford
S. Ouichaoui et al., Nuovo Cimento 94 (1986) 133	Original paper	122.7° 148.5° 161.1°	2.00-3.40	C_2F_6 gas target (2÷8 Torr)	10%	Graphical	
J.M. Knox and J.F. Harmon, Nucl. Instr. Meth. B44 (1989) 40	IBANDL	165°	0.85-1.01	85 μg/cm² LuF_3, deposited on polycarbonate film	2% statistical, 3-4% reproducibility	Tabular	Ratio to Rutherford
J.M. Knox and J.F. Harmon, Nucl. Instr. Meth. B44 (1989) 40	IBANDL	153°	1.00-1.88	137.9 μg/cm² LiF, deposited on 38 μg/cm² Cu, deposited on 50 μg/cm² C	2% statistical, 3-4% reproducibility	Tabular	Ratio to Rutherford
I. Bogdanović et al., Nucl. Instr. Meth. B79 (1993) 524	IBANDL	150°	2.50-4.79	158.5 μg/cm² CeF_3	8%	Tabular	
A.P. Jesus et al., Nucl. Instr. Meth. B174 (2001) 229	Original paper	165°	1.40-2.71	69, 45 and 78 μg/cm² GdF_3 on thin C foil	5%	Tabular	Ratio to Rutherford
A. Caciolli et al., Nucl. Instr. Meth. B249 (2006) 95	Original paper	150°	3.0-7.2	50 μg/cm² LiF on 30 μg/cm² C, coated with 20 μg/cm² Au	5%	Graphical	

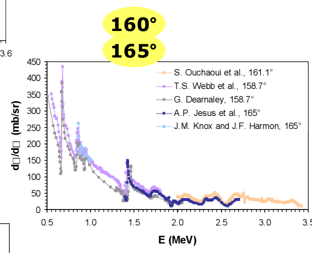
DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS

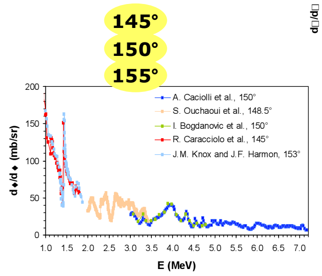
Research Co-ordination Meeting, Vienna, 18-21 June 2007

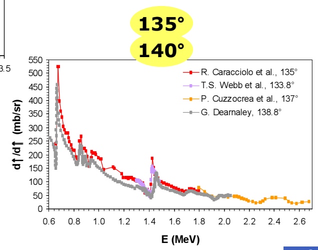
Data review on $^{19}F(p,p)^{19}F$ cross-section











DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS
Research Co-ordination Meeting, Vienna, 18-21 June 2007

Data review on $^{7}Li(p,p)^{7}Li$ cross-section

Reference	Data source	θ_{lab}	E_p (MeV)	Target	Quoted uncertainties	Data presentation	Notes
A.B. Brown et al., Phys. Rev. 82 (1951) 159	EXFOR	137.8°	0.28-1.40	Li evaporated on Be foil	20%	Tabular	cs per 4π steradians in the CM reference system
S. Bashkin and H.T. Richards, Phys. Rev. 84 (1951) 1124	IBANDL	164°	0.88-3.68	Ordinary Li metal evaporated upon thin Ni foil	20%	Tabular	
W.D. Warters et al., Phys. Rev 91 (1953) 917	IBANDL, EXFOR	102.0° 123.1° 137.9° 156.70°	0.37-1.40	Natural Li on Cu backing	5%	Tabular	
D. Liberman Ph.D. thesis (California Institute of Technology, 1955)	IBANDL	90°	1.36	-	4%	Tabular	37 mb/sr
P.R. Malmberg, Phys. Rev. 101 (1956) 114	IBANDL, original paper	102.0° 123.1° 145.3° 164.9°	1.35-3.00	Thin lithium layer evaporated on a thin Zapon film	10%	Tabular, Graphical	
U. Fasoli et al., Nuovo Cimento 34 (1964) 542	Original paper	101.5° 117.9° 134.6° 144.5° 166.2°	3.0-5.5 1.2-5.5	Isotopically enriched ^{7}Li (99.3%) evaporated on a 1000 Å Ni foil	-	Graphical	
R. Gleyvod et al., Nucl. Phys. 63 (1965) 650	EXFOR	123.1° 145.4° 163.9°	2.36-12.1	Thin isotopically enriched ^{7}Li (99.97%) layer evaporated on a thin Formvar film	15%	Tabular	

Reference	Data source	θ_{lab}	E_p (MeV)	Target	Quoted uncertainties	Data presentation	Notes
R. Gleyvod et al., Nucl. Phys. 63 (1965) 650	EXFOR	39.5°-164.6°	4.2	Thin isotopically enriched ^{7}Li (99.97%) layer evaporated on a thin Formvar film	15%	Tabular	Angular distribution
K. Kilian et al., Nucl. Phys. A126 (1969) 529	EXFOR	90° 120° 140°	2.58-10.6	Enriched ^{7}Li (99.99%, 150 $\mu g/cm^2$) evaporated onto 45 $\mu g/cm^2$ Ni backings	-	Tabular	
K. Kilian et al., Nucl. Phys. A126 (1969) 529	EXFOR	39.0°-170.5°	3.1 4.0 5.0 6.15 10.3	Enriched ^{7}Li (99.99%, 150 $\mu g/cm^2$) evaporated onto 45 $\mu g/cm^2$ Ni backings	-	Tabular	Angular distribution
G.M.Lerner and J.B.Marion, Nucl. Instr. Meth. 69 (1969) 115	EXFOR	90°	1.36	0.03 to 0.1 mg/cm^2 natural LiF evaporated on a C foil	12% statistical and systematic	Tabular	34 ± 4 mb/sr
H.G. Bingham et al., Nucl. Phys. A173 (1971) 265	Original paper	95.0°	6.868	Natural lithium LiI evaporated on a Formvar backing	2%	Tabular	36.80 ± 0.70 mb/sr Differential cs in CM reference system
A. Caciolli et al., Nucl. Instr. Meth. B249 (2006) 95	Original paper	150°	3.0-7.2	50 $\mu g/cm^2$ LiF on 30 $\mu g/cm^2$ C, coated with 20 $\mu g/cm^2$ Au	4%	Graphical	

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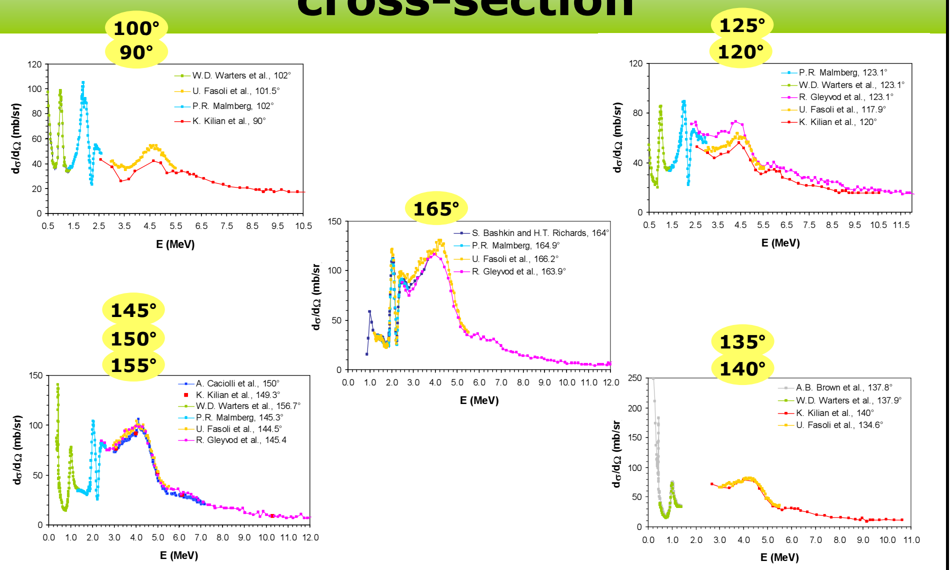

DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS
Research Co-ordination Meeting, Vienna, 18-21 June 2007

Data review on $^6Li(p,p)^6Li$ cross-section

Reference	Data source	θ_{lab}	E_p (MeV)	Target	Quoted uncertainties	Data presentation	Notes
S. Bashkin and H.T. Richards, Phys. Rev. 84 (1951) 1124	EXFOR	164°	1.14–3.07	Natural Li metal evaporated onto thin Ni foil	20%	Tabular	
J.A. McCray, Phys. Rev. 130 (1963) 2034	EXFOR	118.2° 155.8°	0.4-2.9	^{6}Li metal samples (94.5% and 99.7% purity)	5%	Tabular	Ratio to Rutherford
W.D. Harrison and A.B. Whitehead, Phys. Rev. 132 (1963) 2607	EXFOR	33.8°-160.0°	2.40-12.0	30-300 μg/cm^2 ^{6}Li (enriched to 99%) evaporated on a thin C or Ni foil.	1-15% (statistics, background subtraction, normalization)	Tabular	
W.D. Harrison and A.B. Whitehead, Phys. Rev. 132 (1963) 2607	EXFOR	116.7°	5.50 6.50 7.50 8.50 9.50 10.50 11.50	30-300 μg/cm^2 ^{6}Li (enriched to 99%) evaporated on a thin C or Ni foil.	2-4% (statistics, background subtraction, normalization)	Tabular	
U. Fasoli et al., Nuovo Cimento 34 (1964) 1832	EXFOR	100.3° 116.7° 140.6° 143.8° 166.4°	1.25-5.55	99.3% enriched ^{6}Li metal evaporation on a 1000 Å Ni foil	1.5% statistical, 1% background correction	Tabular	
U. Fasoli et al., Nuovo Cimento 34 (1964) 1832	EXFOR	47.6°-163.8°	2.84-5.55	99.3% enriched ^{6}Li metal evaporation on a 1000 Å Ni foil	1.5% statistical, 1% background correction	Tabular	Angular distribution

Reference	Data source	θ_{lab}	E_p (MeV)	Target	Quoted uncertainties	Data presentation	Notes
G.M. Lerner and J.B. Marion, Nucl. Instr. Meth. 69 (1969) 115	EXFOR	90°	1.36	0.03 to 0.1 mg/cm^2 ^{6}LiF (95% enriched in ^{6}Li) evaporated on a C foil	15% statistical and systematic	Tabular	61 ± 9 mb/sr
M. Laurat, Centre d`Etudes Nucleaires, Saclay Reports No.3727 (1969)	EXFOR	150° 135°	1.75-10.5	-	-	Tabular	Differential cs in CM reference system
M. Laurat, Centre d`Etudes Nucleaires, Saclay Reports No.3727 (1969)	EXFOR	49.7°-180°	3.6-9	-	-	Tabular	Angular distribution
H.G. Bingham et al., Nucl. Phys. A173 (1971) 265	Original paper	95.0°	6.868	Enriched ^{6}LiI (99.32%), natural LiF and LiI evaporated on a Formvar backing	5%	Tabular	34.02 ± 2.00 mb/sr 34.40 ± 1.00 mb/sr 34.00 ± 1.50 mb/sr Differential cs in CM reference system
M. Haller et al., Nucl. Phys. A496 (1989) 189	EXFOR	90°-165° (5° steps)	1.06-11.8	LiF on Ni backing, Al-^{6}Li-C, C-^{6}Li-C (50 μg/cm^2 ^{6}Li)	7.0%	Tabular	Differential cs in CM reference system Energy in CM reference system in original graphs (EXFOR energy in Lab reference system??)
M. Skill et al., Nucl. Phys.	EXFOR	90°-160°	0.80-2.20	C-^{6}LiF target (10	0.2% statistical	Tabular	

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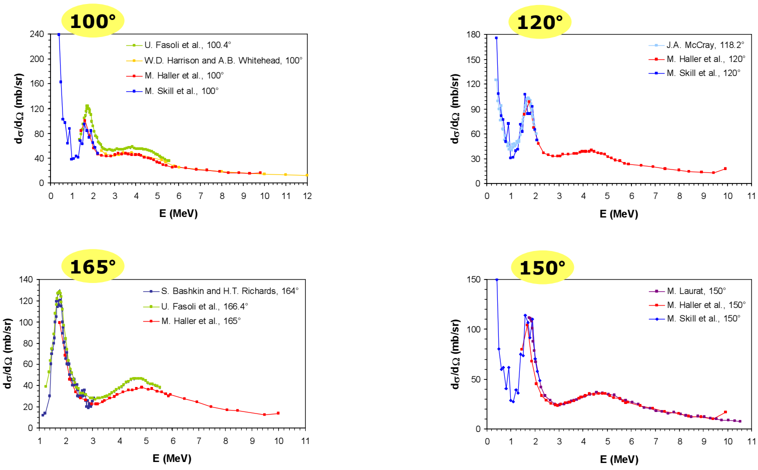
Data review on $^{6}Li(p,p)^{6}Li$ cross-section



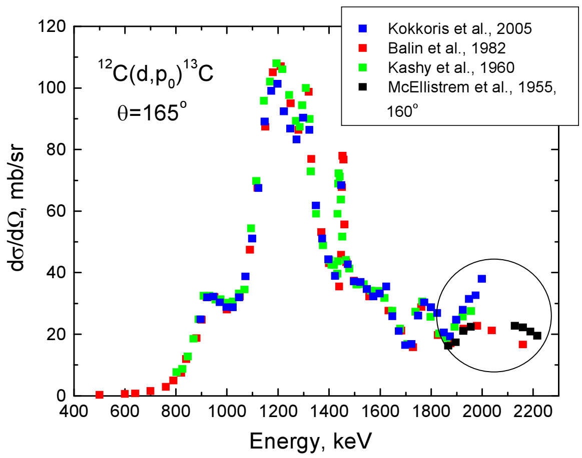
DEVELOPMENT OF A REFERENCE DATABASE FOR ION BEAM ANALYSIS

Research Co-ordination Meeting, Vienna, 18-21 June 2007

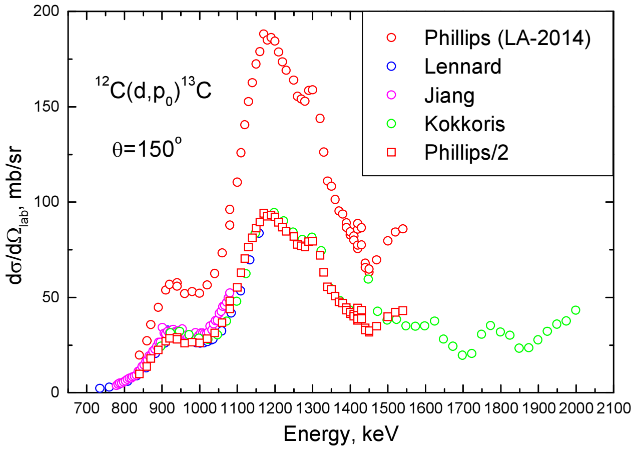
Assessment of the $^{12}C(d,p)^{13}C$ cross sections

A. Gurbich
Institute of Physics and Power Engineering
Obninsk, Russia

Comparison of $^{12}C(d,p_0)^{13}C$ experimental data for 165°

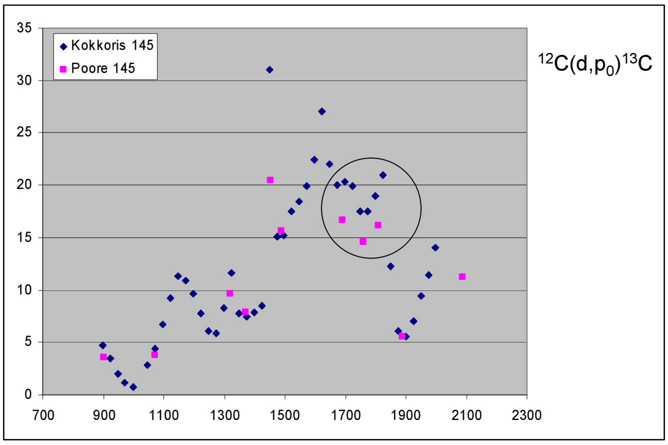


Comparison of the $^{12}C(d,p_0)^{13}C$ experimental data for 150°



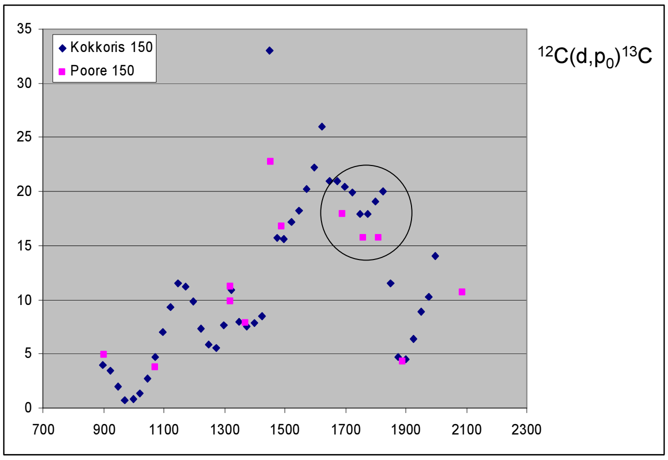
Kokkoris vs Poore

[R.V. Poore, P.E. Shearin, D.R. Tilley, R.M. Willamson, Nucl. Phys. A 92(1967) 97]



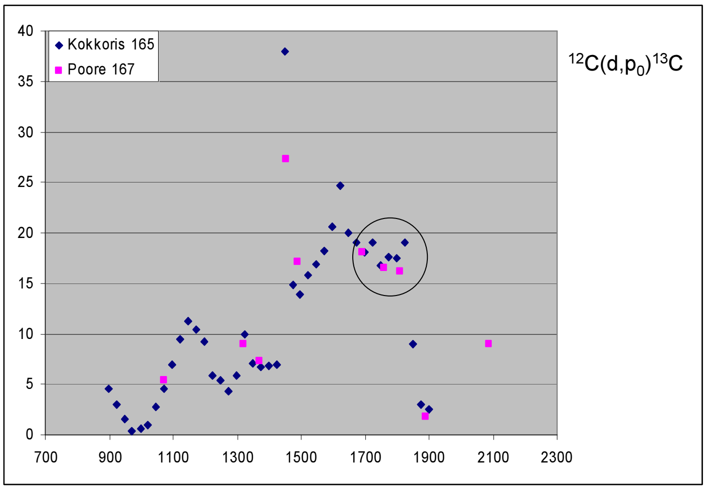
Kokkoris vs Poore

[R.V. Poore, P.E. Shearin, D.R. Tilley, R.M. Willamson, Nucl. Phys. A 92 (1967) 97]



Kokkoris vs Poore

[R.V. Poore, P.E. Shearin, D.R. Tilley, R.M. Willamson, Nucl. Phys. A 92 (1967) 97]

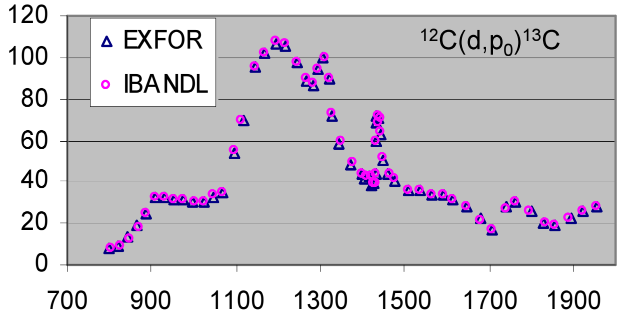


Absolute values for the $^{12}C(d,p_0)^{13}C$ cross section at 150°

Energy, keV	Cross section, mb/sr	Target	Reference
968	29.5±1.2	Polystyrene	Quillet
970	27.9±1.4	Frozen gas	Lennard91
970	25.5±0.8	Frozen CO_2	Davies80
969	29.25±1.2	C/Glass	Jiang

EXFOR vs IBANDL

[E. Kashy, R.R. Perry, J.R. Risser, Phys.Rev. 117 (1960) 1289]

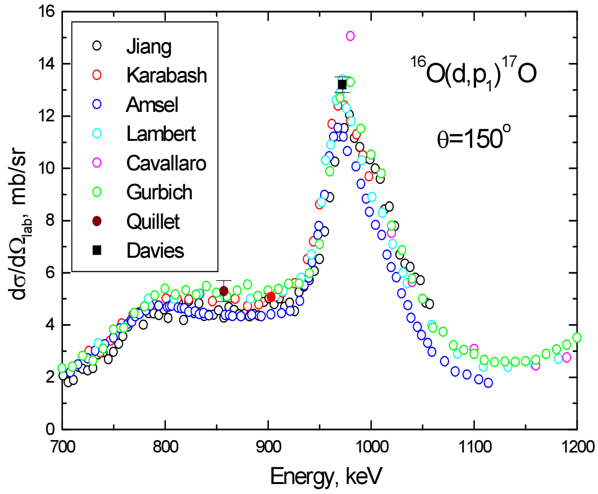


Cumulative information on the deuteron induced reactions for ^{12}C.

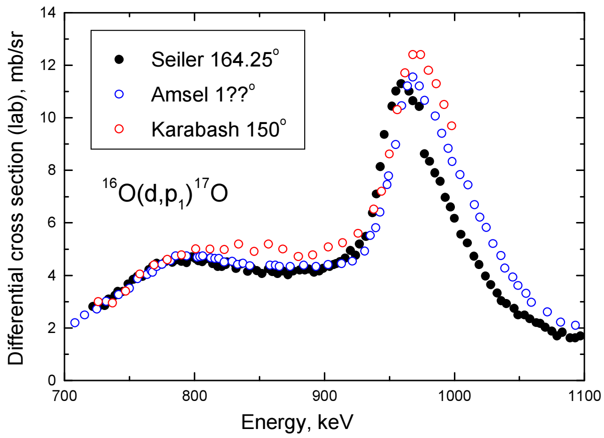
Energy range (MeV)	Reaction	Target	The energy (MeV) of angular distribution measurement	The angle of excitation function measurement	Error	Data presentation	Notes	Ref.
0.9-2.1	(d,p_1)	Thin self-supporting ^{12}C targets made from a suspension of graphite in alcohol	0.9, 1.07, 1.32, 1.37, 1.452, 1.49, 1.69, 1.76, 1.809, 1.89, 2.088			Graph	EXFOR F0334002 Excitation function for 145°, 150°, 167° derived from angular distributions are shown in Figs. 2-4	Poore
0.968	(d,p_0)	Polystyrene film		150	4%	Value		Quillet
0.970	(d,p_0)	Frozen CO_2		150	2%	Value	Added to IBANDL	Davies
0.74-1.18	(d,p_0)	Frozen gas		150	5%	Table	Added to IBANDL	Lennard
0.8-1.1	(d,p_0)	C/Glass		150	4%	Table, Graph	Added to IBANDL	Jiang
0.5-3.0	(d,p_0)	Carbon foil		135	12%	Graph	Jarjis' data are presented in IBANDL	Debras
0.75-1.98	(d,d), (d,p_0), (d,p_1)	Carbon foil	0.92, 1.19, 1.31, 1.61, 1.76	47.6, 80.5, 158.4, 165.0	8%	Graph	Cross section for 158.4° was added to IBANDL (EXFOR 1007003). Data for (d,p_1) are presented only for 80.5°.	Kashy
0.78-1.55	(d,p_0)	Cracking benzene vapor on silver foils	0.75, 0.91, 0.99, 1.09, 1.16, 1.286, 1.30, 1.32	0, 90, 150		Graph	Data from LA-2014 report are presented in IBANDL	Phillips
0.5-2.16	(d,p_0)	Carbon foil		165	7%	Graph	Data supplied by the authors are presented in IBANDL	Balin
1.87-3.51	(d,p_0)	Gas		160, 168.7…	5%	Graph	Cross section for 160° was added to IBANDL (EXFOR C0993006 converted to lab.)	McEllistrem
0.8-1.5	(d,p_0)	Thick target		165		Graph		Barit
0.9 – 2.0	(d,p_{0-3})	Carbon foils		145, 150, 155, 160, 165, 170		Graph, Table	Added to IBANDL	Kokkoris

Assessment of the $^{16}O(d,p)^{17}O$ cross sections

Experimental data available for the $^{16}O(d,p_1)^{17}O$ reaction in the energy range from 700 to 1200 keV at 150°. Solid points represent the data reported in numerical form

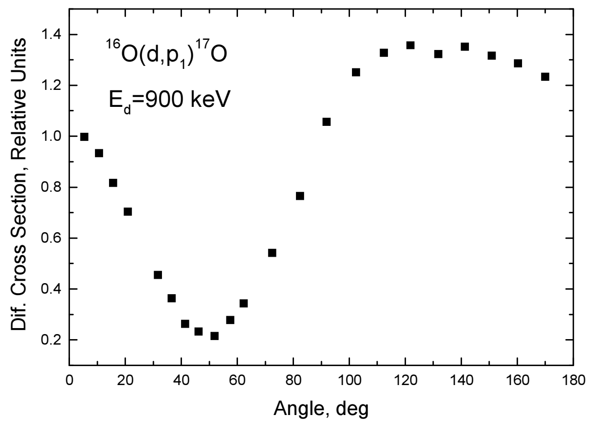


Comparison of Amsel's data with other results obtained for 150° and 165°

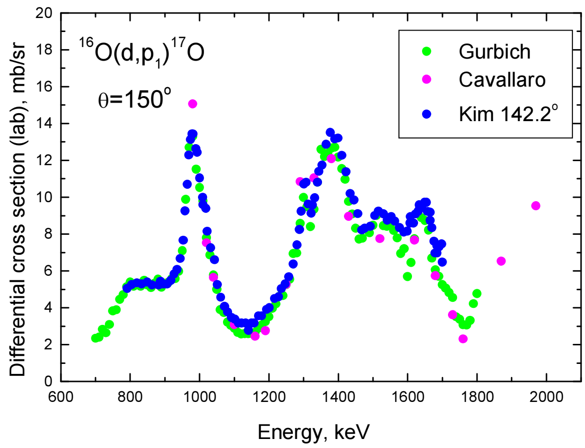


G. Amsel, D. Samuel, Anal. Chem. 39 (1967) 1689.
G. Amsel, G. Bernager, B. de Gelas, P. Lacombe, J. Appl. Phys. 39 (1968) 2246.
G. Amsel, D. David, G. Beranger, P. Boisot, Rev. Phys. Appl. 3 (1968) 373.
G. Amsel, J.P. Nadai, E. d'Artemare, D. David, E. Girard, J. Moulin, Nucl. Instr. and Meth. 92 (1971) 481.

