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

Reaction		Hot/warm	Cold
Beam		^{48}Ca	^{70}Zn
	E (A.MeV); I (pµA)	5;10	5;10
Targets		$Ti + Cm_2O_3$ (electro-deposition)	C + Pb (Evaporation)
	Thickness (µg/cm²)	900 (=2µm) + 500	30 + 450
	dE (MeV)	12.3 + 4.2	1.0 + 6.1
	dP(W)	165	71

→ **Rotating wheels → gas or liquid targets ?**
→ **Compound material with higher melting point**
→ **R&D on target manufacturing and study of irradiation damage**

Target stations

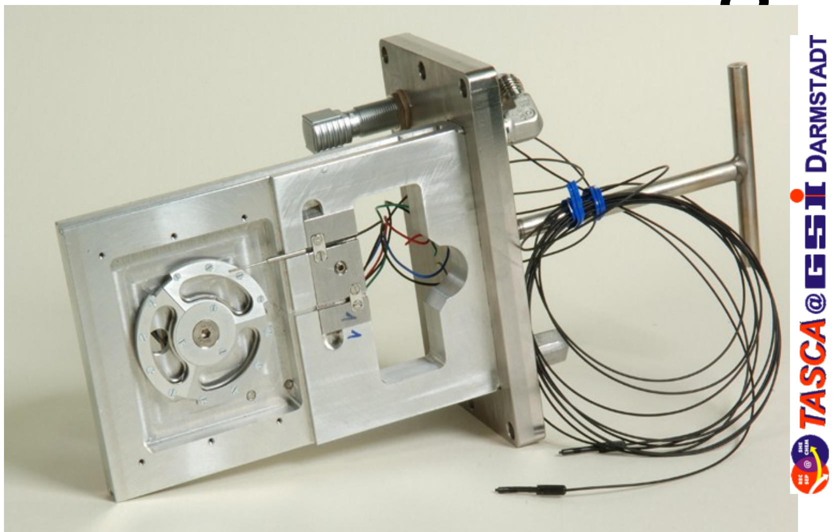
Lab	GSI		JINR		RIKEN	GANIL		
Accelerator	UNILAC (pulsed, 25% duty cycle)		U-400R	DC-280		CSS1	LINAC	
Separator	TASCA	SHIP	DGFRS		GARIS	FULIS, LISE 3	S3	S3
Beams			^{48}Ca	^{48}Ca	^{64}Ni, ^{70}Zn		^{48}Ca	^{70}Zn
I (pµA)	1 – 2		2.5	10	1	0.5-2	5-10	2-5
Isotopes	^{244}Pu, ^{243}Am, ^{249}Bk, ^{249}Cf	^{206,208}Pb, ^{209}Bi, ^{238}U, ^{248}Cm	^{245,246,248}Cm, ^{242,244}Pu, ^{243}Am, ^{249}Cf, ^{249}Bk		^{208}Pb, ^{209}Bi	^{208}Pb, ^{209}Bi	Am, Cm, Pu…	Pb, Bi
-Thickness(µg/cm^2)	500-700		300-400		450	350	450	450
-Area (cm^2)	6	30 or 3 (for Cm)	8		7.85	15	~8	21
Wheel								
-Speed (rpm)	2249	1125	2000		3000	2000	5000	3000
-Radius (cm)	5	15.5	5		15	33.5	8	33.5
-Number targets	4	8	6		16	18	12	18

