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Emilio Andrea Maugeri :: Paul Scherrer Institut

The importance of targetry in nuclear physics and astrophysics experiments

Nuclear Physics in Astrophysics – X. CERN, 9 September 2022

How important is the target for cross section measurement?

No target, No measurement

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How important is to have a “good” target for cross section measurement?

Neutron capture cross section of unstable isotopes in the *s*-process

PHYSICAL REVIEW LETTERS **125,** 142701 (2020)

Neutron Capture on the *s*-Process Branching Point ^{171}Tm via Time-of-Flight and Activation

C. Guerrero,[1,2,*] J. Lerendegui-Marco,[1] M. Paul,[3] M. Tessler,[4] S. Heinitz,[5] C. Domingo-Pardo,[6] S. Cristallo,[7,8] R. Dressler,[5] S. Halfon,[4] N. Kivel,[5] U. Köster,[9] E. A. Maugeri,[5] T. Palchan-Hazan,[3] J. M. Quesada,[1] D. Rochman,[5] D. Schumann,[5]

DE GRUYTER Radiochim. Acta 2017; 105(10): 801–811

Stephan Heinitz*, Emilio A. Maugeri, Dorothea Schumann, Rugard Dressler, Niko Kivel, Carlos Guerrero, Ullrich Köster, Moshe Tessler, Michael Paul, Shlomi Halfon and the n_TOF Collaboration[a]

Production, separation and target preparation of ^{171}Tm and ^{147}Pm for neutron cross section measurements

3.5 mg of ^{171}Tm were produced by thermal neutron irradiation (~54 days), at ILL, Grenoble, of 240 mg of enriched $^{170}Er_2O_3$

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How important is to have a “good” target for cross section measurement?

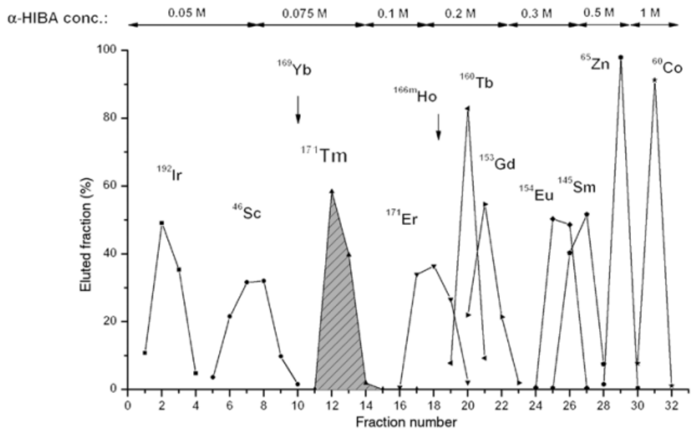

Figure 3: Separation profile of ^{171}Tm on the Aminex HPX87H cation resin. The gradual elution of different radioisotopes with increasing α-HIBA concentration is shown.

Figure 7: The final arrangement of the ^{171}Tm target provided to n_TOF CERN.

The final deposition efficiency for the ^{171}Tm target of 93.6 ± 0.4 %

PHYSICAL REVIEW LETTERS **125,** 142701 (2020)

illustrative example, Neyskens *et al.* [3] have recently been able to determine an upper limit of 2.5×10^8 K for the *s*-process temperature in low-mass asymptotic giant branch (AGB) stars (see also Ref. [4]). This result has been possible thanks to a combination of the HERMES spectrograph observations [5] of the Zr/Nb abundance ratio in red giants and the availability of the new experimental Maxwellian-

The quality of the ^{171}Tm sample has been key to the success of the experiments presented herein. In the context of a larger project involving the production of ^{79}Se, ^{147}Pm, ^{163}Ho, and ^{204}Tl as well, a pellet of 240 mg $^{170}Er_2O_3$ enriched to 98.1% was irradiated for 55 days at the high-flux reactor Institut Laue-Langevin (ILL) in France, where neutron capture on stable ^{170}Er produced sizable quantities of ^{171}Er (7.516 h) that decayed into ^{171}Tm (2.92 y).

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How important is chemistry for cross section measurement?

^{148}Gd ($T_{1/2}$: 74 years)

ISSN 1063-7788, Physics of Atomic Nuclei, 2011, Vol. 74, No. 4, pp. 573–579. © Pleiades Publishing, Ltd., 2011.
Original Russian Text © Yu.E. Titarenko, V.F. Batyaev, A.Yu. Titarenko, M.A. Butko, K.V. Pavlov, S.N. Florya, R.S. Tikhonov, V.M. Zhivun, A.V. Ignatyuk, S.G. Mashnik, S. Leray, A. Boudard, J. Cugnon, D. Mancusi, Y. Yariv, K. Nishihara, N. Matsuda, H. Kumawat, G. Mank, W. Gudowski, 2011, published in Yadernaya Fizika, 2011, Vol. 74, No. 4, pp. 596–603.

