Differential Cross Section Measurements for EBS and NRA in the Framework of the LIBRA Project

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Acknowledgements
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TOPICS:

1. CURRENT STATUS (IBANDL) AND EFFORTS – NRA vs EBS
2. WORK SUBMITTED BY OUR GROUP:
   - *A) CURRENT EXPERIMENTAL SETUP*
   - *B) THE Sc AND K CASES (EBS, NRA)*
   - *C) THE d+Li SYSTEM (NRA)*
5. NEW NEEDS IN THE FRAMEWORK OF THE LIBRA PROJECT
6. CONCLUSIONS / FUTURE PERSPECTIVES

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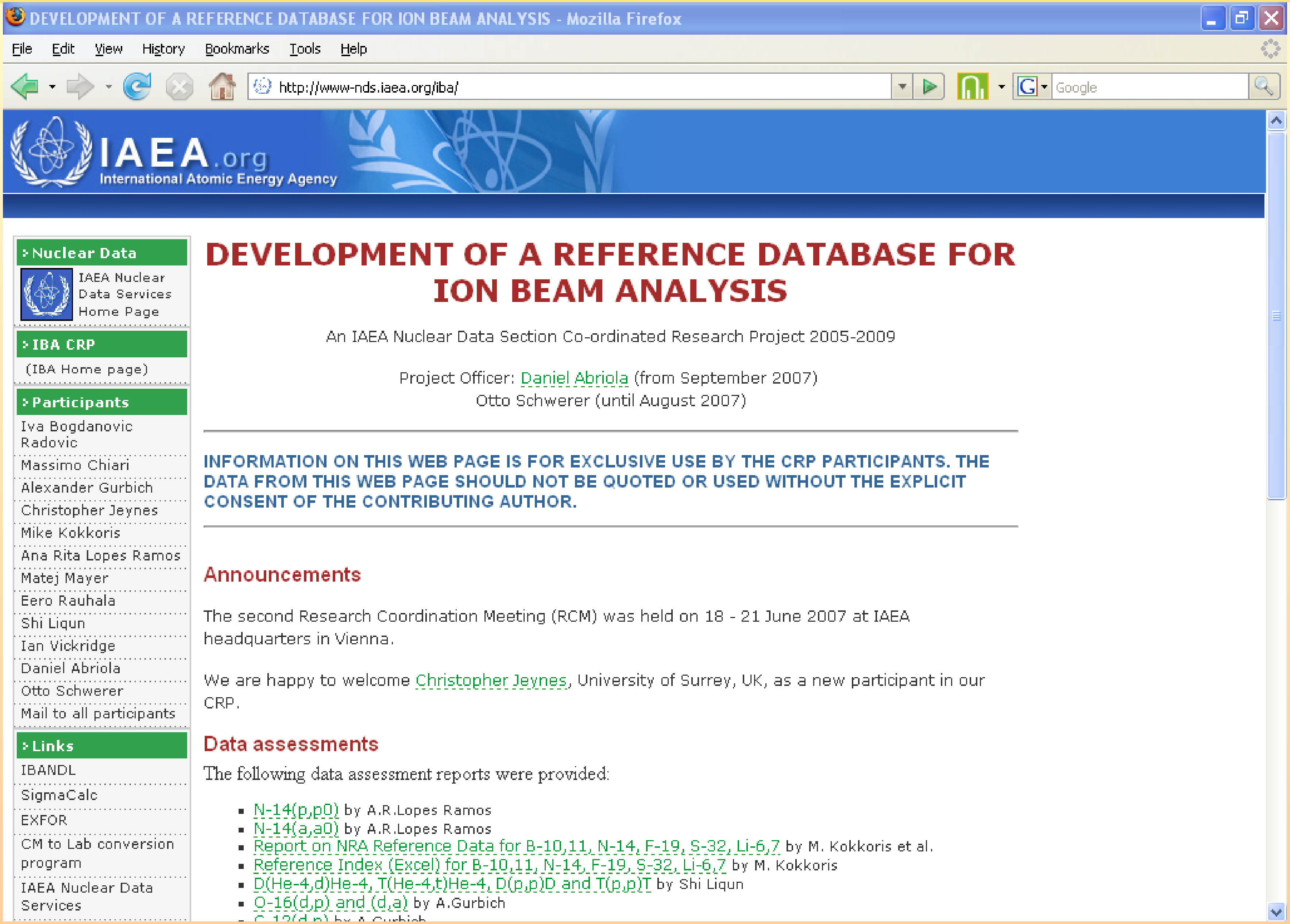