Angular distribution for the $^{16}O(d,p_1)^{17}O$ reaction at 900 keV
[G. Amsel, Ann. Phys. 9 (1964) 197]



Comparison of different data for the $^{16}O(d,p_1)^{17}O$ reaction in a wide energy region (Cavallaro's excitation function was constructed from angular distributions)

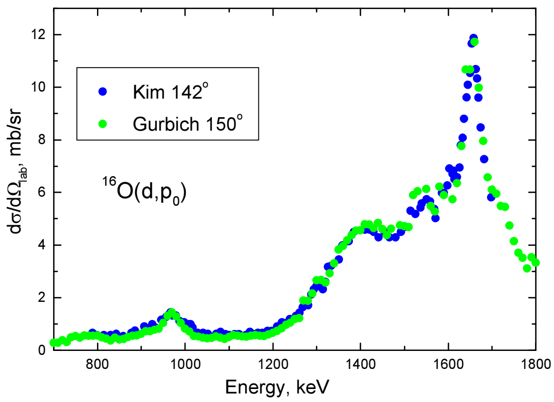


Absolute values for the $^{16}O(d,p_1)^{17}O$ cross section

Energy, keV	Cross section, mb/sr	Target	Reference
857	5.3±0.4	Ta_2O_5	Quillet
903	5.07±0.15	Al_2O_3	Karabash
972	13.6±0.4	Ta_2O_5	Lennard89
972	13.3±0.4	Ta_2O_5	Davies80
972	13.2±0.3	Ta_2O_5	Davies83
857 969 974 979	4.28±0.11 11.22±0.45 11.53±0.46 12.05±0.48	SiO_2	Jiang

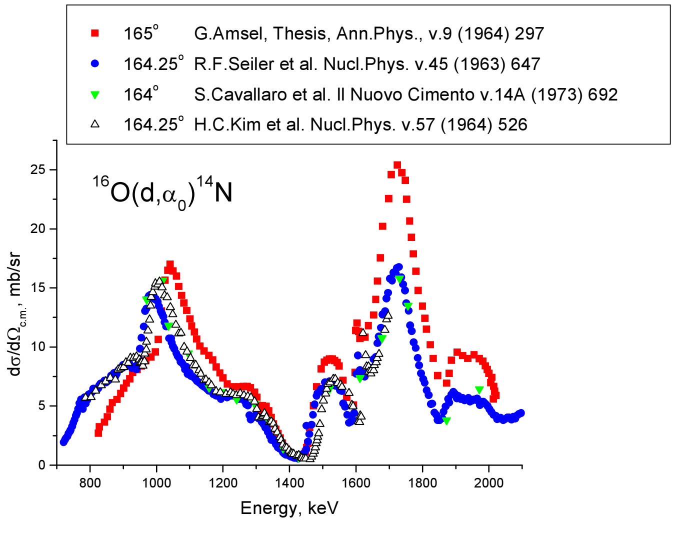
The peak in the cross section [Jiang] is shifted by 7 keV and the values are lower both at the plateau and for the peak. The peak to plateau ratio is 2.82 in [Jiang] versus 2.57 in average for the other works.

Comparison of different data sets for the $^{16}O(d,p_0)^{17}O$ reaction

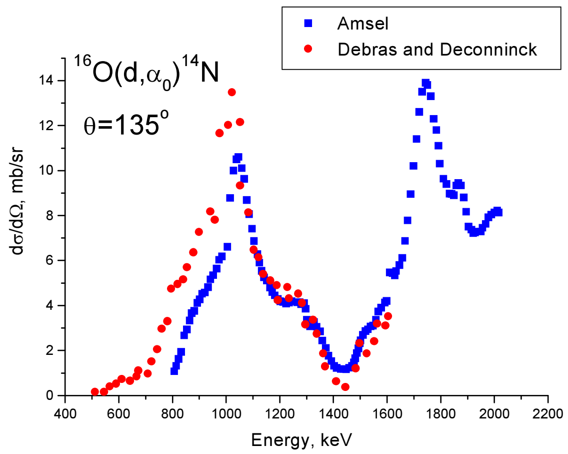


Assessment of the $^{16}O(d,\alpha)^{14}N$ cross sections

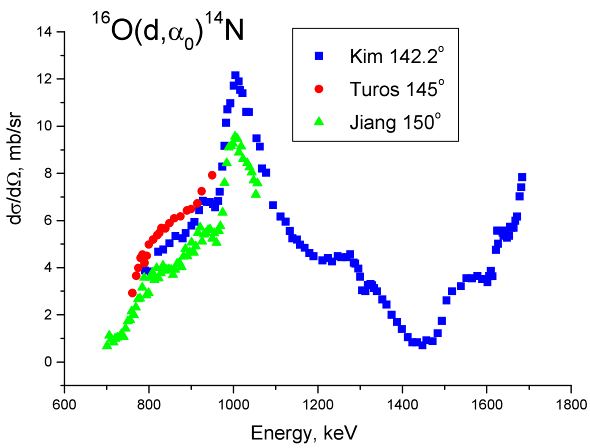
Comparison of the $^{16}O(d,\alpha_0)^{14}N$ experimental data for ~165°



Comparison of the $^{16}O(d,\alpha_0)^{14}N$ experimental data for 135°

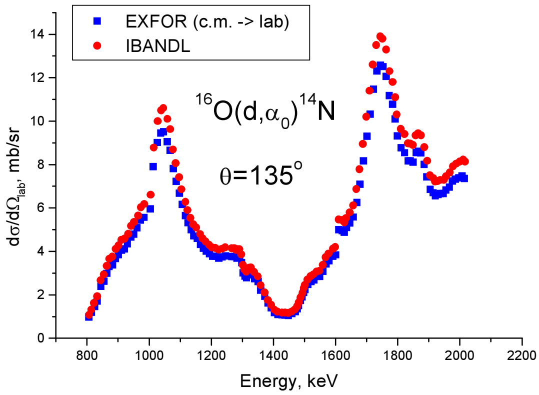


Comparison of the $^{16}O(d,\alpha_0)^{14}N$ experimental data for ~145°



EXFOR vs IBANDL

[G.Amsel, Thesis, Ann.Phys., v.9 (1964) 297]



Cumulative information on the deuteron induced reactions for ^{16}O.

Energy range (MeV)	Reaction	Target	The energy (MeV) of angular distribution measurement	The angle of excitation function measurement	Error	Data presentation	Notes	Ref.
0.8-1.7	(d,p_0), (d,p_1), (d,α_0)	Gas		51.4, 66.9, 86.7, 127.7, 142.2, 164.3	5%	Graph	Added to IBANDL	Kim
0.7-1.0	(d,p_1)	Al_2O_3, 62.8 μg/cm^2		150	3-5%	Table		Karabash
0.98-1.97	(d,d_0), (d,p_0), (d,p_1), (d,α_0)	Gas	0.98, 1.02, 1.04, 1.10, 1.16, 1.19, 1.25, 1.29, 1.34, 1.38, 1.43, 1.52, 1.62, 1.68, 1.73, 1.76, 1.87, 1.977		6%	Graph	Excitation function for 150° derived from angular distributions was added to IBANDL	Cavallaro
0.857	(d,p_1)	Ta_2O_5, $361\cdot10^{15}$ cm^{-2}		150	7.5%	Value		Quillet
0.972	(d,p_1)	Ta_2O_5		150	2%	Value	Added to IBANDL	Davies80, Davies83
0.7-1.8	(d,p_0), (d,p_1)	Al_2O_3, 60 μg/cm^2		150	7.5%	Graph, IBANDL	Mistakes were corrected in the IBANDL files	Gurbich
0.972	(d,p_1)	Ta_2O_5		150		Value	Added to IBANDL	Lennard89
0.7-1.2	(d,p_1)	Ta_2O_5		150	5%	Table	Added to IBANDL	Lennard91
0.7-1.06	(d,p_1), (d,α_0)	SiO_2		150	4%	Table, Graph		Jiang
0.55-0.66	(d,p_0)	Ta_2O_5		150	10%	Graph		Berty
0.65-2.0	(d,p_0), (d,p_1), (d,α_0)	Gas		164.25	5%	Graph	Added to IBANDL (EXFOR data converted from c.m. to lab.) instead of data from NDT.	Seiler
0.5-3.0	(d,p_0), (d,p_1), (d,α_0)	SiO_2, Ta_2O_5		135	12%	Graph	Added to IBANDL (EXFOR data) instead of Jarjis' data.	Debras
0.8-2.0	(d,p_0), (d,p_1), (d,α_0)	Ta_2O_5	0.900, 0.950, 0.986, 1.013, 1.040, 1.067, 1.069, 1.145, 1.206, 1.266, 1.299, 1.310, 1.385	90, 135, 165 (d,α); 10, 87, (d,p0,1)		Graph		Amsel64
0.42-1.12	(d,p_1)	Presumably Ta_2O_5		150(?), 165(?)		Graph		Amsel [1-5]
0.84-1.02	(d,α_0)	SiO_2		160		Graph		Picraux
0.76-0.95	(d,p_1), (d,α_0)	SiO_2		145		Graph		Turos

ASSESSEMENT OF ALPHA AND PROTON ELASTIC SCATTERING CROSS SECTIONS FOR N

A.R. Ramos, N.P. Barradas, E. Alves

$^{14}N(p,p_0)^{14}N$

Summary

- The data sets on IBANDL were compared with the data in the original references.
- Details were given on the discrepancies found.
- A thorough search for other available experimental data was performed.
- Most of the existing data correspond to scattering angles in the 150º-170º region, below 3 MeV.
- Existing measured cross sections were compared and checked for discrepancies and gaps.
  - Most discrepancies occur around the resonances at proton energies ~1050 keV, ~1750 keV and ~2350 keV. The exact height and position of these resonances should be carefully studied to resolve these discrepancies.

Discrepancy Example

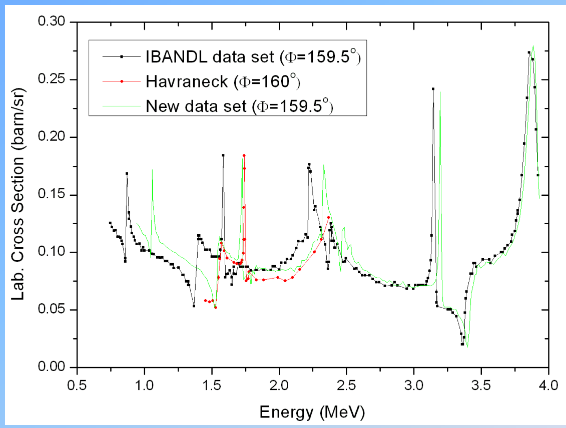


Fig. Comparison between the IBANDL data set for Φ=159.5º from [BAS1959] and the new digitized data set. Data with a similar scattering angle (Φ=160º) from [HAV1991] is included for comparison.

[BAS1959] S. Bashkin, R.R. Carlson, R.A. Douglas, Phys. Rev. 114 (1959) 1552.
[HAV1991] V. Havranek, V. Hnatowic, J. Kvitek, Czech. J. Phys. 41 (1991) 921.

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IBA RCM, 18-22 Jun 2007

Additional Data Sets

Digitalization procedure

The appropriate figure in the pdf file of the original paper was copied as a bmp file.

This file was imported on to an ORIGIN© graph with the exact dimensions and scale of the bmp picture.

When the resolution or scale of the original figure did not permit the exact position of each individual data point to be determined, a smooth curve was drawn by hand over the relevant experimental points. This smooth curve was then digitized at irregular intervals using the screen reader utility of ORIGIN© [TES1995].

[TES1995] Handbook of Modern Ion Beam Material Analysis, Eds. J.R. Tesmer, M. Nastasi, J.C. Barbour, C.J. Maggiore, J.W. Mayer, MRS, Pittsburgh, PA, USA (1995).

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IBA RCM, 18-22 Jun 2007

Additional Data Sets

Nº	Reaction	Lab. Scat. Ang	Energy Range (keV)	Reference	Comments	Digitizing procedure
19	$^{14}N(p,p_0)^{14}N$	109.1º	1900-3000	[LAM1967]	Data taken from fig. 1 in reference.	(b)
20	$^{14}N(p,p_0)^{14}N$	110.0º	1710-1830	[FEG1959]	Data taken from fig. 4 in reference.	(a)
21	$^{14}N(p,p_0)^{14}N$	110.0º	2300-2540	[FEG1959]	Data taken from fig. 5 in reference.	(a)
22	$^{14}N(p,p_0)^{14}N$	121.5º	1040-1080	[HAG1957]	Data taken from fig. 2 in reference.	(a)
23	$^{14}N(p,p_0)^{14}N$	121.5º	1460-1620	[HAG1957]	Data taken from fig. 3 in reference.	(a)
24	$^{14}N(p,p_0)^{14}N$	121.5º	1730-1760	[HAG1957]	Data taken from fig. 4 in reference.	(a)
25	$^{14}N(p,p_0)^{14}N$	121.5º	1790-1810	[HAG1957]	Data taken from fig. 4 in reference.	(a)
26	$^{14}N(p,p_0)^{14}N$	121.8º	1500-3500	[BOL1957]	Data taken from fig. 2 in reference.	(b)
27	$^{14}N(p,p_0)^{14}N$	130.0º	1710-1830	[FEG1959]	Data taken from fig. 4 in reference.	(a)
28	$^{14}N(p,p_0)^{14}N$	130.0º	2300-2540	[FEG1959]	Data taken from fig. 5 in reference.	(a)
29	$^{14}N(p,p_0)^{14}N$	138.1º	1500-3500	[BOL1957]	Data taken from fig. 2 in reference.	(b)
30	$^{14}N(p,p_0)^{14}N$	153.4º	1000-3000	[FEG1959]	Data taken from fig. 3 in reference. Data in 1710-1830 and 2300-2550 keV range taken from detailed figure 4 and 5 in reference.	(b)
31	$^{14}N(p,p_0)^{14}N$	159.5º	900-3920	[BAS1959]	Data taken from fig. 2 in reference.	(b)
32	$^{14}N(p,p_0)^{14}N$	167.2º	1000-4080	[OLN1958]	Data taken from fig. 1 in reference. Data in 3610-4080 keV range, detailed in figure 3 in reference, was already on IBANDL (data set nº5, table 1) and was incorporated in the file.	(b)

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Data Comparison

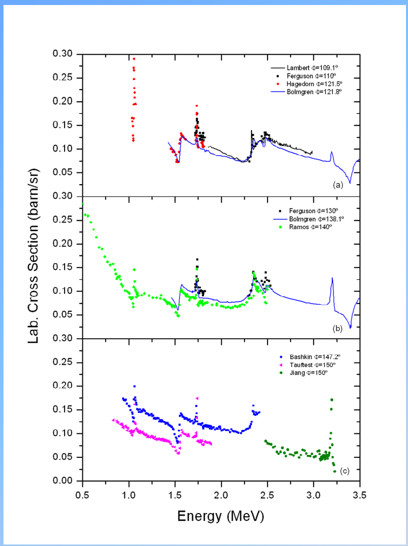

Fig. Cross section for the 14N(p,p$_0$)14N reaction at scattering angles in the 109.1º-150º range. Proton energy, scattering angles and cross-section values are given in the laboratory frame of reference.

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Data Comparison

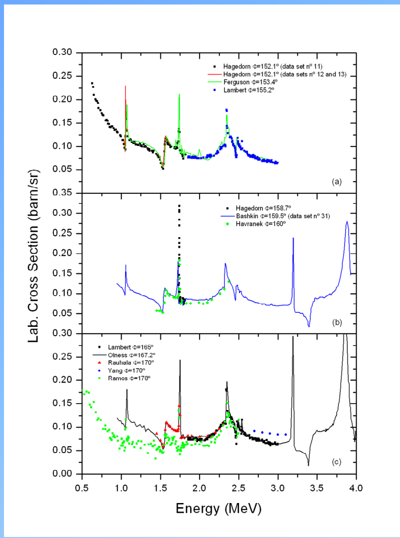

Fig. Cross section for the 14N(p,p_0)14N reaction at scattering angles in the 152.1º-178º range. Proton energy, scattering angles and cross-section values are given in the laboratory frame of reference.

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

Summary

• The data sets on IBANDL were compared with the data in the original references.

• Details were given on the discrepancies found.

• A thorough search for other available experimental data was performed.

• Most of the existing data correspond to scattering angles in the 160º-170º region, between 3 and 9 MeV.

Existing measured cross sections were compared and checked for discrepancies and gaps.

➢Most discrepancies found occur around the resonances. Their exact height and position should be carefully studied.

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Discrepancy Example

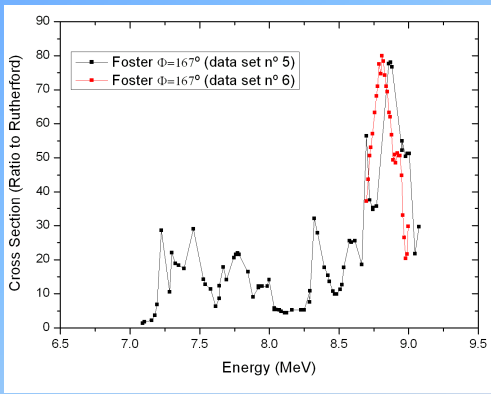

Fig. Comparison between the IBANDL data sets for Φ=167º from [FOS1993].

[FOS1993] L.A.Foster et al. Nucl.Instr.& Meth. B79 (1993) 454.

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Additional Data Sets

Table – Additional data sets found in the literature and digitized.

Nº	Reaction	Lab. Scattering Angle	Energy Range (keV)	Reference	Comments
13	$^{14}N(\alpha,\alpha_0)^{14}N$	109.5º	2010-3840	[HER1958]	Data taken from fig. 3 in reference.
14	$^{14}N(\alpha,\alpha_0)^{14}N$	127.5º	2010-3840	[HER1958]	Data taken from fig. 3 in reference.
15	$^{14}N(\alpha,\alpha_0)^{14}N$	172.0º	5200-7500	[ART1992]	Data taken from fig. 1 in reference.
16	$^{14}N(\alpha,\alpha_0)^{14}N$	177.0º	2300-2540	[QIU1992]	Data taken from table 1 in reference.

[HER1958] Herring et al., Phys. Rev. 112 (1958) 1210.

[ART1992] H. Artigalas et al., Nucl. Instr.& Meth. B66 (1992) 237.

[QIU1992] Y. Qiu, A.P. Rice, T.A. Tombrello, Nucl.Instr.& Meth. B71 (1992) 324.

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Data Comparison

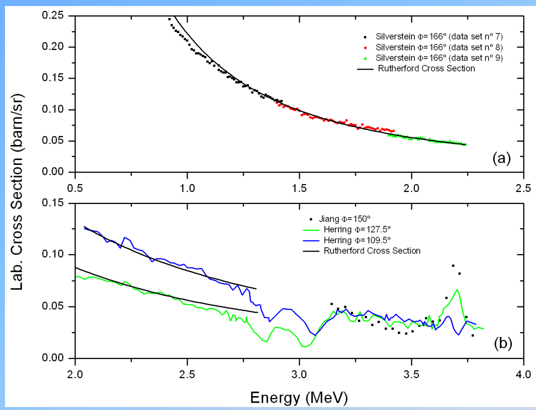

Fig. Cross section for the $^{14}N(\alpha,\alpha)^{14}N$ reaction.
(a) Cross section values measured at low energy for a scattering angle of 166º.
(b) Cross section values measured at scattering angles in the 109.5º-150º range.

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Data Comparison

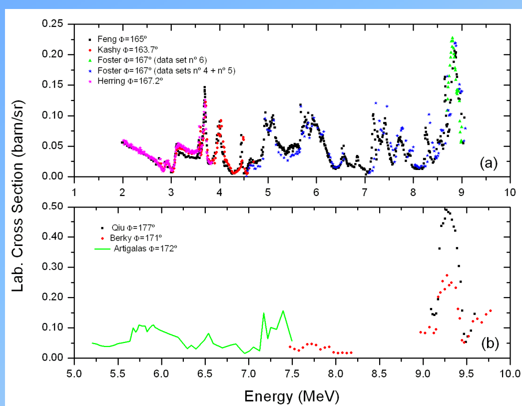

Fig. Cross section for the $^{14}N(\alpha,\alpha)^{14}N$ reaction at scattering angles in the 163.7º-177º range, measured for energies up to 9.750 MeV.

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Assessment of Cross-Section Data for Boron

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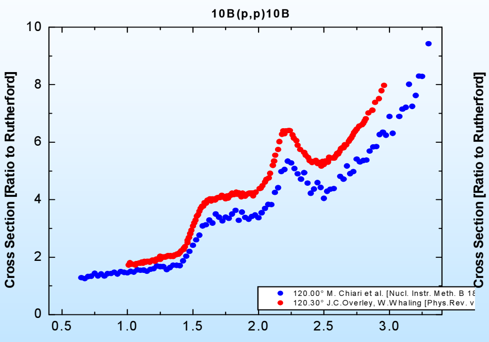
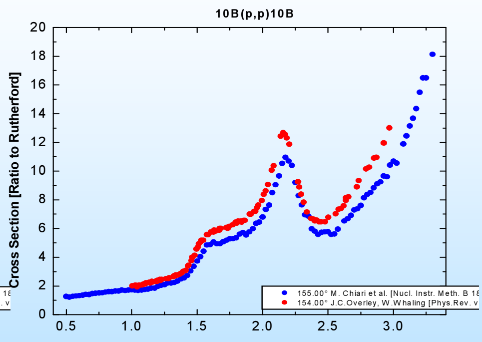
$^{10}B(p,p)^{10}B$

120°



155°

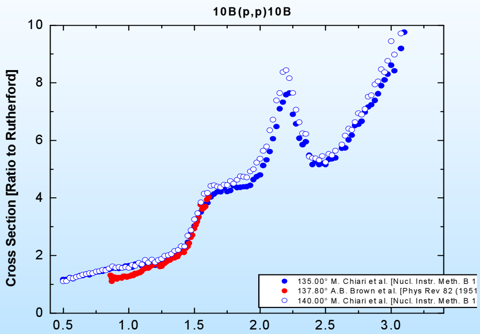


- Similar shape, but 20% difference

⇒ Systematic error in one of the measurements

$^{10}B(p,p)^{10}B$

135° - 140°



- Partly consistent, difference < 10%

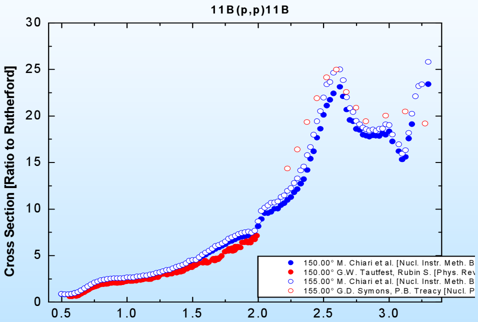
$^{10}B(p,p)^{10}B$: Conclusions

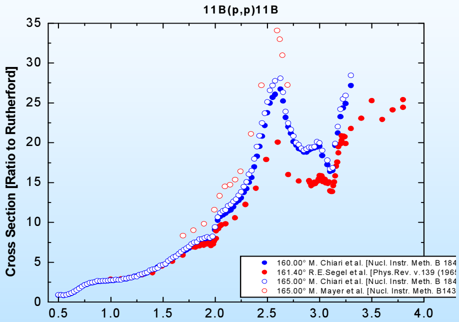
- Very few data available
- Differences up to 20%
- Additional measurements necessary
- Chiari's data seem to be most reliable
- Additional data available for energies > 5 MeV, but unsuitable for IBA

$^{11}B(p,p)^{11}B$

150° - 155°

160° - 165°





- Differences > 20%
- Mayer data can be scaled to Chiari, but not Segel

$^{11}B(p,p)^{11}B$: Conclusions

- Very few data available
- Differences > 20%
- Additional measurements necessary
- Chiari's data in between the measurements, seem to be most reliable
- Additional data available for energies > 5 MeV, but unsuitable for IBA

$^{10}B(\alpha,\alpha)^{10}B$: Data and Conclusions

Energy Range (MeV)	Angle in the Lab.(°)	Error	Data Presentation	Reference	IBANDL
5.0-30.0	57.4	-	Graph	David [1]	*data unsuitable for RBS due to angle*
2.0-4.3	50	-	Graph	Mo/Weller [2]	*data unsuitable for RBS due to angle*
2.0-4.3	68	-	Graph	Mo/Weller [2]	*data unsuitable for RBS due to angle*
2.0-4.3	90	-	Graph	Mo/Weller [2]	**data digitised**
2.0-4.3	122	-	Graph (2x)	Mo/Weller [2]	**data digitised**
2.0-4.3	140	-	Graph	Mo/Weller [2]	**data digitised**
2.0-4.3	162	-	Graph (2x)	Mo/Weller [2]	**data digitised**
1.0-3.3	170.5	7%	Graph	McIntyre Jr. [3]	data included

- No overlap of angles, not comparable
- Additional measurements necessary

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$^{11}B(\alpha,\alpha)^{11}B$: Data and Conclusions

Energy Range (MeV)	Angle in the Lab.(°)	Error	Data Presentation	Reference	IBANDL
4.0-4.9	50.0	3%	Graph	Ott/Weller [1]	*data unsuitable for RBS due to angle*
4.0-8.0	130.0	3%	Graph	Ott/Weller [1]	**data digitised**
4.0-4.9	140.0	3%	Graph	Ott/Weller [1]	**data digitised**
4.0-8.0	150.0	3%	Graph (2x)	Ott/Weller [1]	***data corrected****
2.1-3.9	70.4	-	Graph	Ramirez [2]	*data unsuitable for RBS due to angle*
2.1-3.9	90.5	-	Graph	Ramirez [2]	**data digitised**
2.1-3.9	150.8	-	Graph	Ramirez [2]	data included
1.0-3.3	170.5	7%	Graph	McIntyre Jr. [3]	data included
1.0-5.3	165	2%	Graph & Table	Liu [4]	**data digitised**

- Few overlap of angles, difficult to compare
- Additional measurements necessary

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Assessment on cross sections for D,T(α,α) and D,T(p,p) scattering

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一、T(^{4}He, T) ^{4}He forward cattering

During the 50's and 60', All the measurement of cross sections for the scattering T(α,α) were done only by detecting α-particles scattered on T gas targets[1-4]

(1) Spiger and Tombrello measured T(α,α) :

E_α=3.6-18.2 MeV, $\psi_{cm}=36^0-150^0$

Two resonances located at ~5MeV and ~10 MeV

(2)Similar measurements were conducted by Ivanovitch et al

E_α=4-11 MeV, $\psi_{cm}=32^0-159^0$

[1] Spiger and Tombrello , Phys. Rev. 163(1967)964

[2] M. Ivanovitch, P. G. Yong, Nucl. Phys. A110(1968)441

The statistical error they alleged is 2% except at resonances point where the error gets as large as 15%

Due to the high energy losses and energy straggling in the windows of the tritium container, no attempt was made in early gas target work to measure the cross sections at energy <~3 MeV.

