High Power Targets – Task 1

- Proposal
- Deliverables
- Summary of the state-of-the-art about High Power Targets
- Conclusions
ECOS-task 1 Proposal

Description

Task 1 High-power thin-target technology (participants: CNRS + GANIL+GSI)

The maximum usable primary-beam current with thin targets is among others determined by the long-term stability of the thin targets under irradiation. High beam intensities lead to a considerable heating of the targets, and, hence to thermal stress, possibly phase transitions, oxidation or reduction of the chemical compounds and diffusion into the target backing, respectively.

We propose to study these phenomena in detail and to compare for example the performance of thin actinide targets as function of the production method (painting, spray-painting, electrolysis, electro-deposition, evaporation and sputtering), the used chemical compounds (oxide, carbide, others) and backings/coatings, respectively.

The way is to bring together labs that use different techniques for target preparation and those that can test the target performance under “real” conditions.

For this task ECOS will have the duty to organize the collaboration and exchange of expertise on the development of high-power target technology.

✓ Manufacturing of targets
✓ Availability of target materials
ECOS-task 1 Deliverables

**Deliverables**
D-NA02.1: Report on the development of high-power thin-target technology with special emphasis on new techniques and methods that will allow increasing the primary-beam intensity usable with such targets. [month 40]

- **Chapter 2.3.2** in the written contribution of the ENSAR-ECOS Workshop on FUture Super-Heavy Element Strategy: http://www.ensarfp7.eu/workshops/fushe2012
  “Exploring and Harvesting the Island of stability
  Strategy for near and far future developments in superheavy element research”
  Contributors: B. Lommel, B. Kindler (GSI); J. B. Roberto (ORNL); K. Eberhardt (univ. Mainz)

- First test experiments at GANIL with the S3 prototype target station
### Problematic

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Hot/warm</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E$ (A.MeV); $I$ ($\mu$A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{48}$Ca</td>
<td></td>
<td>$^{70}$Zn</td>
</tr>
<tr>
<td>$5;10$</td>
<td></td>
<td>$5;10$</td>
</tr>
<tr>
<td>Targets</td>
<td>Ti + Cm$_2$O$_3$ (electro-deposition)</td>
<td>C + Pb (Evaporation)</td>
</tr>
<tr>
<td>Thickness ($\mu$g/cm$^2$)</td>
<td>900 (=2µm) + 500</td>
<td>30 + 450</td>
</tr>
<tr>
<td>$dE$ (MeV)</td>
<td>12.3 + 4.2</td>
<td>1.0 + 6.1</td>
</tr>
<tr>
<td>$dP$ (W)</td>
<td>165</td>
<td>71</td>
</tr>
</tbody>
</table>

- Rotating wheels ➔ gas or liquid targets?
- Compound material with higher melting point
- R&D on target manufacturing and study of irradiation damage
## Target stations

<table>
<thead>
<tr>
<th>Lab</th>
<th>GSI</th>
<th>JINR</th>
<th>RIKEN</th>
<th>GANIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerator</td>
<td>UNILAC (pulsed, 25% duty cycle)</td>
<td>U-400R</td>
<td>DC-280</td>
<td>CSS1</td>
</tr>
<tr>
<td>Separator</td>
<td>TASCA</td>
<td>SHIP</td>
<td>DGFRS</td>
<td>GARIS</td>
</tr>
<tr>
<td>Beams</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I (µA)</td>
<td>1 – 2</td>
<td>2.5</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Isotopes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>244Pu, 243Am, 249Bk, 249Cf</td>
<td></td>
<td>206,208Pb, 209Bi, 238U, 248Cm</td>
<td>245,246,248Cm, 242,244Pu, 243Am, 249Cf, 249Bk</td>
<td>208Pb, 209Bi</td>
</tr>
<tr>
<td>Thickness (µg/cm²)</td>
<td>500-700</td>
<td>300-400</td>
<td>450</td>
<td>350</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>6</td>
<td>30 or 3 (for Cm)</td>
<td>8</td>
<td>7.85</td>
</tr>
<tr>
<td>Wheel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed (rpm)</td>
<td>2249</td>
<td>1125</td>
<td>2000</td>
<td>3000</td>
</tr>
<tr>
<td>Radius (cm)</td>
<td>5</td>
<td>15.5</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Number targets</td>
<td>4</td>
<td>8</td>
<td>6</td>
<td>16</td>
</tr>
</tbody>
</table>

