First report on the inventory of radionuclides in 1.4 GeV proton irradiated thick Lead-Bismuth Eutectic (LBE) target

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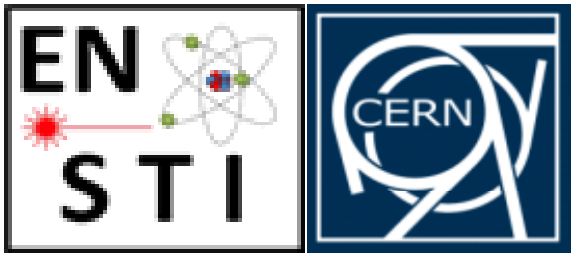
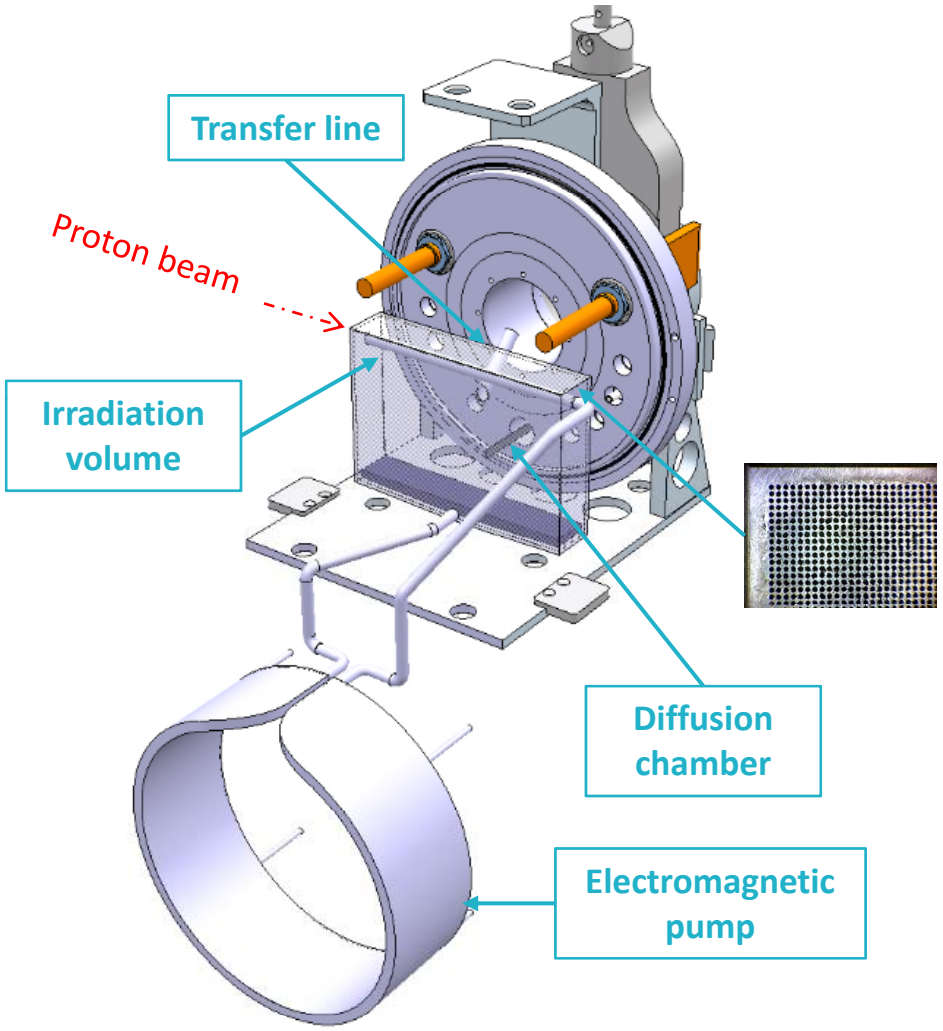


