

LFN @ LATR: NRA

Detecção de B em materiais tecnológicos por reacções nucleares

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Detecção de B em materiais tecnológicos por reacções nucleares

A fim de compreender e perspetivar de forma integradora e interligada a Física Nuclear e as suas potenciais aplicações tecnológicas, nas vertentes das reacções nucleares e detecção de elementos leves de grande importância tecnológica, como é o caso do boro, este projecto envolve...

Trabalho e objetivos:

- compreensão da física das dispersões elásticas e inelásticas (reacções nucleares): fundamentação, realização prática e resultados espectáveis – espectros
- separação das contribuições elástica, EBS, e inelástica, NRA
- aplicação à caracterização de materiais a nível microscópico: informação pertinente – composição elementar, quantificação, estrutura e espessura – e extracção da informação pertinente: análise dos espectros
- familiarização com a cadeia electrónica de detecção: fundamentação e realização prática – detectores de radiação, processadores de sinal e analisadores multicanal
- familiarização com o equipamento de produção e transporte de feixes de partículas: acelerador, campos deflectores e linhas de transporte
- montagem das amostras a utilizar com operação (limitada) dos sistemas de vácuo; estabelecimento de condições de operação, irradiação das amostras e recolha de dados

Análise de dados e resultados a atingir:

- análise (sumária) de espectros com calibração (conversão canal-energia) e identificação da composição elementar: identificação de elementos de $Z \geq 11$ por EBS, identificação de elementos de ^{11}B , $Z < 11$ (e.g. $^6,^7\text{Li}$ e $^{10,^{11}}\text{B}$) – por NRA
- quantificação integral de B detectado a partir de cálculo simples
- apresentação de resultados

Detecção de B em materiais tecnológicos por reacções nucleares

Justificação do B:

o boro – $\sim 20\%$ ^{10}B e 80% ^{11}B - é um elemento com aplicações relevantes em áreas de grande importância e impacto tecnológico, nomeadamente

- electrónica: semicondutores (o B introduzido no Si em posições substitucionais é um aceitador de electrões, contribui p/ a condução c/ portadores positivos (buracos), devido à sua valência 3 (falta um electrão p/ saturar as 4 ligações c/ Si vizinhos da sua posição na rede);
- OLEDs azuis ou de cdo ajustável (o B incorporado em moléculas específicas torna-as activas na emissão de luz, p/ alterações na estrutura electrónica molecular);
- energética: electrólitos sólidos para baterias;
- armazenamento de hidrogénio;
- química: catálise (sequestração de óxidos de N, S, etc.);
- medicina: terapias BNCT/BPCT (o $^{10}\text{B}/^{11}\text{B}$ incorporados em moléculas específicas é útil na eliminação de gliomas pela radiação emitida como resultado de reacções nucleares provocadas por neutrões/protões).

...

Justificação das reacções nucleares:

pela sua especificidade – ditada p/ estrutura nuclear dos isótopos envolvidos – são praticamente o único meio de detectar, de forma não destrutiva (preservando qto possível a amostra) isótopos leves ($Z < 12$) a energias baixas (e.g. $< 3\text{-}5$ MeV, disponíveis em "pequenos" aceleradores): em geral, a razão sinal-ruído é favorável (p/ ausência de fundo significativo), e as interferências de outras reacções (devidas a outros isótopos), qdo existem são pouco significativas.