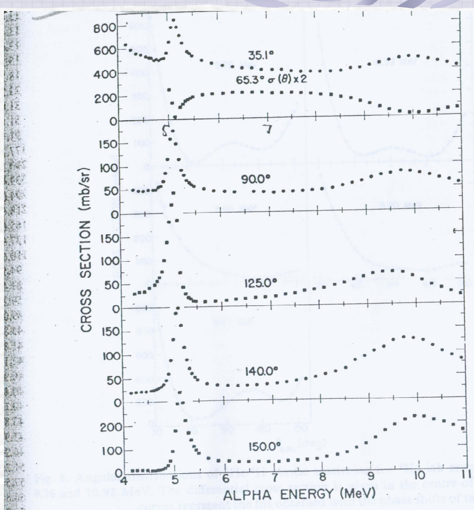


Fig. 9. Excitation functions of ^{4}He-^{3}H elastic scattering. The scattering angles and differential cross section are given in the centre-of-mass system. The energy scale is in the lab system.

These data can be found in this paper. It will upload to IBANDL

(3) In 1988, J. A. Sawicki measured recoil cross sections T(α,α) at:

- Incident α energy: E_α=0.5-2.5 MeV;
- Forward recoil angles : $\psi_{lab}=30^0$
- :

*Solid target: $Ti(H_{0.8}T_{0.2})_2$ and Si-T (more stable)

* T(α,α) recoil yields was measured relative to the nuclear reaction of T(d, α)n , with a quoted accuracy of 2% for this cross section

*Tritium losses were almost 0.1% per uC for Si-T target.

the total error is not larger than 10%.

$$\left(\frac{d\sigma}{d\Omega}\right)_{lab}^{rec} = \frac{Y_{rec}}{Y_{nuc}}\frac{Q_{nuc}}{Q_{rec}}\left(\frac{d\sigma}{d\Omega}\right)_{lab}^{nuc}\left(\frac{d\Omega_{cms}}{d\Omega_{lab}}\right)^{nuc}$$

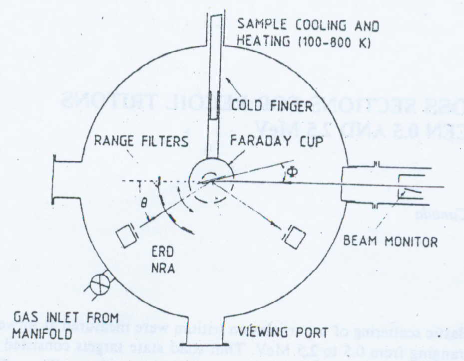


Fig. 1. Schematic of the experimental setup for elastic-recoil detection of tritium under $^4He^+$ bombardment, using very thin tritiated solid targets.

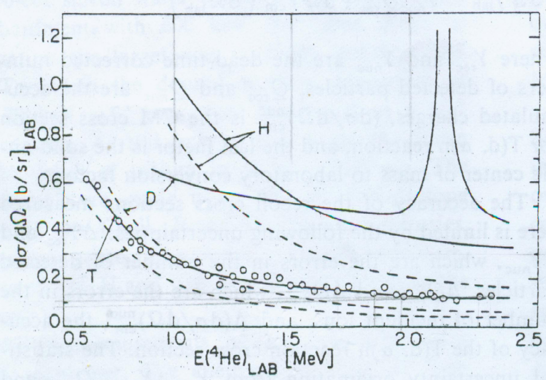


Fig. 4. Differential recoil cross sections for T recoils vs α-particle energy measured at laboratory angle of 30° (points). The data for for H and D recoils, adopted from [10–12] and [14], respectively, are represented by continuous lines. Dashed lines correspond to recoil cross sections calculated in the approximation of Rutherford scattering.

二、D(4He, D) 4He forward scattering

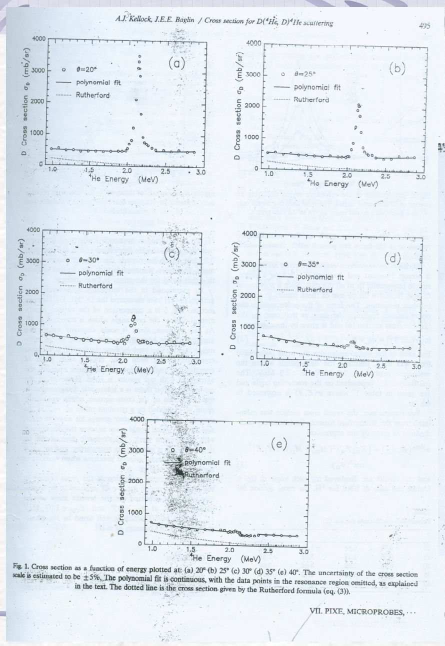
(1) In 1993, Kellock and Baglin measured the cross sections at

Eα=0.5-2.5 MeV.

ψlab= 10^0, 20^0, 25^0, 30^0, 35^0 and 40^0,

Target: deuterated polystyrene$(C_8\ D_8)_n$

$$\sigma_D(E^*,\theta_D)=\frac{A_D\Omega_\alpha\sigma_C(E^*)}{A_C\Omega_D\sigma_C{}^{Ruth}(E^*)}\sigma_C{}^{Ruth}(E^*,170^0)$$



A.J. Kellock, J.E.E. Baglin / Cross section for $D(^4He, D)^4He$ scattering 495

Fig. 1. Cross section as a function of energy plotted at: (a) 20° (b) 25° (c) 30° (d) 35° (e) 40°. The uncertainty of the cross section scale is estimated to be ±5%. The polynomial fit is continuous, with the data points in the resonance region omitted, as explained in the text. The dotted line is the cross section given by the Rutherford formula (eq. (3)).

VII. PIXE, MICROPROBES, ···

All data have been loaded to IBANDL

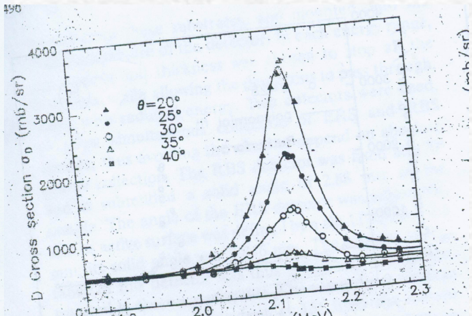


Fig. 2. Enlargement of the resonance region displaying an overlay of all measured angles. The solid lines are meant only as a guide, and do not imply any fit to the data points.

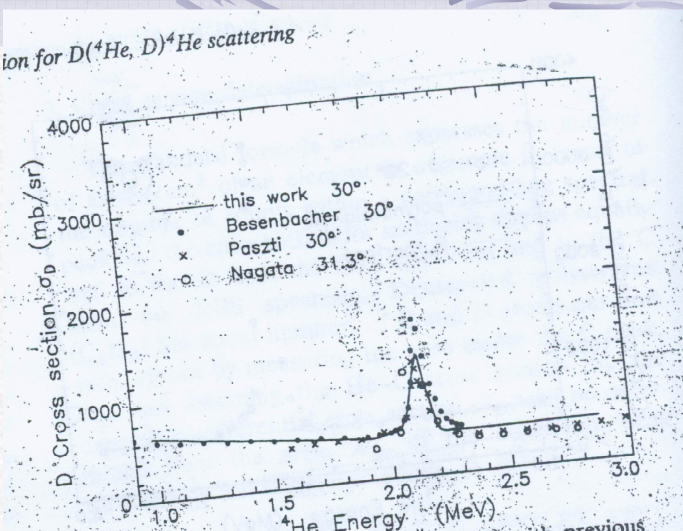


Fig. 3. A comparison of this work (solid line) with previous measurement data at $\theta \simeq 30°$ [9–11]. Note that Nagata et al.'s measurement was made at 31.3°.

The above equation is dependent of the amount of charge collected. The main error of the cross section comes from the Ω , θ and *A* . if the ratio of C to D is exact. But, Deuterium loss of about 1% due to the ion beam bombardment during each 20 uC run is also factor of error.

The uncertainty of the cross section scale is estimated to be $\pm 5\%$

$\pm 2^{\circ}$

the various experimental data shows some disparity among the absolute values both within and outside of the resonance region. The work by Besenbacher is the most complete, having been done over a wide range of energies and angles. Below the resonance energies, there is a agreement with Kellock results. However, in the resonance region there is a systematic disagreement in the magnitude of the cross section, which apparently could be explained by a constant offset of ~2^0 in the detector angle. Besenbacher quotes his angular precision to which would seem to cover the discrepancy with Kellock's work .The dramatic dependence on detector angle is nonetheless noteworthy, and indicates the need for special angular precision when working in the resonance region.

(2) In 1986, F. Besenbacher used a self-supporting target:

$TiD_{0.8}$(100 $\overset{0}{A}$) /Au(400 $\overset{0}{A}$)layer.

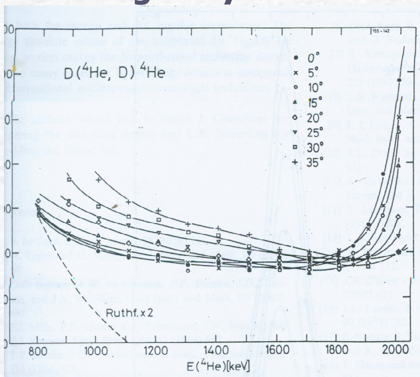
Eα=0.5-2.5 MeV.

ψlab= 10- 35degree , step is 5 degree

The D(^{4}He, D) ^{4}He –recoil yields was measured relative to the $D(^3He,\alpha)p$ nuclear reaction. The ^{3}He+D cross section that Moller and Besenbacher determined with the absolute accuracy of $\pm 4\%$ for c.m.s energies less than 500 keV. Since the detector solid angle is consult during the rotation around the center line, the laboratory cross section can be easily be obtained from the nuclear –reaction cross section as follows,

$$\left(\frac{d\sigma}{d\Omega}\right)_{lab}^{rec} = \frac{Y_{rec}}{Y_{nuc}}\frac{Q_{nuc}}{Q_{rec}}\left(\frac{d\sigma}{d\Omega}\right)_{lab}^{nuc}\left(\frac{d\Omega_{cms}}{d\Omega_{lab}}\right)^{nuc}$$

When the above statistical uncertainty of Y(yields) and Q is 2-3%, the absolute accuracy of cross section is in $\pm 6\%$, which is almost same that as alleged by Kellock.



Laboratory cross sections of the D(^{4}He, D)^{4}He reaction as a function of incident ^{4}He energy for different D-recoil angles. The ...rves through the data are to guide the eye only, whereas the dashed curve shows the Rutherford-recoil cross section for θ = 0° ...ied by a factor of two.

I will compare these data with that of Kellock

(3) **In recent measuring of cross –sections for the interaction D(^{4}He, D) ^{4}He and T(^{4}He, T) ^{4}He forward scattering(2004) , J.F.Browning et al. used the original formula to calculate the cross section in energy range of 9-11 MeV. i.e.,**

$$\left(\frac{d\sigma}{d\Omega}\right)=\frac{Y(E)\cos\theta_{target}}{NQ\Omega}$$

N: is measured by thermal desorption;
Q : by a chopper system
Ω: by using ^{238} Pu α source.

the error of N, Q and Ω can be controlled in ±2.0, ±2.0 and ±1.0%, respectively. So the overall uncertainty in the measured cross section is to be 3.2%.

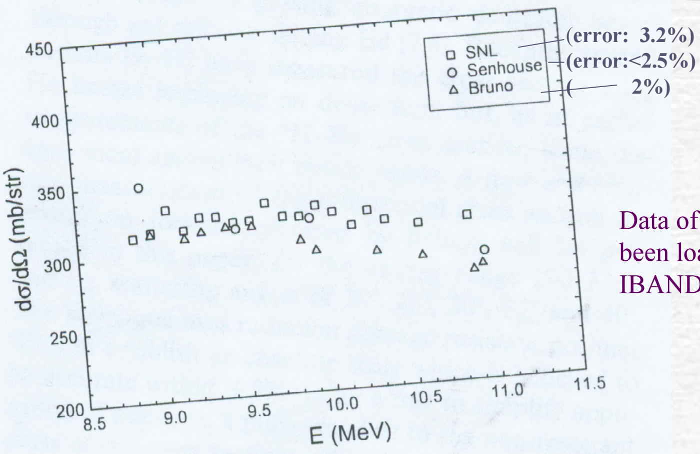
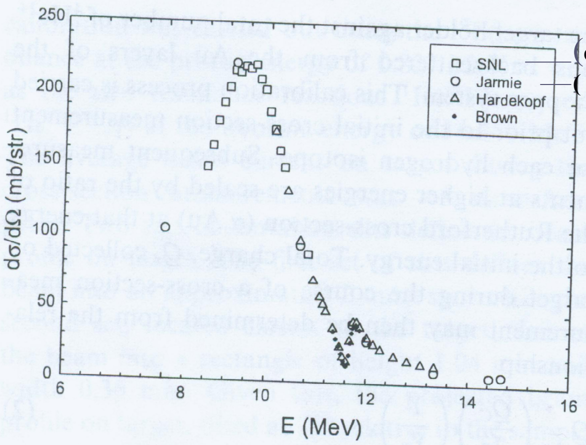


Fig. 4. Comparison of the current measurement of the $^2H(\alpha,d)\alpha$ cross-section with several previous measurements (see text for reference).

Data of SNL has been loaded to IBANDL



(error: 3.2%
: <2.5%)

Fig. 5. Comparison of the current measurement of the $^3H(\alpha,t)\alpha$ cross-section with several previous measurements (see text for reference).

- The data in Fig. 4 agree quite well (?)with those of Senhouse and Tombrello and Bruno **for D**.
  Uncertainty in the Senouse data is < ±2.5% (gas target) and that of Bruno's work is ±2%(deuterated polystyrene).
- For tritium data, a broad resonance in the energy range of interest exist. Uncertainty in the Jamie data is < ±2.5%
- Metal hydride holds an advantage over polymer targets in that metal hydride is more resistant to beam induced loss of hydrogen.

- [1]S.Nagata et al. Nucl.Instrum. & Meth. v.B6(1985) 533
- [2]A.J.Kellock and J.E.E.Baglin Nucl.Instrum.Methods B79 (1993) 493
- [3]V. Quillet et al., Nucl. Instr. Meth. B83 (1993) 47
- [4]F.Besenbacher et al, Nucl. Instr. Meth. B15 (1986) 123
- [5] J.A. Sawicki, Nucl. Instr. Meth. B30 (1988) 459
- [6] J.F.Browning et al., Nucl. Instr. Meth. B161-163 (2000) 211
- [7]J.F.Browning et al., Nucl. Instr. Meth. B219-220 (2004) 317

二、 Assessment on cross sections for D(p, p) D and T(p, p) T scattering

During the about two decades(1950-1968), most measurements of the cross-section for D(p, p) D reaction have been made [1-4]. EXFOR presents data at least 45 publication. However:

- most of scattering materials employed gases or hydrogen containing non-metal(such as, Nylon, p.e.t foils),
- from the view of IBA, only several publications are potentially useful. Most of works only present relevant cross sections for one to several energy value.

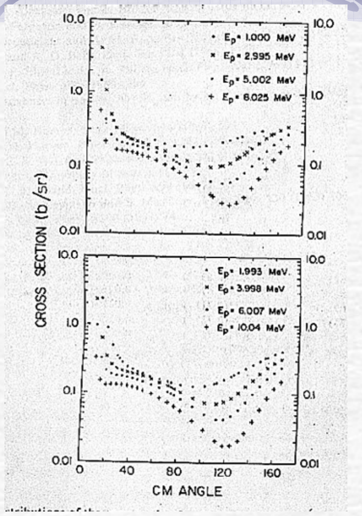
Drawback of gas target:

1. **The particle beam impacting target is energy dispersed after passing foil separating gas in the scattering room from the high vacuum.**
2. **Also, the direction of incidence angle in the center of scattering is a little divergent.**

Measurement data are declaimed in the error range of ±3-5%,

Main data source:

(1) In 1969, D.C Kocher[5] made angular distribution measurements at eight energies between 1.00-10.04 MeV. Because employing precision gas scattering chamber with differential pumping and high resolution solid state detectors, total maximum uncertainty can be within 2.1% and median uncertainty for all data points is ±0.6%. Type of uncertainty



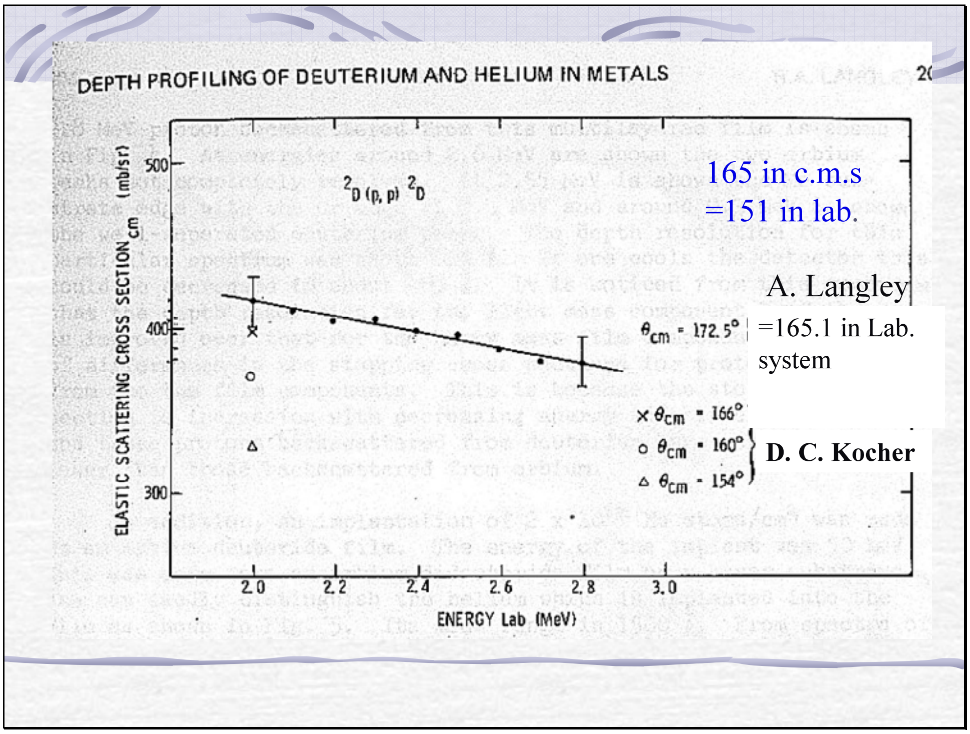
Angular distribution of the cross section for the elastic scattering of protons from deuterium

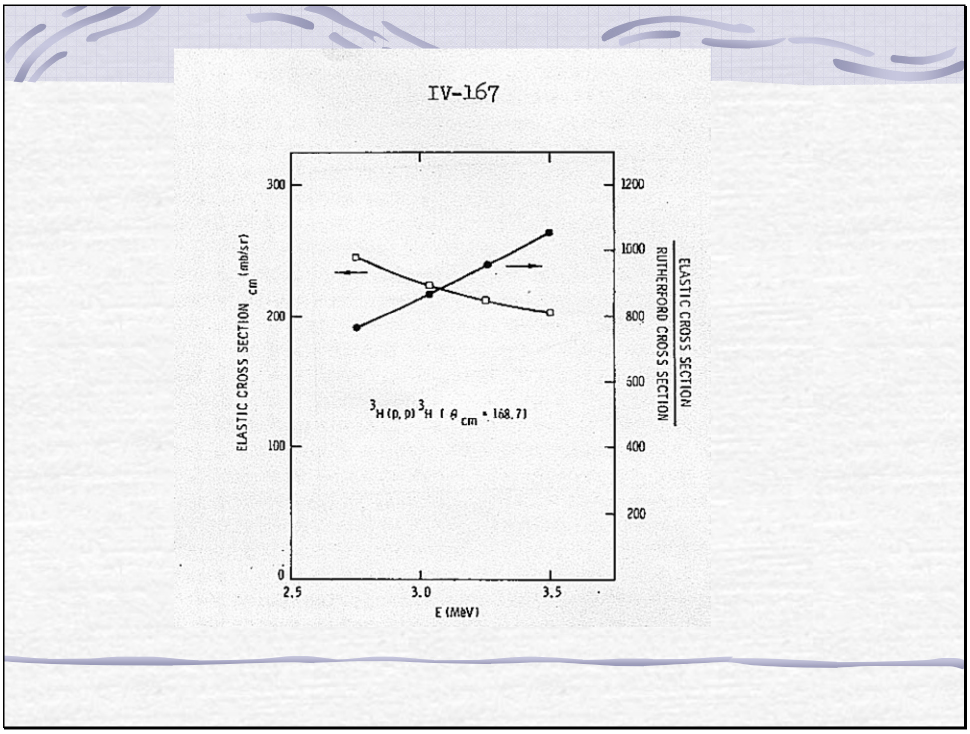
includes background substraction in particle yield determination(0.19%), contamination corrections(0.34%), statistical uncertainty(0.1%), **gas density and G-factor and integrator calibration(0.2%),** angle uncertainty(1.7 %), energy uncertainty(0.98%), correction uncertainty(0.05%), and other uncertainty(0.36%).

(2) In 1975,R. A. Langley[6] used erbium deuteride films of 800 nm deposited on kovar or alumina substrates as a solid target to measure the elastic scattering cross section for proton on deuterium and tritium .

- **The amount of deuterium was determined by mass spectrometric determination outgassing of the substrate.**
- **The amount of erbium was measured by weight.**

Data of Langley for D and T can all be found in IBANDL


DEPTH PROFILING OF DEUTERIUM AND HELIUM IN METALS
ELASTIC SCATTERING CROSS SECTION cm (mb/sr)
500
400
300
2D (p, p) 2D
165 in c.m.s
=151 in lab.
A. Langley
θcm = 172.5°
=165.1 in Lab. system
× θcm = 166°
○ θcm = 160°
△ θcm = 154°
D. C. Kocher
2.0
2.2
2.4
2.6
2.8
3.0
ENERGY Lab (MeV)


IV-167
ELASTIC CROSS SECTION cm (mb/sr)
300
200
100
0
ELASTIC CROSS SECTION / RUTHERFORD CROSS SECTION
1200
1000
800
600
400
200
3H (p, p) 3H (θcm = 168.7)
2.5
3.0
3.5
E (MeV)

(3)

SMALL-ANGLE CROSS SECTIONS

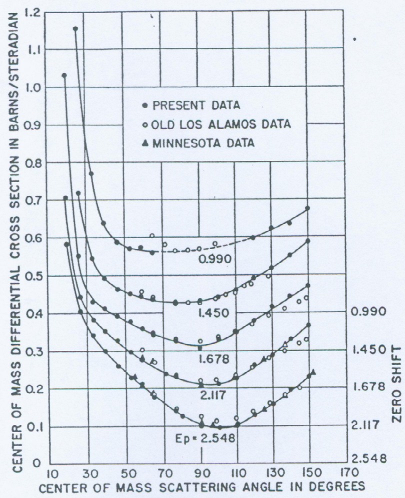


FIG. 5. The $p-T$ cross section as a function of angle (c. system) for five energies, including all of the earlier measuremer at the energies selected.