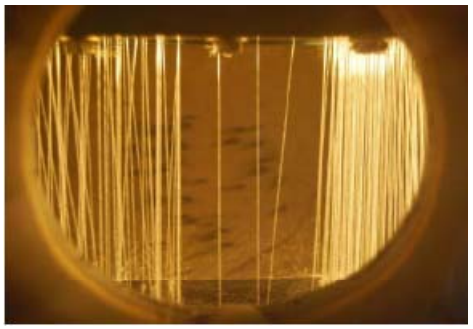
This work is a part of LIEBE Project

Liquid euctectic Pb/Bi loop for EURISOL
LIEBE project

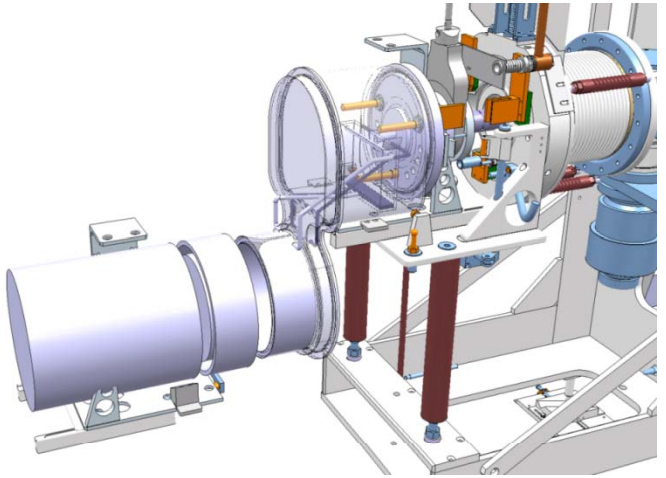


Courtesy of V. Barozier and M. Delonca

Pb/Bi shower at diffusion chamber (at the exit of interchangeable grid)



@IPUL, Latvia
Molten Pb/Bi loop



Final Report of the EURISOL Design Study 2009, J. Cornell Ed., GANIL

LIEBE project: Instituts and timeline

WP Definition	WP Holder
WP1: Coordination	CERN
WP2: Conceptual Design and Simulation	SCK-CEN
WP3: Construction, Assembly	CERN
WP4: Instrumentation	CERN
WP5: Safety and Licensing	CEA
WP6: Target characterization and analysis	PSI
WP7: Radiochemistry	SINP
WP8: Offline Commissioning	IPUL
WP9: Online Operation	CERN

LIEBE project planning - endorsed 2nd SC, Lisbon, Oct 2012

WP	Q3-12	Q4-12	Q1-13	Q2-13	Q3-13	Q4-13	Q1-14	Q2-14	Q3-14	Q4-14	Q1-15	Q2-15	2018
				CERN-wide Long Shutdown 1									
2 Design			1st design	CFD, FEM		Final design							
3 Assembl						Techn. drawings	components	Procurement	Construction	Adaptation			
4 Instr.			Definition		Tests@ipul/cern			software					
5 Safety		CERN authorities.	Safety constraints	Risk analysis + RP			Risk analysis + RP II			Safety file	Beam permit		
6 Target charact					Release (Po…)	Inventory							*Waste PIE*
7 Chemist		Activation Pb/Bi			Compar MC code				Activation Pb/Bi-II				
8 Offline		Test pumps IPUL	Test IPUL CERN						commissioning	commissioning	Cold check-out		
9 Online		Operational parameters		Definition of online tests				Modif target area I			Modif target area II	1 week online – Report	Final report

Aim of this experiment:

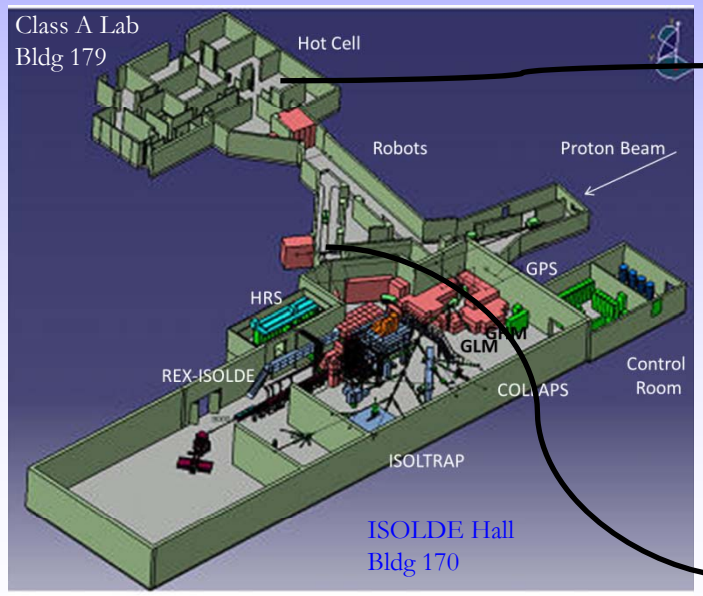
- **To make total inventory and quantification of the radionuclides produced by bombardment of 1.4 GeV proton on LBE targets.**
- **To investigate the production of highly radiotoxic Po and At radionuclides occurring through secondary particle reaction channels.**