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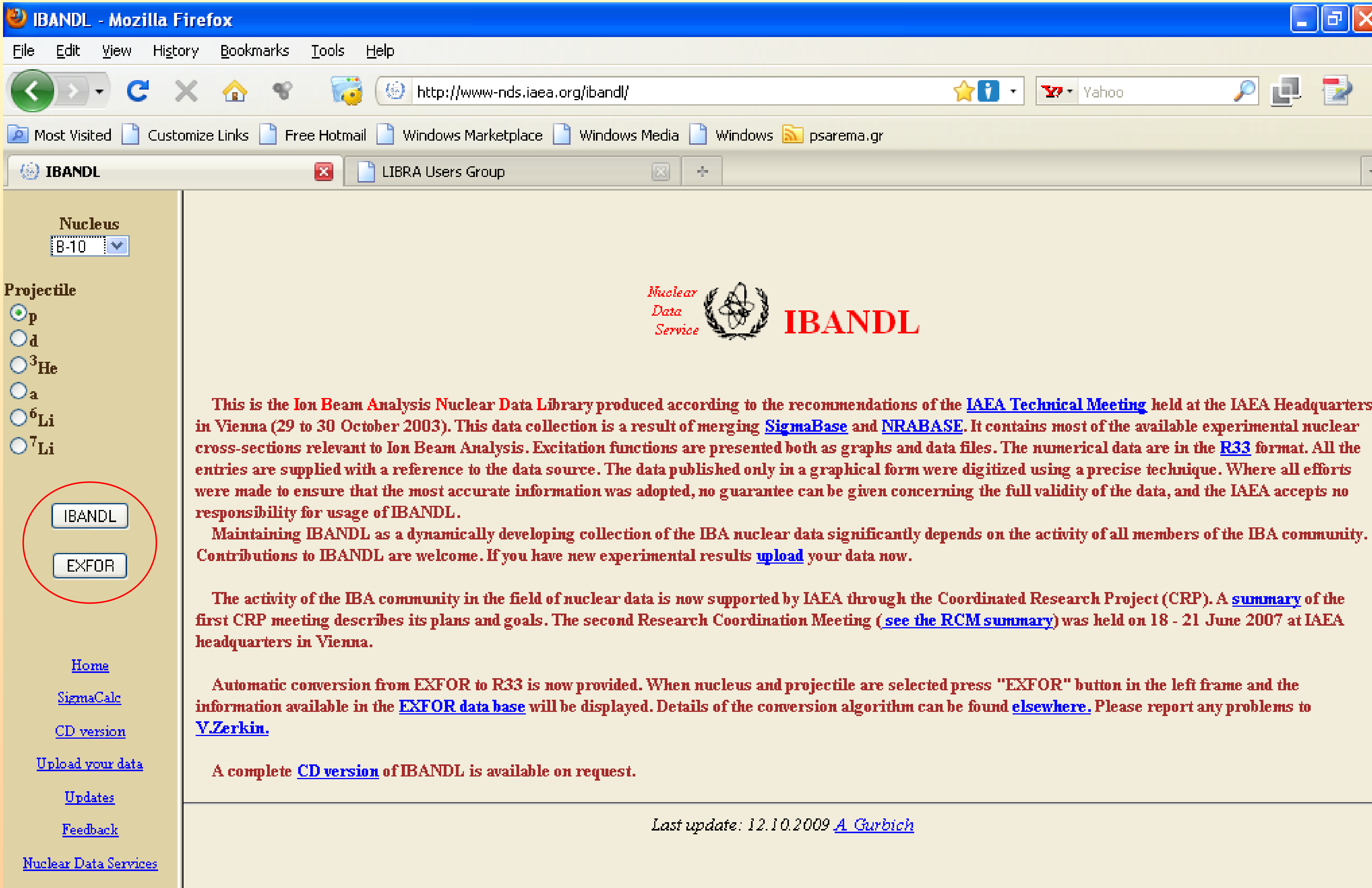

IBANDL - Mozilla Firefox

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http://www-nds.iaea.org/ibandl/

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IBANDL | LIBRA Users Group

Nucleus

B-10

Projectile

- p
- d
- ^{3}He
- a
- ^{6}Li
- ^{7}Li

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IBANDL

This is the Ion Beam Analysis Nuclear Data Library produced according to the recommendations of the IAEA Technical Meeting held at the IAEA Headquarters in Vienna (29 to 30 October 2003). This data collection is a result of merging SigmaBase and NRABASE. It contains most of the available experimental nuclear cross-sections relevant to Ion Beam Analysis. Excitation functions are presented both as graphs and data files. The numerical data are in the R33 format. All the entries are supplied with a reference to the data source. The data published only in a graphical form were digitized using a precise technique. Where all efforts were made to ensure that the most accurate information was adopted, no guarantee can be given concerning the full validity of the data, and the IAEA accepts no responsibility for usage of IBANDL.

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

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

Automatic conversion from EXFOR to R33 is now provided. When nucleus and projectile are selected press "EXFOR" button in the left frame and the information available in the EXFOR data base will be displayed. Details of the conversion algorithm can be found elsewhere. Please report any problems to V.Zerkin.

A complete CD version of IBANDL is available on request.

Last update: 12.10.2009 A. Gurbich

Nucleus

C-12

Projectile

- (•) p
- ( ) d
- ( ) ^{3}He
- ( ) a
- ( ) ^{6}Li
- ( ) ^{7}Li

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Request #897

Results: Reactions: 14 Datasets: 97

Data Selection

Retrieve (•) Selected ( ) Unselected ( ) All Reset

Output: [✓] EXFOR [ ] EXFOR+ [✓] Bibliography [ ] TAB [ ] C4 [ ] PlotC4

Plot: [ ] Quick-plot (cross-sections only) [ ] Advanced plot [how-to] [ ] convert ratios (if any) to cross sections using [IAEA-standards,2006]

Corrections: [ ] [example]

