Target developments/target lab (incl. actinide targets)

Christelle Stodel, GANIL
Outline

1. GANIL/SPIRAL2 Context & New challenges
2. GANIL Target Activities:
   a. Existing Target lab
   b. Updating target lab
   c. Investigation of external potentials
   d. Project « Target Lab »
3. Actinide Activities
   a. Requirements
   b. Project « Actinide Targets »
4. Collaborations
5. Conclusions
1. GANIL/SPIRAL2 Context & new challenges
Mg, Ti, Ni, Au 2-5 mg/cm²

Au, Fe 200-600 µg/cm²….

U 600 µg/cm²
Au 90 µg/cm²

C 236 mg/cm²
Au 320mg/cm²

Liquid H 7 mg/cm²

CD₂/CH₂ 1-2 mg/cm²

C, Ni, Sn, Ta, Au, Ca… 0,02-10 mg/cm²

Pb, Bi, Sn, Yb 0,3-0,6 mg/cm²
+C 30-50 µg/cm²

Gas ¹H, ³⁴He, ¹⁰F
X 10⁻²⁰ at/cm²

Courtesy V. Watt-Morel, JC Thomas, Q. Delignac, N. Leneindre, T. Roger, P. Jardin
- \( n + Ce, ^{A}Pb, ^{A}Sn, Ni, C \): ~ cylinder of 4 cm diameter, weight = 250 g, thickness = 3 cm
- \( n + \text{actinides} \)

- Converters: Be, Li
- Activation targets
- Radioisotopes: \((p,d,\alpha) + Bi \ (70\mu m)\)…

- Targets @ S\(^3\) for commissioning – 2024-25
  \( ^{116}\text{Sn}, ^{144,148}\text{Sm}, ^{160, 164}\text{Dy}, ^{60}\text{Ni}, ^{45}\text{Sc}, ^{170}\text{Er}, ^{174}\text{Yb}, ^{180}\text{Hf}, ^{160}\text{Gd}, ^{184,186}\text{W} \& ^{181}\text{Ta} \)

- Targets @ S\(^3\) for 1\(^{st}\) day …. Experiments – 2025-XXX
  - Low Energy Branch (0.5 – 1 mg/cm\(^2\))
    \( ^{50}\text{Cr}, ^{58}\text{Ni}, ^{175}\text{Lu}, ^{180}\text{Hf}, ^{208}\text{Pb}, ^{238}\text{U} \)
  - SIRIUS – 300-500 \(\mu g/cm^2\)
    \( ^{204}/^{207/208}\text{Pb}, ^{209}\text{Bi}, ^{238}\text{U} \)

- Future: Actinide targets

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Courtesy J.C. Foy, M. Michel
Why a high - quality Target is needed?

- Astrophysics: Cross-section of key isotopes for s-process determined with uncertainties of about 1%
- Standards database requested by the IAEA: cross-section data with uncertainties below 1%
- Fuel cycle, criticality safety studies of spent fuel storages and transportation: total and capture cross-sections requested with an uncertainty less 2%
- Thorium-Uranium fuel cycle: neutron-induced capture cross-section of $^{232}$Th with an uncertainty better than 2%

$\sigma_f^{meas} = \sigma_f^{238U} + \alpha(\%) \times \sigma_f^{235U} + \beta(\%) \times \sigma_f^{239Pu}$

$587.6 (\pm 2.6) \mu{barns}$

$741.9 \text{ barns}$

$2^{238U}$ samples with 170 or 12 ppm $^{235U}$

$P.\text{Schillebeeckx et al., NIMA 613 (2010) 378-385}$

Why a high-quality Target is needed?

Ex: Fusion-evaporation

Thickness & homogeneity $\rightarrow$ ions Kinematics
$\rightarrow$ Optimal tuning of the spectrometer:
transmission of desired residues
and control of unwanted particles
$\rightarrow$ Accuracy ($< 5\%$)

$\llbracket$ Robust $\rrbracket$ - Long $\llbracket$ lifetime $\rrbracket$
Why a high-quality Target is needed?