NUCLEI
Experiment

Measurement and Simulation of the Cross Sections for the Production of ^{148}Gd in thin ^{nat}W and ^{181}Ta Targets Irradiated with 0.4- to 2.6-GeV Protons

Yu. E. Titarenko[1)]*, V. F. Batyaev[1)], A. Yu. Titarenko[1)], M. A. Butko[1)], K. V. Pavlov[1)], S. N. Florya[1)], R. S. Tikhonov[1)], V. M. Zhivun[1)], A. V. Ignatyuk[2)], S. G. Mashnik[3)], S. Leray[4)], A. Boudard[4)], J. Cugnon[5)], D. Mancusi[5)], Y. Yariv[6)], K. Nishihara[7)], N. Matsuda[7)], H. Kumawat[8)], G. Mank[9)], and W. Gudowski[10)]

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SCIENCE DIRECT
Nuclear Physics A 760 (2005) 225–233
NUCLEAR PHYSICS A

^{148}Gd production cross section measurements for 600- and 800-MeV protons on tantalum, tungsten, and gold ☆

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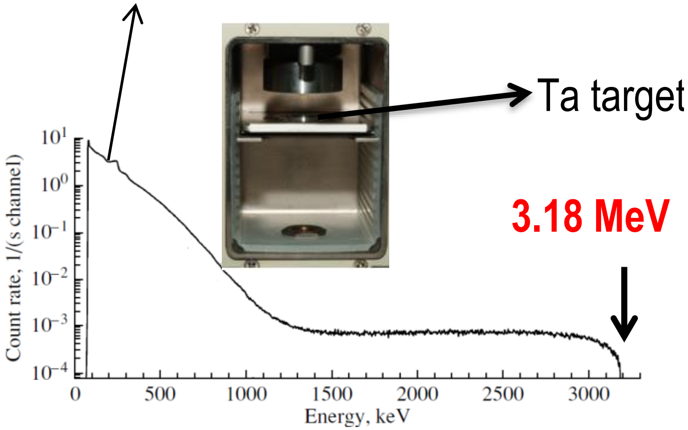
[b] Georgia Institute of Technology, Atlanta, GA 30332-0425, USA

Received 30 March 2005; received in revised form 1 June 2005; accepted 2 June 2005
Available online 24 June 2005

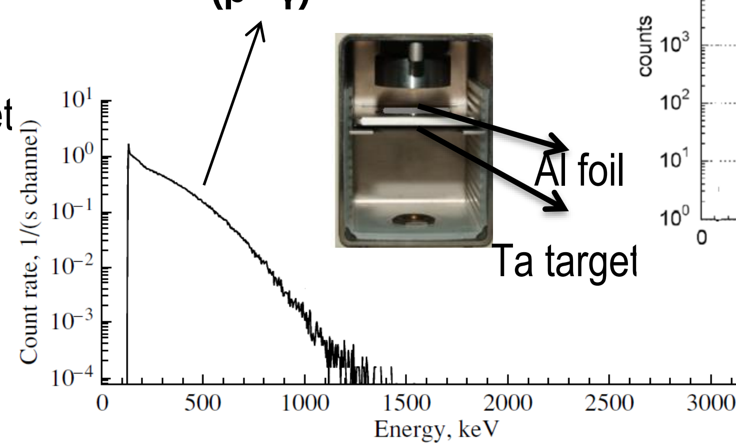
Alpha spectrum of 800 MeV p-irradiated Ta

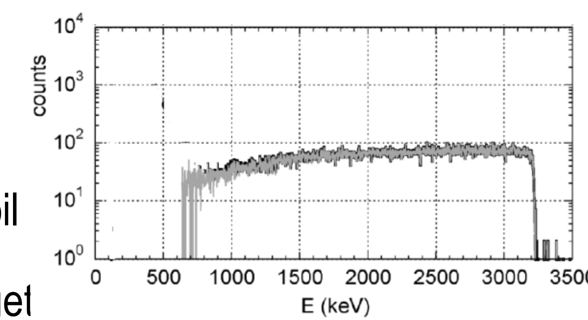
(α +β+ γ)



Alpha spectrum of 800 MeV p-irradiated Ta + Al foil

(β+ γ)

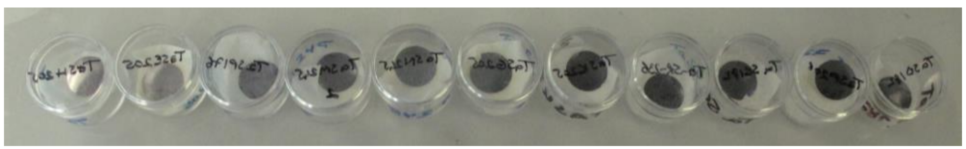




How important is chemistry for cross section measurement?