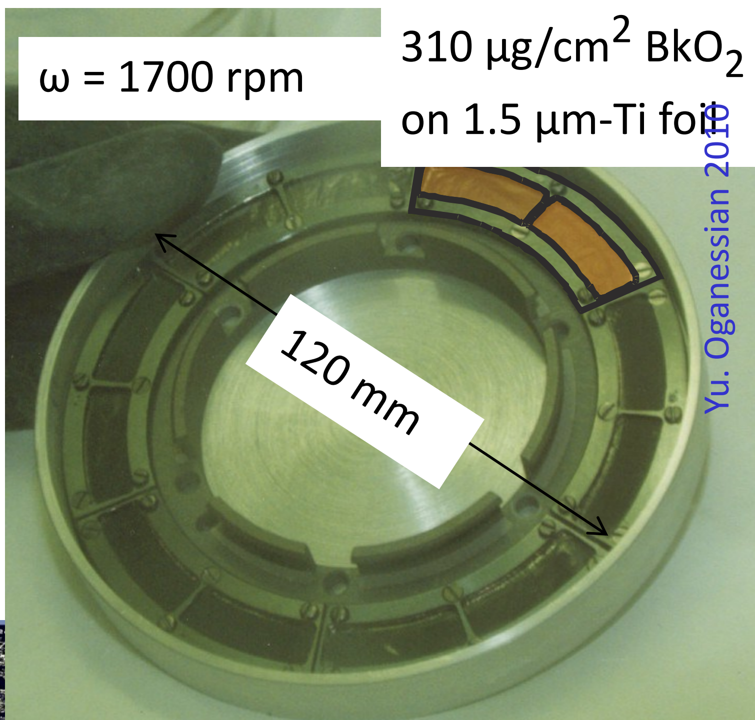
➔ **Beam spot size: gaussian ➔ rectangular**

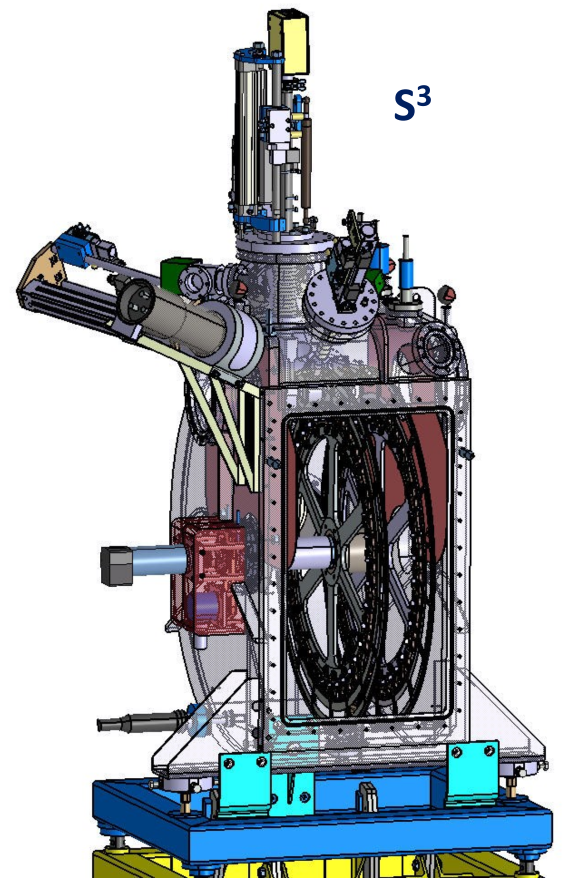
➔ **Cooling ?** (S. Antalic et al, NIMA 530 (2004)185-193)