Experiment:

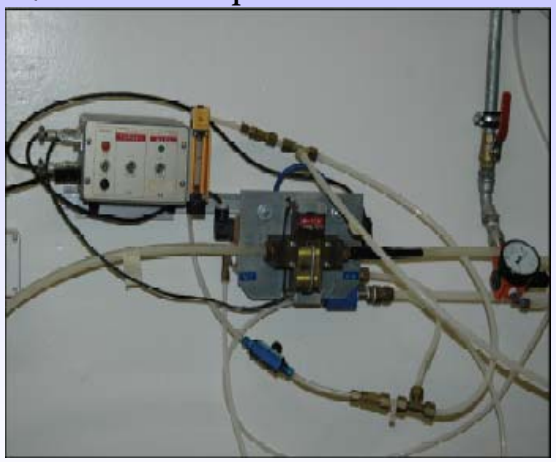
- Eight cylindrical LBE samples (Fixed diameter of 6 mm and lenghts from 1 to 8 mm) weighing between 0.43 to 2.83 g.
- LBE samples were encapsulated.
- Irradiation with 1.4 GeV proton beam using RaBIT setup at ISOLDE.
- Irradiation time 1-3 s.
- Intensity of the proton beam was 3.18×10^{12} protons/pulse for 1 and 2 mm length target and 3.22×10^{13} protons/pulse for the rest.
- Time resolved gamma measurements.

RaBIT (rapid proton beam irradiation transport) irradiations setup:

- Pneumatic transport system installed in class A lab at ISOLDE
- Samples sent in shuttles into the proton beam line in front of HRS front-end
- Samples transported to class C lab after reduction of dose rate below 10 uSv/h (cooling periods of 7-24 hrs)