1386 MeV proton irradiated Ta

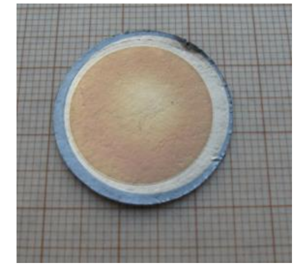
Initial material
~ 200 mg

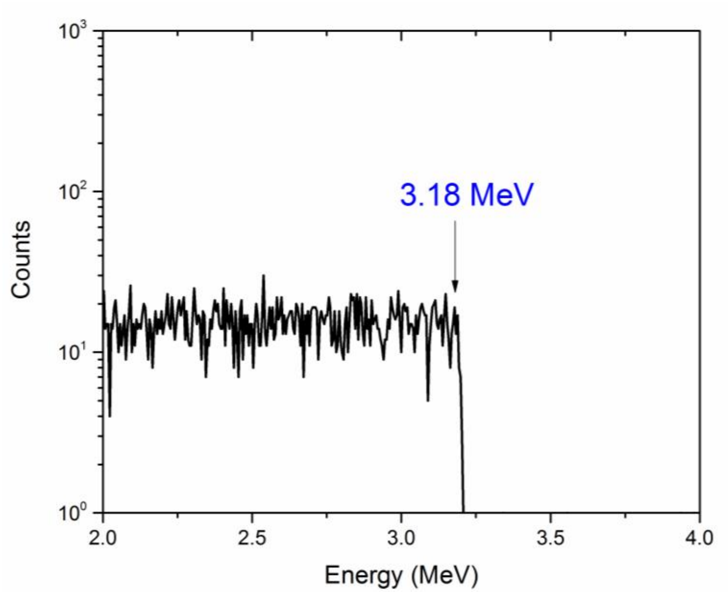


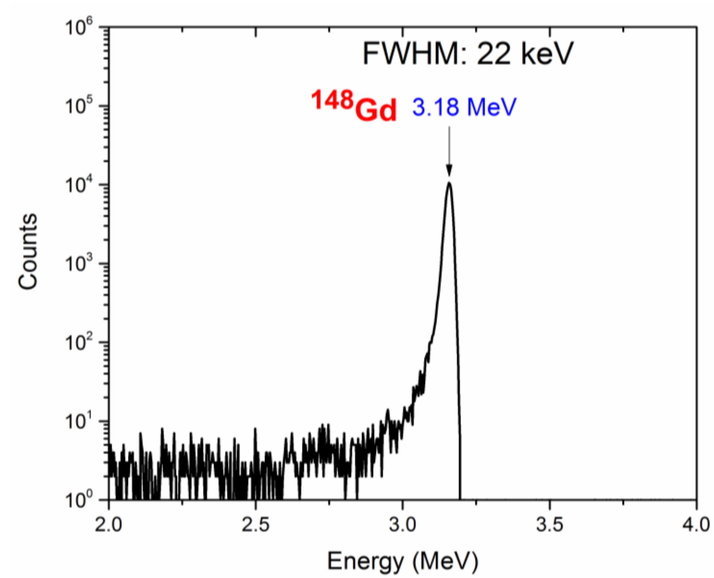
After separation

^{148}Gd

8.3 10^{-9} mg
max 10 Bq







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How important is chemistry for cross section measurement?

analytical chemistry
Article
pubs.acs.org/ac

Analysis of the ^{148}Gd and ^{154}Dy Content in Proton-Irradiated Lead Targets

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[§]IRFU, CEA, Université Paris-Saclay, F-91191, Gif-sur-Yvette, France
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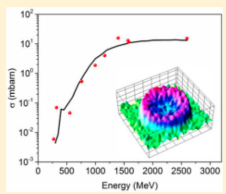
[⊥]Institute for Radioecology and Radiation Protection, Leibniz University of Hannover, 30167 Hannover, Germany

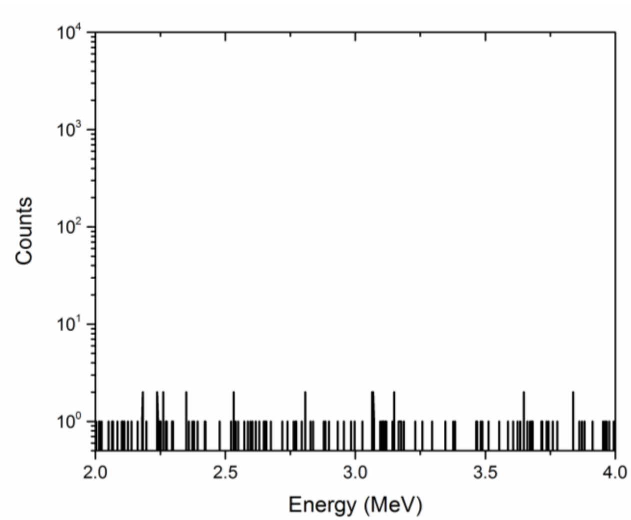
Supporting Information

ABSTRACT: This work presents the determination of the ^{148}Gd and ^{154}Dy content in Pb targets irradiated by 220−2600 MeV protons. It includes the chemical separation of lanthanides, followed by the preparation of proper samples, by molecular plating technique, for α-spectrometry measurements. The experimental cross section results were compared with theoretical predictions, calculated with the INCL++-ABLA07 code. The comparisons showed a satisfactory agreement for ^{148}Gd (less than within a factor two), while measured ^{154}Dy cross sections are higher than the theoretical values.