→ Beam spot size: gaussian → rectangular
→ Limits of Φ (mm)? w (rpm)?
Target Stations

ω = 1700 rpm

310 μg/cm² BkO₂
on 1.5 μm-Ti foil

120 mm

Yu. Oganessian 2010
Thin foils - requirements

- 500 μg/cm² ±2% over active area from 3 to 15 cm²
- High chemical purity of the material (reduce unwanted reaction products)
- For expensive material, recovery of the used material
- High fabrication yields
- Small, simple, reproducible set-up of process
Thin foils – stable material

- Mainly deposition on carbon foils by evaporation process
- For U: magnetron sputtering on Ti or C backings
- Compounds with higher melting points
- Target laboratories in Europe:
  - SHE: GSI; IPNO; (GANIL);
  - Other physics: SLCJ Varsow (Poland); HHNIPNE –IFIN HH (Roumania); STFC Daresbury (UK)

Ref: B. Lommel et B. Kindler, Encyclopedia of Applied High energy and Particle Physics (2009) 619
B. Lommel et al, NIMA 480 (2002) 16-21
Thin foils - Actinides

Supplier

✓ Oak Ridge National Laboratory as part of the Department of Energy’s (DOE) Office of Nuclear Physics Isotope Development and Production for Research and Applications Program:

✓ Pu, Am, Cm, Cf, Bk (➡ Z=113-118 @JINR)
✓ Production facility + chemical separation + purification: High Flux Isotope Reactor (HFIR) + Radiochemical Engineering Development Center (REDC)
✓ $^{249}$Bk (≈80 mg) with pure $^{248}$Cm + thermal neutron filtering
✓ $^{251}$Cf (1 mg/h) @ EMIS project ➡ 40µg of $^{254}$Es

The Bk-249 was produced at ORNL (USA) by irradiation: of Cm and Am targets for approximately **250 days** by thermal-neutron flux of **$2.5 \times 10^{15}$ neutrons/cm²·s** in the HFIR (High Flux Isotope Reactor).

**Irradiation ended**

**December 2008**
Thin foils - Actinides

Fabrication methods

☑️ Electro-deposition on Ti (2 µm) backings by molecular plating
☑️ To be tested: Polymer-assisted deposition, E-D with ionic liquids, super-hydrophobic surfaces or inter-metallic targets
☑️ Target laboratories in Europe:
   SHE: Univ. Mainz; CACAO@IPNO;

M.A. Garcia et al, NIMA 613 (2010) 396-400;
D. Renish et al, NIMA 676 (2012) 84-89;
I. Usoltsev et al, NIMA 691 (2012) 5-9;
C.-O. Bacri et al, NIMA 613 (2010) 357-359
Thin foils - Characterization

- Characterize physical parameters: layer thickness and homogeneity
- Understanding the process of deposition
- Existing modern analytical techniques: XRF (X-ray fluorescence), XRD (X-ray Diffraction), XPS (X-ray Photonelectron Spectrometry), SEM (Scanning Electron Microscopy), AFM (Atomic Force Microscopy)
- Labs: Univ. Mainz, IRMM, LMU


Radiographic images of a $^{232}$Th-Target produced by PVD @ LMU (J. Szeripo)

J. Piot - ECOS Town meeting 2014 - Orsay, 2014 28th October
High intensity target wheel at TASCA: target wheel control system and target monitoring

E. Jäger · H. Brand · Ch. E. Düllmann · J. Khuyagbaatar · J. Kriier · M. Schädel · T. Torres · A. Yakushev

![Graph](image1)

**Fig. 6** Target temperature as registered by the pyrometer as a function of the beam intensity. The real maximum temperature may be higher distributed. The new TASCA target wheel has an array