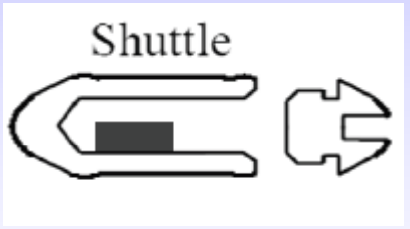


RaBIT setup



HRS front-end

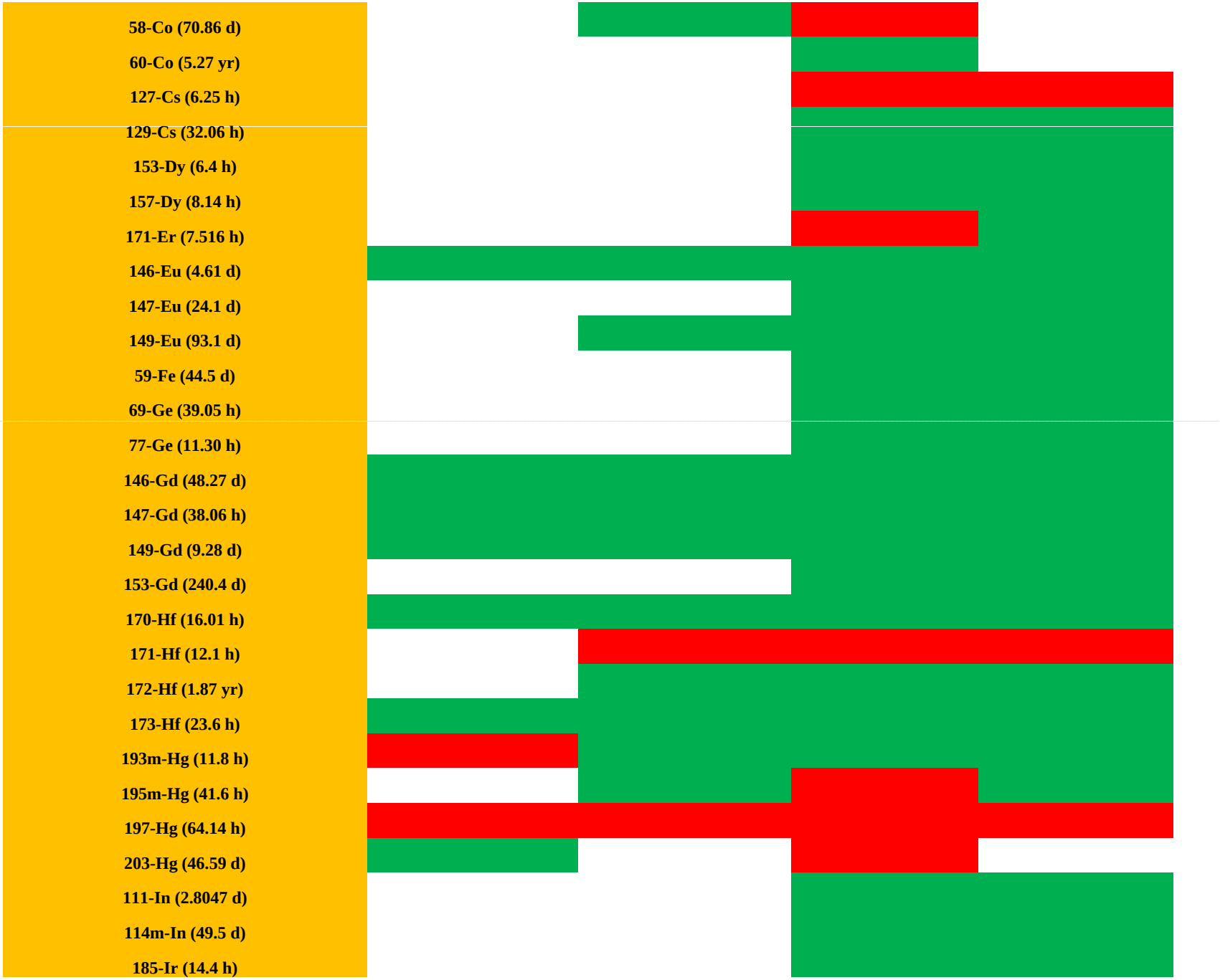
Schematic representation of shuttles used in RaBIT irradiation



Measured activity (Bq) of the long lived (>5 d) radionuclides at EOB in sample #8