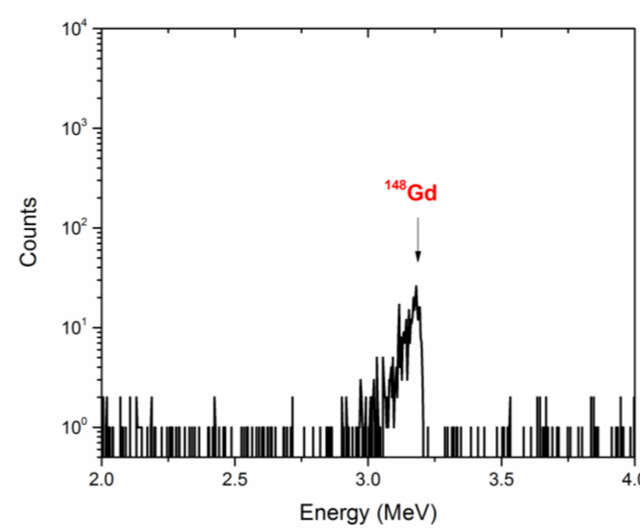


< 500 MeV proton irradiated sample

Before separation



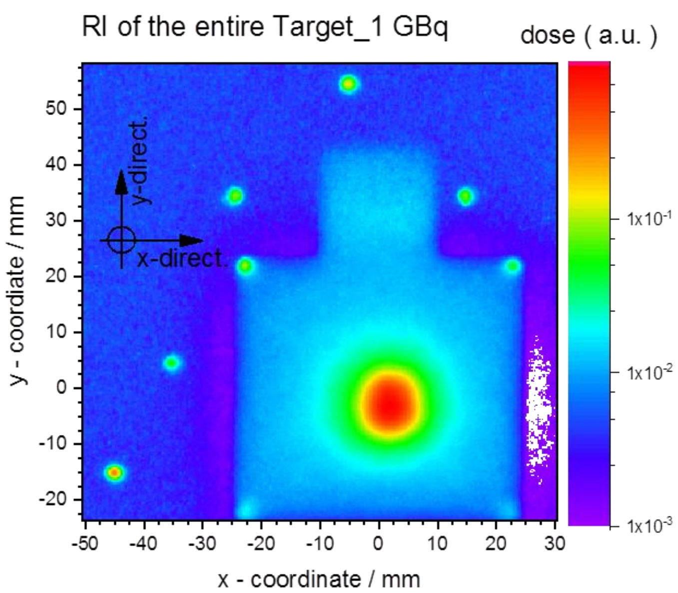
After separation



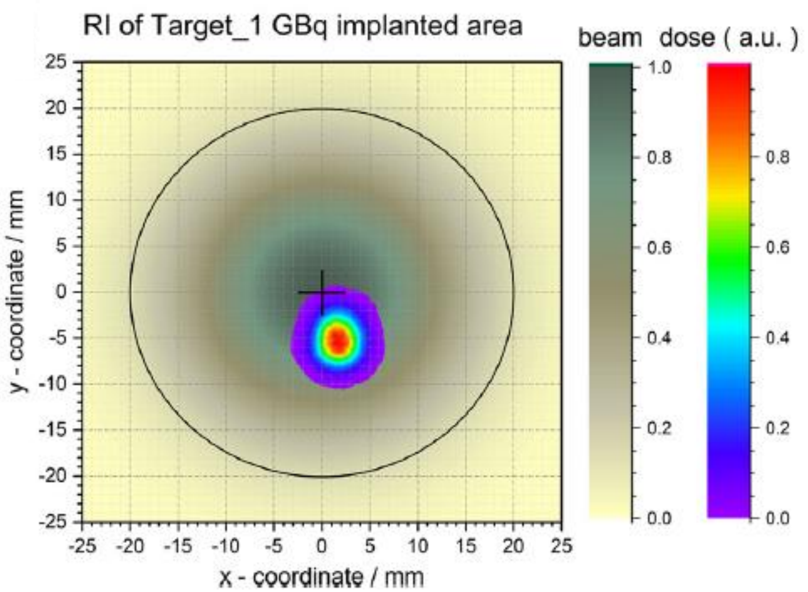
How important is to have a “good-characterized” target for cross section measurement?

$^{7}Be(n,p)^{7}Li$

^{7}Be distribution: Radiographic imaging



RI 2D graphs superimposed to the n_TOF neutron beam profile



The centre of the beam profile was overlapped to the geometrical centre of the target

The implanted area of Target was exposed only to about 85% to 75% of the neutron beam intensity

Target characterization at PSI

Measurement of thickness

alpha spectroscopy

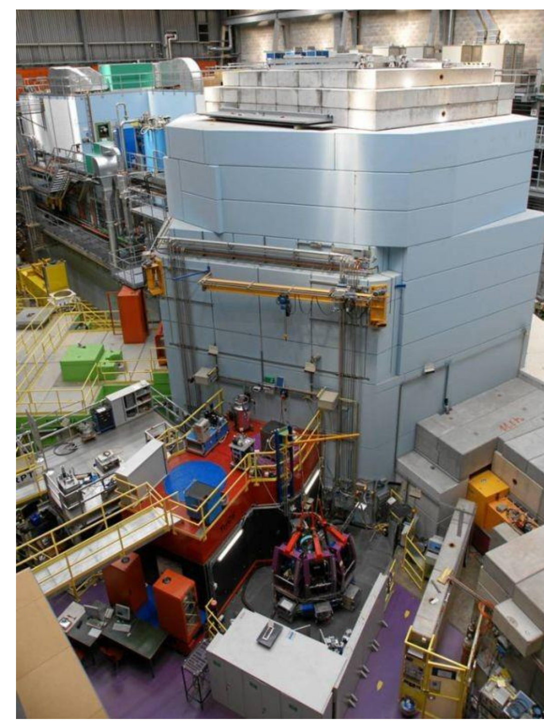
liquid scintillation counter

TriCarb CA2110 scintillation counter

gamma spectroscopy

HPGe detector Canberra GmbH

Neutron Activation Analysis



Inductively coupled plasma mass spectrometry (**ICP-MS**)

Element 2, Thermo Fisher Scientific,

Inductively Coupled Plasma Optical Emission spectroscopy (**ICP-OES**)