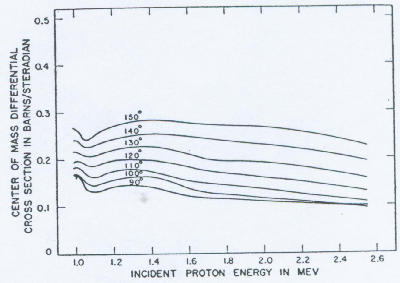


FIG. 6. The $p-T$ cross section as a function of energy system) for large angles, showing the minimum near 1-Mev p energy.

1954, E E Maloclm measured p-T differential scattering cross section for

C. m. angle 20-150^{0}

E_p = 1-2.55 MeV

Probable errors 3-5%

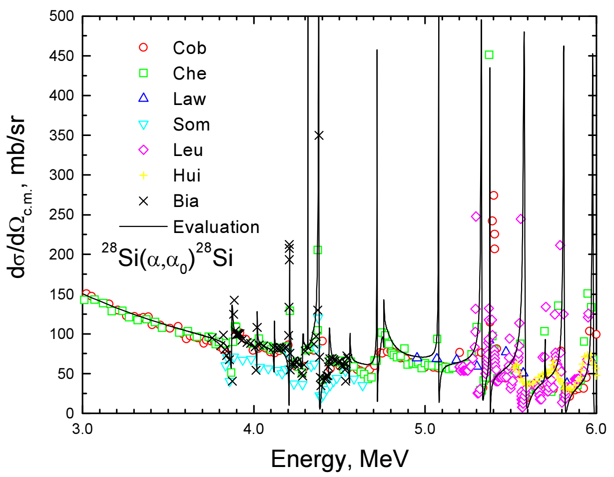
These data may be loaded to **IBANDI**

- 1. F. A. Rodegers, etal.,Phys. Rev. 78(1950)656
- 2. R. Sherr, etal.,Phys. Rev. 72(1947)662.
- 3. L. Rosen and J C Allred, Phys. Rev. 52(1951)777
- 4. J. E. Brolley, etal.,Phys. Rev. 78(1960)1307
- 5. D C Kocher and T B Clegg , Bul\clear Pyhsics A132(1969)457
- 6. Langley, R.A. (1976) in Proc. Int. Conf. on Radiation Effect and Tritium Technology for Fusion Reactors, vol IV, (J.S. Walson and F.W. Wiffen, eds.)
- 7. Langley, R.A. Sandia Laboratories Report SaND75-0331,1975
- 8. R S Classen, etal., Phys. Rev.82(1951)589
- 9. Hemmendinger, Jarvis, and Taschek, Phys. Rev. 76(1949)1137.

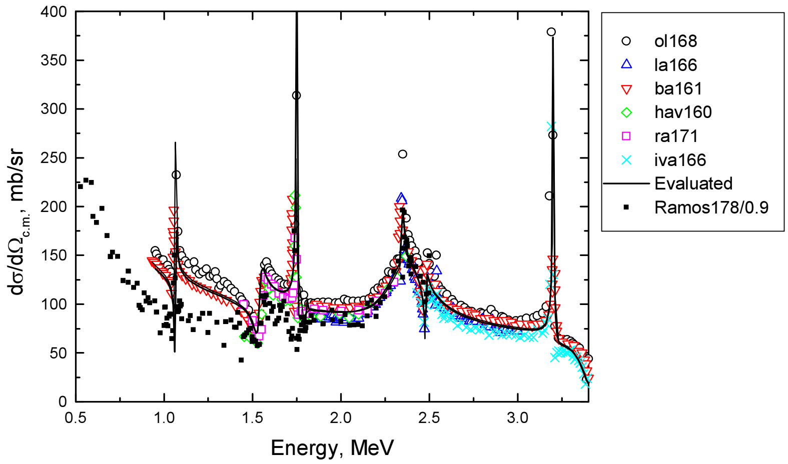
Evaluation

A. Gurbich
Institute of Physics and Power Engineering
Obninsk, Russia

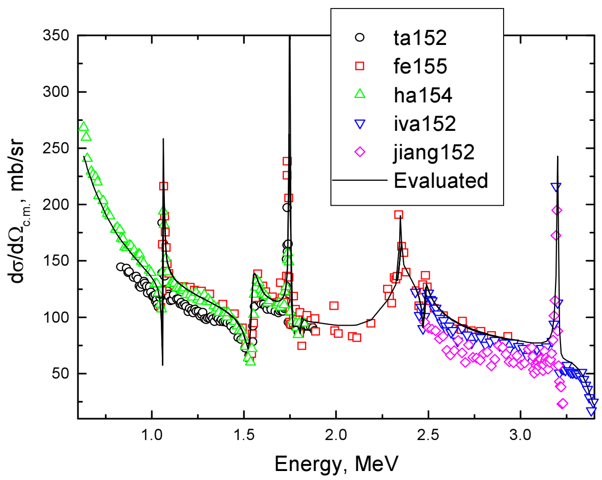
The evaluated differential cross sections and the available experimental data for alpha elastic scattering from silicon at ~170°



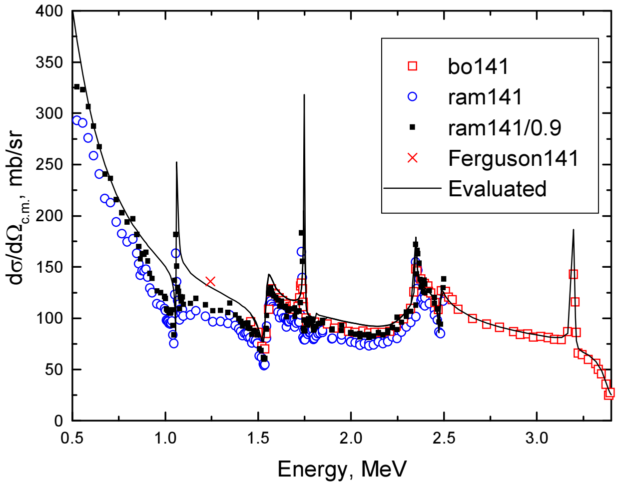
The evaluated differential cross sections and the available experimental data for proton elastic scattering from nitrogen at ~165°

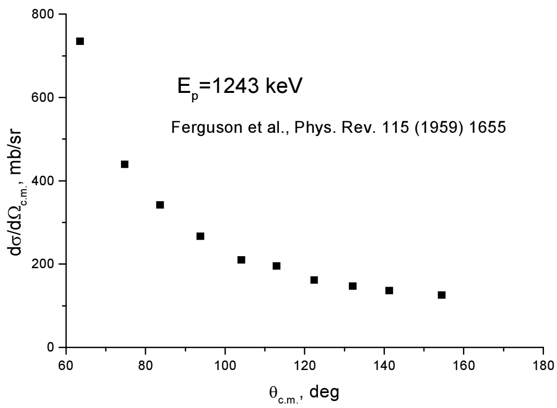


The evaluated differential cross sections and the available experimental data for proton elastic scattering from nitrogen at ~152°

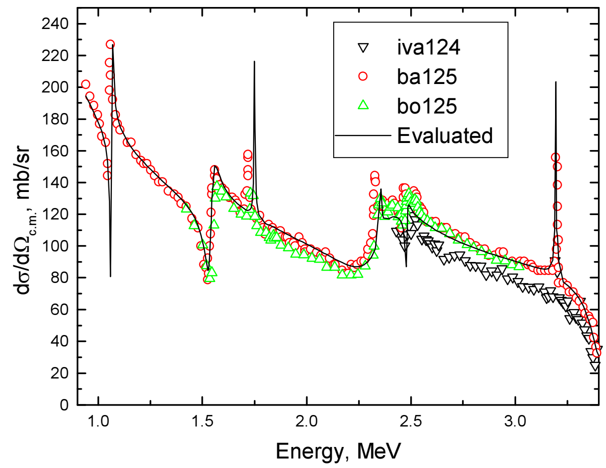


The evaluated differential cross sections and the available experimental data for proton elastic scattering from nitrogen at ~141°

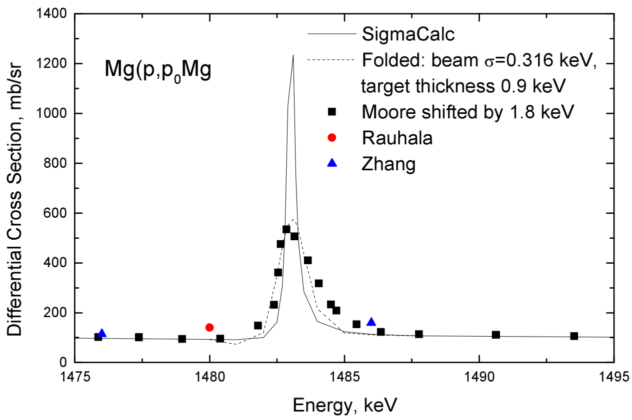




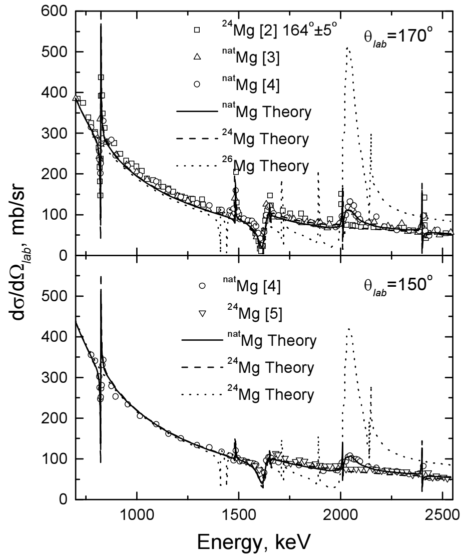
The evaluated differential cross sections and the available experimental data for proton elastic scattering from nitrogen at ~125°



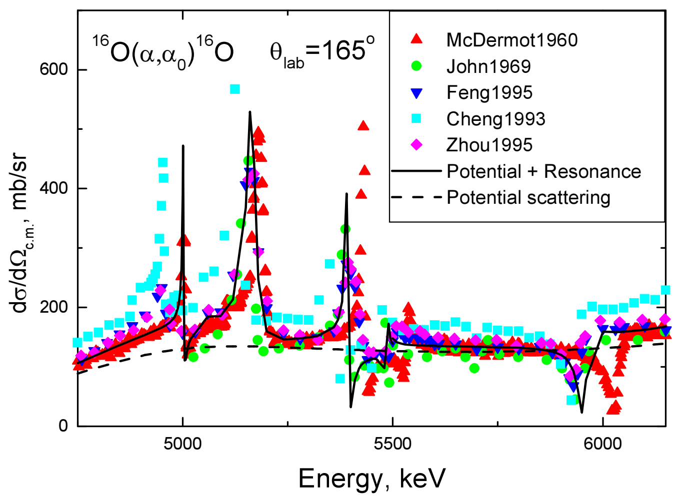
Narrow resonance problem

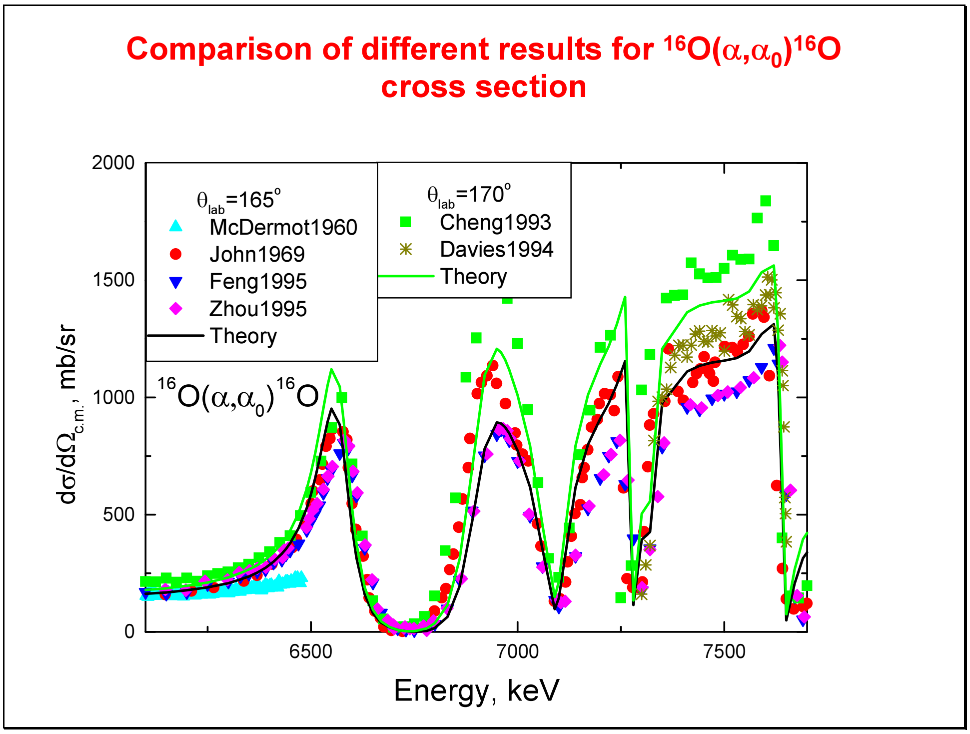


The evaluated differential cross sections and the available experimental data for proton elastic scattering from magnesium



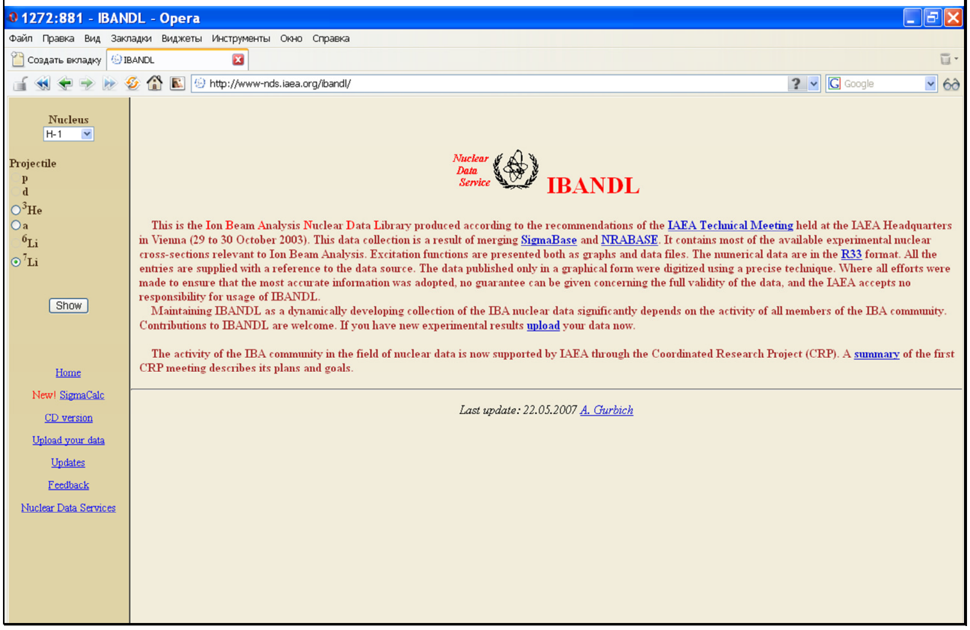
Comparison of different results for $^{16}O(\alpha,\alpha_0)^{16}O$ cross section



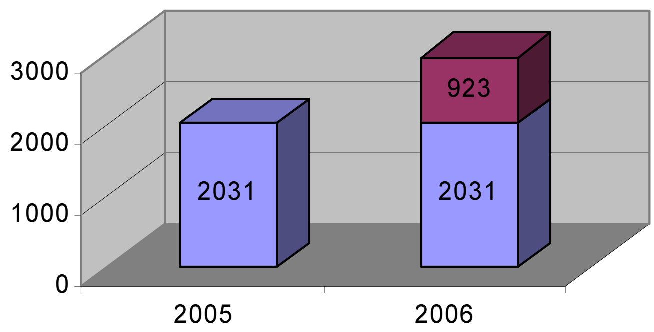

Comparison of different results for $^{16}O(\alpha,\alpha_0)^{16}O$
cross section
θ_{lab}=165°
McDermot1960
John1969
Feng1995
Zhou1995
Theory
θ_{lab}=170°
Cheng1993
Davies1994
Theory
$^{16}O(\alpha,\alpha_0)^{16}O$
$d\sigma/d\Omega_{c.m.}$, mb/sr
Energy, keV
2000
1500
1000
500
0
6500
7000
7500

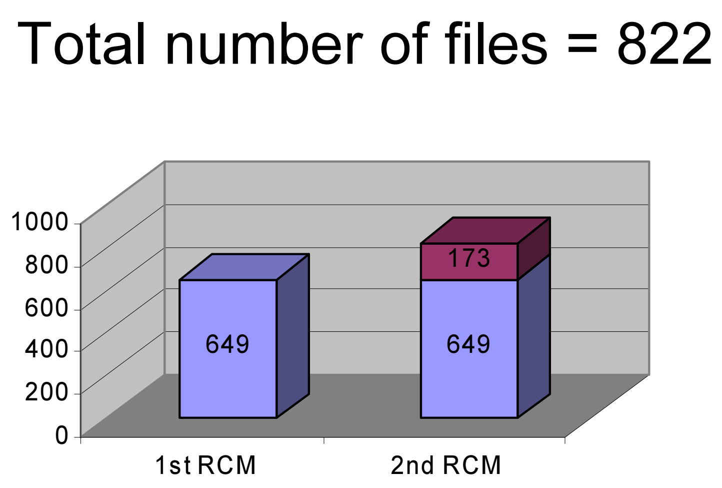
Present status of IBANDL

A. Gurbich



Number of hits per year

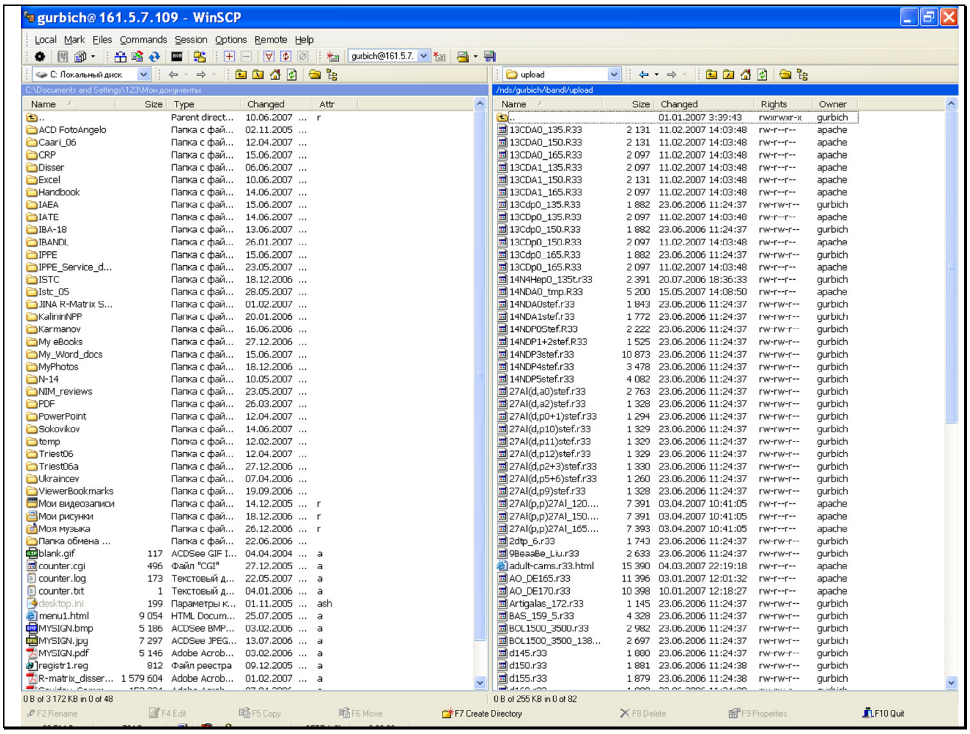




Updates

No.	Date	Cross section	Source	Comments
72	10.06.07	$^{16}O(d,a)^{14}N$	G.Amsel, Thesis, Ann.Phys., 9(1964), 297	Theta values 165 and 135 were interchanged
72	22.05.07	$^{14}N(d,p)^{15}N$ $^{14}N(d,a)^{12}C$	To be published	
71	13.04.07	$^{32}S(d,p_{0-3,7})^{33}S$	Submitted to Nucl. Instrum. Meth.	Thanks to M.Kokkoris.
70	04.04.07	$^{27}Al(p,p_0)^{27}Al$	To be published in CAARI-06 Proceedings	Thanks to Z.Siketic
69	20.03.07	$^{10}B(d,a_{0,1})^{8}Be$ $^{10}B(d,p_{0-6})^{11}B$	Submitted to Nucl. Instrum. Meth.	Thanks to M.Kokkoris.
68	20.03.07	$^{16}O(d,p_1)^{17}O$	Il Nuovo Cimento 14A (1973) 692	EXFOR SUBENT D0152001
67	13.02.07	$^{13}C(d,a_{0,1})^{11}B$ $^{13}C(d,p_0)^{14}C$	Nucl. Instrum. Meth. B254 (2007) 25	The (d,a) cross sections are new and the (d,p_0) data are corrected. Thanks to Tristan Thome.
66	30.01.07	$^{nat}B(a,a)^{nat}B$ $^{12}C(a,a)^{12}C$ $^{14}N(a,a)^{14}N$ $^{16}O(a,a)^{16}O$ $^{1}H(a,p)^{4}He$	C.J.Wetteland et al. LA-UR-98-4867	
65	27.01.07	$^{27}Al(d,p)^{28}Al$ $^{27}Al(d,a)^{25}Mg$ $^{27}Al(p,g)^{28}Si$	to be published	
64	11.01.07	$^{16}O(a,a_0)^{16}O$	J. Appl. Phys. 100 (2006) 124909	File for 170^0 was corrected
63	03.01.07	$^{16}O(a,a_0)^{16}O$	J. Appl. Phys. 100 (2006) 124909	Thanks to Julien Demarche
62	06.10.06	$^{16}O(a,a_0)^{16}O$	Feng at al., 1994	Comment concerning the data source was added
61	27.07.06	$^{7}Li(p,p'g)^{7}Li$ $^{7}Li(p,ng)^{7}Be$ $^{19}F(p,p'g)^{19}F$ $^{19}F(p,ag)^{16}O$	Nucl. Instr. and Meth. B 249 (2006) 98	Thanks to M.Chiari
60	27.07.06	$^{7}Li(p,p_0)^{7}Li$ $^{12}C(p,p_0)^{12}C$ $^{19}F(p,p_0)^{19}F$	Nucl. Instr. and Meth. B 249 (2006) 95	Thanks to M.Chiari
59	20.07.06	$^{14}N(a,p_0)^{17}O$	Nucl. Instr. and Meth. B 249 (2006) 85	Thanks to Peng Wei
58	29.05.06	$^{12}C(d,p_0)^{13}C$	Nucl. Instr. and Meth. B 227 (2005) 450	
57	28.05.06	$^{12}C(d,p_0)^{13}C$	Phys.Rev. 104 (1956) 1008	Data for 160^0 scattering angle were added (EXFOR C0993006)

56	27.05.06	$^{12}C(d,p_0)^{13}C$	Phys.Rev. 117 (1960) 1289	Data for 158.4° scattering angle were added (EXFOR C1007003)
55	22.05.06	$^{12}C(d,p_{1-3})^{13}C$	to be published	Q-values were corrected in Kokkoris' files (see #44 in this table).
54	16.05.06	$^{16}O(d,p_0)^{17}O$ $^{16}O(d,p_1)^{17}O$ $^{16}O(d,\alpha_0)^{14}N$	J. Rad. Chem. 38 (1977) 193	
53	16.05.06	$^{16}O(d,p_0)^{17}O$ $^{16}O(d,p_1)^{17}O$ $^{16}O(d,\alpha_0)^{14}N$	Nucl.Phys. 45 (1963) 647	
52	16.05.06	$^{14}N(p,p_0)^{14}N$	Phys. Rev. 114 (1959) 1552	The file with mistakes was substituted by a new one. Thanks to Rita Ramos.
51	14.05.06	$^{16}O(d,p_{0,1})^{17}O$	Nucl. Instr. and Meth. B 226 (2004) 637	Mistakes were corrected in the data in the energy range of 1330-1620 keV.
50	12.05.06	$^{16}O(d,p_0)^{17}O$ $^{16}O(d,p_1)^{17}O$ $^{16}O(d,\alpha_0)^{14}N$	Nucl. Phys. 57 (1964) 526	
49	10.05.06	$^{14}N(\alpha,\alpha_0)^{14}N$	Phys. Rev. 112 (1958) 1210. Nucl. Instr.& Meth. B66 (1992) 237 Nucl.Instr.& Meth. B71 (1992) 324	4 data files added. Thanks to Rita Ramos.
48	09.05.06	$^{16}O(d,p_1)^{17}O$	Nucl. Instr. and Meth. B43 (1989) 187	
47	09.05.06	$^{16}O(d,p_1)^{17}O$ $^{12}C(d,p_0)^{13}C$	Nucl. Instr. and Meth. 168 (1980) 611	
46	08.05.06	$^{12}C(d,p_0)^{13}C$ $^{16}O(d,p_1)^{17}O$	Nucl. Instr. and Meth. B61 (1991) 1	
45	06.05.06	$^{14}N(p,p_0)^{14}N$	Phys. Let. 24B (1967) 287 Phys. Rev. 115 (1959) 1655 Phys. Rev. 105 (1957) 210 Phys. Rev. 105 (1957) 219 Phys. Rev. 112 (1958) 475	13 data files added. Thanks to Rita Ramos.
44	03.05.06	$^{12}C(d,p_{1-3})^{13}C$	to be published	Thanks to M.Kokkoris
43	30.03.06	$^{6}Li(^{3}He,p_{0,1})^{8}Be$	Phys.Rev. 104 (1956) 1064	Correction of mistakes. Thanks to M.Mayer for pointing out the mistakes.
42	07.03.06			Modification of the files was perfomed by Ian Vickridge because of the update of the R33 format.
41	25.11.05	$^{2}H(^{3}He,p_0)^{4}He$	Nucl. Instr. Meth. B234 (2005) 169	Thanks to M.Mayer
40	24.10.05	$^{12}C(p,p_0)^{12}C$	Nucl. Instr. and Meth. B 77 (1993) 110	Data for 150° and 110° scattering angles were added
39	24.10.05	$^{12}C(p,p_0)^{12}C$	Nucl. Instr. and Meth. B 227 (2005) 450	See comment in NIM B 229 (2005) 157