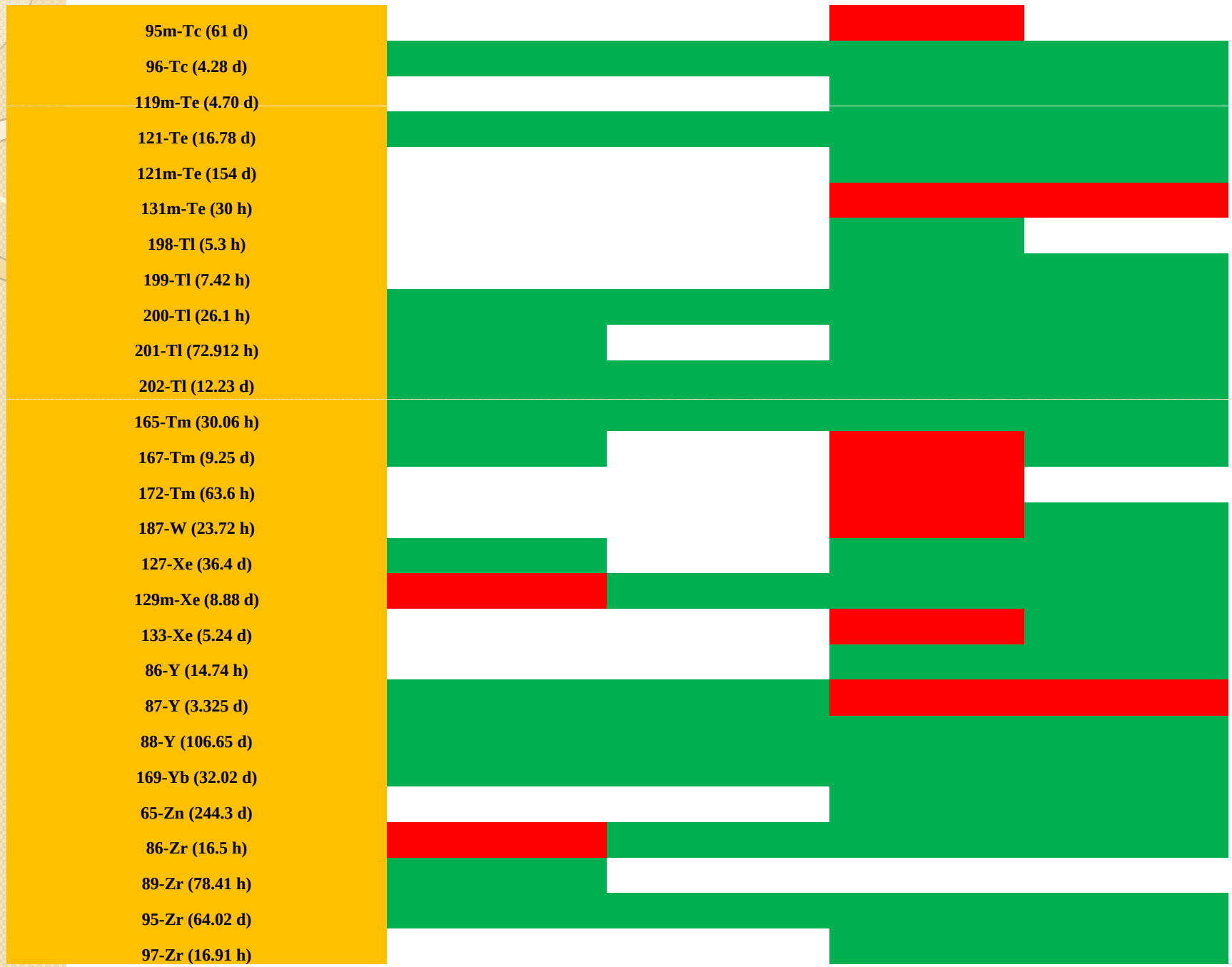
Isotopes ($T_{1/2}$)	Activity (Bq)	Isotopes ($T_{1/2}$)	Activity (Bq)	Isotopes ($T_{1/2}$)	Activity (Bq)
^{74}As (17.77 d)	**130±6**	^{114m}In (49.5 d)	**61±7**	^{85}Sr (64.84 d)	**34±1**
^{131}Ba (11.5 d)	**89±2**	^{171}Lu (8.24 d)	**2507±447**	^{183}Ta (5.1 d)	**1544±125**
^{7}Be (53.12 d)	**236±50**	^{54}Mn (0.85 yr)	**3±0.4**	^{121}Te (16.78 d)	**85±9**
^{205}Bi (15.31 d)	**2783±99**	^{95}Nb (34.975 d)	**150±5**	^{121m}Te (154 d)	**1±0.1**
^{207}Bi (31.55 yr)	**7±0.8**	^{185}Os (93.6 d)	**286±5**	^{202}Tl (12.23 d)	**965±34**
^{139}Ce (137.6d)	**5±0.05**	^{143}Pm (265 d)	**7±0.8**	^{167}Tm (9.25 d)	**517±91**
^{147}Eu (24.1 d)	**308±45**	^{206}Po (8.8 d)	**609±18**	^{127}Xe (36.4 d)	**13±2**
^{149}Eu (93.1 d)	**66±6**	^{188}Pt (10.2 d)	**1753±78**	^{88}Y (106.65 d)	**65±0.8**
^{59}Fe (44.5 d)	**23±1**	^{83}Rb (86.2 d)	**45±1**	^{169}Yb (32.02 d)	**83±6**
^{146}Gd (48.27 d)	**3±0.2**	^{103}Ru (39.26 d)	**71±13**	^{65}Zn (244.3 d)	**4±0.9**
^{149}Gd (9.28 d)	**145±9**	^{46}Sc (83.8 d)	**7±0.3**	^{95}Zr (64.02 d)	**31±0.7**
^{153}Gd (240.4 d)	**1±0.2**	^{75}Se (119.8 d)	**2±0.1**		
^{172}Hf (1.87 yr)	**3±0.9**	^{117m}Sn (13.6 d)	**11±4**		