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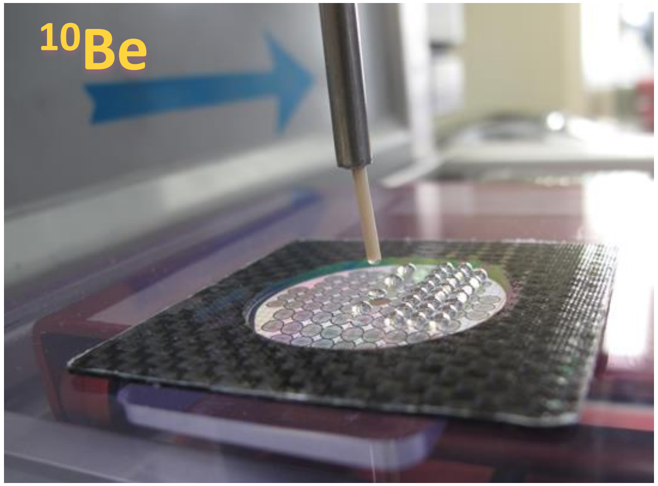
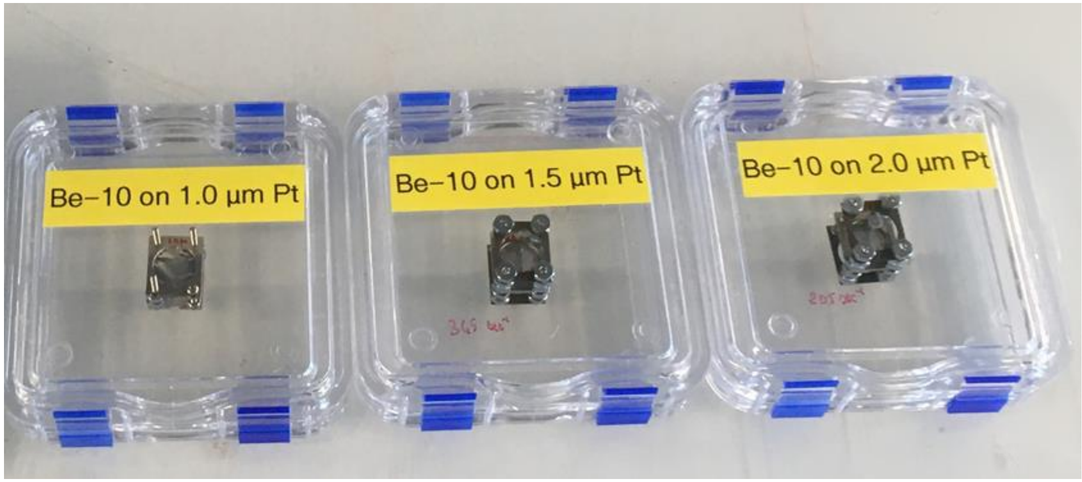
How long does it take to get a “good-characterized” target for cross section measurement?





Start taking care about the target as soon as you decide to submit a proposal, even when it you think “it s a simple target”!

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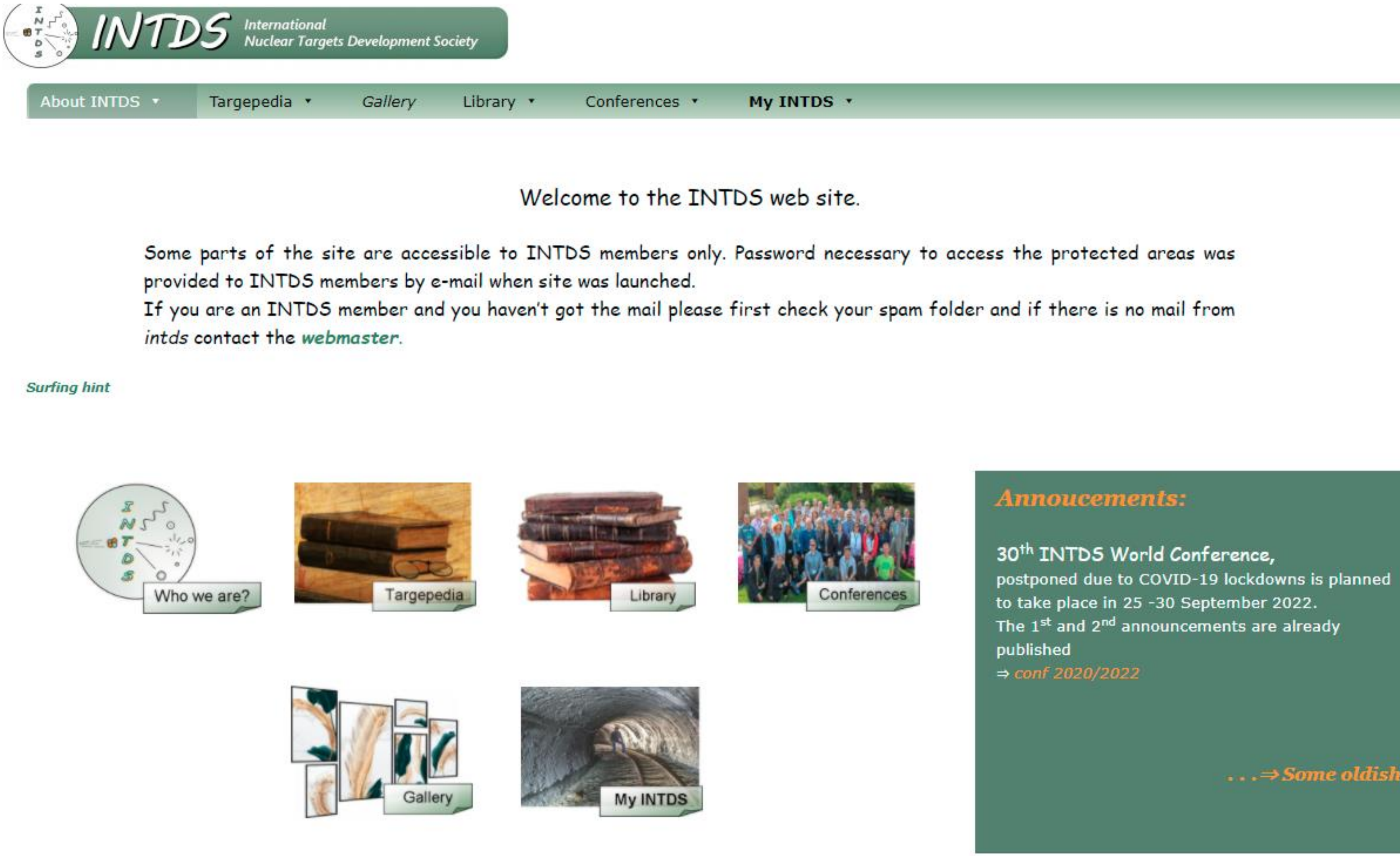
How much does "good-characterized" target for cross section measurement cost?