➔ **Limits of Φ (mm)? w (rpm)?**

Target Stations







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

B. Kindler et al, NIMA 561 (2006) 107-111

Thin foils - Actinides

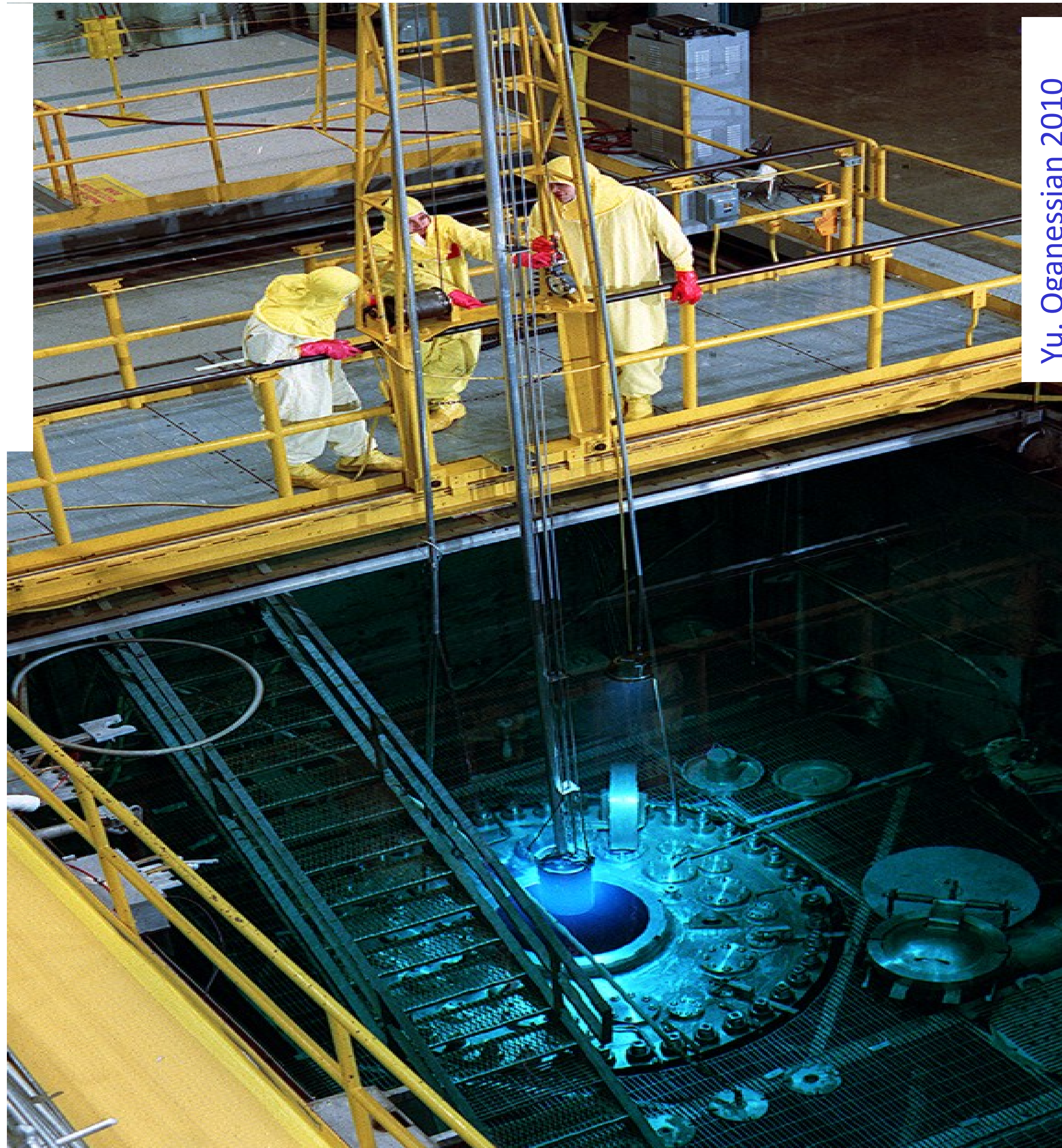
Supplier

- ✓ 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

  Ref: J. B.Roberto et al, "Actinide Isotopes for Synthesis of Superheavy Nuclei," 5th International Conference of Fission and Properties on Neutron-Rich Nuclei, Sanibel Island, Florida, November 4-10, 2012