LATR VG – the place

The machine...!
2.5MV VG
accelerator

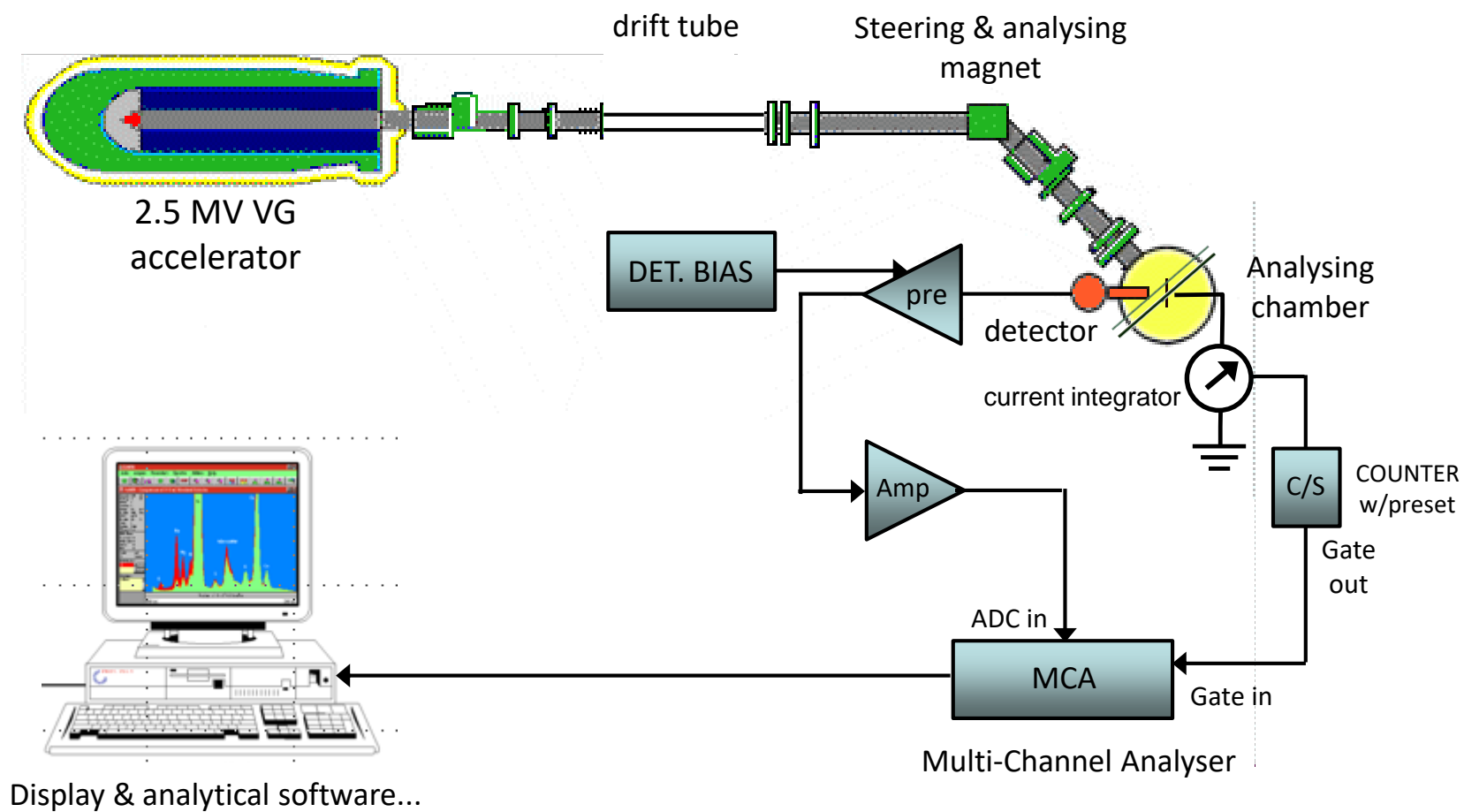


control & data acq.

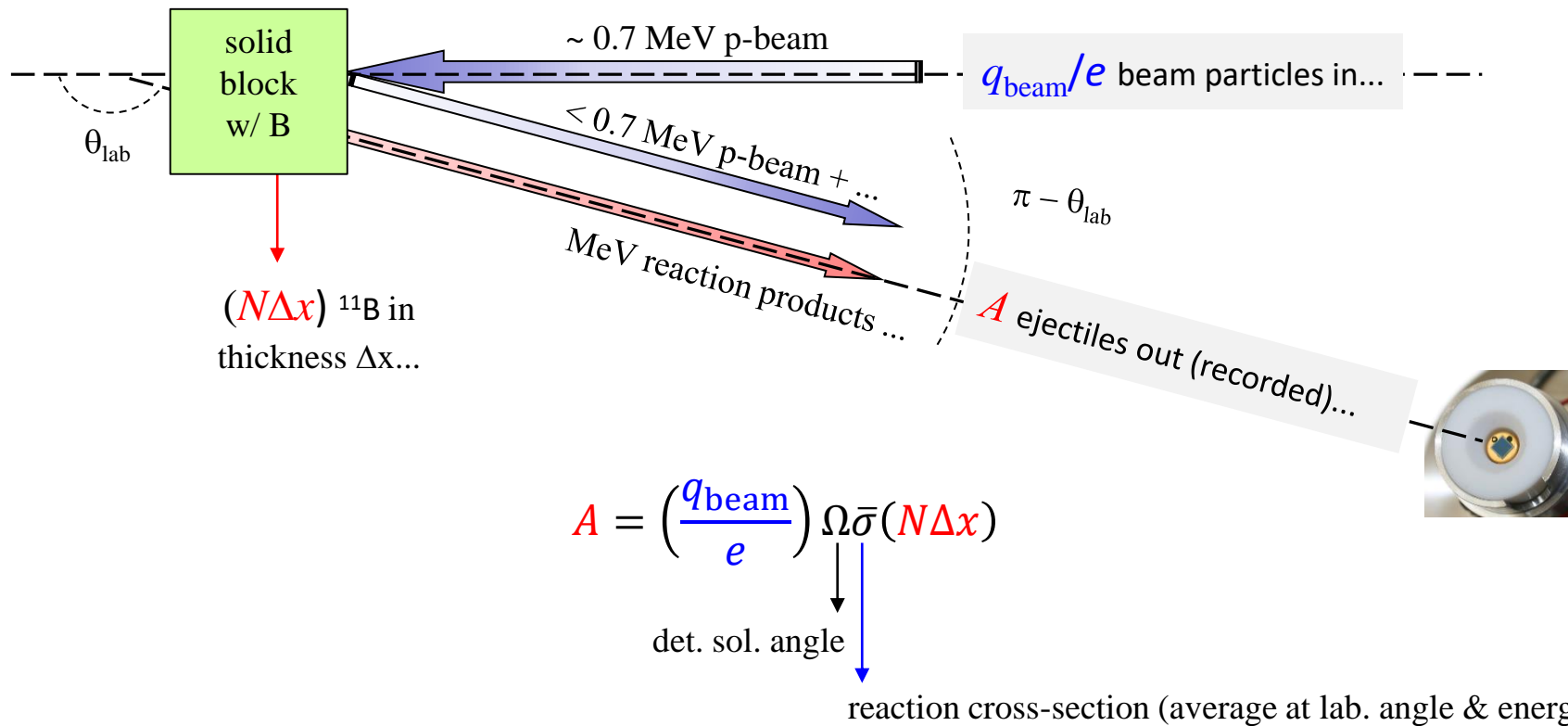


beam lines experiment hall

The 'production' chain...