Whatever, but zero! Start taking care about the budget for the target as soon as you decide to submit a proposal, even when it you think "it s a simple target"!

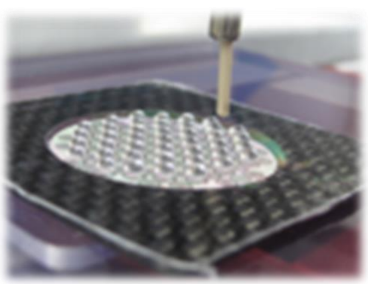
Many thanks for your attention

https://www.intds.org/



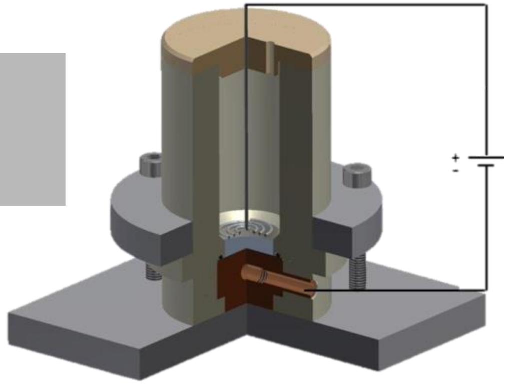
Methods implemented at PSI

Physical Vapor Deposition (PVD):is a process where a solid or liquid precursor is vaporized under high vacuum and condensed onto all the surfaces of the reactor chamber among which the backing material. This method allows controlling the thickness of the target in a wide range from µg cm^{-2} to mg cm^{-2}, obtaining homogeneous layers. The main drawback is the low yields in the order of 2-10%.



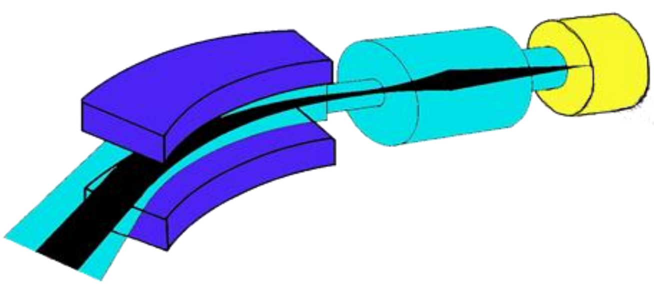
Casting: is a process where the target material is solubilized in a liquid solution, which is dispersed, by spraying or droplet deposition, onto a backing material. The solvent is then evaporated leaving the target material deposited onto the backing. This method is generally fast and quantitative, but the obtained targets are not uniform and homogenous and the adherence between target material and backing can be insufficient.

Methods implemented at PSI



Molecular plating: high yields close to 100%, fast and relative cheap process. However chemical processes involved in MP are still not clear, and co-precipitation of different species can not be avoided yet, which cause target thickening.

ISOLDE General Purpose Separator (GPS)



The **implantation** of mass separated ion technique allows obtaining very thin and relatively uniform and homogenous implanted Layers, with no contaminants, except for co- Implantation of isobaric isotopes. The main problem related with this method is the low yield, which is typically not better than 10% (30-40%).