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

Irradiation ended
December 2008



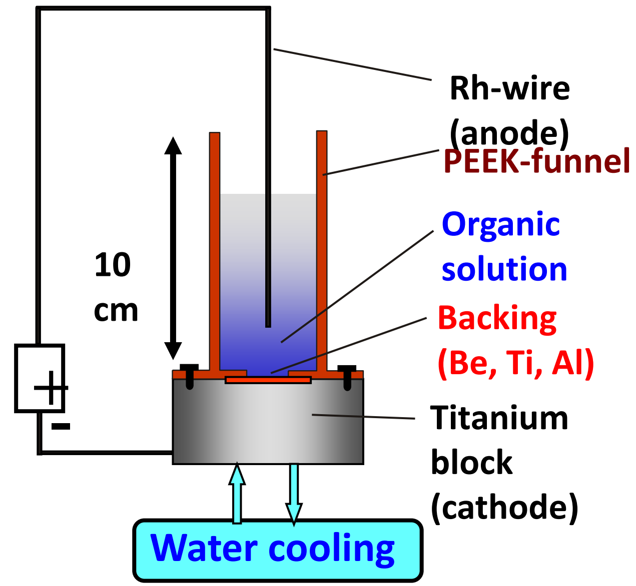
Yu. Oganessian 2010

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;

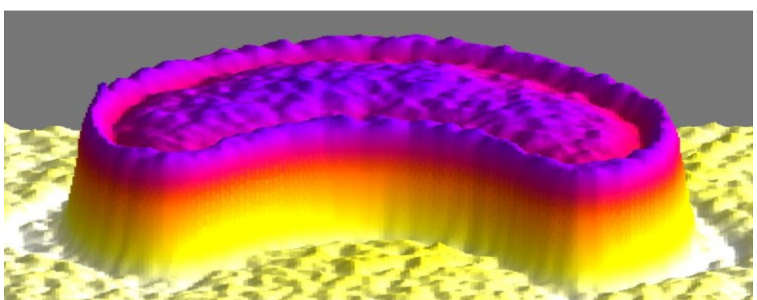


Ref: K. Eberhardt et al, NIMA 590 (2008) 134-140;
M.A. Garcia et al, NIMA 613 (2010) 396-400;
D. Renish et al, NIMA 676 (2012) 84-89;
I.Usoltsev et al, NIMA 691 (2012) 5-9;
C.-O. Bacri et al, NIMA 613 (2010) 357-359

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

Ref: D. Liebe et al NIMA 590 (2008) 145-150



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

D. Liebe et al. / Nuclear Instruments and Methods in Physics Research A 590 (2008) 145 150 147

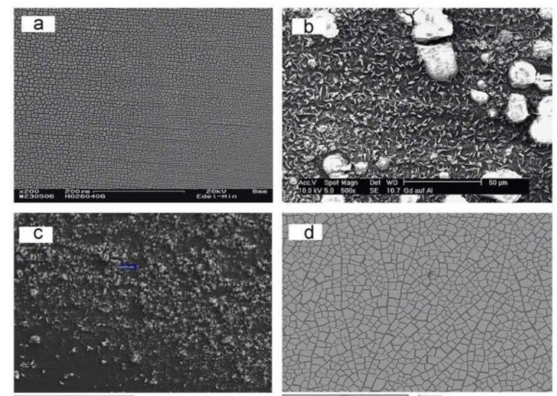


Fig. 2. Scanning electron micrographs of (a) Ho (on Ti, 200 ×, 20 kV), (b) Gd (on Al, 500 ×, 10 kV), (c) Sm (on Ti, 200 ×, 20 kV), and (d) U (on Ti, 200 ×, 20 kV).

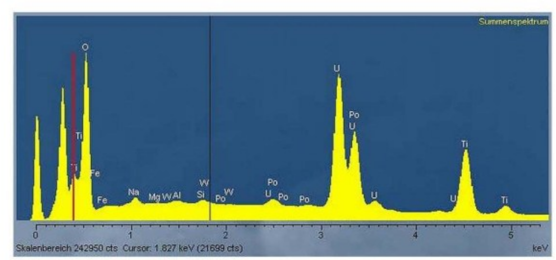


Fig. 3. EDX spectrum of U on a Ti backing.