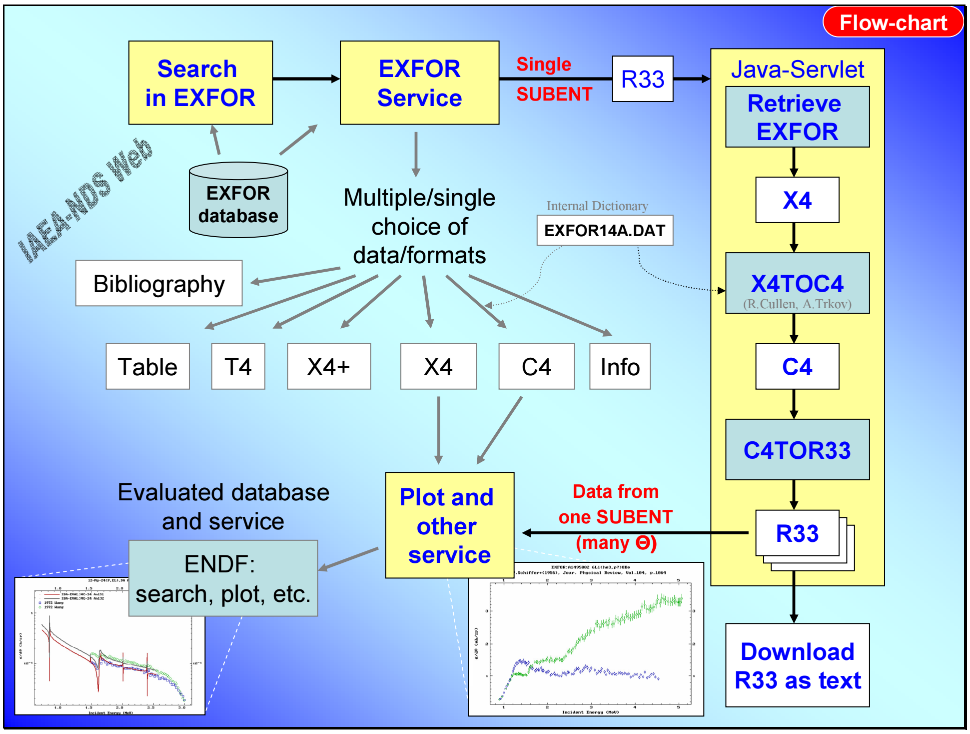
"EXFOR to R33" on NDS Web

V.Zerkin, IAEA-NDS

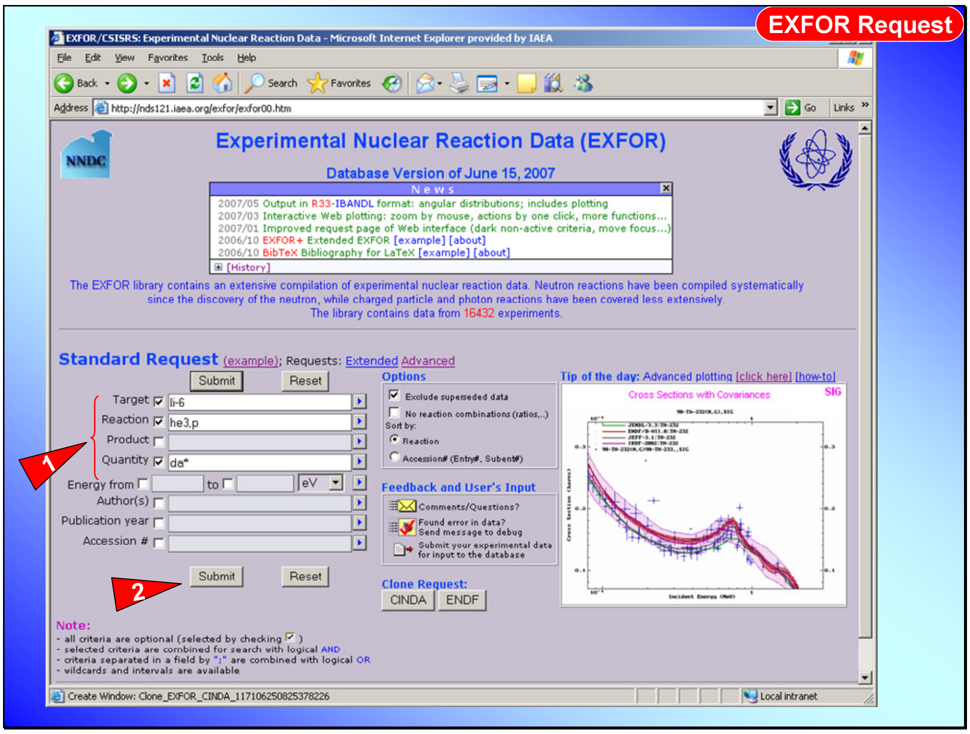
Second Research Co-ordination Meeting on
Development of a Reference Database for Ion Beam Analysis
IAEA Headquarters, Vienna, Austria
18-21 June 2007

GOAL

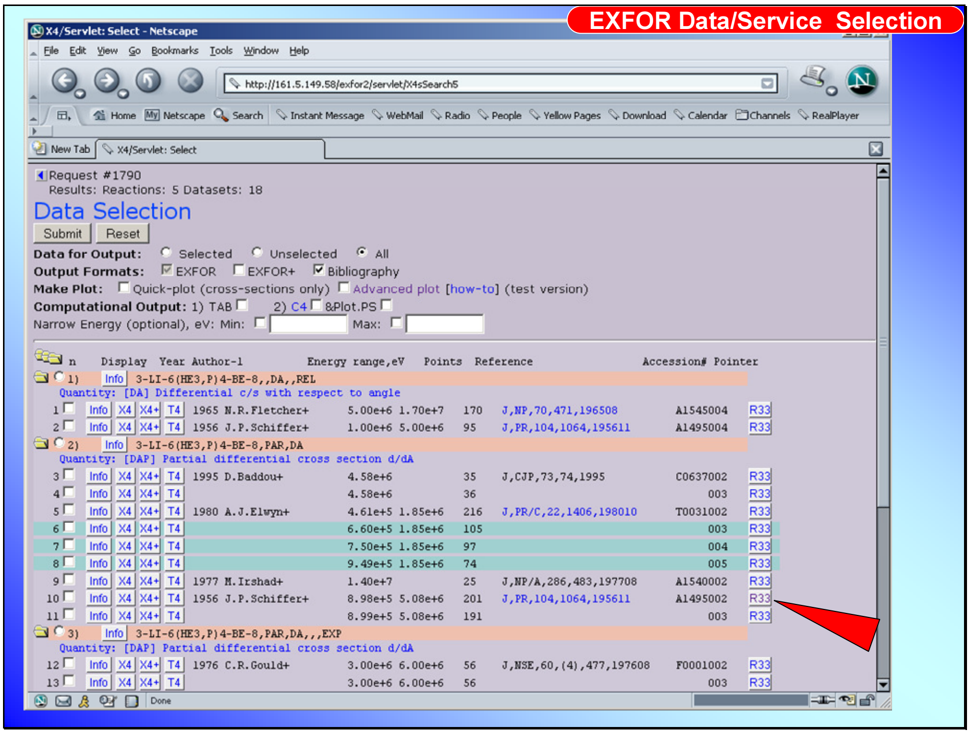
To provide access to EXFOR data in R33 format via Internet.

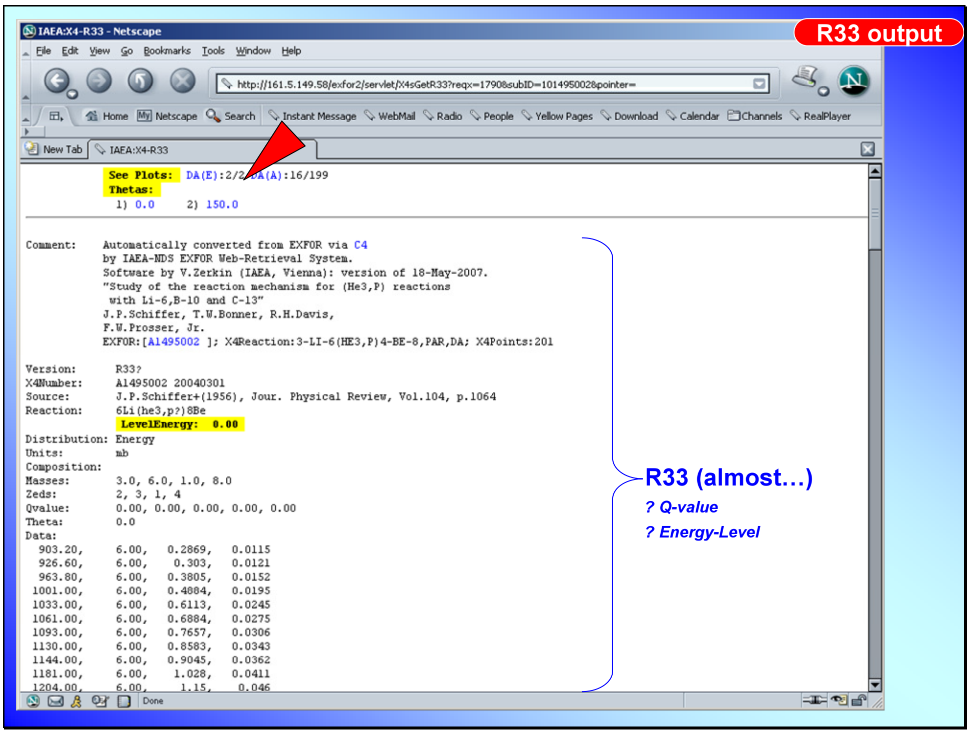


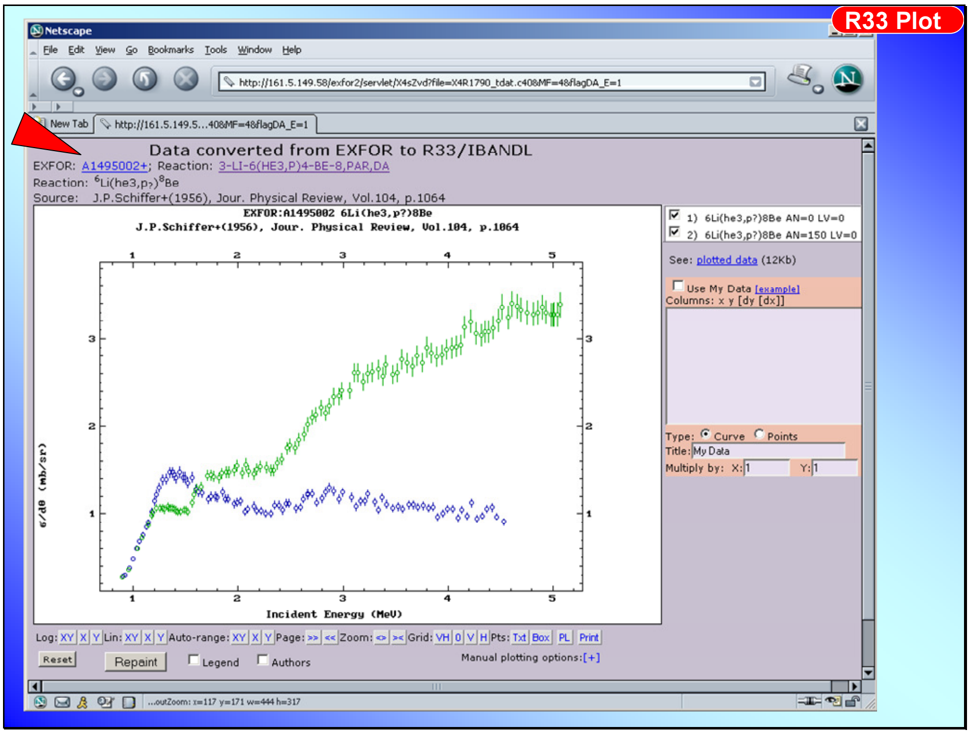
Flow-chart
Search in EXFOR
EXFOR Service
Single SUBENT
R33
Java-Servlet
Retrieve EXFOR
X4
X4TOC4
(R.Cullen, A.Trkov)
C4
C4TOR33
R33
Download R33 as text
IAEA-NDS Web
EXFOR database
Multiple/single choice of data/formats
Internal Dictionary
EXFOR14A.DAT
Bibliography
Table
T4
X4+
X4
C4
Info
Evaluated database and service
ENDF: search, plot, etc.
Plot and other service
Data from one SUBENT (many Θ)

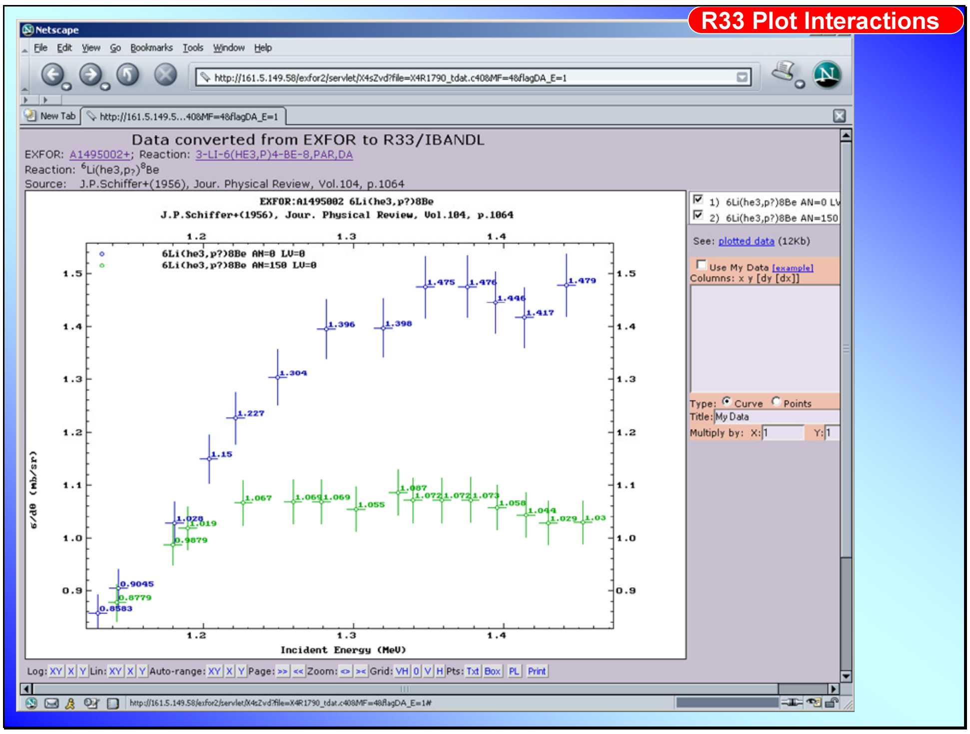


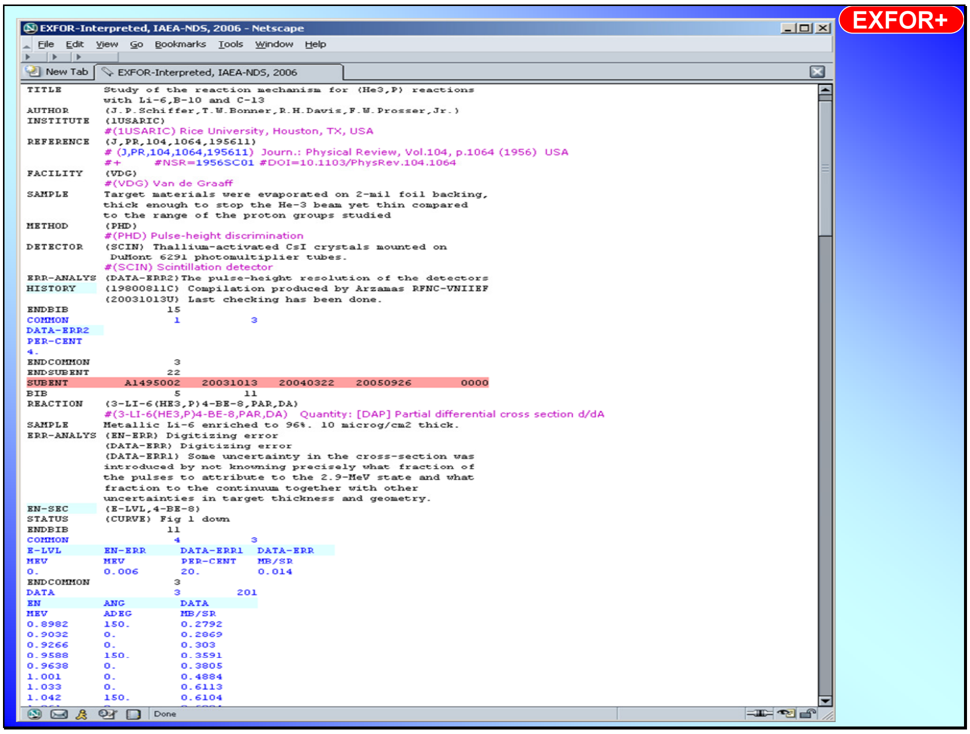
EXFOR Request
EXFOR/CSISRS: Experimental Nuclear Reaction Data - Microsoft Internet Explorer provided by IAEA
http://nds121.iaea.org/exfor/exfor00.htm
NNDC
Experimental Nuclear Reaction Data (EXFOR)
Database Version of June 15, 2007
News
2007/05 Output in R33-IBANDL format: angular distributions; includes plotting
2007/03 Interactive Web plotting: zoom by mouse, actions by one click, more functions...
2007/01 Improved request page of Web interface (dark non-active criteria, move focus...)
2006/10 EXFOR+ Extended EXFOR [example] [about]
2006/10 BibTeX Bibliography for LaTeX [example] [about]
[History]
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 16432 experiments.
Standard Request (example); Requests: Extended Advanced
Submit Reset
Target li-6
Reaction he3,p
Product
Quantity da*
Energy from to eV
Author(s)
Publication year
Accession #
Submit Reset
1
2
Options
Exclude superseded data
No reaction combinations (ratios,..)
Sort by:
Reaction
Accession# (Entry#, Subent#)
Feedback and User's Input
Comments/Questions?
Found error in data? Send message to debug
Submit your experimental data for input to the database
Clone Request:
CINDA ENDF
Tip of the day: Advanced plotting [click here] [how-to]
Cross Sections with Covariances
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
Local intranet


EXFOR Data/Service Selection
X4/Servlet: Select - Netscape
http://161.5.149.58/exfor2/servlet/X4sSearch5
Request #1790
Results: Reactions: 5 Datasets: 18
Data Selection
Submit
Reset
Data for Output: Selected Unselected All
Output Formats: EXFOR EXFOR+ Bibliography
Make Plot: Quick-plot (cross-sections only) Advanced plot [how-to] (test version)
Computational Output: 1) TAB 2) C4 &Plot.PS
Narrow Energy (optional), eV: Min: Max:
n Display Year Author-1 Energy range,eV Points Reference Accession# Pointer
1) Info 3-LI-6(HE3,P)4-BE-8,,DA,,REL
Quantity: [DA] Differential c/s with respect to angle
1 Info X4 X4+ T4 1965 N.R.Fletcher+ 5.00e+6 1.70e+7 170 J,NP,70,471,196508 A1545004 R33
2 Info X4 X4+ T4 1956 J.P.Schiffer+ 1.00e+6 5.00e+6 95 J,PR,104,1064,195611 A1495004 R33
2) Info 3-LI-6(HE3,P)4-BE-8,PAR,DA
Quantity: [DAP] Partial differential cross section d/dA
3 Info X4 X4+ T4 1995 D.Baddou+ 4.58e+6 35 J,CJP,73,74,1995 C0637002 R33
4 Info X4 X4+ T4 4.58e+6 36 003 R33
5 Info X4 X4+ T4 1980 A.J.Elwyn+ 4.61e+5 1.85e+6 216 J,PR/C,22,1406,198010 T0031002 R33
6 Info X4 X4+ T4 6.60e+5 1.85e+6 105 003 R33
7 Info X4 X4+ T4 7.50e+5 1.85e+6 97 004 R33
8 Info X4 X4+ T4 9.49e+5 1.85e+6 74 005 R33
9 Info X4 X4+ T4 1977 M.Irshad+ 1.40e+7 25 J,NP/A,286,483,197708 A1540002 R33
10 Info X4 X4+ T4 1956 J.P.Schiffer+ 8.98e+5 5.08e+6 201 J,PR,104,1064,195611 A1495002 R33
11 Info X4 X4+ T4 8.99e+5 5.08e+6 191 003 R33
3) Info 3-LI-6(HE3,P)4-BE-8,PAR,DA,,,EXP
Quantity: [DAP] Partial differential cross section d/dA
12 Info X4 X4+ T4 1976 C.R.Gould+ 3.00e+6 6.00e+6 56 J,NSE,60,(4),477,197608 F0001002 R33
13 Info X4 X4+ T4 3.00e+6 6.00e+6 56 003 R33
Done


R33 output
IAEA:X4-R33 - Netscape
http://161.5.149.58/exfor2/servlet/X4sGetR33?reqx=1790&subID=101495002&pointer=
See Plots: DA(E):2/2 DA(A):16/199
Thetas:
1) 0.0 2) 150.0
Comment: Automatically converted from EXFOR via C4
by IAEA-NDS EXFOR Web-Retrieval System.
Software by V.Zerkin (IAEA, Vienna): version of 18-May-2007.
"Study of the reaction mechanism for (He3,P) reactions
with Li-6,B-10 and C-13"
J.P.Schiffer, T.W.Bonner, R.H.Davis,
F.W.Prosser, Jr.
EXFOR:[A1495002]; X4Reaction:3-LI-6(HE3,P)4-BE-8,PAR,DA; X4Points:201
Version: R33?
X4Number: A1495002 20040301
Source: J.P.Schiffer+(1956), Jour. Physical Review, Vol.104, p.1064
Reaction: 6Li(he3,p?)8Be
LevelEnergy: 0.00
Distribution: Energy
Units: mb
Composition:
Masses: 3.0, 6.0, 1.0, 8.0
Zeds: 2, 3, 1, 4
Qvalue: 0.00, 0.00, 0.00, 0.00, 0.00
Theta: 0.0
Data:
903.20, 6.00, 0.2869, 0.0115
926.60, 6.00, 0.303, 0.0121
963.80, 6.00, 0.3805, 0.0152
1001.00, 6.00, 0.4884, 0.0195
1033.00, 6.00, 0.6113, 0.0245
1061.00, 6.00, 0.6884, 0.0275
1093.00, 6.00, 0.7657, 0.0306
1130.00, 6.00, 0.8583, 0.0343
1144.00, 6.00, 0.9045, 0.0362
1181.00, 6.00, 1.028, 0.0411
1204.00, 6.00, 1.15, 0.046
R33 (almost…)
? Q-value
? Energy-Level
Done


R33 Plot
Data converted from EXFOR to R33/IBANDL
EXFOR: A1495002+; Reaction: 3-LI-6(HE3,P)4-BE-8,PAR,DA
Source: J.P.Schiffer+(1956), Jour. Physical Review, Vol.104, p.1064
EXFOR:A1495002 6Li(he3,p?)8Be
J.P.Schiffer+(1956), Jour. Physical Review, Vol.104, p.1064
Incident Energy (MeV)
1) 6Li(he3,p?)8Be AN=0 LV=0
2) 6Li(he3,p?)8Be AN=150 LV=0
See: plotted data (12Kb)
Use My Data [example]
Columns: x y [dy [dx]]
Type: Curve Points
Title: My Data
Multiply by: X: 1 Y: 1
Reset
Repaint
Legend
Authors
Manual plotting options:[+]


R33 Plot Interactions
Data converted from EXFOR to R33/IBANDL
EXFOR: A1495002+; Reaction: 3-LI-6(HE3,P)4-BE-8,PAR,DA
Source: J.P.Schiffer+(1956), Jour. Physical Review, Vol.104, p.1064
EXFOR:A1495002 6Li(he3,p?)8Be
J.P.Schiffer+(1956), Jour. Physical Review, Vol.104, p.1064
6Li(he3,p?)8Be AN=0 LV=0
6Li(he3,p?)8Be AN=150 LV=0
Incident Energy (MeV)
See: plotted data (12Kb)
Use My Data [example]
Columns: x y [dy [dx]]
Type: Curve Points
Title: My Data
Multiply by: X: 1 Y: 1