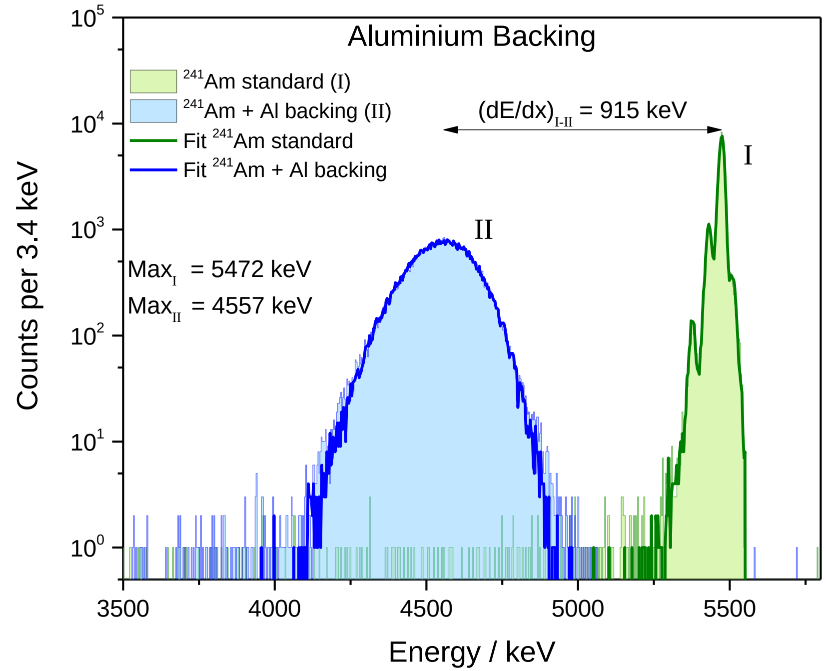
New method: Electrodeposition from ionic liquid

Standard Cathode (Reduction) Half-Reaction	Standard Reduction Potential E° (volts)
$Li^{+}(aq) + e^{-} \rightleftharpoons Li(s)$	-3.040
$Rb^{+} + e^{-} \rightleftharpoons Rb(s)$	-2.98
$K^{+}(aq) + e^{-} \rightleftharpoons K(s)$	-2.93
$Ba^{2+} + 2e^{-} \rightleftharpoons Ba(s)$	-2.92
$Cs^{+}(aq) + e^{-} \rightleftharpoons Cs(s)$	-2.92
$Ba^{2+}(aq) + 2e- \rightleftharpoons Ba(s)$	-2.91
$Sr^{2+}(aq) + 2e- \rightleftharpoons Sr(s)$	-2.89
$Ca^{2+}(aq) + 2e- \rightleftharpoons Ca(s)$	-2.84
$Na^{+}(aq) + e^{-} \rightleftharpoons Na(s)$	-2.713
$Mg(OH)_2(s) + 2e^{-} \rightleftharpoons Mg(s) + 2OH^{-}$	-2.687
$La^{3+} + 3e^{-} \rightleftharpoons La(s)$	-2.38
$Mg^{2+}(aq) + 2e^{-} \rightleftharpoons Mg(s)$	-2.356
$Ce^{3+} + 3e^{-} \rightleftharpoons Ce(s)$	-2.336
$Al(OH)_4^{-} + 3e^{-} \rightleftharpoons Al(s) + 4OH^{-}$	-2.310
$AlF_6^{3-} + 3e^{-} \rightleftharpoons Al(s) + 6F^{-}$	-2.07
$Be^{2+} + 2e^{-} \rightleftharpoons Be(s)$	-1.99
$B(OH)_4^{-} + 3e^{-} \rightleftharpoons B(s) + 4OH^{-}$	-1.811
$Al^{3+}(aq) + 3e^{-} \rightleftharpoons Al(s)$	-1.676
$U^{3+} + 3e^{-} \rightleftharpoons U(s)$	-1.66
$ZnO_2 + 4H^{+} + 4e^{-} \rightleftharpoons Zr(s) + 2H_2O$	-1.473
$SiF_6^{2-} + 4e^{-} \rightleftharpoons Si(s) + 6F^{-}$	-1.37
$Zn(CN)_4^{2-} + 2e^{-} \rightleftharpoons Zn(s) + 4CN$	-1.34
$Zn(OH)_4^{2-} + 2e^{-} \rightleftharpoons Zn(s) + 4OH^{-}$	-1.285
$Mn^{2+} + 2e^{-} \rightleftharpoons Mn(s)$	-1.17

- High yields: 80-90%
- Precipitation of the element in its metallic form
- No co-precipitation of different other species.

Measurement of thickness

Target characterization at PSI



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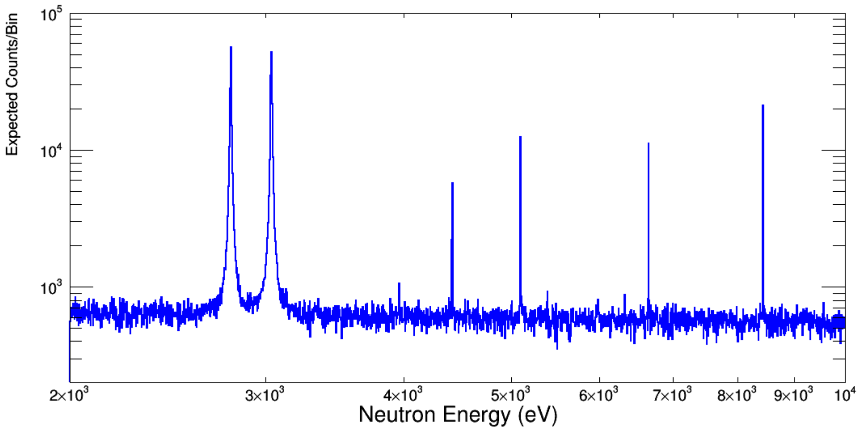
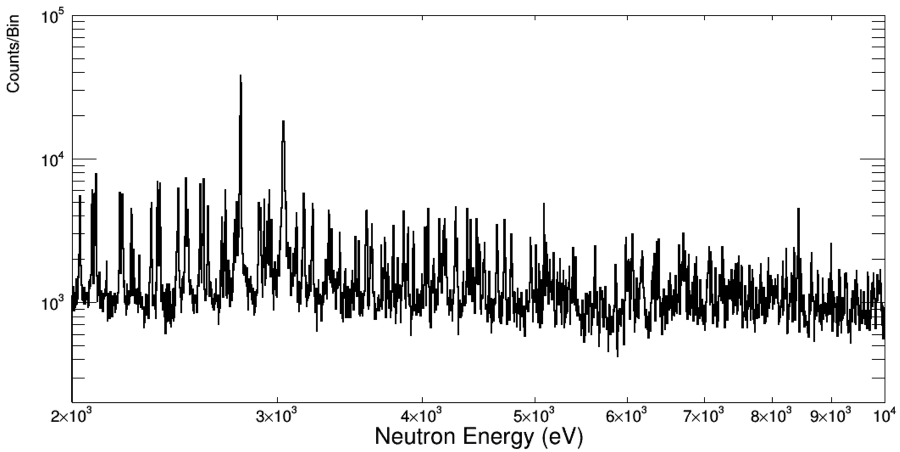
^{205}Tl(n,γ) cross section measurement at n_TOF EAR1