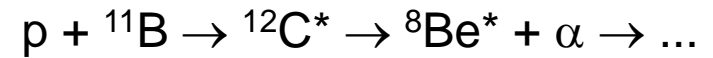
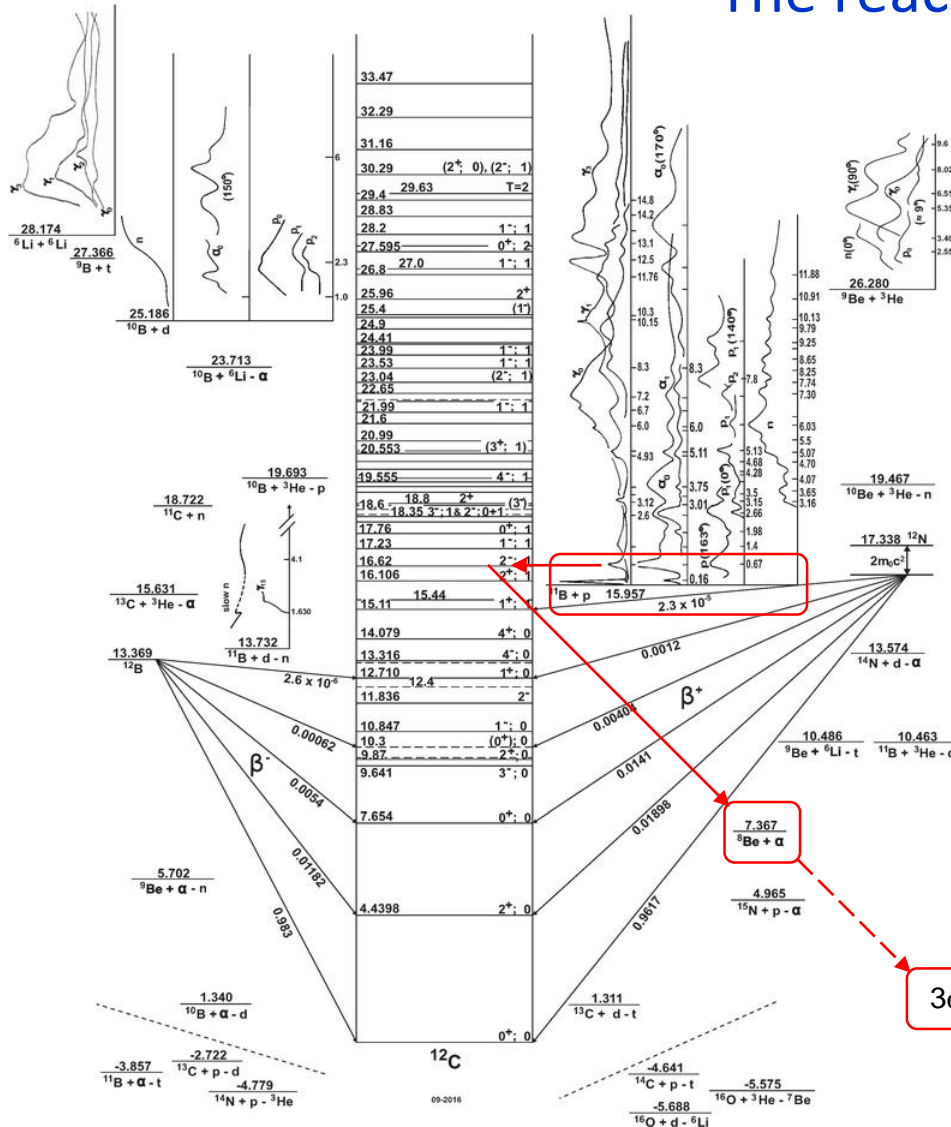


The experiment layout...



$N\Delta x$ "wanted" !

The reaction...

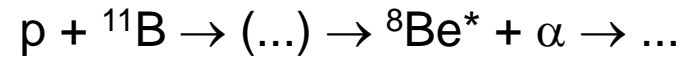
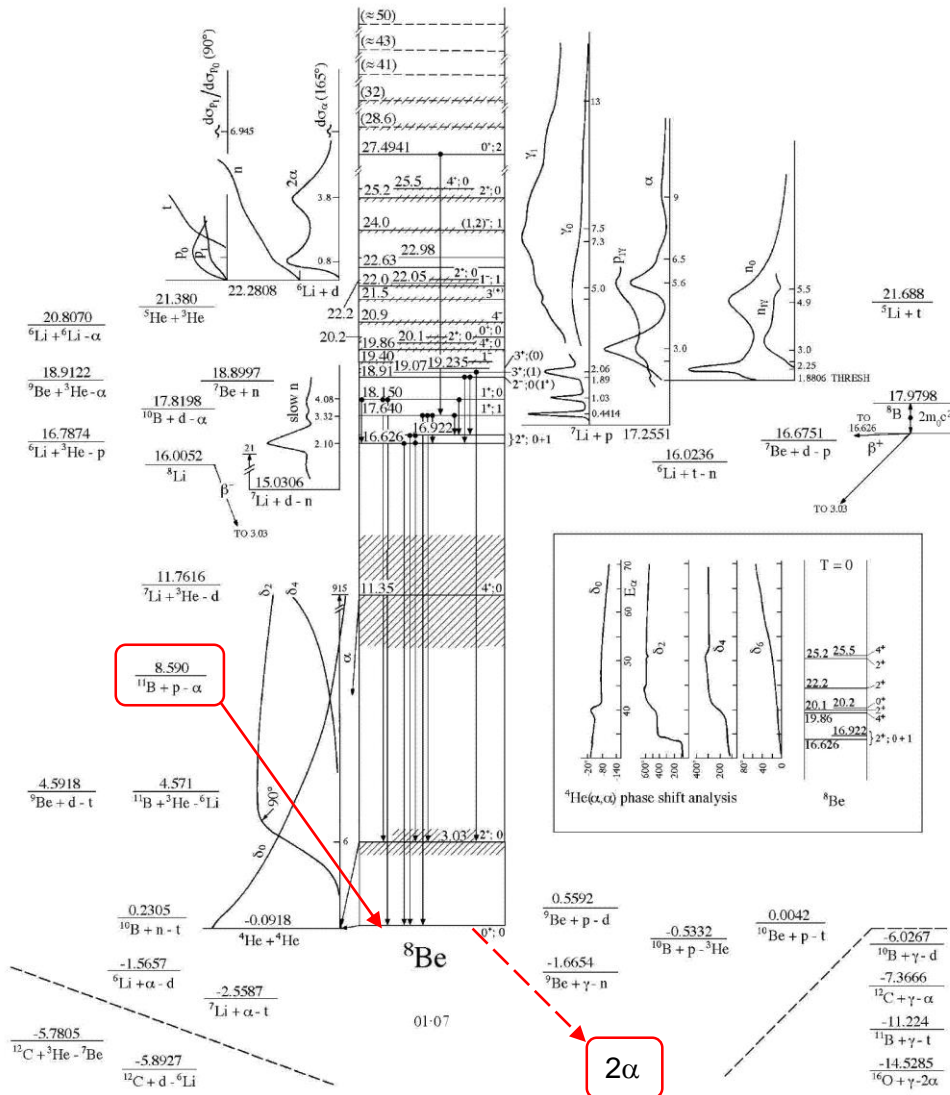


$$E^* = 16.62 \text{ MeV}$$

$$I_\pi = 2^-, \Gamma = 0.28 \text{ MeV}$$

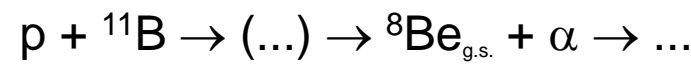
cf. <https://www.tunl.duke.edu/nucldata>

The reaction...