EXFOR+
EXFOR-Interpreted, IAEA-NDS, 2006 - Netscape
TITLE Study of the reaction mechanism for (He3,P) reactions with Li-6,B-10 and C-13
AUTHOR (J.P.Schiffer,T.W.Bonner,R.H.Davis,F.W.Prosser,Jr.)
INSTITUTE (1USARIC)
#(1USARIC) Rice University, Houston, TX, USA
REFERENCE (J,PR,104,1064,195611)
(J,PR,104,1064,195611) Journ.: Physical Review, Vol.104, p.1064 (1956) USA
#+ #NSR=1956SC01 #DOI=10.1103/PhysRev.104.1064
FACILITY (VDG)
#(VDG) Van de Graaff
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 (PHD)
#(PHD) Pulse-height discrimination
DETECTOR (SCIN) Thallium-activated CsI crystals mounted on DuMont 6291 photomultiplier tubes.
#(SCIN) Scintillation detector
ERR-ANALYS (DATA-ERR2)The pulse-height resolution of the detectors
HISTORY (19800811C) Compilation produced by Arzamas RFNC-VNIIEF
(20031013U) Last checking has been done.
ENDBIB 15
COMMON 1 3
DATA-ERR2
PER-CENT
4.
ENDCOMMON 3
ENDSUBENT 22
SUBENT A1495002 20031013 20040322 20050926 0000
BIB 5 11
REACTION (3-LI-6(HE3,P)4-BE-8,PAR,DA)
#(3-LI-6(HE3,P)4-BE-8,PAR,DA) Quantity: [DAP] Partial differential cross section d/dA
SAMPLE Metallic Li-6 enriched to 96%. 10 microg/cm2 thick.
ERR-ANALYS (EN-ERR) Digitizing error
(DATA-ERR) Digitizing error
(DATA-ERR1) Some uncertainty in the cross-section was introduced by not knowing precisely what fraction of the pulses to attribute to the 2.9-MeV state and what fraction to the continuum together with other uncertainties in target thickness and geometry.
EN-SEC (E-LVL,4-BE-8)
STATUS (CURVE) Fig 1 down
ENDBIB 11
COMMON 4 3
E-LVL EN-ERR DATA-ERR1 DATA-ERR
MEV MEV PER-CENT MB/SR
0. 0.006 20. 0.014
ENDCOMMON 3
DATA 3 201
EN ANG DATA
MEV ADEG MB/SR
0.8982 150. 0.2792
0.9032 0. 0.2869
0.9266 0. 0.303
0.9588 150. 0.3591
0.9638 0. 0.3805
1.001 0. 0.4884
1.033 0. 0.6113
1.042 150. 0.6104
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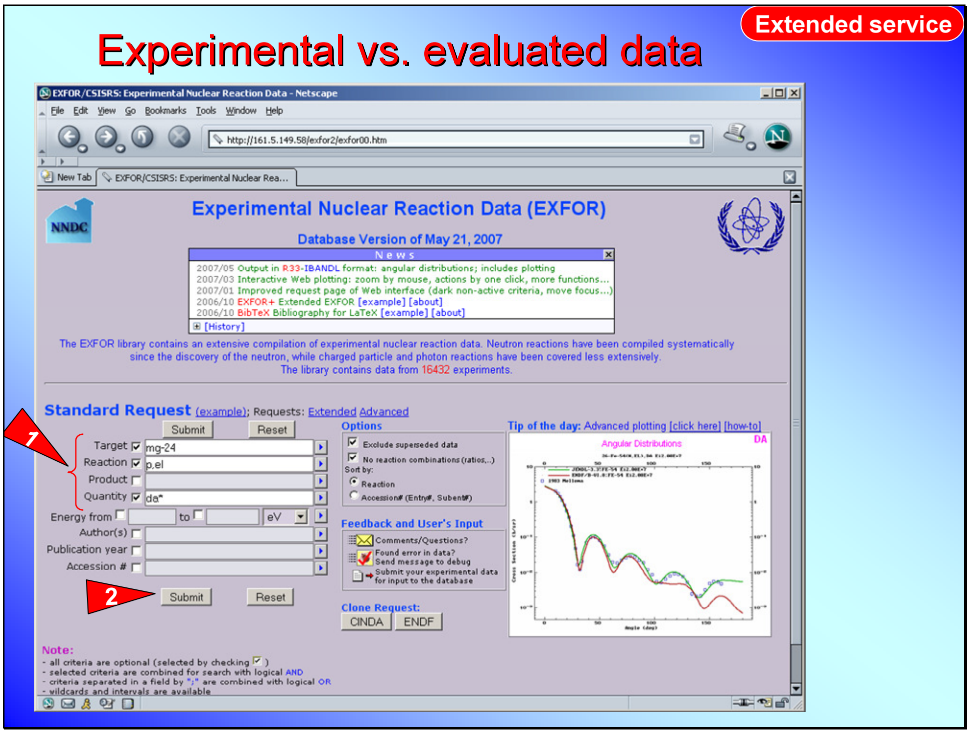
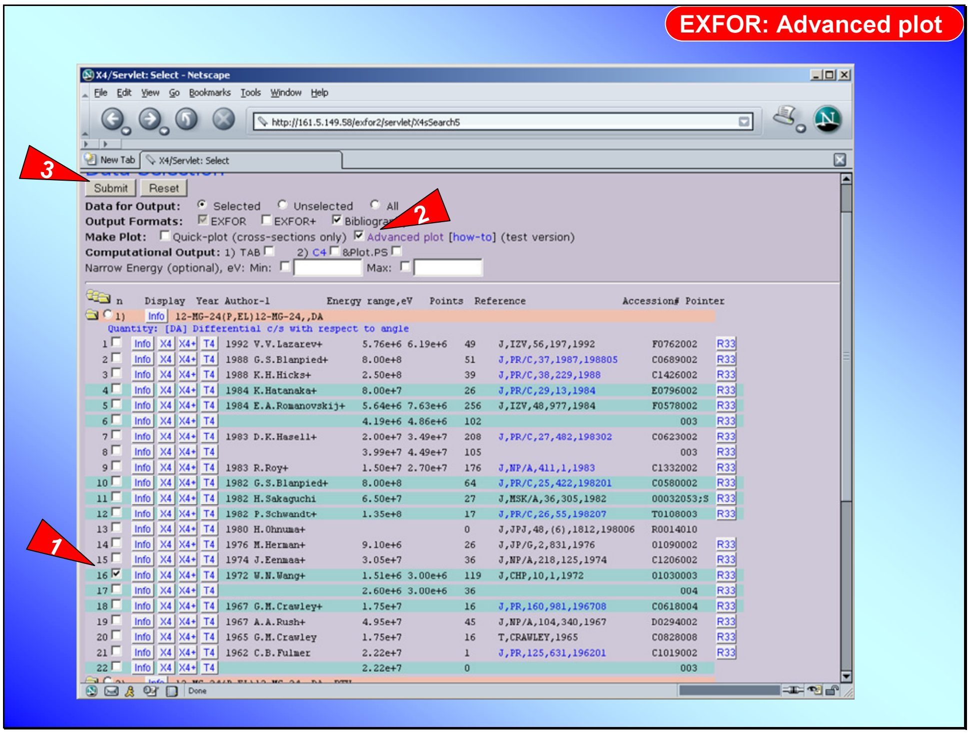
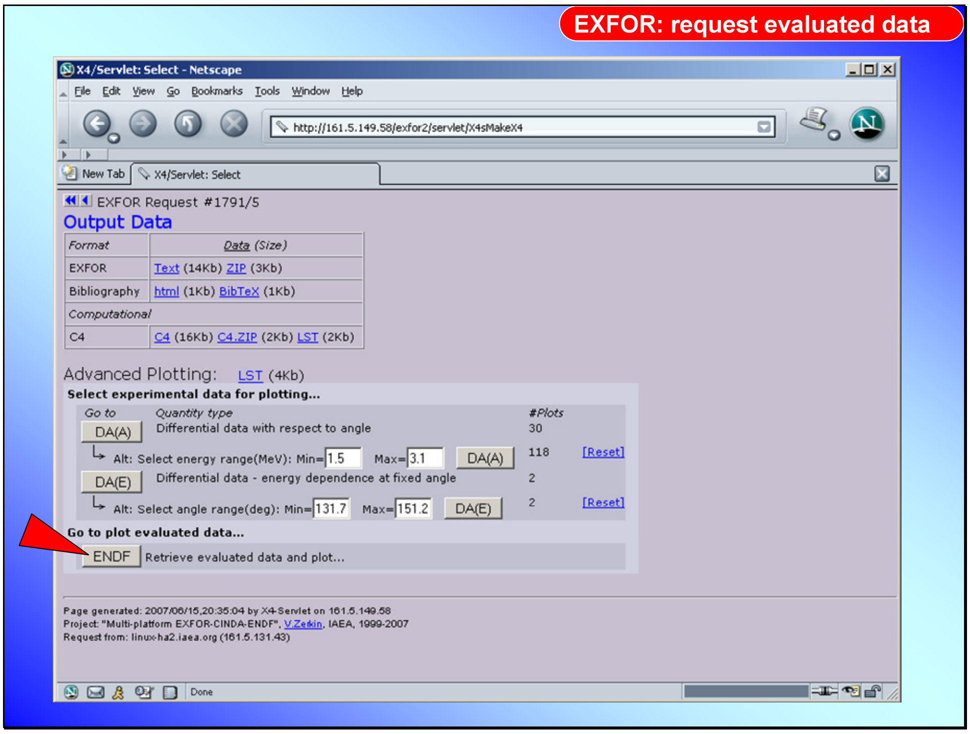


Extended service
Experimental vs. evaluated data
EXFOR/CSISRS: Experimental Nuclear Reaction Data - Netscape
http://161.5.149.58/exfor2/exfor00.htm
NNDC
Experimental Nuclear Reaction Data (EXFOR)
Database Version of May 21, 2007
News
2007/05 Output in R33-IBANDL format: angular distributions; includes plotting
2007/03 Interactive Web plotting: zoom by mouse, actions by one click, more functions...
2007/01 Improved request page of Web interface (dark non-active criteria, move focus...)
2006/10 EXFOR+ Extended EXFOR [example] [about]
2006/10 BibTeX Bibliography for LaTeX [example] [about]
[History]
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 16432 experiments.
Standard Request (example); Requests: Extended Advanced
Submit Reset
1
Target mg-24
Reaction p,el
Product
Quantity da*
Energy from to eV
Author(s)
Publication year
Accession #
2
Submit Reset
Options
Exclude superseded data
No reaction combinations (ratios,..)
Sort by:
Reaction
Accession# (Entry#, Subent#)
Feedback and User's Input
Comments/Questions?
Found error in data?
Send message to debug
Submit your experimental data for input to the database
Clone Request:
CINDA ENDF
Tip of the day: Advanced plotting [click here] [how-to]
Angular Distributions
DA
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


EXFOR: Advanced plot
X4/Servlet: Select - Netscape
http://161.5.149.58/exfor2/servlet/X4sSearch5
Submit
Reset
Data for Output: Selected Unselected All
Output Formats: EXFOR EXFOR+ Bibliography
Make Plot: Quick-plot (cross-sections only) Advanced plot [how-to] (test version)
Computational Output: 1) TAB 2) C4 &Plot.PS
Narrow Energy (optional), eV: Min: Max:
n Display Year Author-1 Energy range,eV Points Reference Accession# Pointer
12-MG-24(P,EL)12-MG-24,,DA
Quantity: [DA] Differential c/s with respect to angle
1
2
3


EXFOR: request evaluated data
X4/Servlet: Select - Netscape
http://161.5.149.58/exfor2/servlet/X4sMakeX4
EXFOR Request #1791/5
Output Data
Format
Data (Size)
EXFOR
Text (14Kb) ZIP (3Kb)
Bibliography
html (1Kb) BibTeX (1Kb)
Computational
C4
C4 (16Kb) C4.ZIP (2Kb) LST (2Kb)
Advanced Plotting: LST (4Kb)
Select experimental data for plotting...
Go to
Quantity type
#Plots
DA(A)
Differential data with respect to angle
30
Alt: Select energy range(MeV): Min=1.5 Max=3.1 DA(A)
118
[Reset]
DA(E)
Differential data - energy dependence at fixed angle
2
Alt: Select angle range(deg): Min=131.7 Max=151.2 DA(E)
2
[Reset]
Go to plot evaluated data...
ENDF
Retrieve evaluated data and plot...
Page generated: 2007/06/15,20:35:04 by X4-Servlet on 161.5.149.58
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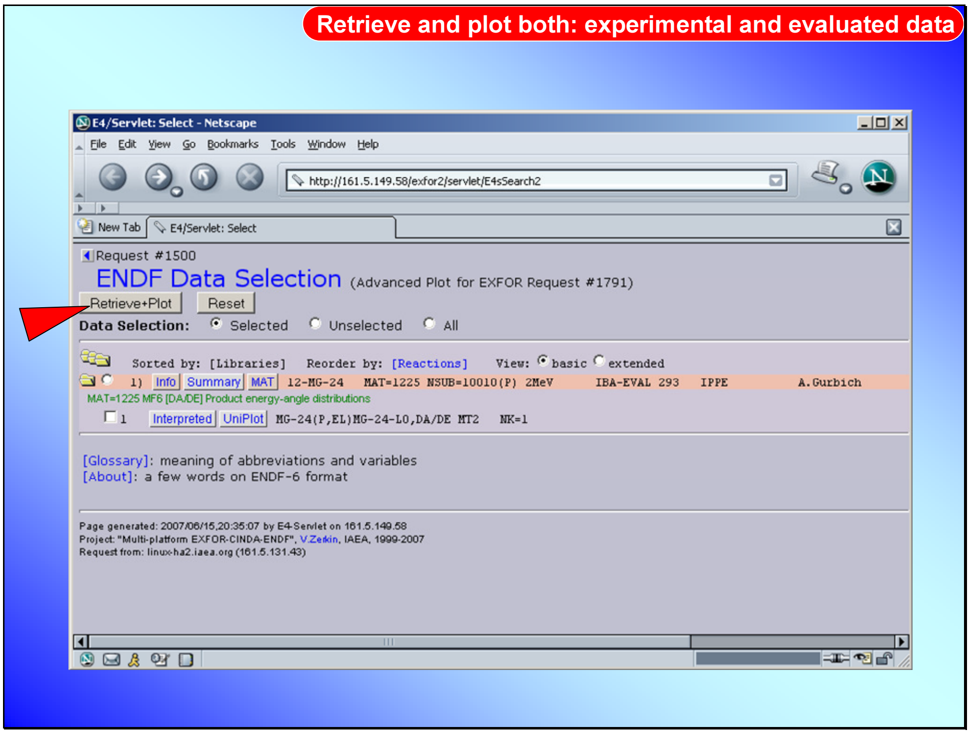
Request from: linux-ha2.iaea.org (161.5.131.43)


Retrieve and plot both: experimental and evaluated data
E4/Servlet: Select - Netscape
http://161.5.149.58/exfor2/servlet/E4sSearch2
Request #1500
ENDF Data Selection (Advanced Plot for EXFOR Request #1791)
Retrieve+Plot
Reset
Data Selection: Selected Unselected All
Sorted by: [Libraries] Reorder by: [Reactions] View: basic extended
1) Info Summary MAT 12-MG-24 MAT=1225 NSUB=10010(P) 2MeV IBA-EVAL 293 IPPE A.Gurbich
MAT=1225 MF6 [DA/DE] Product energy-angle distributions
1 Interpreted UniPlot MG-24(P,EL)MG-24-L0,DA/DE MT2 NK=1
[Glossary]: meaning of abbreviations and variables
[About]: a few words on ENDF-6 format
Page generated: 2007/06/15,20:35:07 by E4-Servlet on 161.5.149.58
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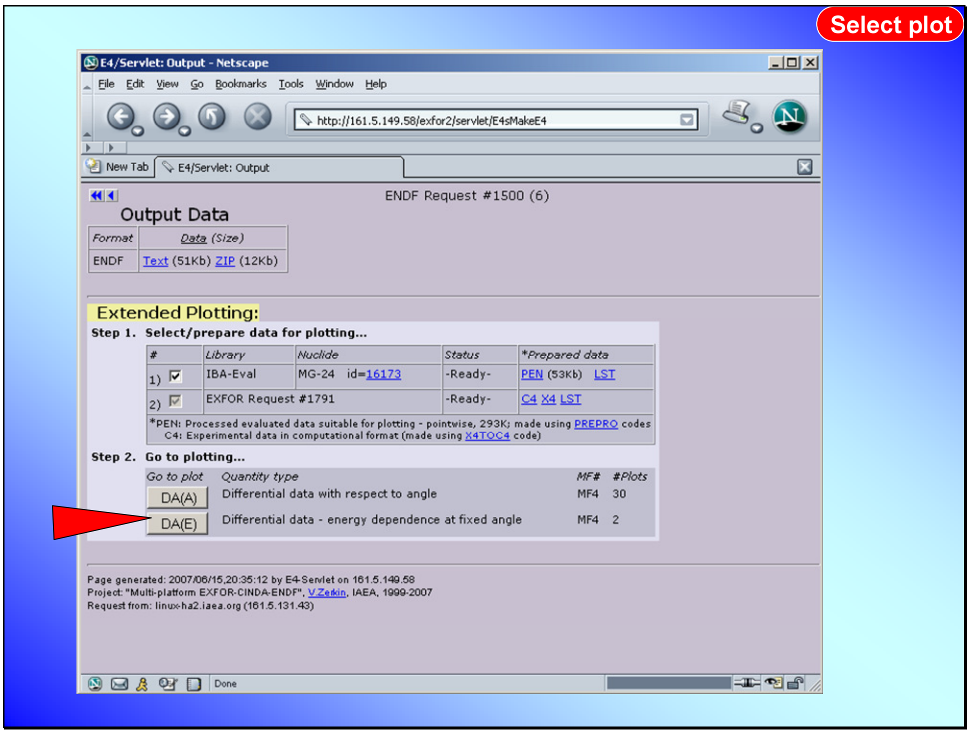
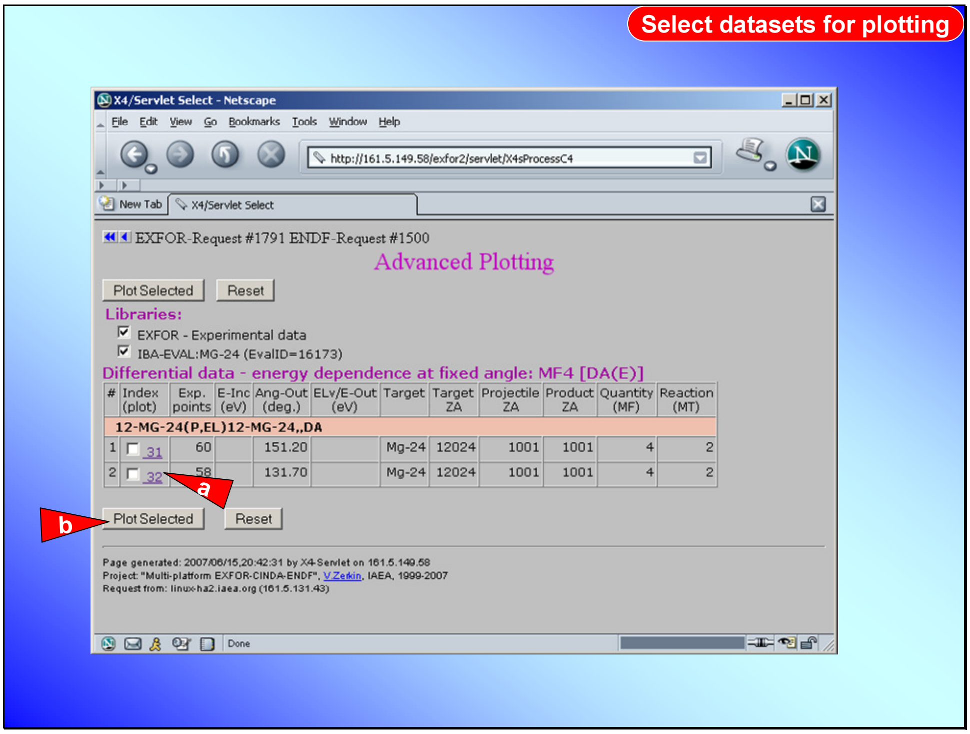
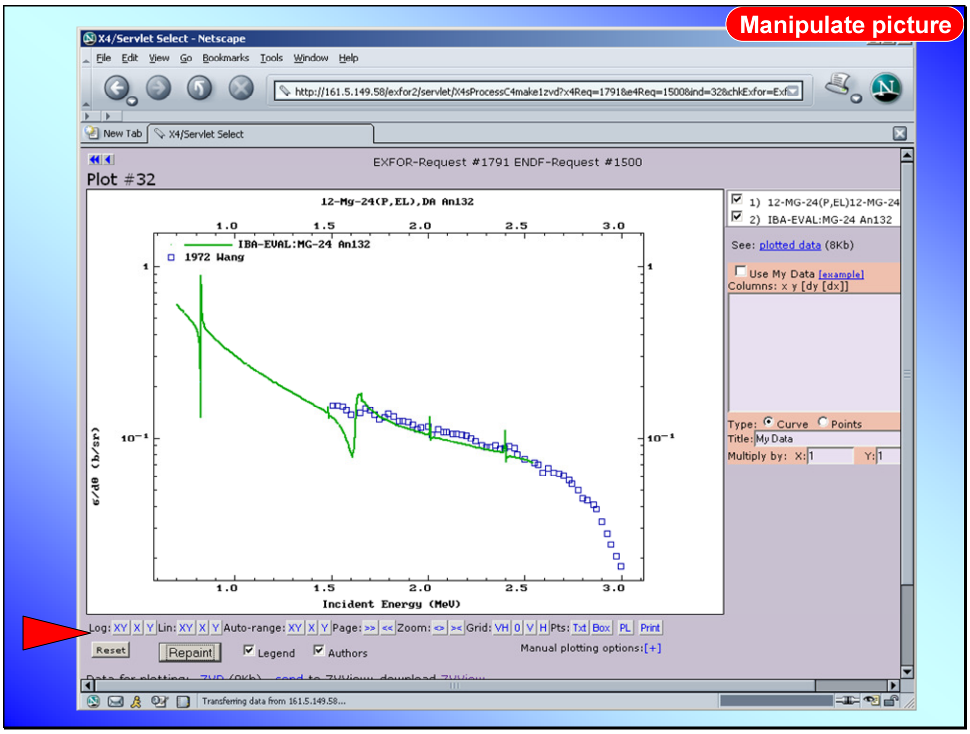
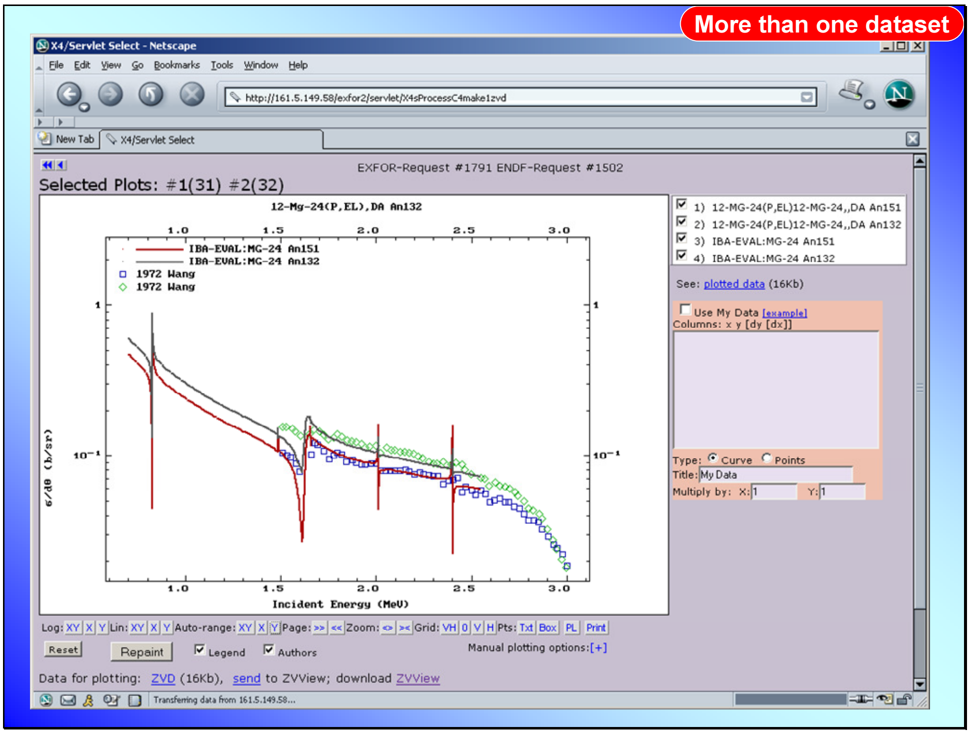
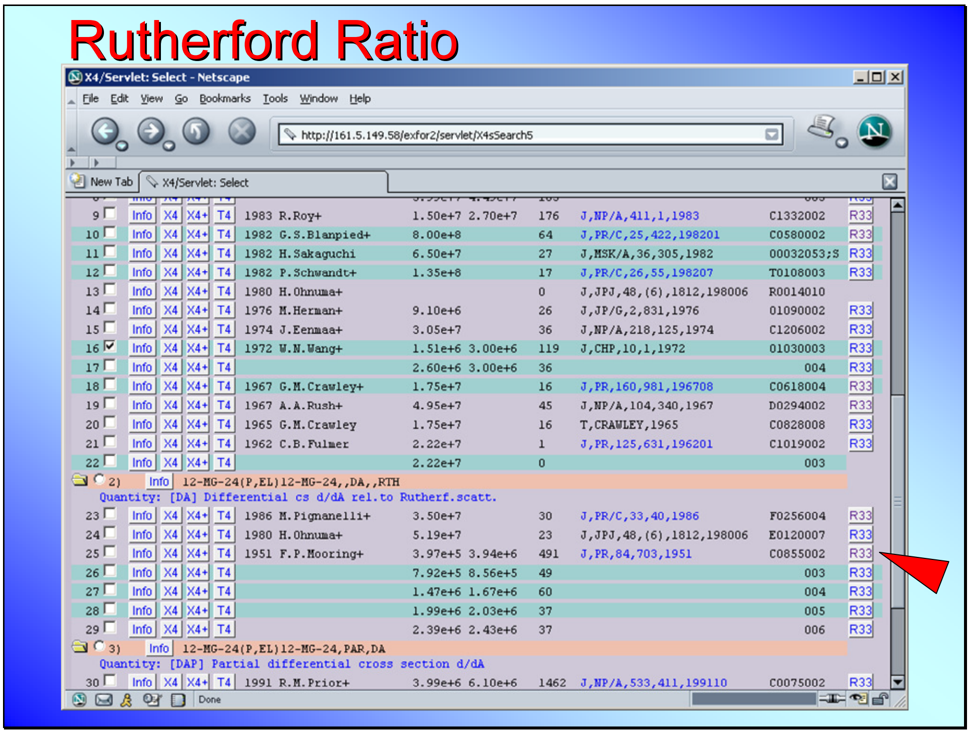