n	Display	Year	Author-1	Energy range,eV		Points	Reference	Accession#		NSR-Key
1)	6-C-12(P,D)6-C-11,PAR,DA									
	Quantity: [DAP] Partial differential cross section d/dA									
1	Info X4 X4+ X4± T4	1980	H.Ohnuma+			0	J,JPJ,48,(6),1812,198006	R0014002		1980OH06
2	Info X4 X4+ X4± T4					0		003		1980OH06
3	Info X4 X4+ X4± T4					0		004		1980OH06
2)	6-C-12(P,EL)6-C-12,,DA									
	Quantity: [DA] Differential c/s with respect to angle									
4	Info X4 X4+ X4± T4	2006	V.M.Lebedev+	7.50e+6		19	J,IZV,70,1645,2006	F0747002	R33	
5	Info X4 X4+ X4± T4	2006	A.Caciolli+	3.01e+6	7.17e+6	163	J,NIM/B,249,95,2006	01409003	R33	2006CA19
6	Info X4 X4+ X4± T4	2002	A.R.Ramos+	4.93e+5	2.50e+6	122	J,NIM/B,190,95,2002	D0078003	R33	2002RA17
7	Info X4 X4+ X4± T4	2000	M.Tosaki+	4.00e+6	6.60e+6	55	J,NIM/B,168,(4),543,200008	E1831002	R33	
8	Info X4 X4+ X4± T4	1998	S.Mazzoni+	3.43e+5	3.00e+6	1845	J,NIM/B,136,86,1998	00852002	R33	1998MA41
9	Info X4 X4+ X4± T4	1996	S.M.Duvanov+	1.65e+3	1.80e+3	32	P,JINR-P15-96-69,1996	F0565002	R33	
10	Info X4 X4+ X4± T4	1994	B.Fabre+	1.60e+6	1.79e+6	74	J,NP/A,572,349,1994	F0202002	R33	1994FA05
11	Info X4 X4+ X4± T4	1993	J.Liu+	4.50e+5	2.15e+6	30	J,NIM/B,79,468,1993	C1358002	R33	
12	Info X4 X4+ X4± T4	1993	R.Amirikas+	9.96e+5	3.50e+6	229	J,NIM/B,77,110,1993	D0107002	R33	1993AM13
13	Info X4 X4+ X4± T4	1993	A.D`arrigo+	1.58e+3	1.82e+3	49	J,NP/A,564,217,1993	F0531003	R33	1993DA16
14	Info X4 X4+ X4± T4	1993	R.Salomonovic	1.60e+6	1.79e+6	132	J,NIM/B,82,1,1993	F0571003	R33	1993SA43
15	Info X4 X4+ X4± T4	1993	Zhengmin Liu+	3.01e+5	3.00e+6	74	J,NIM/B,74,439,1993	F0573002	R33	1993LI61
16	Info X4 X4+ X4± T4	1990	N.V.Eremin+	1.57e+6	1.90e+6	67	J,NP/A,510,125,1990	F0533002	R33	1990ER02
17	Info X4 X4+ X4± T4	1980	H.Ohnuma+			0	J,JPJ,48,(6),1812,198006	R0014005		1980OH06
18	Info X4 X4+ X4± T4	1976	H.O.Meyer+	2.97e+5	1.99e+6	132	J,ZP/A,279,41,1976	D0125002	R33	1976ME22
19	Info X4 X4+ X4± T4	1972	K.Wienhard+	9.94e+6	1.09e+7	141	J,ZP,256,457,1972	01367002	R33	1972WI26
20	Info X4 X4+ X4± T4			9.95e+6	1.07e+7	48		004	R33	1972WI26
21	Info X4 X4+ X4± T4	1969	H.Guratzsch+	7.00e+6		29	J,NP/A,129,405,1969	01242003	R33	1969GU02
22	Info X4 X4+ X4± T4	1964	L.Drigo+	4.49e+6	5.22e+6	45	J,PR,136,B1662,1964	F0904002	R33	1964DR03
23	Info X4 X4+ X4± T4	1953	H.L.Jackson+			0	J,PR,89,365,195301	C0848002		
24	Info X4 X4+ X4± T4	1953	H.L.Jackson+	3.76e+5	4.38e+6	655	J,PR,89,365,1953	C1000002	R33	
3)	6-C-12(P,EL)6-C-12,,DA,,,EXP									
	Quantity: [DA] Differential c/s with respect to angle									

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Projectile
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^{12}C+p

No.	Reaction	Angle	Energy(keV)	Reference	File	Plot
1	$^{12}C(p,p0)^{12}C$		360-3500	SigmaCalc Calculate		
2	$^{12}C(p,p0)^{12}C$	179.20°	4000-6600	M. Tosaki et. al. Nucl. Instr. Meth. B168 (2000) 543		
3	$^{12}C(p,p0)^{12}C$	170.00°	300-2970	Z.Liu et al. Nucl. Instr. Meth. v.B74 (1993) 439		
4	$^{12}C(p,p0)^{12}C$	170.00°	300-720	Z.Liu et al. Nucl. Instr. Meth. v.B74 (1993) 439		
5	$^{12}C(p,p0)^{12}C$	170.00°	340-3000	S. Mazzoni et al., Nucl. Instr. Meth. B136-138 (1998) 86		
6	$^{12}C(p,p0)^{12}C$	170.00°	700-2500	E.Rauhala Nucl.Instrum.Methods B12 (1985) 447		
7	$^{12}C(p,p0)^{12}C$	170.00°	720-2970	Z.Liu et al. Nucl. Instr. Meth. v.B74 (1993) 439		
8	$^{12}C(p,p0)^{12}C$	170.00°	1000-3500	Amirikas,, R., Jamieson, D.N. and Dooley, S.P. (1993) Nucl. Instr. and Meth. B77, 110.		
9	$^{12}C(p,p0)^{12}C$	170.00°	1600-1790	R.Salomonovic, Nucl. Instr. Meth. v.B82 (1993) 1		
10	$^{12}C(p,p0)^{12}C$	170.00°	2700-3100	Yang Guohua et al. Nucl.Instr.& Meth. v.B61 (1991) 175		
11	$^{12}C(p,p0)^{12}C$	168.2°	390-4360	H.L.Jackson+(1953), Jour. Physical Review, Vol.89, p.365		
12	$^{12}C(p,p0)^{12}C$	165.00°	340-3000	S. Mazzoni et al., Nucl. Instr. Meth. B136-138 (1998) 86		
13	$^{12}C(p,p0)^{12}C$	160.00°	340-3000	S. Mazzoni et al., Nucl. Instr. Meth. B136-138 (1998) 86		
14	$^{12}C(p,p0)^{12}C$	160.00°	1600-1790	R.Salomonovic, Nucl. Instr. Meth. v.B82 (1993) 1		
15	$^{12}C(p,p0)^{12}C$	155.00°	340-3000	S. Mazzoni et al., Nucl. Instr. Meth. B136-138 (1998) 86		
16	$^{12}C(p,p0)^{12}C$	155.00°	450-2150	J.Liu, T.Xie, H.J.Fischbeck. Nucl.Instr.& Meth. v.79 (1993) 468		
17	$^{12}C(p,p0)^{12}C$	150.00°	340-3000	S. Mazzoni et al., Nucl. Instr. Meth. B136-138 (1998) 86		