$$E^* = 3.03 \text{ MeV}$$

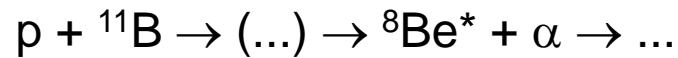
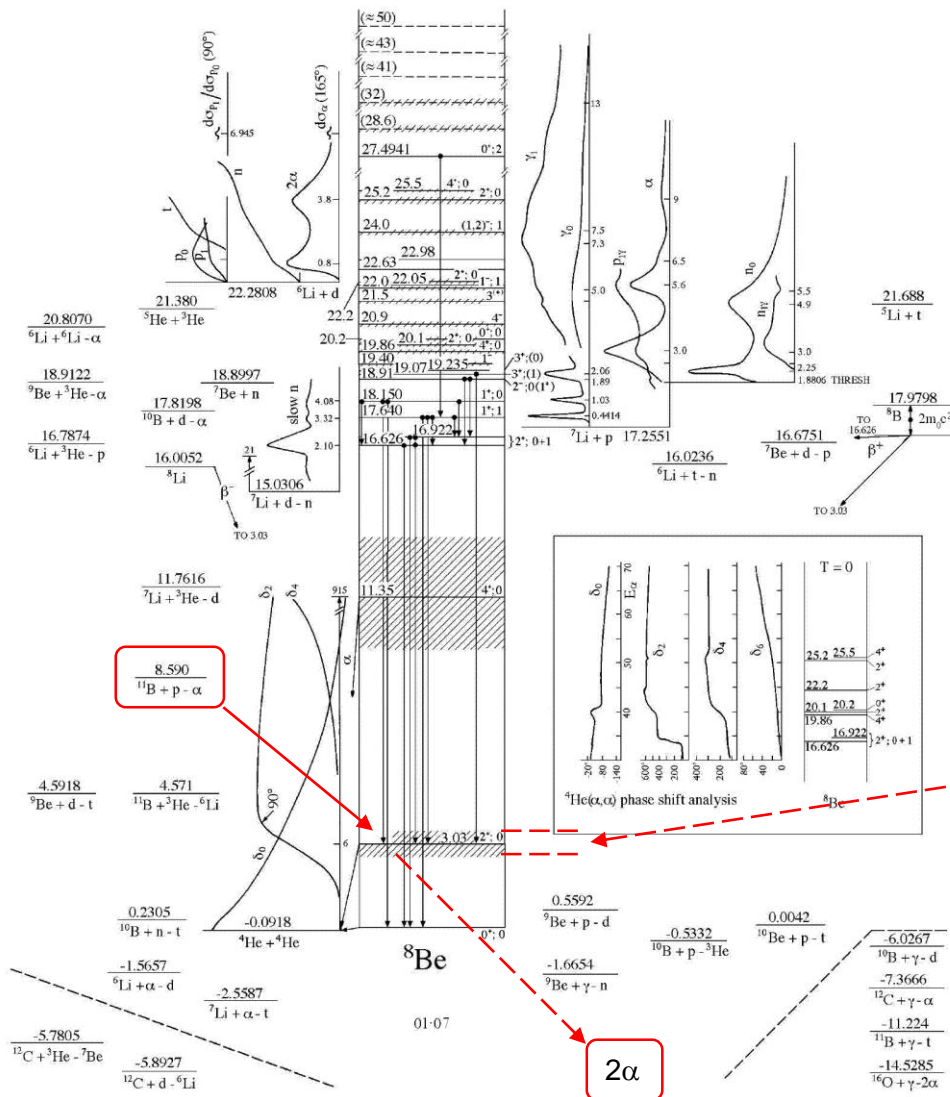
$$I\pi = 2^+, \Gamma = 1.513 \text{ MeV}$$



$$I\pi = 0^+, \Gamma = 5.57 \text{ eV}$$

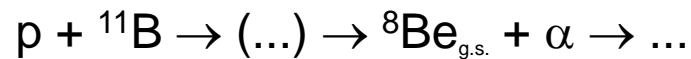
cf. <https://www.tunl.duke.edu/nucldata>

The reaction...



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$$I_{\pi} = 0^+, \Gamma = 5.57 \text{ eV}$$

cf. <https://www.tunl.duke.edu/nucldata>

The reaction...

NRA CALCulator

(C) R.C. da Silva (DECN/IST, 2019)

Type reaction as ${}^AX(a,b){}^{A'}Y$:

(Target AX taken as stationary in laboratory frame)

EXAMPLES: type ${}^9\text{Be}(p,\alpha){}^6\text{Li}$ as ${}^9\text{Be}(p,a){}^6\text{Li}$ or ${}^9\text{Be}(p,4\text{He}){}^6\text{Li}$

type ${}^{241}\text{Am}(g,a)$ for α decay of ${}^{241}\text{Am}$

type ${}^{241}\text{Am}(g,p/n)$ for p/n separation energy

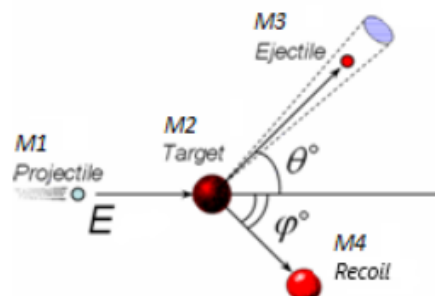
type ${}^{70}\text{Ga}(+e,g)$ for E.C. decay of ${}^{70}\text{Ga}$

type ${}^{70}\text{Ga}(g,e-/e+)$ for $\beta-/+$ decay of ${}^{70}\text{Ga}$

PRIMARY ION energy E/MeV =

Recoil/Daughter EXCITED STATE energy/MeV =

SCATTERING ANGLE/ejectile angle θ /degrees =



CALC

LAB OUTPUTS: _____ ZMF OUTPUTS: _____

The reaction...