Select plot
E4/Servlet: Output - Netscape
http://161.5.149.58/exfor2/servlet/E4sMakeE4
ENDF Request #1500 (6)
Output Data
Format Data (Size)
ENDF Text (51Kb) ZIP (12Kb)
Extended Plotting:
Step 1. Select/prepare data for plotting...
Library Nuclide Status *Prepared data
1) IBA-Eval MG-24 id=16173 -Ready- PEN (53Kb) LST
2) EXFOR Request #1791 -Ready- C4 X4 LST
*PEN: Processed evaluated data suitable for plotting - pointwise, 293K; made using PREPRO codes
C4: Experimental data in computational format (made using X4TOC4 code)
Step 2. Go to plotting...
Go to plot Quantity type MF# #Plots
DA(A) Differential data with respect to angle MF4 30
DA(E) Differential data - energy dependence at fixed angle MF4 2
Page generated: 2007/06/15,20:35:12 by E4-Servlet on 161.5.149.58
Project: "Multi-platform EXFOR-CINDA-ENDF", V.Zerkin, IAEA, 1999-2007
Request from: linux-ha2.iaea.org (161.5.131.43)
Done

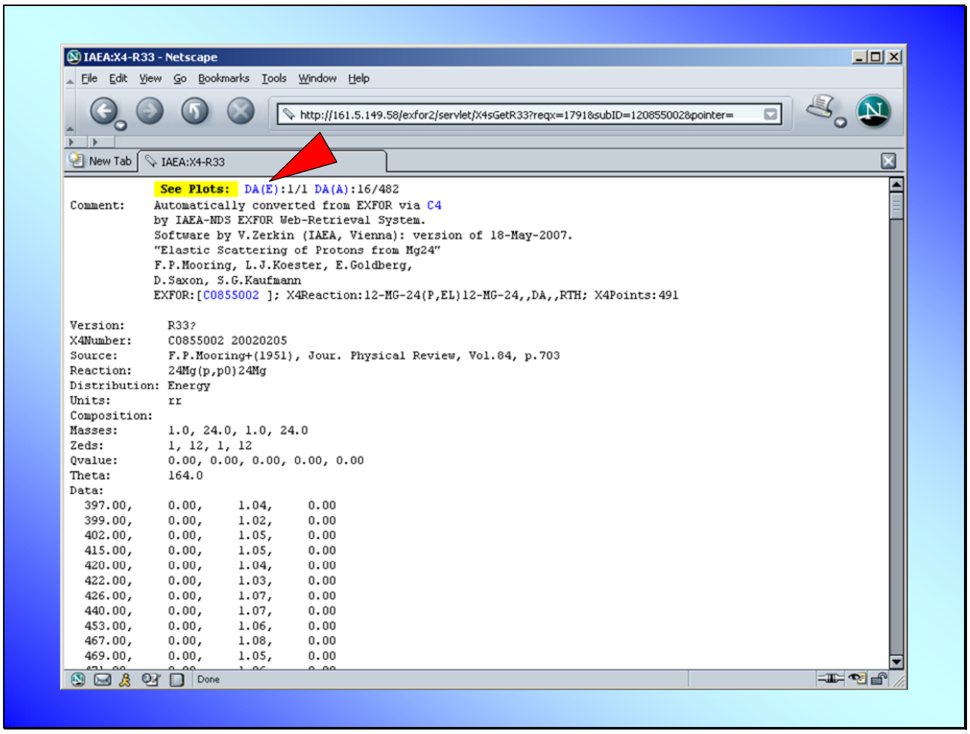


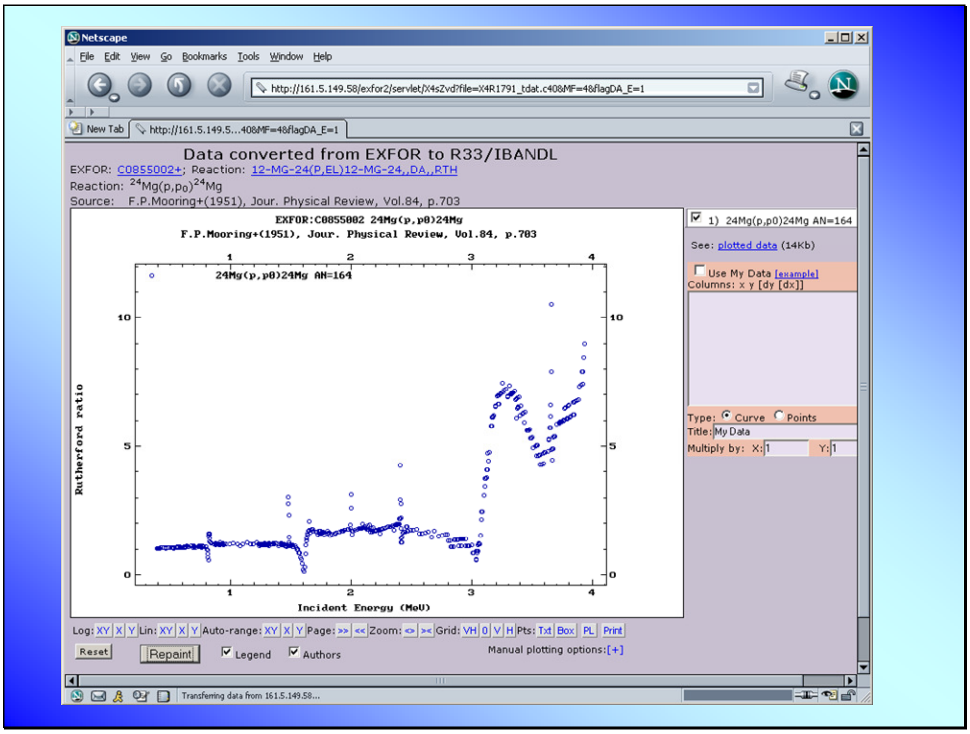
#	Index (plot)	Exp. points	E-Inc (eV)	Ang-Out (deg.)	ELv/E-Out (eV)	Target	Target ZA	Projectile ZA	Product ZA	Quantity (MF)	Reaction (MT)
1	31	60		151.20		Mg-24	12024	1001	1001	4	2
2	32	58		131.70		Mg-24	12024	1001	1001	4	2




More than one dataset
X4/Servlet Select - Netscape
http://161.5.149.58/exfor2/servlet/X4sProcessC4make1zvd
EXFOR-Request #1791 ENDF-Request #1502
Selected Plots: #1(31) #2(32)
12-Mg-24(P,EL),DA An132
IBA-EVAL:MG-24 An151
IBA-EVAL:MG-24 An132
1972 Wang
1972 Wang
Incident Energy (MeV)
1) 12-MG-24(P,EL)12-MG-24,,DA An151
2) 12-MG-24(P,EL)12-MG-24,,DA An132
3) IBA-EVAL:MG-24 An151
4) IBA-EVAL:MG-24 An132
See: plotted data (16Kb)
Use My Data [example]
Columns: x y [dy [dx]]
Type: Curve Points
Title: My Data
Multiply by: X: 1 Y: 1
Reset
Repaint
Legend
Authors
Manual plotting options:[+]
Data for plotting: ZVD (16Kb), send to ZVView; download ZVView


Rutherford Ratio
X4/Servlet: Select - Netscape
http://161.5.149.58/exfor2/servlet/X4sSearch5
9 Info X4 X4+ T4 1983 R.Roy+ 1.50e+7 2.70e+7 176 J,NP/A,411,1,1983 C1332002 R33
10 Info X4 X4+ T4 1982 G.S.Blanpied+ 8.00e+8 64 J,PR/C,25,422,198201 C0580002 R33
11 Info X4 X4+ T4 1982 H.Sakaguchi 6.50e+7 27 J,MSK/A,36,305,1982 00032053;S R33
12 Info X4 X4+ T4 1982 P.Schwandt+ 1.35e+8 17 J,PR/C,26,55,198207 T0108003 R33
13 Info X4 X4+ T4 1980 H.Ohnuma+ 0 J,JPJ,48,(6),1812,198006 R0014010
14 Info X4 X4+ T4 1976 M.Herman+ 9.10e+6 26 J,JP/G,2,831,1976 O1090002 R33
15 Info X4 X4+ T4 1974 J.Eenmaa+ 3.05e+7 36 J,NP/A,218,125,1974 C1206002 R33
16 Info X4 X4+ T4 1972 W.N.Wang+ 1.51e+6 3.00e+6 119 J,CHP,10,1,1972 O1030003 R33
17 Info X4 X4+ T4 2.60e+6 3.00e+6 36 004 R33
18 Info X4 X4+ T4 1967 G.M.Crawley+ 1.75e+7 16 J,PR,160,981,196708 C0618004 R33
19 Info X4 X4+ T4 1967 A.A.Rush+ 4.95e+7 45 J,NP/A,104,340,1967 D0294002 R33
20 Info X4 X4+ T4 1965 G.M.Crawley 1.75e+7 16 T,CRAWLEY,1965 C0828008 R33
21 Info X4 X4+ T4 1962 C.B.Fulmer 2.22e+7 1 J,PR,125,631,196201 C1019002 R33
22 Info X4 X4+ T4 2.22e+7 0 003
2) Info 12-MG-24(P,EL)12-MG-24,,DA,,RTH
Quantity: [DA] Differential cs d/dA rel.to Rutherf.scatt.
23 Info X4 X4+ T4 1986 M.Pignanelli+ 3.50e+7 30 J,PR/C,33,40,1986 F0256004 R33
24 Info X4 X4+ T4 1980 H.Ohnuma+ 5.19e+7 23 J,JPJ,48,(6),1812,198006 E0120007 R33
25 Info X4 X4+ T4 1951 F.P.Mooring+ 3.97e+5 3.94e+6 491 J,PR,84,703,1951 C0855002 R33
26 Info X4 X4+ T4 7.92e+5 8.56e+5 49 003 R33
27 Info X4 X4+ T4 1.47e+6 1.67e+6 60 004 R33
28 Info X4 X4+ T4 1.99e+6 2.03e+6 37 005 R33
29 Info X4 X4+ T4 2.39e+6 2.43e+6 37 006 R33
3) Info 12-MG-24(P,EL)12-MG-24,PAR,DA
Quantity: [DAP] Partial differential cross section d/dA
30 Info X4 X4+ T4 1991 R.M.Prior+ 3.99e+6 6.10e+6 1462 J,NP/A,533,411,199110 C0075002 R33


IAEA:X4-R33 - Netscape
File Edit View Go Bookmarks Tools Window Help
http://161.5.149.58/exfor2/servlet/X4sGetR33?reqx=1791&subID=120855002&pointer=
New Tab
IAEA:X4-R33
See Plots: DA(E):1/1 DA(A):16/482
Comment: Automatically converted from EXFOR via C4
by IAEA-NDS EXFOR Web-Retrieval System.
Software by V.Zerkin (IAEA, Vienna): version of 18-May-2007.
"Elastic Scattering of Protons from Mg24"
F.P.Mooring, L.J.Koester, E.Goldberg,
D.Saxon, S.G.Kaufmann
EXFOR:[C0855002]; X4Reaction:12-MG-24(P,EL)12-MG-24,,DA,,RTH; X4Points:491
Version: R33?
X4Number: C0855002 20020205
Source: F.P.Mooring+(1951), Jour. Physical Review, Vol.84, p.703
Reaction: 24Mg(p,p0)24Mg
Distribution: Energy
Units: rr
Composition:
Masses: 1.0, 24.0, 1.0, 24.0
Zeds: 1, 12, 1, 12
Qvalue: 0.00, 0.00, 0.00, 0.00, 0.00
Theta: 164.0
Data:
397.00, 0.00, 1.04, 0.00
399.00, 0.00, 1.02, 0.00
402.00, 0.00, 1.05, 0.00
415.00, 0.00, 1.05, 0.00
420.00, 0.00, 1.04, 0.00
422.00, 0.00, 1.03, 0.00
426.00, 0.00, 1.07, 0.00
440.00, 0.00, 1.07, 0.00
453.00, 0.00, 1.06, 0.00
467.00, 0.00, 1.08, 0.00
469.00, 0.00, 1.05, 0.00
Done


Netscape
File Edit View Go Bookmarks Tools Window Help
http://161.5.149.58/exfor2/servlet/X4sZvd?file=X4R1791_tdat.c40&MF=4&flagDA_E=1
New Tab
http://161.5.149.5...40&MF=4&flagDA_E=1
Data converted from EXFOR to R33/IBANDL
EXFOR: C0855002+; Reaction: 12-MG-24(P,EL)12-MG-24,,DA,,RTH
Reaction: 24Mg(p,p0)24Mg
Source: F.P.Mooring+(1951), Jour. Physical Review, Vol.84, p.703
EXFOR:C0855002 24Mg(p,p0)24Mg
F.P.Mooring+(1951), Jour. Physical Review, Vol.84, p.703
24Mg(p,p0)24Mg AN=164
Rutherford ratio
Incident Energy (MeV)
1) 24Mg(p,p0)24Mg AN=164
See: plotted data (14Kb)
Use My Data [example]
Columns: x y [dy [dx]]
Type: Curve Points
Title: My Data
Multiply by: X: 1 Y: 1
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
Manual plotting options:[+]
Transferring data from 161.5.149.58...

Evaluation of non-Rutherford proton elastic scattering cross section for magnesium

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Abstract

The experimental data available for magnesium (p,p) elastic scattering cross section at angles and energies suitable for Ion Beam Analysis have been evaluated using the theoretical model approach together with additional measurements and benchmark experiments. The results obtained provide the evaluated differential cross sections for magnesium (p,p) elastic scattering in the energy region up to 2.7 MeV.

Key words: proton elastic scattering, magnesium, cross section, evaluation

PACS: 25.40.Cm

1. Introduction

This article continues a series of papers devoted to the evaluation of non-Rutherford cross sections for Ion Beam Analysis (IBA). The results achieved so far are summarized in [1]. It was demonstrated that the evaluation of the cross sections by combining different sets of experimental data in the framework of a theoretical model makes it possible to calculate the smooth curves of $d\Omega/d\theta(E,\theta)$ needed for simulation of IBA spectra with a reliability exceeding that of any individual measurement.

The evaluation procedure consists of the following: Firstly, a search of the literature and of nuclear data bases is made to compile and compare relevant experimental data. The apparently reliable experimental points are critically selected. Free parameters of the theoretical model, which involve appropriate physics for the given scattering process, are then fitted within the limits of reasonable physical constraints. Details of the physics are described elsewhere [2]. Additional experimental data can be incorporated *a posteriori*. If necessary, benchmark experiments are performed to arbitrate discrepancies.

Magnesium is an important element. It is the crucial component of, for example, light strong metal alloys important for aerospace structural materials and certain automotive components. In any application where thin film coatings or tribological layers are investigated we may expect the ability to use IBA to be useful.

Magnesium diboride is also an interesting new superconductor with a critical temperature of 39K. Rutherford backscattering (RBS) has been used to determine the elemental depth profile in ion beam synthesised MgB_2 [3], but the sensitivity to B is poor in RBS. An alternative approach is to use elastic (non-Rutherford) backscattering (EBS) where the sensitivity to B is enhanced by an order of magnitude for a 2.6 MeV beam. However, at this proton energy the elastic scattering cross-section for Mg is also strongly non-Rutherford, and must be determined for EBS depth profiling to be used.

In this work, we have identified a discrepancy between the *a priori* most likely theoretical excitation function (elastic scattering cross-section) for Mg, and existing data in the region 850-1250 keV, just above the first resonance at 823 keV. Additional benchmarking measurements on both thin and thick films have supported the theoretical function.

2. Evaluation

The differential proton elastic scattering cross sections for magnesium in the energy range from Coulomb scattering to 2.5 MeV were found in four papers: Mooring *et al* (1951) [4], Rauhala *et al* (1988) [5], Zhang *et al* (2003) [6], and Wang *et al* (1972) [7]. The reported data were measured at laboratory angles of 164.5° (Mooring), 170° (Rauhala), 140°, 150°, 160°, 170° (Zhang), and 130°,150° (Wang) in the energy range of 0.40-3.95, 0.8-2.7, 0.8-2.5, and 1.5-3.0 MeV respectively. Natural magnesium (78.99% of ^{24}Mg, 10.00% of ^{25}Mg, and 11.01% of ^{26}Mg) was used for manufacturing targets in Rauhala and Zhang, the target material in Mooring was $^{24}MgF_2$ enriched by the ^{24}Mg isotope up to 99.50%, and the target in Wang was also of high enrichment (~99%). The measurements reported in Mooring, Zhang and Wang were made with thin targets prepared by evaporation of magnesium onto graphite backing and with a thick sample in Rauhala. A computer fit using the simulation program GISA [8] and TRIM77 [9] stopping powers for Mg provided the cross sections in the last case. The spectra of elastically scattered protons were measured by means of a magnetic analyzer (Mooring) and with silicon surface barrier detectors for all the others. A large background scattering from the impurities contained in the graphite backing was found in Mooring and the corresponding correction was made for the cross-section determination.

For Zhang, the absolute values of differential cross sections were determined assuming that the scattering was Rutherford below 0.8 MeV. The absolute normalization was made against the yield of protons elastically scattered from the Au layer evaporated on the Mg one. The experimental standard error assigned to the data in was 5%. The target thickness in Wang was determined by assuming that the scattering was Rutherford near 1 MeV and the total experimental uncertainty was estimated to be about 10%.

The absolute normalization in Rauhala was made in a similar way as in Zhang and the error assigned to the data was estimated to be less than 5% including inaccuracies due to possible errors in the stopping powers which were used in order to determine the cross section from the relative backscattering yields of Au and Mg. The estimate of 5% in Rauhala depends on the reliability of the shape of the stopping power curve since the absolute yields are all interpreted relative to the Rutherford regime below 800 keV. However Ziegler's more recent SRIM2003 estimates of stopping power (www.srim.org) have a *ratio* between the values at 778 keV and 1216 keV that are more than 3% different from those Ziegler *et al* published in 1985 [10] (the stopping power for H in Mg is (8.93 and 6.74) eV/(10^{15} atoms/cm^2) for TRIM90 and (8.30 and 6.47) eV/(10^{15} atoms/cm^2) for SRIM03 with proton energies of (776 and 1216) keV respectively).

For the sake of completeness Valter *et al* (1963) [11] should also be mentioned. The differential cross sections for ^{24}Mg(p,p_0)^{24}Mg were measured at 90°, 125° and 141° (c.m.) from 1.45 to 4.20 MeV. Unfortunately the data were only presented for energies above 2.7 MeV.

As a whole, the data obtained are in a reasonable mutual agreement and some differences caused by the different isotopic content of the targets employed are observed between the data of Rauhala and Zhang, and the earlier work of Mooring and Wang on isotopically enriched targets.

The differential scattering cross section function is Rutherford below ~800 keV and shows several scattering anomalies at higher energies (Fig. 1). A remarkable feature of the curve discovered in Mooring was that on the low energy side of the narrow 0.823 MeV resonance the observed cross section values followed closely the expected Coulomb scattering, whereas on the high energy side it was found to be about 10% higher. Since the data below and above 0.85 MeV were taken in Mooring with different targets, the authors made additional efforts to confirm the result and they claimed that the reported deviation from Rutherford scattering above the 0.823 MeV resonance was real. A similar ~10% excess of the cross section over the Rutherford value above the 0.823 MeV resonance was obtained also by both Rauhala and Zhang for the differential cross sections measured at different scattering angles with exception of the results for 150° reported by Zhang (Fig. 2).

It is known that broad shape resonances may significantly influence the cross section [12]. The fact that the $l = 4$ Legendre polynomial is zero at the scattering angle of 149.27° c.m. could in principle account for the dip in the angular distribution at the 150° scattering angle measured in Zhang. However, this can be ruled out since the contribution of this partial wave to the cross section is negligible because of its extremely small transmission coefficient at low energy.

Theoretical calculations in the present work were made in the framework of the R-matrix theory of Lane and Thomas (1958) [13]. The formulae (2.6)-(2.7) of Sect. VIII of this reference were programmed for the one channel multilevel case. The cross section for natural magnesium was calculated as a sum of the cross sections for its three stable isotopes weighted by the relative abundance. The resonance parameters were taken from the compilation of Endt and van der Leun (1973) [14]. The general trend of the observed cross sections, including resonances, was well reproduced theoretically (see Fig. 1). The theoretical analysis was facilitated by the previous investigation of Koester (1952) [15] where the energy dependence of the cross section for ^{24}Mg(p,p_0)^{24}Mg measured by Mooring was interpreted in terms of the combination of Coulomb and nuclear potential scattering with resonant scattering. This resonant scattering arises from the excitation of energy levels of the compound nucleus ^{25}Al. In the case of proton scattering from natural magnesium the excitation of the ^{26}Al and ^{27}Al energy levels should also be taken into account. For the p+^{25}Mg scattering a lot of resonances are observed in the excitation function [16], however they are relatively narrow and rather weak. Being weighted accordingly to the isotope abundance the p+^{25}Mg contribution to the natural magnesium cross section is practically indistinguishable and so the corresponding curve is not shown in Fig. 1. The p+^{26}Mg case is another matter [17]. The large anomaly with a peak just above 2 MeV substantially influences the differential cross section for natural magnesium (see Fig. 1) and is responsible for the observed difference in the cross sections for natural magnesium and the ^{24}Mg isotope.

3. Benchmark Measurements

In order to resolve the problem with the cross-section behaviour around the resonance at E_p = 823 keV benchmark measurements were made with a thin film target. Proton backscattering spectra above the various resonances were also obtained with a thick uniform natural magnesium target as benchmark measurements to validate the structure of the fine resonances. These measurements were all done using a 2 MV Tandetron capable of generating proton beams up to 4 MeV [18]. This machine has a terminal voltage controlled (with a precision generating voltmeter) with an accuracy better than 0.1%. No slit stabilisation on the analysing magnet is needed (or used).

Surface barrier detectors at scattering angles of 172.8° (Cornell geometry) and 148.2° (IBM geometry) with solid angles of 1.25 and 3.5msr were used simultaneously in the measurements. A Mg foil sample (Goodfellow Metals Ltd.) served as a target. It was 99.9% pure (impurity mostly Fe), 25x25 mm, 0.25 mm thick, as rolled. The surface oxide and carbon contamination was evaluated (see Fig. 3). Beam current was ~10 nA, nominal beam size (normal incidence) was 1 mm. A second test sample was a Au/Mg multilayer on vitreous carbon, sputter deposited by Teer Coatings Ltd, and containing (270, 958, 371).10^{15}/cm^2 of (Au, Mg, O) respectively.

The electronics calibration was made with a Au/Ni/SiO_2/Si sample (see [19]), using Lennard's pulse height defect (PHD) correction for the non-ionising energy loss [20] and an assumed surface electrode thickness of (246, 100).10^{15} Au/cm^2 for the A and B detectors respectively (equivalent to (80, 32.5) µg/cm^2 or (42, 17) nm, including dead layer). The average offset determined for the whole energy range with fixed gain was (-6.5±0.8, -3.5±0.7) keV for the two detectors, where the uncertainty given is the standard error. This offset is equivalent to (1.4, 0.8) channels in the MCAs (multichannel analysers). The gain had an apparent uncertainty (standard error over the whole dataset) of less than 0.1%. Without the PHD correction the apparent gain changes by 5% across the energy range. This would be enough to destroy the relative energy correlations of the spectra. With the PHD correction we can compare the energies of the various resonances since the gain is constant across the whole dataset. Determination of electronic gain at comparable precision is reported by Bianconi *et al* (2000 [21], see Barradas *et al* 2007, [22]) and Munnik *et al* (1995 [23]).