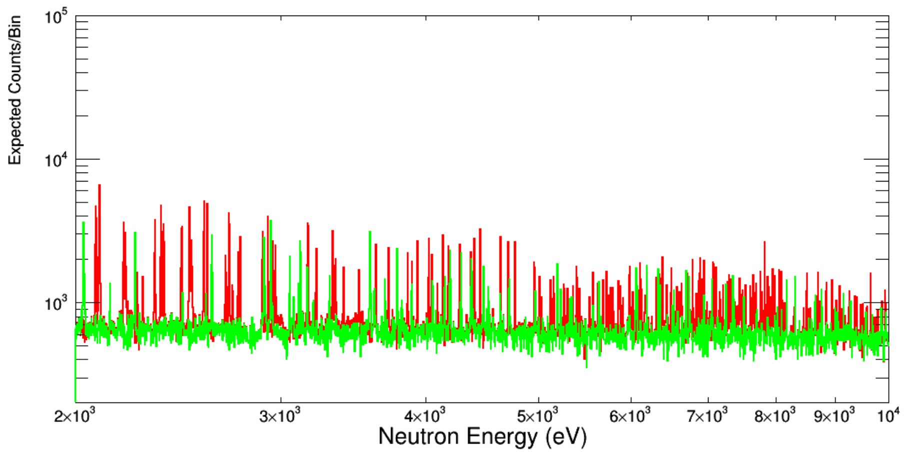
A. Casanovas (UPC), A.Tarifeño-Saldivia (UPC), C. Domingo-Pardo (IFIC), F. Calviño (UPC), C. Guerrero (US), J. Lerendegui-Marco (US) and the n_TOF Collaboration

[1] Universitat Politècnica de Catalunya (UPC), Barcelona, Spain
[2] Instituto de Fisica Corpuscular (CSIC-Universitat de Valencia), Valencia, Spain
[3] Universidad de Sevilla, Spain

INTC meeting
CERN, 7/2/18







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Certificate of Analysis

CAMPRO SCIENTIFIC

Product name : ^{205}Tl
Cat. # : **CS22-20096462**
Lot # : **7**

CHARACTERISTICS OF ISOTOPE-ENRICHED PRODUCT

1. Weight of enriched isotope:

Compound weight: **Element weight:**

Form: Tl_2O_3

2. Isotopic composition:

Isotope	203	205						
Enrichment (%)	0.43	99.57						

3. Chemical Impurities:

Element	Symbol	Impurity Measurement(ppm)
Silver	Ag	20
Aluminum	Al	300
Barium	Ba	15
Bismuth	Bi	<100
Calcium	Ca	50
Cadmium	Cd	<50
Chromium	Cr	5
Copper	Cu	<10
Iron	Fe	800
Gallium	Ga	10
Indium	In	<10
Magnesium	Mg	30
Manganese	Mn	20

Element	Symbol	Impurity Measurement(ppm)
Molybdenum	Mo	10
Sodium	Na	<20
Nickel	Ni	10
Lead	Pb	200
Platinum	Pt	<200
Antimony	Sb	<200
Silicon	Si	500
Tin	Sn	<20
Strontium	Sr	<50
Titanium	Ti	30
Zirconium	Zr	<20

4. Analytical method: ICP-MS

	^{nat}Tl	^{205}Tl
Ag	6.2	22.0
Ba	0.42	0.27
Bi	8.2	9.9
Br	1130564	1855875
Br	1309558	1889452
Cd	0.52	0.48
Cr	1.8	2.4
Cu	1891	1545
Fe	156	236
Mn	2.6	5.2
Mo	0.976	1.5
Na	13013	6084
Ni	3228	2241
Pb	52	57
Pt	0.20	0.19
Sb	0.44	0.58
Si	3153	3813
Sn	3.1	4.9
Sr	11	3.6
Ti	100	58
Zr	0.35	0.52
$^{79}Br/^{81}Br$	1.04077803	1.01386354
natural $^{79}Br/^{81}Br$	1.02782171	

factor by which signal is higher than the background. NOT COUNTRATE! A sign that the element is there in copious amounts if high