NRA: **Well – established nowadays as one of the principal IBA techniques for accurate quantitative depth profiling of light elements in complex matrices.**

Based on the use of nuclear reactions. More frequently used:

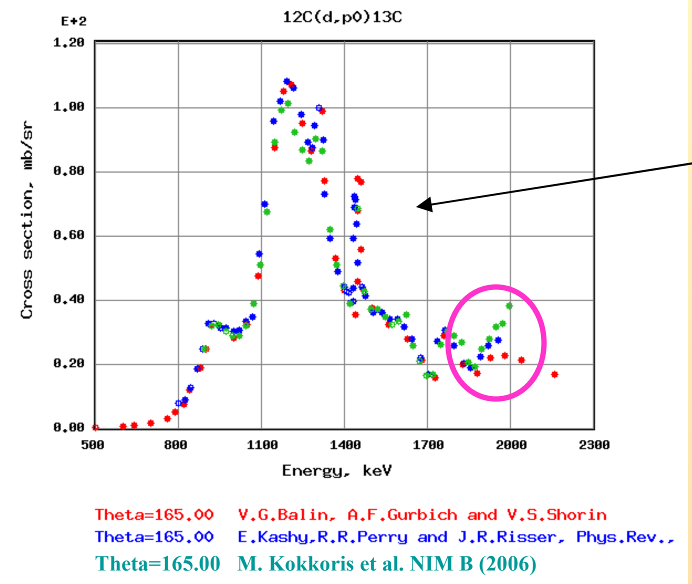
1. (p,α): Low Q-value (^{6}Li, ^{9}Be, ^{10}B, ^{27}Al) and high Q-value (^{7}Li, ^{11}B, ^{18}O, ^{19}F, ^{23}Na, ^{31}P). No absorber foil can be applied. Highly selective.
2. (α,p): Very few elements have positive Q-values (^{10,11}B, ^{19}F, ^{23}Na, ^{27}Al, ^{31}P, ^{35}Cl) thus the background is severely reduced. Cross sections are high enough only at high beam energies.
3. (d,p) and (d,α): Almost all light isotopes have high positive Q-values. They permit simultaneous analysis of many light elements in complex matrices (e.g. C, O, N, B, S etc.) at the expense of peak overlaps or background interference in some cases. Require very low beam energies. Radiation safety precautions are mandatory because the (d,n) reaction channel is almost always open.
4. *Less frequently used: (p,d), (p,^{3}He), ^{3}He-NRA*

NRA vs EBS – Which is preferable?

- Data acquisition is much faster in the case of EBS.
- Depth profiling is more accurate due to the lower energies (enhanced stopping power) generally involved (e.g. oxygen profiling using the 3.05 resonance in $^{16}O(\alpha,\alpha)$ rather than the $^{16}O(d,p_0,p_1,\alpha_0)$ reactions).
- Significantly more differential cross section data are available, over a wide range of beam energies and detector angles.
- For the most important elements with resonances in elastic scattering evaluated differential cross section data already exist.

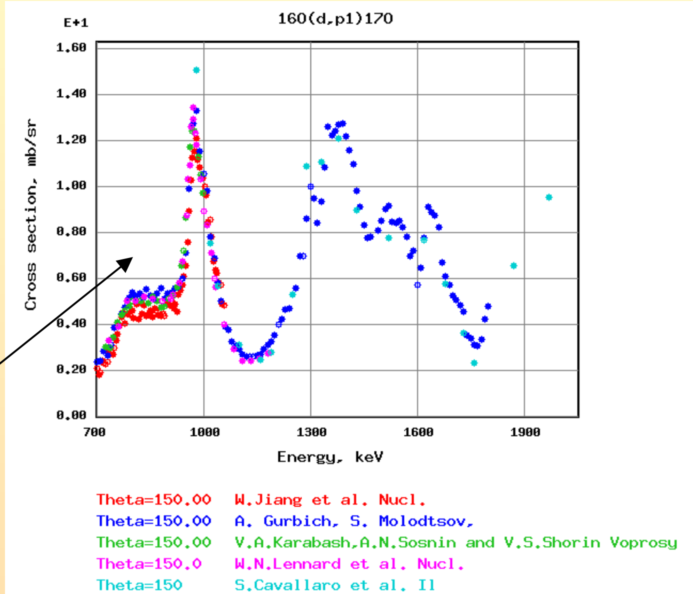
Nevertheless NRA is still the only technique that can provide accurate results for the profiling of light elements when the matrix is complex.