NRA CALCulator

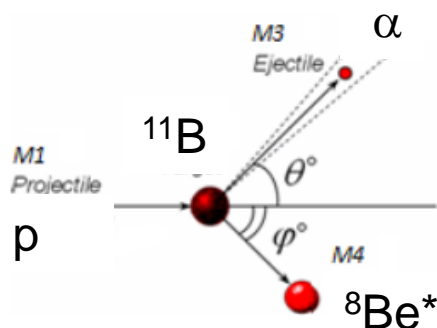
(C) R.C. da Silva (DECN/IST, 2019)

Type reaction as ${}^AX(a,b){}^AY$:

(Target AX taken as stationary in laboratory frame)



PRIMARY ION energy E/MeV =



EXAMPLES: type ${}^9\text{Be}(p,\alpha){}^6\text{Li}$ as ${}^9\text{Be}(p,\alpha){}^6\text{Li}$ or ${}^9\text{Be}(p,4\text{He}){}^6\text{Li}$

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Recoil/Daughter EXCITED STATE energy/MeV =

SCATTERING ANGLE/ejectile angle θ /degrees =

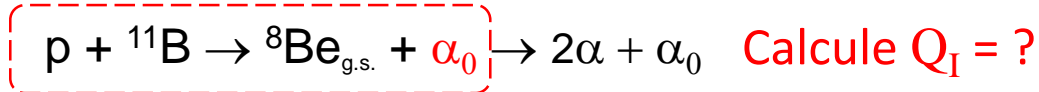
CALC

LAB OUTPUTS: ? ZMF OUTPUTS:

The reaction(s)...

Canais possíveis:

I



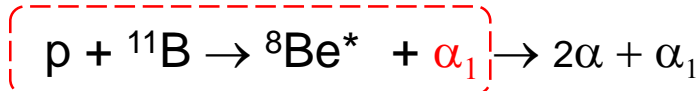
$$E_{\text{g.s.}} = 0 \text{ MeV}$$

$$I\pi = 0^+, \Gamma = 6.8 \text{ eV}, \tau = ?$$

$$\text{Calcule } T_{\alpha_0}(\theta_{\text{lab}} = 150^\circ) = ?$$

{cf. K. Krane, Ch.11 ("Nuclear Reactions")}

II



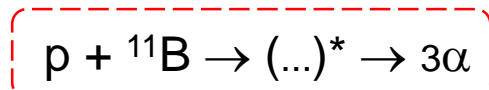
$$E^* = 3.04 \text{ MeV}$$

$$I\pi = 0^+, \Gamma = 1.53 \text{ MeV}, \tau = ?$$

$$\text{Calcule } T_{\alpha_1}(\theta_{\text{lab}} = 150^\circ) = ?$$

{cf. K. Krane, Ch.11 ("Nuclear Reactions")}

III



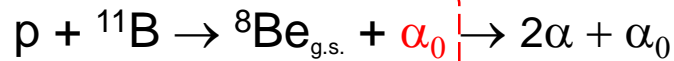
$$E^* = 3.04 \text{ MeV}$$

$$\text{Calcule } Q_{\text{III}} = ? \quad \dots (T_{\alpha})_{\text{max}} = ?$$

Qual o intervalo de energias esperado p/ o espectro ? $> 0 \text{ MeV}$ até $E = \dots \text{ MeV}$?

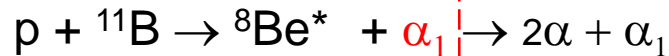
The reaction...