Thermal measurements

J Radioanal Nucl Chem (2014) 299:1073–1079
DOI 10.1007/s10967-013-2645-1

High intensity target wheel at TASCA: target wheel control system and target monitoring

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

1078 J Radioanal Nucl Chem (2014) 299:1073–1079

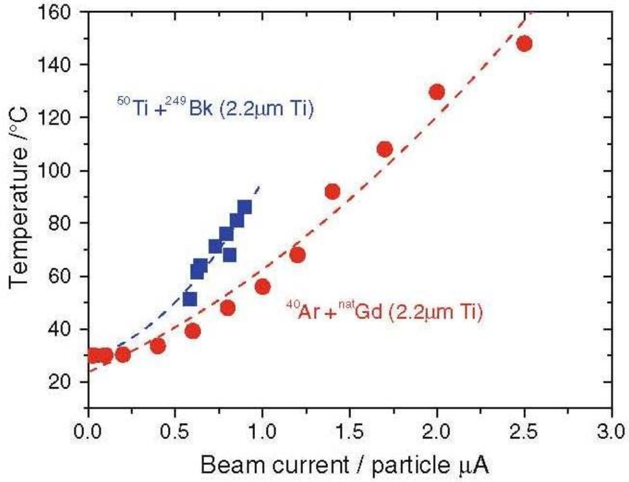


Fig. 6 Target temperature as registered by the pyrometer as a function of the beam intensity. The real maximum temperature may be higher

distributed. The new TASCA target wheel has an approx-

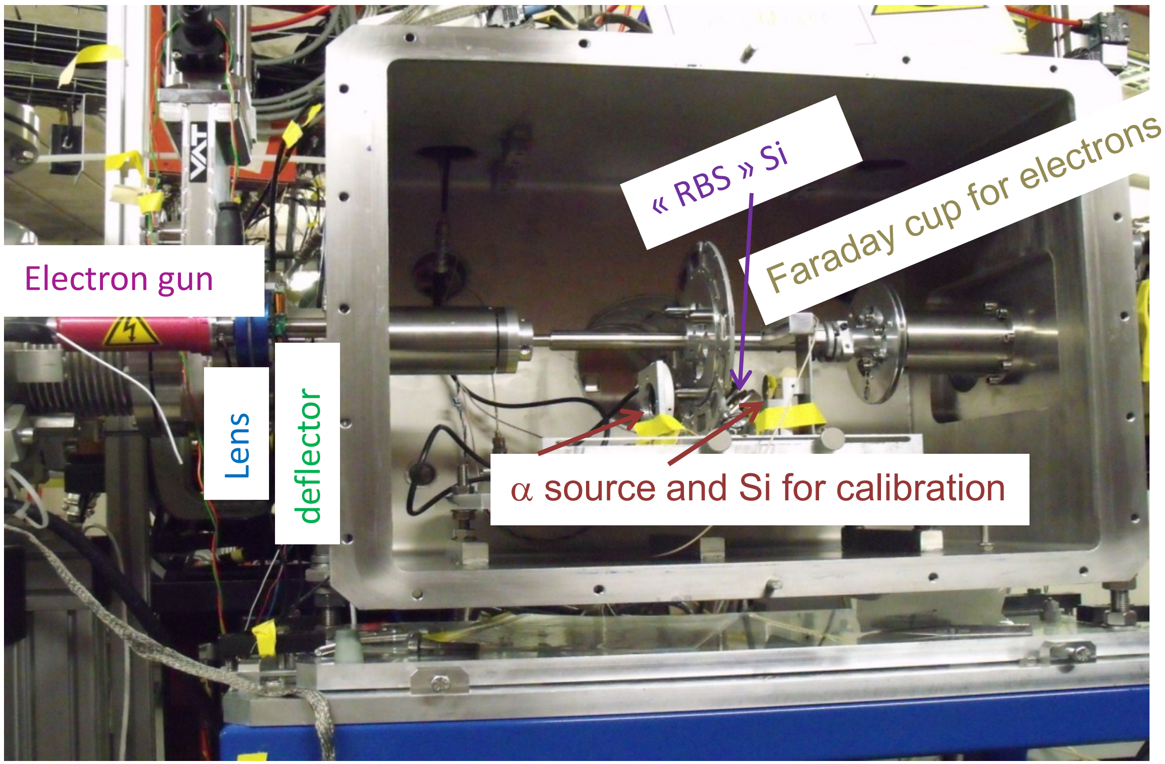
Fig. 7 The ^{249}Cf target wheel after the bombardment with the ^{50}Ti beam dose of 1×10^{19}