The present situation of NRA:



Favorable case

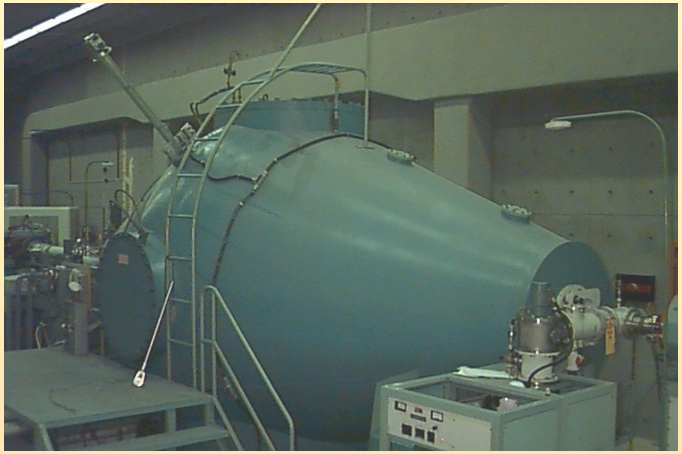
Severe problems



The theoretical complexities of d-NRA:

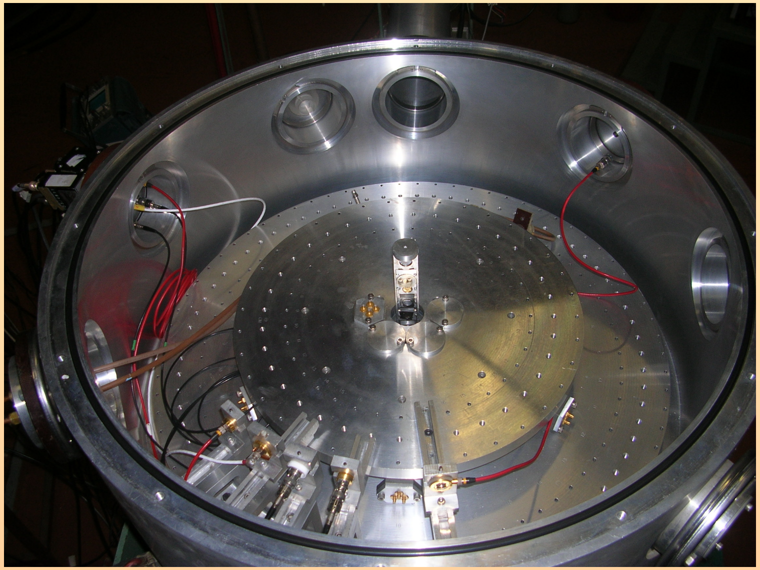
1. Coexistence of many open reaction channels.
2. Electric charge asymmetry of the deuteron.
3. Multiple projectile-target exchange of nucleons.
4. Existence of direct exchange processes (e.g. knock-out, stripping).
5. Overlapping resonances.

EXPERIMENTAL SETUP:

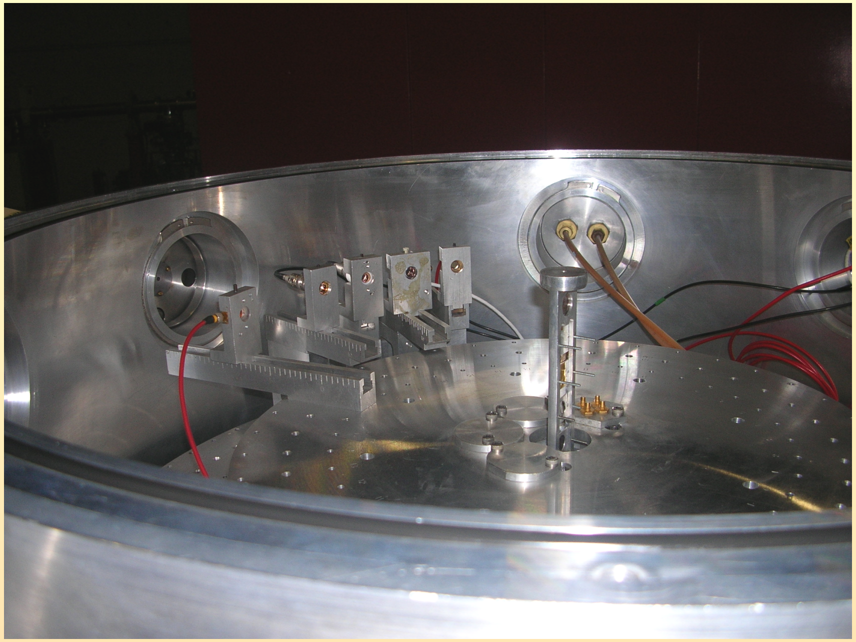


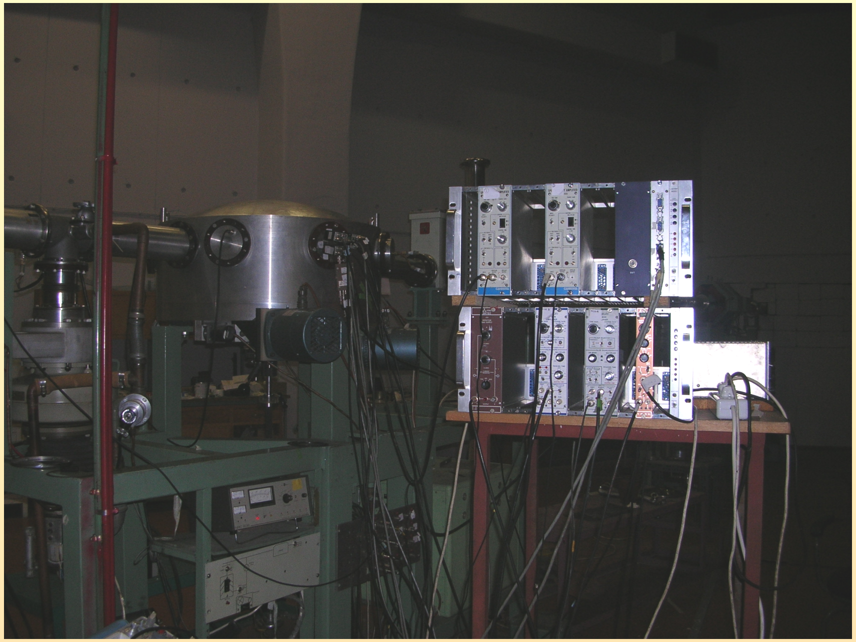
5.5 MV HV Tandem Accelerator, N.C.S.R. 'Demokritos'

Motor driven goniometer
Great angular accuracy (0.01 deg.)