Comparison on the presence of Radioisotopes in various samples

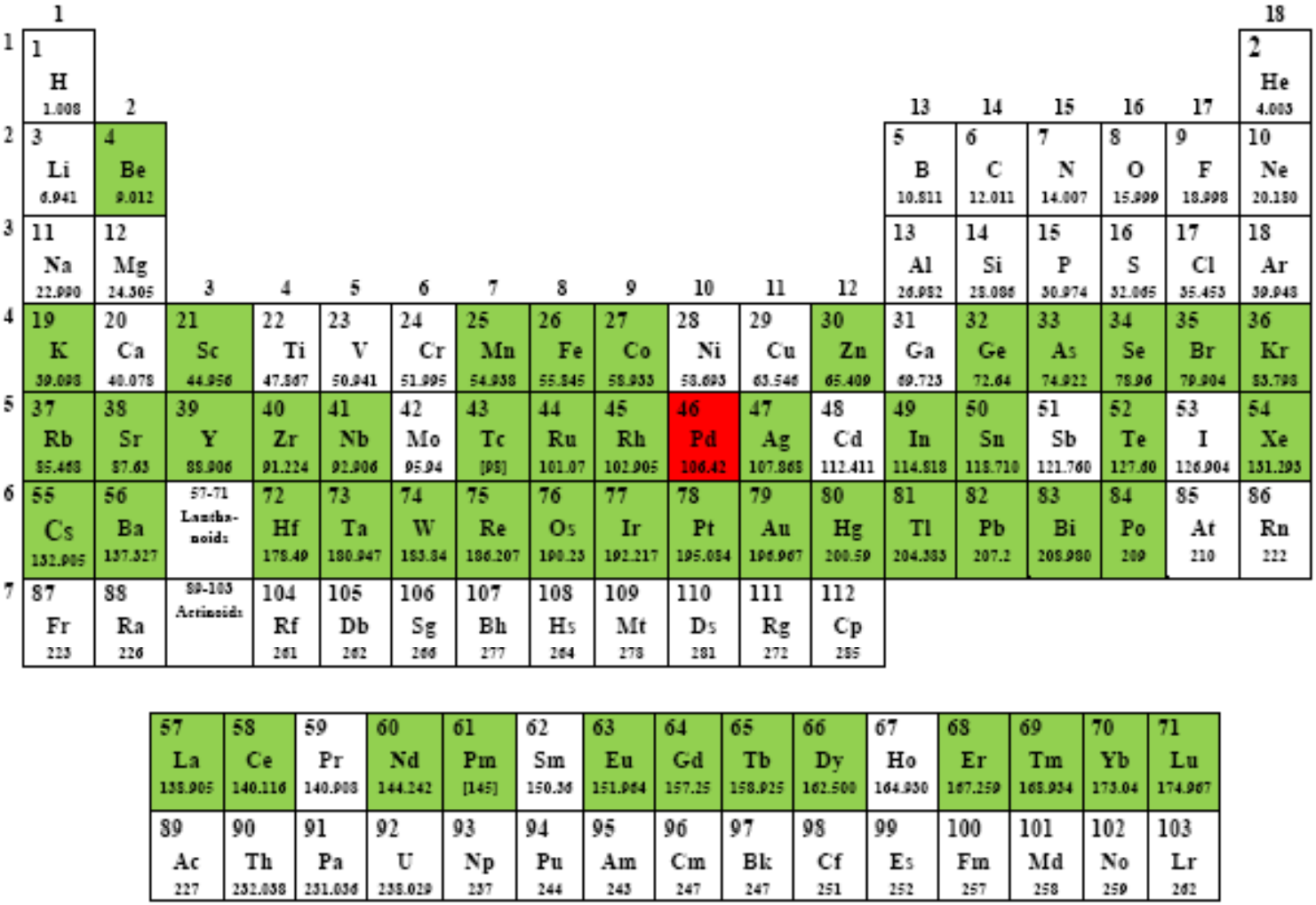

58-Co (70.86 d)
60-Co (5.27 yr)
127-Cs (6.25 h)
129-Cs (32.06 h)
153-Dy (6.4 h)
157-Dy (8.14 h)
171-Er (7.516 h)
146-Eu (4.61 d)
147-Eu (24.1 d)
149-Eu (93.1 d)
59-Fe (44.5 d)
69-Ge (39.05 h)
77-Ge (11.30 h)
146-Gd (48.27 d)
147-Gd (38.06 h)
149-Gd (9.28 d)
153-Gd (240.4 d)
170-Hf (16.01 h)
171-Hf (12.1 h)
172-Hf (1.87 yr)
173-Hf (23.6 h)
193m-Hg (11.8 h)
195m-Hg (41.6 h)
197-Hg (64.14 h)
203-Hg (46.59 d)
111-In (2.8047 d)
114m-In (49.5 d)
185-Ir (14.4 h)