As secções eficazes: cf. <https://www-nds.iaea.org/exfor/ibandl.htm>



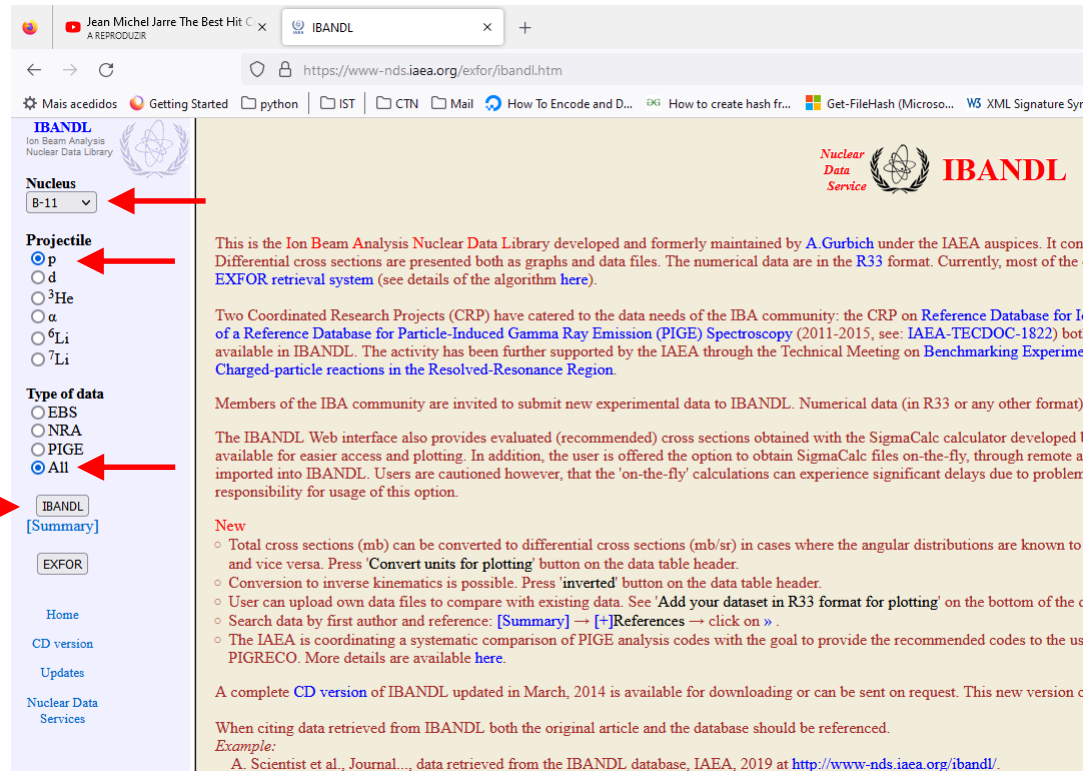
$$E_{\text{g.s.}} = 0 \text{ MeV}$$

$$I\pi = 0^+, \Gamma = 6.8 \text{ eV}$$



$$E^* = 3.04 \text{ MeV}$$

$$I\pi = 0^+, \Gamma = 1.53 \text{ MeV}$$



The screenshot shows the IBANDL web interface. On the left, there is a sidebar with search filters. The 'Nucleus' dropdown is set to 'B-11'. The 'Projectile' section has radio buttons for 'p', 'd', '3He', 'alpha', '6Li', and '7Li', with 'p' selected. The 'Type of data' section has radio buttons for 'EBS', 'NRA', 'PIGE', and 'All', with 'All' selected. Below these filters are buttons for 'IBANDL' and 'EXFOR', and a '[Summary]' link. The main content area on the right contains text about the IBANDL database, its history, and its purpose. It mentions that the database was developed and formerly maintained by A. Gurbich under the IAEA auspices. It also states that the database provides differential cross sections in both graph and data file formats, and that it is available in the R33 format. The text further explains that the database is a result of two coordinated research projects (CRP) and is supported by the IAEA through the Technical Meeting on Benchmarking Experiment Charged-particle reactions in the Resolved-Resonance Region. It also mentions that members of the IBA community are invited to submit new experimental data to IBANDL. The interface also provides evaluated (recommended) cross sections obtained with the SigmaCalc calculator, which is available for easier access and plotting. The user is offered the option to obtain SigmaCalc files on-the-fly, through remote access, but is cautioned that these calculations can experience significant delays due to problem responsibility for usage of this option. A 'New' section lists several features: total cross sections can be converted to differential cross sections, conversion to inverse kinematics is possible, users can upload their own data files, and the IAEA is coordinating a systematic comparison of PIGE analysis codes. A complete CD version of IBANDL is available for downloading or can be sent on request. The interface also provides instructions on how to cite data retrieved from IBANDL, with an example citation provided.

The reaction...

As secções eficazes: cf. <https://www-nds.iaea.org/exfor/ibandl.htm>

VANGELIS Greatest Hits 202 x IBANDL

https://www-nds.iaea.org/exfor/ibandl.htm

Mais acedidos Getting Started python IST CTN Mail How To Encode and D... How to create hash fr... Get-FileHash (Microso... XML Signature Syntax ... The Risk Assessment I... Convert Coordinates

IBANDL
Ion Beam Analysis
Nuclear Data Library

Nucleus
B-11

Projectile
☒ p
☐ d
☐ ³He
☐ α
☐ ⁶Li
☐ ⁷Li

Type of data
☐ EBS
☐ NRA
☐ PIGE
☒ ALL

IBANDL
[Summary]

EXFOR

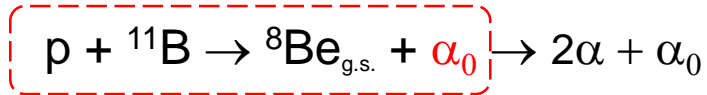
Home
CD version
Updates
Nuclear Data
Services

$^{11}\text{B} + \text{p}$

Reaction	Energy	Q-value	Reference	View	Save	mb	
$^{11}\text{B}(p,\alpha_0)^8\text{Be}$	122.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
48 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	120°	1790-2940	68 2011-09-01 X4+	Ju.G.Mashkarov+(1975), Jour. Izv. Rossiiskoi Akademii Nauk, Ser.Fiz., Vol.39, p.1736 »	View	Save	<input type="checkbox"/>
49 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	117.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
50 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	112.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
51 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	107.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
52 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	102.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
53 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	97.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
54 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	87.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
55 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	82.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
56 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	77.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
57 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	72.5°	900-3500	24 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
58 $^{11}\text{B}(p,\alpha_0)^8\text{Be}$	67.5°	900-3500	25 2021-04-28 X4+	M.Munch+(2020), European Physical Journal A: Hadrons and Nuclei, Vol.56, p.17 »	View	Save	<input type="checkbox"/>
9 $^{11}\text{B}(p,\alpha_1)^8\text{Be}$	150°	460-1530	33 2018-09-10 X4+	J.Liu+(2002), Jour. Nucl. Instrum. Methods in Physics Res., Sect.B, Vol.190, p.107 »	View	Save	<input checked="" type="checkbox"/>
60 $^{11}\text{B}(p,\gamma_0)^{12}\text{C}$ E _γ =16103-17231keV	360°	160-1390	3 2020-04-16 X4-	T.Huus and R. Day, Phys. Rev. 91, 599 (1953). »	View	Save	<input type="checkbox"/>
61 $^{11}\text{B}(p,\gamma_0)^{12}\text{C}$ E _γ =16433-19559keV	360°	520-3930	59 2018-12-17 X4+	R.E.Segel+(1965), Jour. Physical Review, Vol.139, p.B818 »	View	Save	<input type="checkbox"/>
62 $^{11}\text{B}(p,\gamma_0)^{12}\text{C}$ E _γ =17249-18560keV	90°	1410-2840	18 2018-12-17 X4+	L.N.Generalov+(2005), Jour. Izv. Rossiiskoi Akademii Nauk, Ser.Fiz., Vol.69, p.85 »	View	Save	<input type="checkbox"/>
63 $^{11}\text{B}(p,\gamma_0)^{12}\text{C}$ E _γ =18615-20192keV	90°	2900-4620	19 2018-12-17 X4+	M.C.Wright+(1982), Jour. Physical Review, Part C, Nuclear Physics, Vol.25, p.2823 »	View	Save	<input type="checkbox"/>

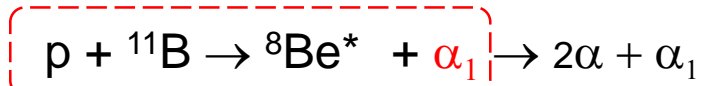
The reaction...