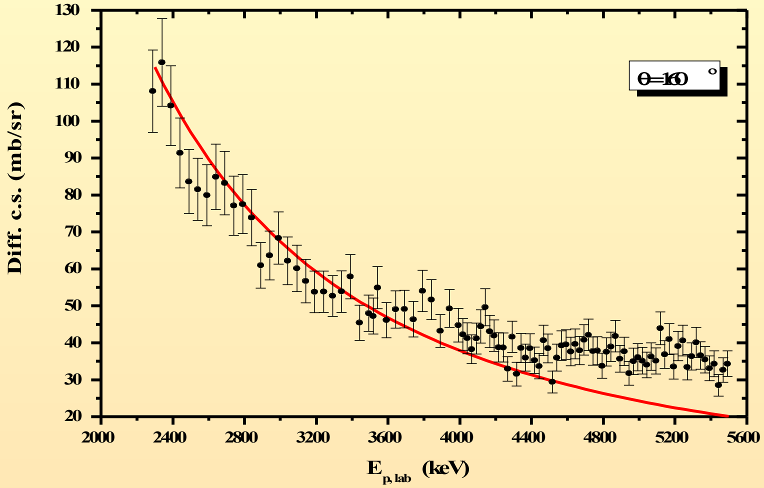
*** A.Pakou et al. , Phys. Rev. Lett. 90 (2003)**

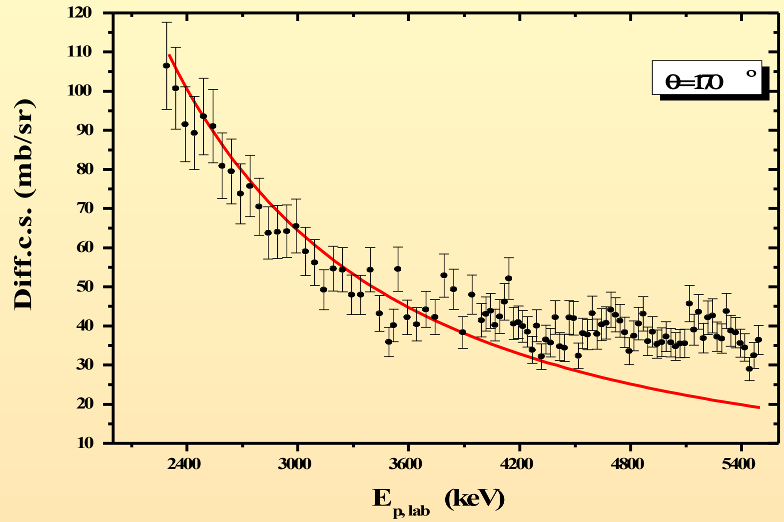




- 4 single SSB, associated with standard NIM/CAMAC electronics. Upgrading is scheduled.
- The current setup allows for target cooling with water or methanol through a closed circuit during acquisition – not implemented so far.
- Voltage suppression up to 300 V on the collimator, target and/or faraday cup.

RESULTS FOR p+Sc EBS (M.Sc. of Mr. G. Provatas):

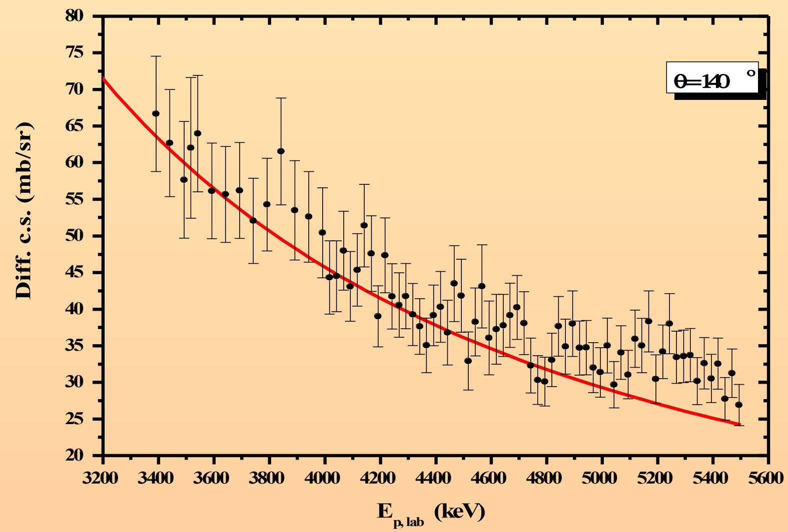




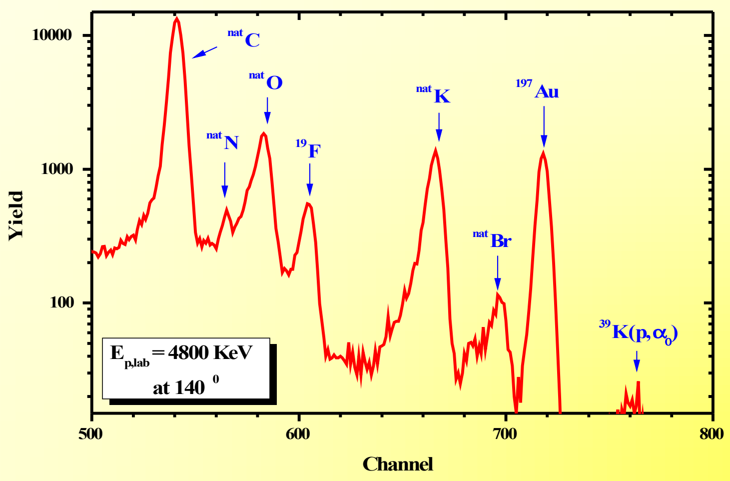
More than ~300 differential cross section values have been determined for 3 different detector angles (at ~10º intervals), in beam energy steps of ~25 keV (2500-5000 keV).