Test bench @ GANIL

- Prototype S^3 Target station @ LISE2000
  - Trick: getting equivalent dP/dV
    - Heavy ion beam ➔ ΔE*2 or 3
    - σ_y smaller

Beam	^{48}Ca	^{70}Zn	^{129}Xe	
E (A.MeV); I (pμA)	5;1	5;1	7.7;0.1	
σx*σy(mm²)	0.5*2.5	0.5*2.5	1.7*1.15	
Φwheel (mm)	160	670	160	
Targets	Ti + Cm_2O_3	C + Pb	Ti + Gd_2O_3	C + Sn
Thickness (μg/cm²)	900 + 500	30 + 450	900 + 500	30 + 450
dE (MeV)	12.3 + 4.2	1.0 + 6.1	43.5 + 18.6	2.0 + 15
dP/dV_{circ}(W/mm³)	1.66 + 1.90	0.49 + 0.99	1.28 + 0.88	0.93 + 1.46

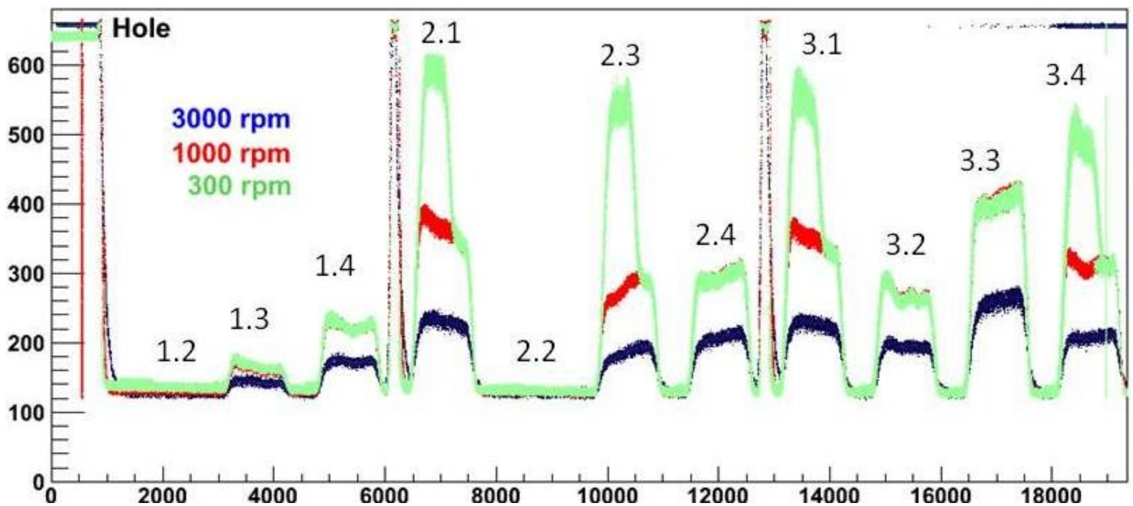
Test bench @ GANIL

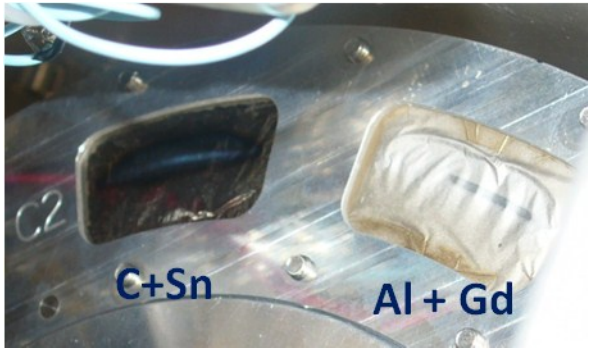


2 wheels
Φ=160 mm
ω up to 5000 rpm
12 targets on each wheel

Test bench @ GANIL

– Few UTs in 2011, 2012, next end November 2014
  - 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

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: Intitut 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.