As secções eficazes: cf. <https://www-nds.iaea.org/exfor/ibandl.htm>



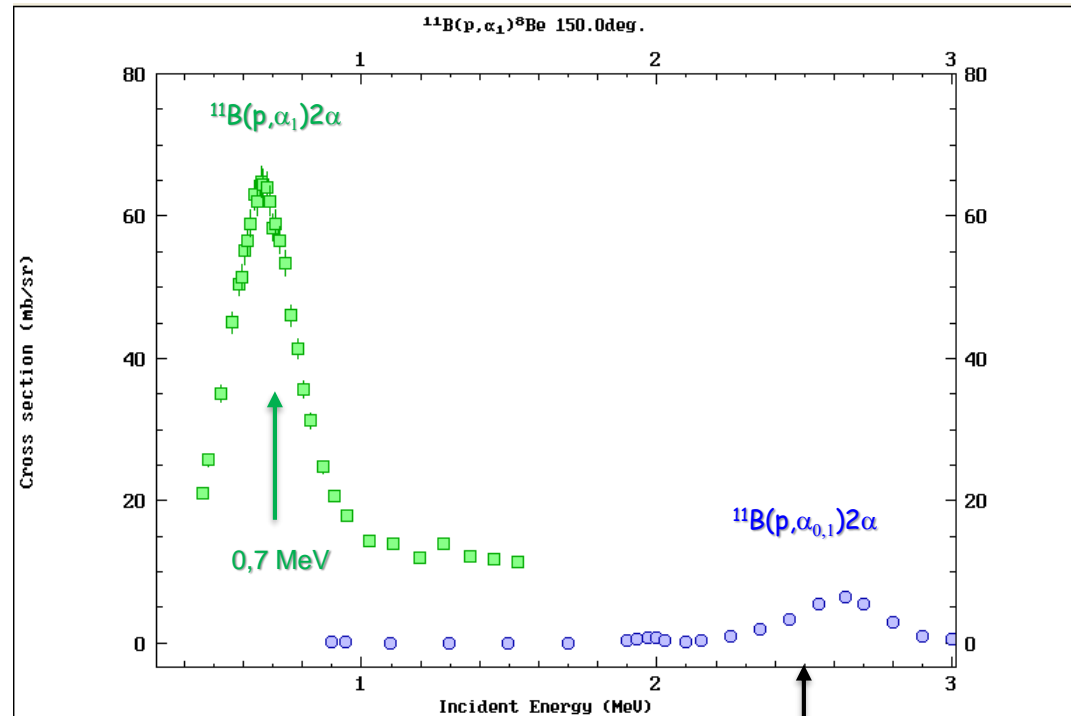
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$$I\pi = 0^+, \Gamma = 6.8 \text{ eV}$$



$$E^* = 3.04 \text{ MeV}$$

$$I\pi = 0^+, \Gamma = 1.53 \text{ MeV}$$



2,5 MeV

Porquê a escolha da energia p/ o feixe ?

The energy calibration...

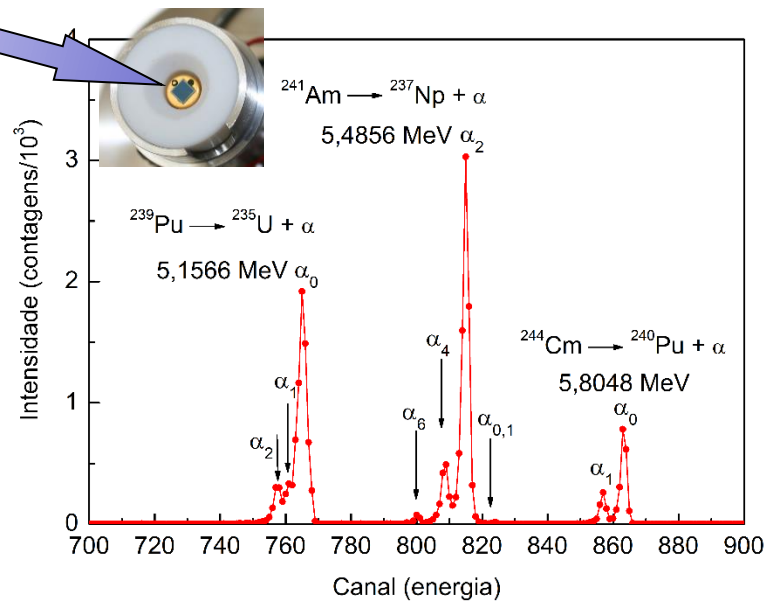
Establishing the channel-to-energy conversions

Exemplo



Triple
 α source

$\sim 5.5 \text{ MeV } \alpha$

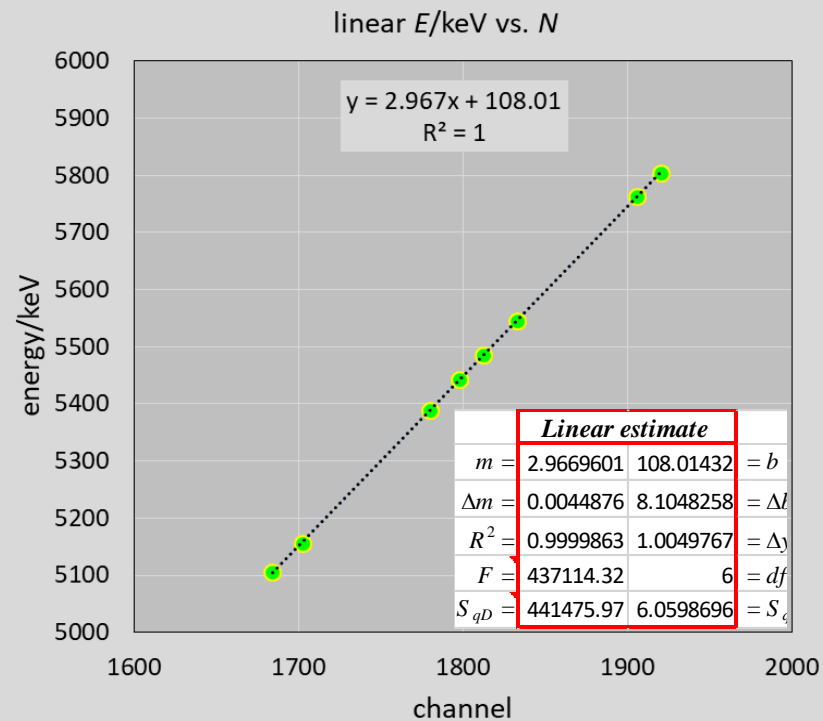


The energy calibration...