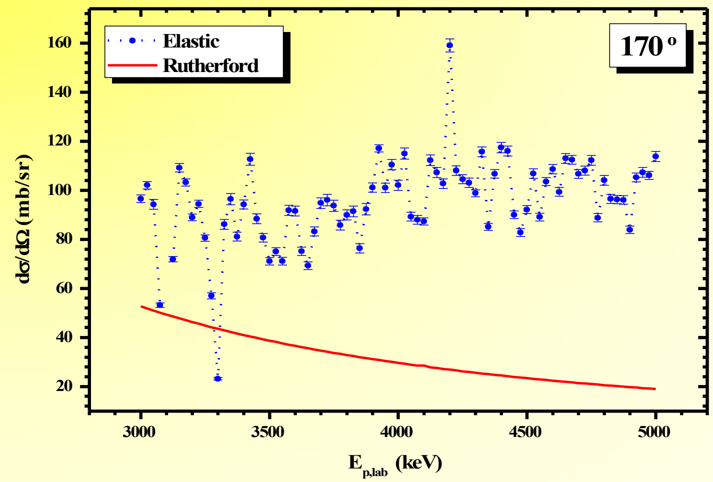
Very difficult target with Br escape – Sc never measured in the past!

Results to be presented at IBANDL, and ECAART10 in 2010, along with benchmarking results.



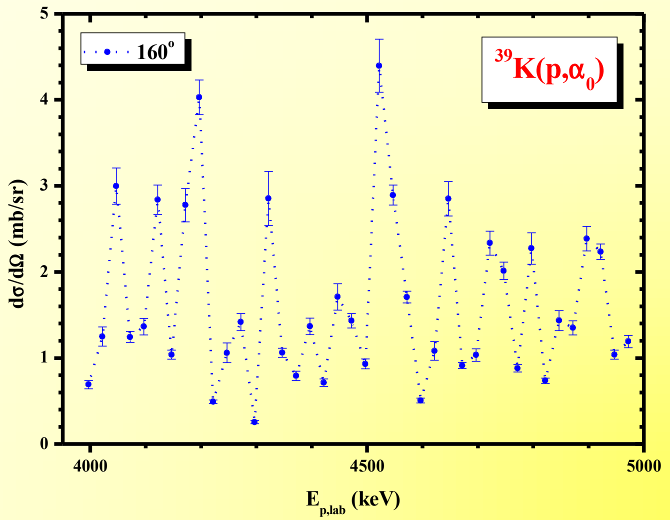
RESULTS FOR p+K EBS, NRA (B. Sc. of Mr. A. Tsaris):



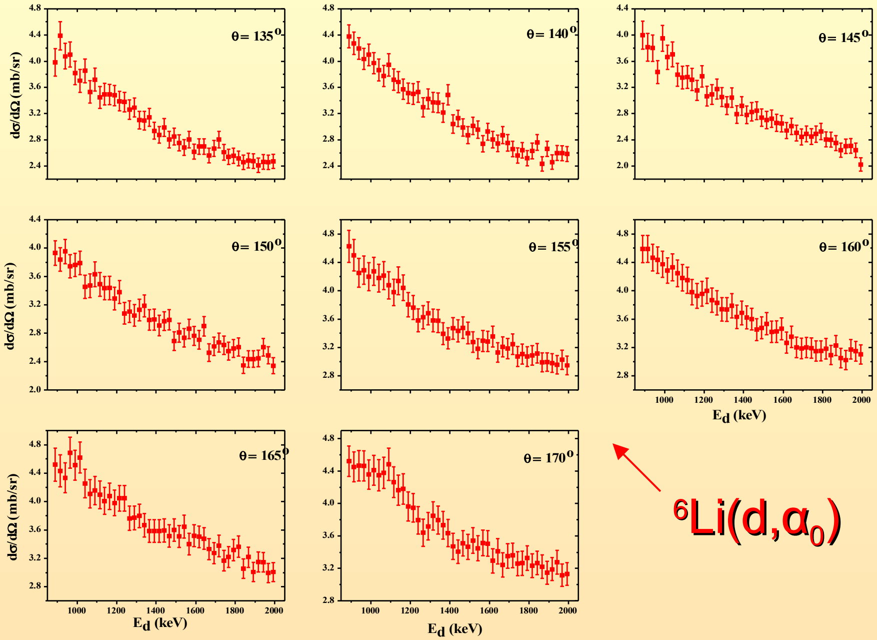


More than ~500 differential cross section values have been determined for 4 different detector angles (at ~10º intervals), in beam energy steps of ~25 keV (3 – 5 MeV for the $^{nat}K(p,p_0)$ and 4 – 5 MeV for the $^{39}K(p,\alpha_0)$ reaction).