The DataFurnace code (NDFv8.1h) [24, 25] was used to calculate the spectra from the excitation function. Unless both the straggling and the convolution of the straggling and the cross-section function are calculated correctly, the spectral shape for buried resonances will not be properly reproduced. DataFurnace has new algorithms to handle non-Rutherford cross-sections correctly. The number of internal calculation layers is determined by the cross-section data file [26]. This is essential for correct interpolation since the system resolution (~14 keV) is often much larger than the the width of resonances (for example, the 1483 keV resonance has a FWHM of only 400 eV). Also, the effect of the energy spread before interaction is large for sharp resonances, and is now correctly taken into account by the DataFurnace code [27]. The "DEPTH" code of Szilágyi et al. [28] was used to correctly determine the effect of straggling on the effective energy resolution as a function of depth.

The accurate pulse pileup correction algorithm of Wielopolski and Gardner [29] was used to maintain the accuracy of the cross-section measurements on the thin film sample [30]. The pileup correction can exceed 3% for the larger detector, and we emphasise that this is a non-linear correction (the pileup-corrected Au signal is *larger* than the measured signal since counts are lost from the peak) and is calculated without free parameters using the amplifier shaping time (500 ns), and the time resolutions of the pileup rejection circuit, which were (520, 550) ns for the two detection channels. In fact the PUR time resolutions were adjusted slightly from the expected 500ns to match the observed pileup probability. The W&G algorithm is exact for 2-pulse pileups, but was extended in the DataFurnace code to give an approximate estimate of 3-pulse pileups. These were negligible in this work.

The pileup calculation is an interative convolution of the observed spectrum with itself. This has the disadvantage that the part of the spectrum below the LLD (lower level discriminator) of the MCA is unobserved. This means that the pileup cannot be calculated correctly near leading edges in the spectrum since the low energy pulses are missing from the spectrum. In the case that there is significant electronic noise in a detection channel this may be a significant effect. For the present data for the Au/Mg ML sample, there is a noticeable high energy tail on the Au signal which is attributable to pileup from the low energy part of the spectrum (below the LLD). We have simulated low energy "noise" to roughly account for this since it is important to have an accurate estimate of the real (pileup corrected) number of Au counts. In these data the calculated pileup correction is large: it *increased* the apparent Au signal by up to 3.3% and *decreased* the apparent Mg signal by up to 4.5%.

Fig. 3 directly compares the scattering cross-sections proposed here with the experimental data for the bulk Mg sample, near the 823, 1483 and 1630 keV resonances. It is clear that the data are well reproduced by the SigmaCalc cross-sections, even at the sharp resonance at 1483 keV which is not well determined by Moore's cross-section measurement because the Mg thin films used are too thick. The bulk data determines the height of the resonance, given the resonance width. The real cross-sections derived from the fitted resonance parameters can be folded with the target thickness and the beam width given by Moore to recover the measured cross-sections (see Fig. 4).

Table 1 shows the analysis of the Au/Mg sample, where results are given relative both to the Rutherford Au signal, and to the C substrate, using evaluated (SigmaCalc) C cross-sections [31]. Evaluated (SigmaCalc) cross-sections are also used for the O contaminant [32]. The sample structure was first determined in the Rutherford region, and then the spectra at different energies were simulated, and the apparent Au and Mg thicknesses determined by comparison of the data with the simulations. If the SigmaCalc cross-sections are correct the Au and Mg thicknesses should be constant. The table shows the quality of the data, with the counting statistics uncertainty and the standard error of the estimated Au and Mg thicknesses calculated separately. The Mg thickness relative to both the carbon substrate and the Rutherford Au signal is also shown, and the two detectors are compared. The latter clearly shows that the detectors are strongly correlated. These data are summarised in Fig. 5.

4. Conclusion

The proton elastic scattering from natural magnesium has been evaluated, and can now be reliably calculated for any scattering angle in the energy range from Coulomb scattering up to 2.7 MeV. The uncertainty of SigmaCalc cross-sections proved to be not worse than 2%.

It is shown that sharp strong resonances observed in the cross-section are also prominent in thick targets. For example, the full structure of the strong resonance at 1483 keV was not reproduced in any reported thin target measurement, but a correct simulation using the theoretical cross-sections reproduced the data well.
The evaluated elastic scattering cross-sections are available from http://www-nds.iaea.org/sigmacalc mirrored at http://www.surreyibc.ac.uk/sigmacalc.

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Table 1: Pileup corrected data quantified by comparison with simulation

Thickness given in thin film units (TFU: 10^{15} atoms/cm^{2}). Detectors A and B have scattering angles of 172.8º and 148.2º

	Energy	**Au**		**Mg**		**O**		**Average Mg**		**Au**	**Mg**	**O**
		A det	**Bdet**	**A det**	**Bdet**	**A det**	**Bdet**	**norm: C**	**norm: Au**	**A/B**	**A/B**	**A/B**
	keV	**TFU**	**TFU**	**TFU**	**TFU**	**TFU**	**TFU**	**TFU**	**TFU**			
1	**706.75**	278	271	976	959	377	386	**968**	968	1.026	1.018	0.976
2	**706.75**	281	274	967	994	399	398	**981**	969	1.025	0.973	1.004
3	**840**	279	269	976	951	354	369	**964**	964	1.037	1.026	0.960
4	**942.5**	281	268	969	929	318	355	**949**	947	1.047	1.043	0.896
5	**1147.5**	283	272	998	933	303	307	**965**	955	1.041	1.069	0.986
6	**1352.5**	285	273	958	930	321	315	**944**	928	1.043	1.030	1.021
7	**1506**	285	275	959	914	322	293	**937**	917	1.035	1.050	1.099
8	**1506**	288	275	942	927	313	295	**935**	911	1.050	1.016	1.062
9	**1752**	280	273	1010	989	308	306	**1000**	991	1.025	1.021	1.008
10	**840**	280	271	964	940	361	369	**952**	947	1.035	1.025	0.978
Uncertainty		0.3%	0.2%	1.2%	0.7%	2.3%	1.3%	1.3%	1.4%	0.4%	1.3%	2.7%
Average		282	272	972	947	338	339	959	950	1.037	1.027	0.999
Standard deviation		**1.1%**	**0.8%**	**2.0%**	**2.8%**	**9.7%**	**11.8%**	**2.3%**	**2.6%**	**0.9%**	**2.5%**	**5.6%**

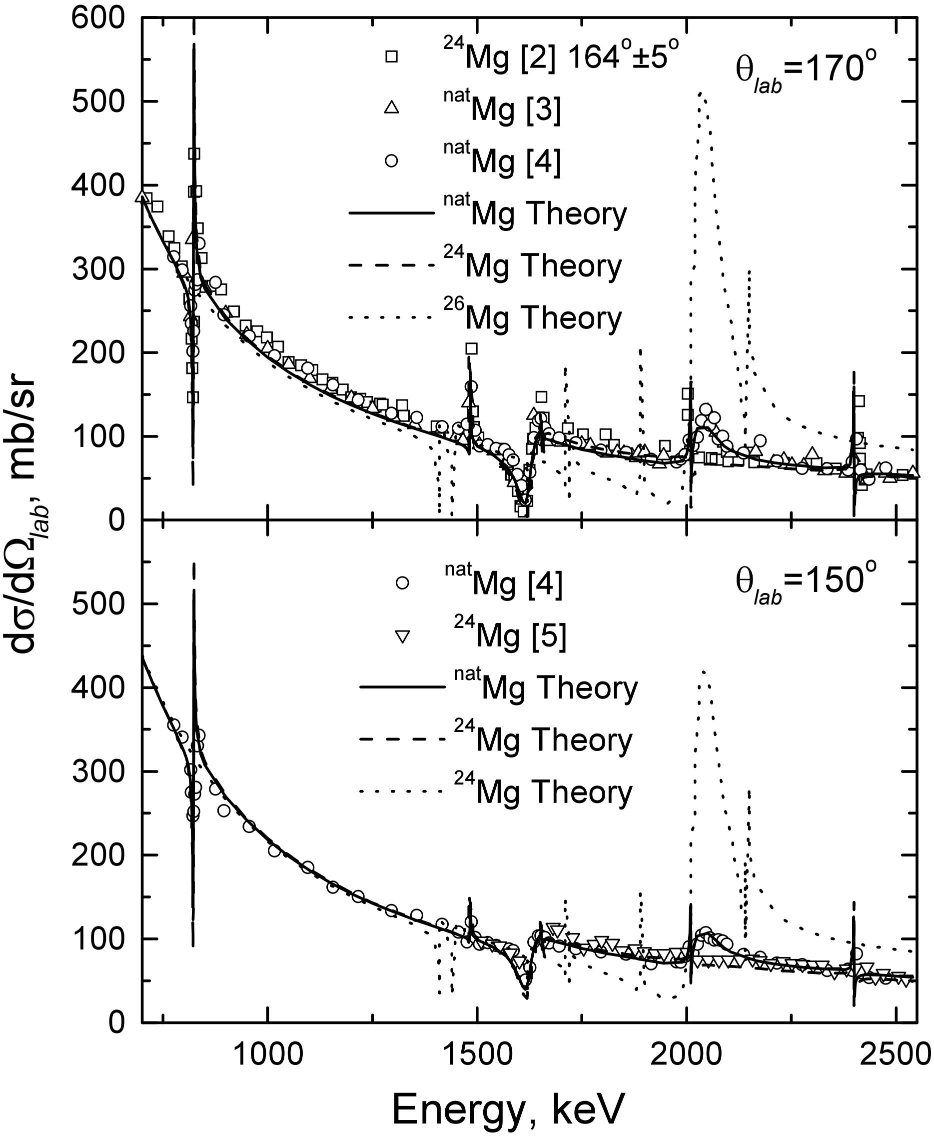

Fig. 1. The evaluated differential cross sections and the available experimental data for proton elastic scattering from magnesium (experimental points from Ref. [2] were thinned out so as not to obscure the figure).

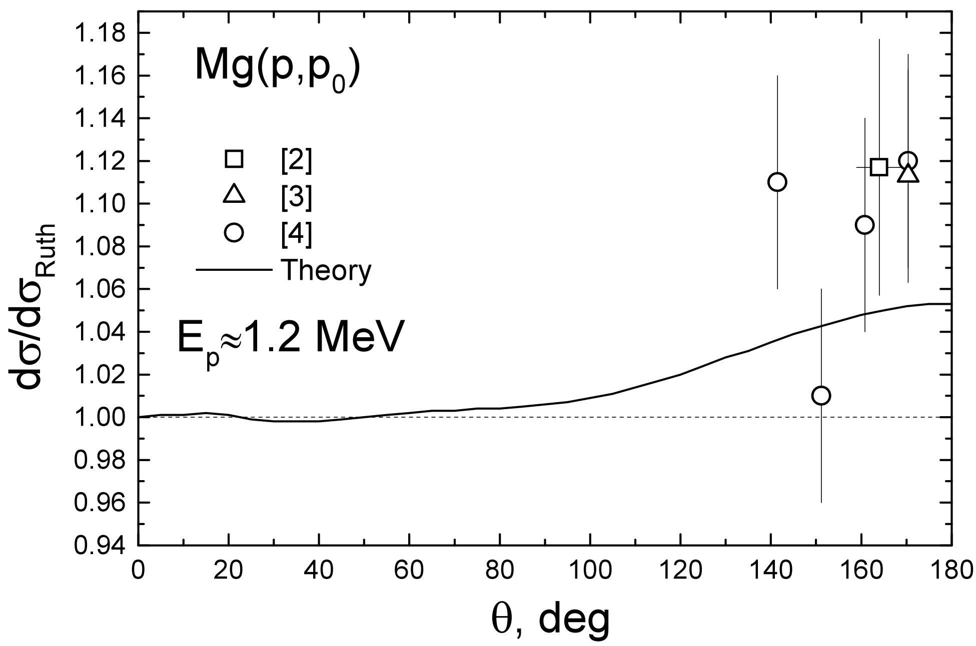

Fig. 2. The angular distribution of protons scattered elastically from magnesium at energy above the 0.823 MeV resonance – SigmaCalc compared with the literature.

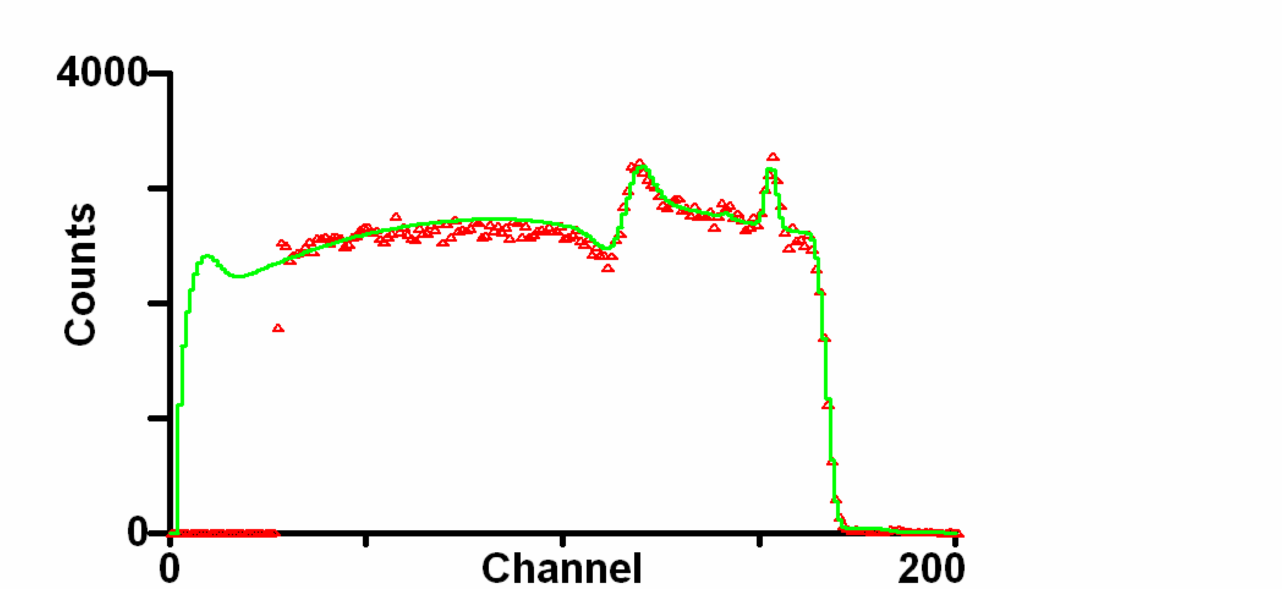

Fig. 3(a)

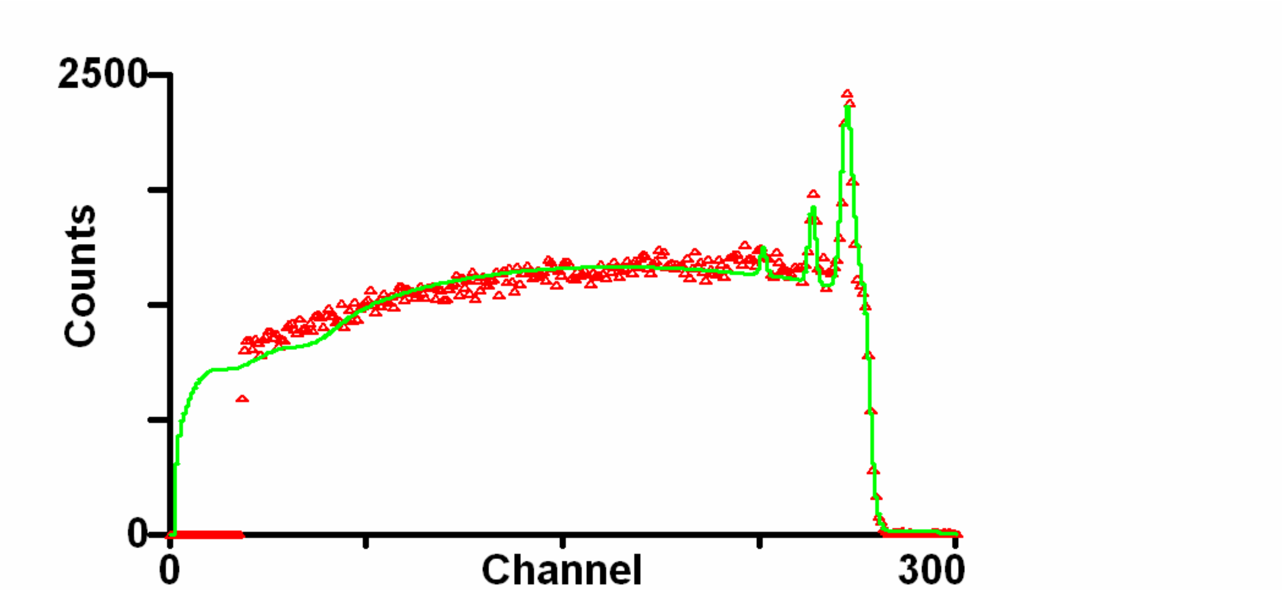

Fig. 3(b)

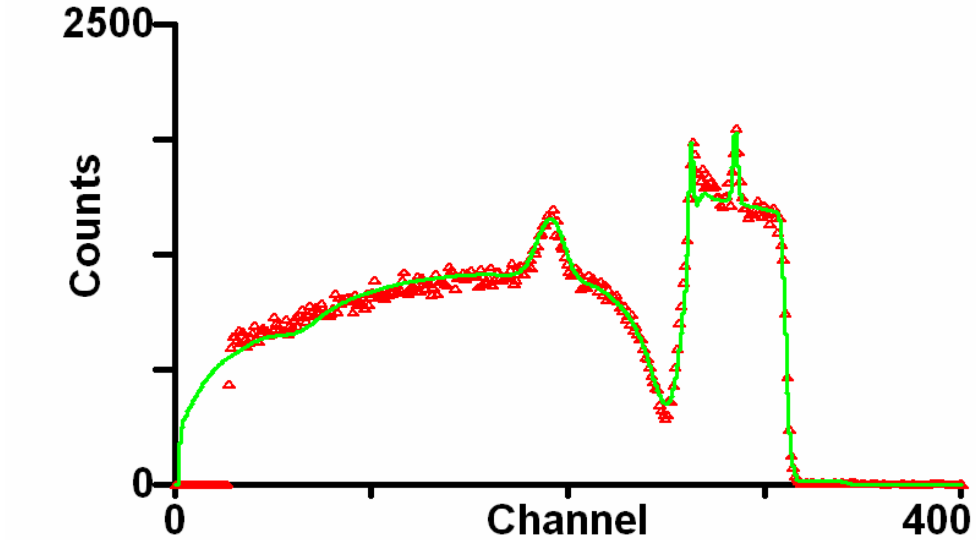

Fig. 3(c)

Fig. 3. Data and simulations for a bulk Mg sample near a) 823 keV, b) 1483 keV and c) 1630 keV resonances, with a scattering angle of 172.8°.

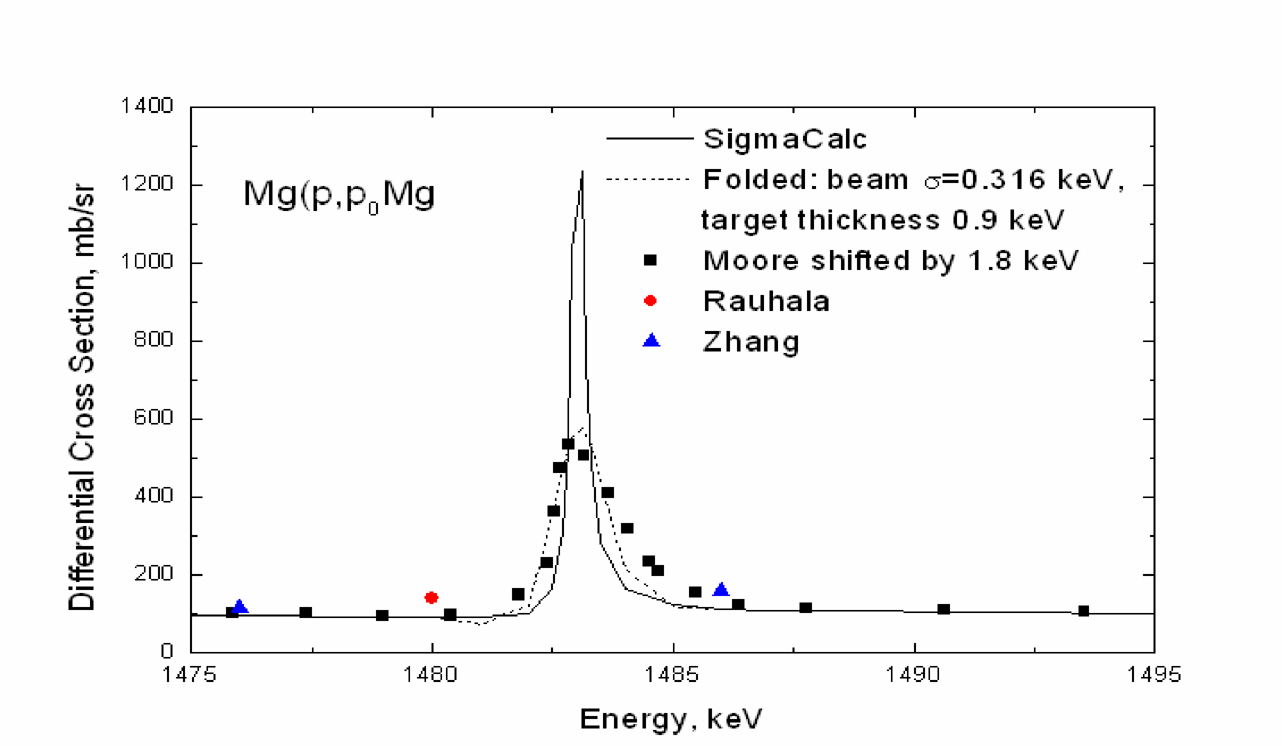

Fig. 4: 1483 keV resonance in absolute (SigmaCalc) and experimental (Moore and folded) representation.

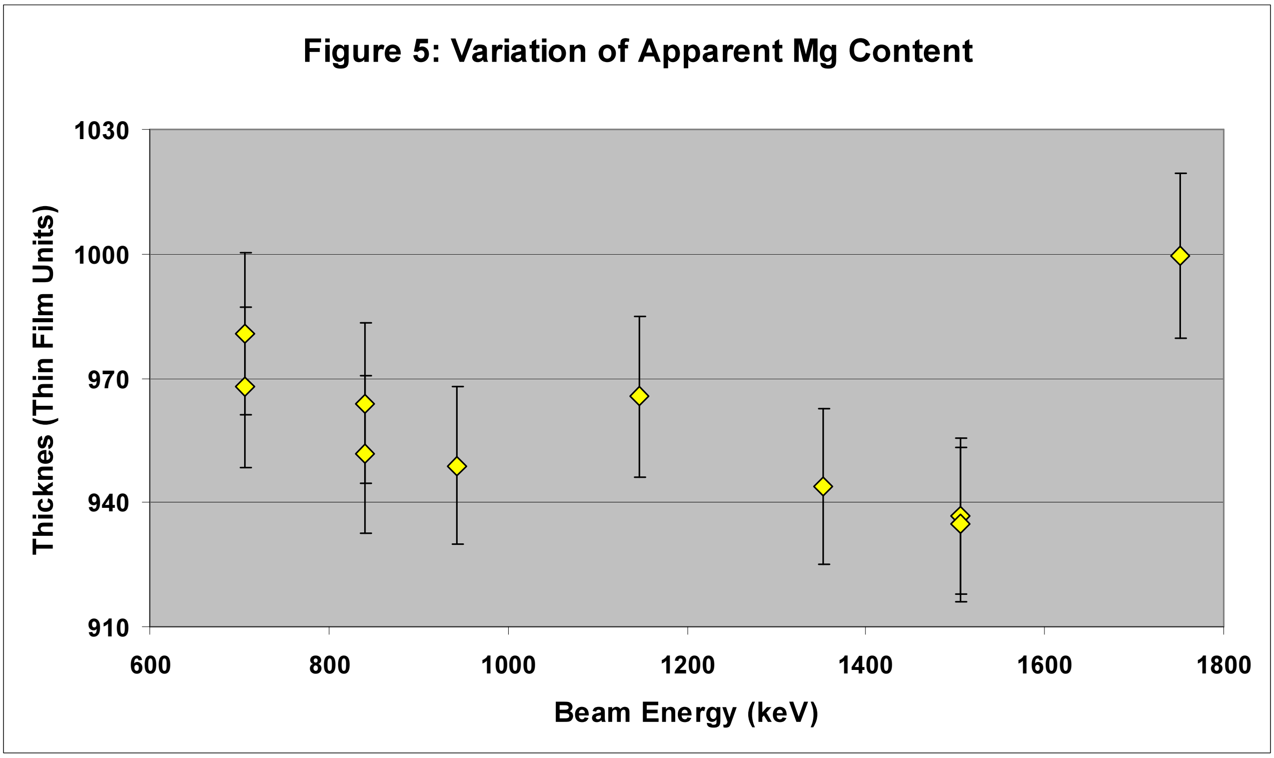

Fig. 5: Apparent Mg content of multilayer sample, normalised to the substrate signal, extracted from Table 1 for the $^{nat}Mg(p,p)^{nat}Mg$ reaction. The ordinate (TFU) is in units of 10^{15} atoms/cm^2, and ±2% uncertainty bars are shown. NDFv8.1h [16] is used with SRIM2003 electronic stopping powers [www.srim.org].

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