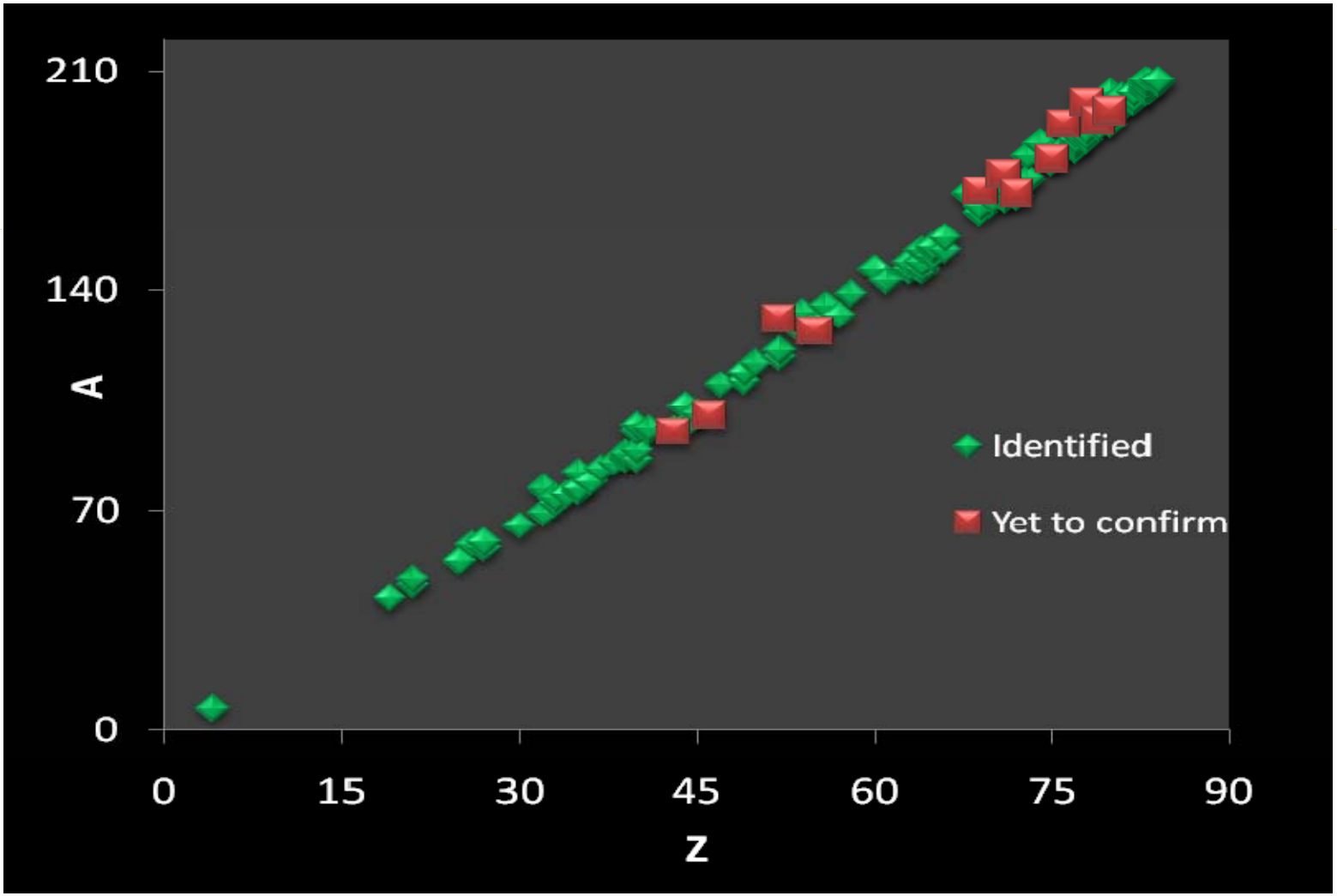

186-Ir (16.64 h)
187-Ir (10.5 h)
188-Ir (41.5 h)
190m2-Ir (3.25 h)
195m-Ir (3.8 h)
42-K (12.360 h)
79-Kr (35.04 h)
132-La (4.8 h)
169-Lu (34.06 h)
170-Lu (2.012 d)
171-Lu (8.24 d)
172-Lu (6.70 d)
173-Lu (1.37 yr)
177-Lu (6.64 d)
54-Mn (0.85 yr)
95-Nb (34.975 d)
96-Nb (23.35 h)
147-Nd (10.98 d)
185-Os (93.6 d)
193-Os (30.11 h)
200-Pb (21.5 h)
201-Pb (9.33 h)
203-Pb (51.873 h)
100-Pd (3.63 d)
143-Pm (265 d)