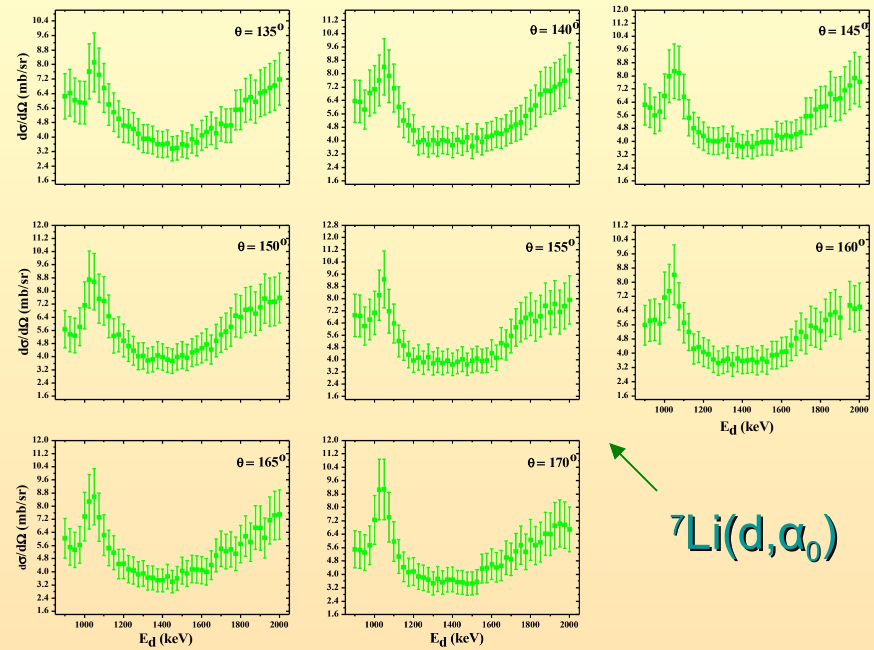
Results were presented at IBA2009 (Cambridge), and will be sent to IBANDL, along with benchmarking results.



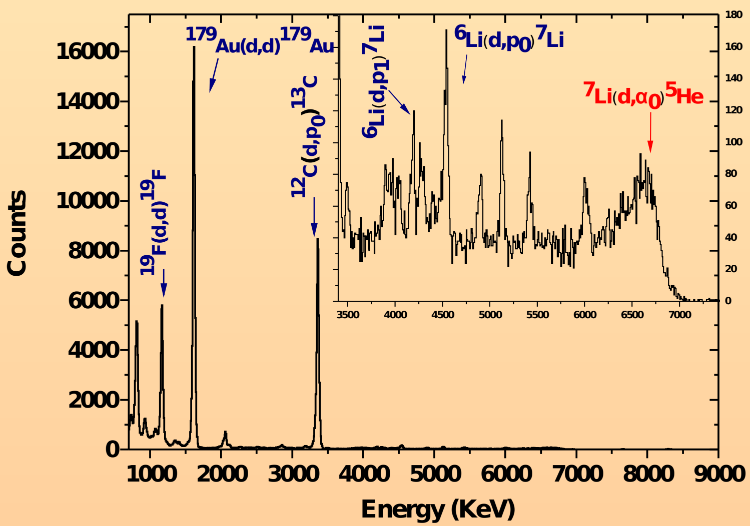
RESULTS FOR d+^{6,7}Li (M. Sc. of Mrs. V. Foteinou):



^{6}Li(d,α_0)



^{7}Li(d,α_0)



More than ~700 differential cross section values have been determined for 8 different detector angles (at 5° intervals), in beam energy steps of ~25 keV (0.9 – 2 MeV for the ^{6,7}Li(d,α_0) reactions).

Results were partially presented at IBA2009 (Cambridge), and will be sent to IBANDL, along with benchmarking results.

NEW NEEDS (IN THE FRAMEWORK OF THE LIBRA PROJECT – starting Ph. D. Mrs. V. Paneta):

(a) More SSB detectors are needed: At least 4 thick (~1000 μm) and 4-8 thin (10-50 μm) for the ΔE/E telescopes.

(b) A new turbomolecular pump should replace the old diffusion pump, now present near the goniometer.

(c) Extra electronic units should be added (preamplifiers, amplifiers, power supplies, discriminators, cabling, extra adc?)

(d) Easily replaceable collimator set.

(e) CCD camera inside.

(f) Fixing of the stepping motor system.

(g) Improvement of insulations (target holder + faraday cup).

(h) Serious improvement of the whole target preparation system + procedure.

CONCLUSIONS / FUTURE PERSPECTIVES:

(a) NRA studies are very promising. Many open questions: Angular distribution at forward angles?

(b) Studies of the d+^{6,7}Li systems are almost completed.

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

(d) In the next phase we will proceed to (p,α) reaction studies on ^{6,7}Li, ^{10,11}B, ^{19}F and ^{23}Na.

(e) The theoretical evaluation – if accomplished – will considerably enhance NRA capabilities, collaboration is in progress.

(f) As far as EBS is concerned, (d,d_0) on ^{6,7}Li, and ^{10,11}B and (α,α_0) on ^{31}P, ^{nat}S and ^{nat}Ca are scheduled in a 5-year plan in order to facilitate the data evaluation process.

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Topics

- Accelerator technology and related equipment
- Characterization and investigation of materials using ion-beam techniques (RBS, ERDA, ion channelling, NRA, PIXE, PIGE, ...)
- Software and nuclear data for applications
- Application of ion beam analysis to art and archaeology, environment, industry and earth sciences
- Micro- and nano- beam devices and probes
- Accelerator mass spectrometry
- Synchrotron radiation sources and related techniques
- Ion beam modification of materials
- Isotope production and medical applications of accelerators