![Image](image2)

**Fig. 7** The $^{249}$Cf target wheel after the bombardment with the $^{50}$Ti beam dose of $1 \times 10^{19}$
Test bench @ GANIL

- Prototype S³ Target station @ LISE2000
  - Trick: getting equivalent dP/dV
  - Heavy ion beam $\rightarrow$ $\Delta E*$2 or 3
  - $\sigma_y$ smaller

<table>
<thead>
<tr>
<th>Beam</th>
<th>$^{48}$Ca</th>
<th>$^{70}$Zn</th>
<th>$^{129}$Xe</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (A.MeV); I (μA)</td>
<td>5;1</td>
<td>5;1</td>
<td>7.7;0.1</td>
</tr>
<tr>
<td>$\sigma_x*\sigma_y$(mm²)</td>
<td>0.5*2.5</td>
<td>0.5*2.5</td>
<td>1.7*1.15</td>
</tr>
<tr>
<td>$\Phi$wheel (mm)</td>
<td>160</td>
<td>670</td>
<td>160</td>
</tr>
<tr>
<td>Targets</td>
<td>Ti + Cm$_2$O$_3$</td>
<td>C + Pb</td>
<td>Ti + Gd$_2$O$_3$</td>
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<td>Thickness (µg/cm²)</td>
<td>900 + 500</td>
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</tr>
<tr>
<td>$dE$ (MeV)</td>
<td>12.3 + 4.2</td>
<td>1.0 + 6.1</td>
<td>43.5 + 18.6</td>
</tr>
<tr>
<td>$dP/dV_{circ}$(W/mm³)</td>
<td>1.66 + 1.90</td>
<td>0.49 + 0.99</td>
<td>1.28 + 0.88</td>
</tr>
</tbody>
</table>
Test bench @ GANIL

2 wheels
Φ=160 mm
ω up to 5000 rpm
12 targets on each wheel
Test bench @ GANIL
  • Experimental set-up tested and to be upgraded
  • tests with different material produced by various techniques (Orsay, Germany ...)

C. Stodel et al, INTDS14, to be published JRNC

J. Piot - ECOS Town meeting 2014 - Orsay, 2014 28th October
Meetings for knowledge exchange and expertise of targets labs

• **Since 2007**: Discussion with GSI/Mainz (S. Hofmann, July 10, Cm targets at GSI-SHIP; C. Dülmann, K. Eberhardt, M. Schaëdel)

• **October 2009**: Discussion on targets for S3: Institut Kernchemie, Mainz (K. Eberhardt, J. Kratz, J. Runke), GSI (B. Lommel, C. Düllmann), LBL (H. Nitsche), CACAO (Ch. O. Bacri, V. Petitbon), GANIL (H. Savajols, Ch. Stodel)

• **November 2010**: Orsay (CO Bacri) with IRMM, Mainz, GSI (presentation of each labs, requests, manpower...)

• **INTDS conferences** (2010, 2012, 2014)

**Conclusions:**

European needs (SHE, astrophysics, fuel cycle...), common questions about the behavior of targets (depending on backings) under irradiation, supply, R&D for fabrication of larger targets, why not common targets???

How to organize together? Enlarge the know-hows, sharings of skills....
CONCLUSIONS

✓ Target stations with present technology (wheels)
  ✓ Soon limited to the beam intensities: 10 pµA ? More ?
  ✓ Common aspects ➔ why not going to a “common design” of targets/wheels ?
✓ Other systems ? Liquid / gas targets R&D ?
✓ Actinide material supply scarce/expensive
✓ R&D on target (stable and actinide) fabrication feasible and needed: alternative backing materials; existing community but not so large
✓ Characterization of targets to be developed (pre- and post-irradiation)
✓ In beam tests possible ➔ chemistry + material + nuclear physics synergia
CONCLUSIONS

- Knowledge exchange and expertise of targets lab
- Feedback from target irradiations (GSI, Dubna...)
  - Joint effort of labs necessary with interdisciplinary
  - Close collaboration between target makers, target users and accelerator specialists.