206-Po (8.8 d)
207-Po (5.80 h)
188-Pt (10.2 d)
189-Pt (10.87 h)
191-Pt (2.802 d)
200-Pt (12.5 h)
83-Rb (86.2 d)
181-Re (19.9 h)
182-Re (64.0 h)
182m-Re (12.7 h)
183-Re (70.0 d)
100-Rh (20.8 h)
101m-Rh (4.34 d)
97-Ru (2.9 d)
103-Ru (39.26 d)
46-Sc (83.8 d)
48-Sc (43.67 h)
75-Se (119.8 d)
117m-Sn (13.6 d)
85-Sr (64.84 d)
175-Ta (10.5 h)
176-Ta (8.09 h)
183-Ta (5.1 d)
151-Tb (17.60 h)
153-Tb (2.34 d)
154-Tb (21.5 h)


95m-Tc (61 d)
96-Tc (4.28 d)
119m-Te (4.70 d)
121-Te (16.78 d)
121m-Te (154 d)
131m-Te (30 h)
198-Tl (5.3 h)
199-Tl (7.42 h)
200-Tl (26.1 h)
201-Tl (72.912 h)
202-Tl (12.23 d)
165-Tm (30.06 h)
167-Tm (9.25 d)
172-Tm (63.6 h)
187-W (23.72 h)
127-Xe (36.4 d)
129m-Xe (8.88 d)
133-Xe (5.24 d)
86-Y (14.74 h)
87-Y (3.325 d)
88-Y (106.65 d)
169-Yb (32.02 d)
65-Zn (244.3 d)
86-Zr (16.5 h)
89-Zr (78.41 h)
95-Zr (64.02 d)
97-Zr (16.91 h)

Elements identified in the Periodic Table




210
140
70
0
A
0
15
30
45
60
75
90
Z
Identified
Yet to confirm

Remarks

- **Radioisotopes identified in the samples ranged from 7-Be (53.12 d) to 207-Po (5.8 h) in the Periodic Table.**

- **The total number of identified radioisotopes in all the four samples are 112. Apart from this, there are 12 more radioisotopes which could not be confirmed due to overlap of photo-peaks and similar half life for different radionuclides.**

- **Most of the radioisotopes identified in the samples belongs to 4^{th}, 5^{th} and 6^{th} Period.**

- **The formation of Po radionuclides is confirmed in the samples. But there is no sign of formation of At radioisotopes in the samples.**

Remarks

- **The modes of production of the radionuclides are mainly fission, electron capture decay of the fission products, fragmentation, spallation, etc,. Also, typical reactions can be found in thick targets like 209Bi(p,pi-xn)210-xPo or 206Pb(alpha,xn)210-xPo.**
- **The activity of the long lived radionuclides at the End Of Beam (EOB) in the experimental condition have been calculated.**
- It has been difficult to calculate the activity of short lived radionuclides, because of high Compton background in the initial spectra.

ılts:

roduction of ^{210}At ($T_{1/2}$ = 8.3 h)

ength of BE target	Intensity of proton beam	Time of irradiation	Time elapsed before first measurement	^{210}At
8 mm	3.22 E+13	3 s	26 h	No signature
7 mm	3.26 E+13	3 s	27 h	No signature
6 mm	3.40 E +13	3 s	26 h	No signature
5 mm	3.43 E +13	3 s	28 h	No signature
4 mm	3.00 E+13	1 s	30 h	No signature

The complex process of production of $^{204-210}$At was bserved earlier in LBE targets of **20 cm length and 1 cm dius** (Tall et al., Int. Conf. on Nuclear Data for Science and echnology, 2007)

In the present experiment maximum length of the ample was **0.8 cm**. No ^{210}At was observed in any f the samples. Therefore release of At through ^{09}Bi(p, π^-xn)^{210}At might be a thick target henomenon, and not observed in thinner targets s used in present experiment.

Thank you