Establishing the channel-to-energy conversions

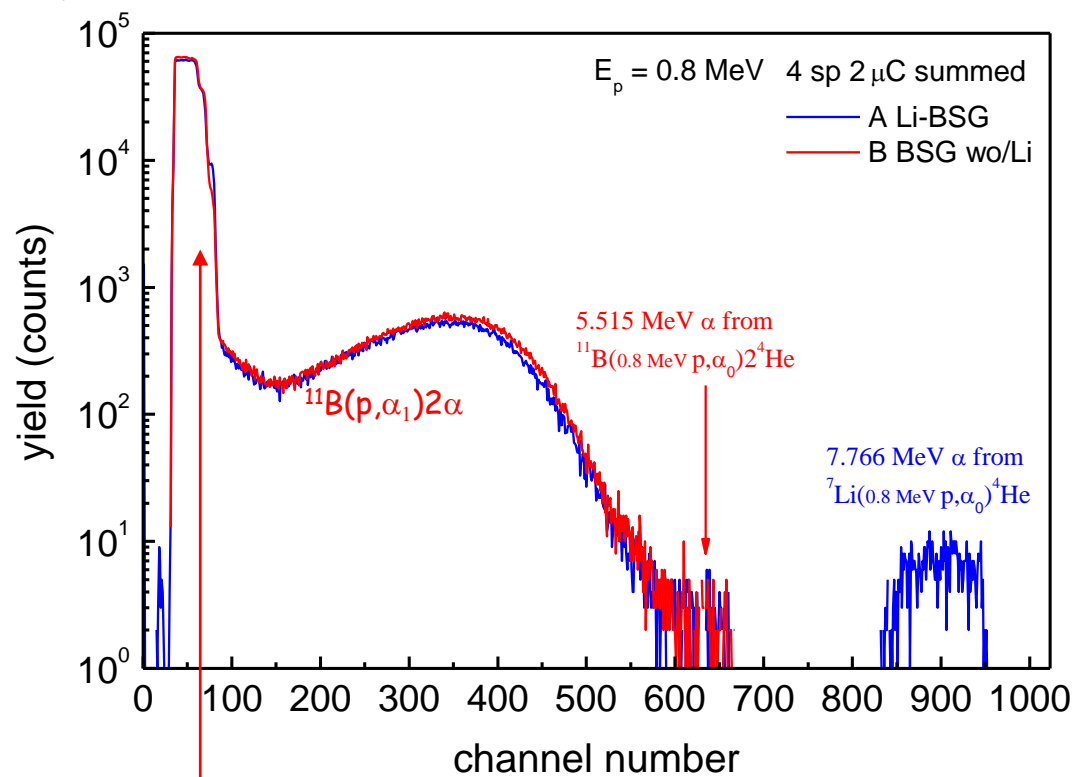
Exemplo

Fonte	Transição	I%	E_n/keV	E/keV
^{244}Cm (0+)	18,1 a			5901.61
	α_0	0+	76.4	0 5804.82
	α_1	2+	23.6	42.824 5762.70
	α_2	4+	0.022	141.690 5664
^{241}Am (5/2-)	432,2 a			5637.81
	α_0	5/2+	0.34	0 5544.5
	α_1	7/2+	0.20	33.192 5511.47
	α_2	5/2-	85.2	59.537 5485.56
	α_3	9/2+	0.04	75.89 5469.45
	α_4	7/2-	12.8	102.96 5442.80
	α_5	11/2+	0.01	130.00 5416.27
	α_6	9/2-	1.40	158.51 5388.23
	α_7	13/2+	-	191.5 5355.9
	α_8	11/2-	0.015	225.96 5321.9
^{239}Pu (1/2+)	24110 a			5244.50
	α_0	7/2-	0.03	0 5156.72
	α_1	1/2+	73.3	0.0768 5156.59
	α_2	3/2+	15.1	13.040 5144.3
	α_3	9/2-	0.03	46.204 5111.2
	α_4	5/2+	11.5	51.701 5105.5



The (kind of) primary 'deliverable'...

Exemplo I: espectros de vidros de borossilicato (BSG) não dopado e dopado c/ Li, obtidos no LATR/IST

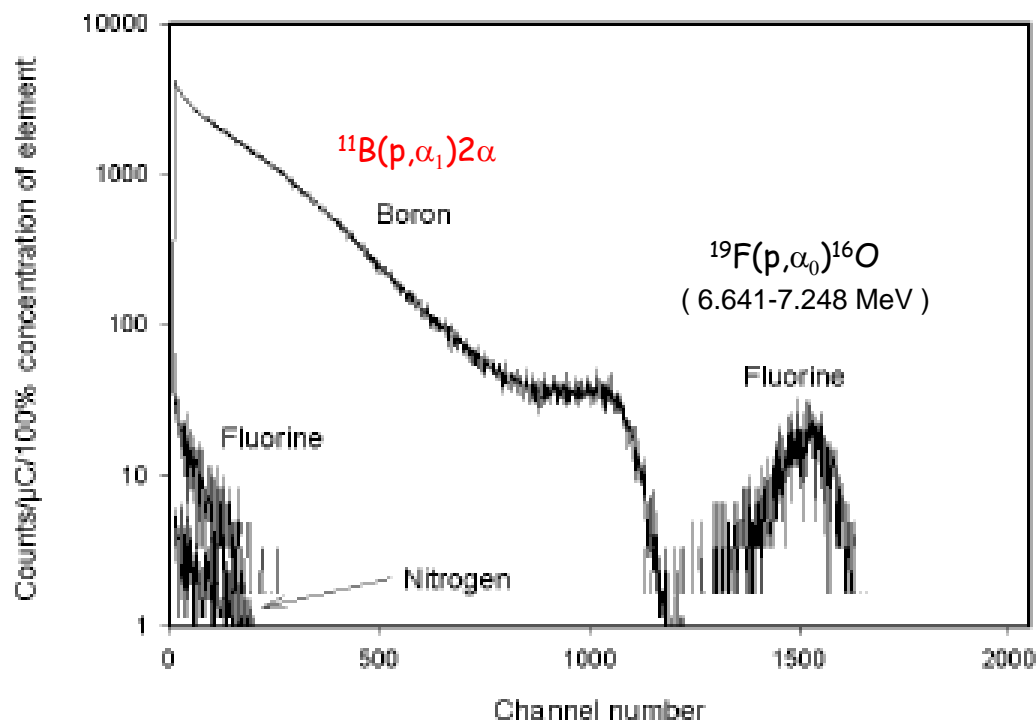


O que é isto ?

Qual dos vidros tem B ?
Qual dos vidros tem Li ?

The (kind of) primary 'deliverable'...

Exemplo: espectros de mistura $\text{H}_2\text{BO}_3 + \text{CaF}_2$, publicado em..



*Journal of Radioanalytical and Nuclear Chemistry,
Vol. 254, No. 1 (2002) 53–57*

The results...