$^{18}\text{O} + ^{64}\text{Ni} @ 39 \text{ MeV but also } ^{18}\text{O} + ^{16}\text{O} (*)$

(γγ – total projection)

Thermal treatment to remove oxygen with an Hydrogen Oven

$(0 + \text{H}_2 = \text{H}_2\text{O})$
New Challenges for targets

Larger sizes
Larger quantity
New Z Target
Higher quality

Commercial if not isotopic
To be made with specific technics

Successful experiment
= Accurate measurements + low background + safe conditions
→ Need of high quality targets with known properties at any time
2. GANIL Targets Activities
   a. Existing Target lab
   b. Updated Target Lab
   c. investigation of external potentials
   d. Project « Target Lab »
G. Frémont: training and skills in target preparation using « physical methods » & Recovery of material from the Strasbourg Target Laboratory in 2004
a. Existing lab & skills

**Mechanical Shaping**

- **Tablet pressing**
  - ~20 mg/cm² → g/cm²

- **Rolling**
  - 0.5 mg/cm² → g/cm²

Press for pellets:
- Metallic powders before evaporation
- Mixture of powders (i.e. oxyde element + reductant) before evaporation
- Thick targets

2 Rolling mills
  - Manual for common metals
  - Motorized for fragile material to be worked under inert atmosphere in glove box


a. Existing lab & skills

Deposition by evaporation
Resistive Heating of carbon
Heating of crucible or material

I-1/ Evaporator for carbon sublimation
Strippers or backings for material deposition.
Thickness: 10 - 70µg/cm²
Surface: 20 X 20 cm

One evaporation =
• 8 glass plates: (100*140) mm², 35 µgr/cm²
• 16 C strippers or 24 C backing

P. Maier-Komor, NIM 102 (1972) 485-486
a. Existing lab & skills

**Deposition by evaporation**

- **Resistive Heating of carbon**
- **Resistive Heating of crucible**
- **Electron heating of crucible**
- **Electron heating of material**

**Tech-Evap 1:** Resistive Heating of the crucible

**Tech-Evap 2:** Electron Heating of the material

**Tech-Evap 3:** Electronic bombardment of the crucible $I_{fil} \rightarrow e^- + dV \rightarrow dP$

- **Backing must not interfere with the nuclear reaction used** ⇒ **Use high purity material**
- **Backing must not interact with the target material**
a. Existing lab & skills

**Deposition by evaporation**

- Resistive Heating of carbon
- Resistive Heating of crucible
- Electron heating of material
- Electron heating of crucible

1.2.a / Evaporator for metals, isotopes with low melting point
Yield = 23% for Bi\(^{208}\)Pb

Optimizing distances crucible/backings, choice of crucible form & nature, temperature of backing...

*Tech-Evap 1: Resistive Heating of the Crucible*

**a. Existing lab & skills**

**Deposition by evaporation**

- Resistive Heating of carbon
- Resistive Heating of crucible
- Electron heating of crucible
- Electron heating of material

1.2.b / **Evaporator with electrostatic focused electrons (EFe-)**

- Thickness ~100s nm
- High melting point materials, oxides → reduction for metallic deposit
- Efficient for low abundance isotopes

**Tech-Evap 3: Electronic bombardment of the crucible**

\[ I_{\text{fil}} \rightarrow e^- + dV \rightarrow dP \]

L. Westgaard et al, Nucl. Inst. Meth. 42 (1966) 77-81
a. Existing lab & skills

**Deposition by evaporation**

- Resistive Heating of carbon
- Resistive Heating of crucible
- Electron heating of crucible
- Electron heating of material

1.2.c / **Evaporator with electron gun (3 kW or 6 kW)**

- Thickness > 1 µm
- High melting point materials

Prevent chemistry reaction with crucible according to temperature

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Tech-Evap 2: Electron Heating of the material

a. Other applications, technics & skills

**Deposition by evaporation**
- CD2/CH2 targets

**Polymerisation**

**Preparation of sensitive material**

**Evaporator large dimension**
(diamètre 700 x1500)

Metallisation of thin foils for detectors
- Non interactive emissive foils, Gold on Drift chamber windows, Gold on diamonds

**Molecular Plating**

**Preparation of osmium targets with carbon backing**
Georges Fremont, Yvette Ngono-Ravache et al
AIP Conf. Proc. 1962, 030002-1–030002-4;
https://doi.org/10.1063/1.5035519
a. Other applications, technics & skills

**Characterization**
- Areal density
- Weighting
- Alpha energy loss
- Homogeneity
- Electron transmission

Proof of principle OK
R. Mann, GSI, *patent DE 10242962 A1-GSI*, in prototype S3 station to be repaired
Commercial one on S3 stable station

**Characterization**
- Composition, Surface
- SEM, EDX, ….

CIMAP, LPC, Crismat, Orsay….
b. New Challenges for targets → Updated Lab

Larger quantity

**S3 Irradiation hypothesis/beam time:**

- 3 to 6 months beam time per year
- Experiment 2/3 weeks: 1 isotope « experiment » + 1 isotope « calibration (= commissioning) »
- 1 target wheel (18 targets) irradiated within 5-7 days

→ 3 wheels/experiment + 2 wheels in spare (extreme case, some targets will certainly be reusable)

→ 500-1000 targets/year

**Larger sizes**

$cm^2 \rightarrow 10s \ cm^2$

Bi @ 70 µm

Thick targets

**New Z Target**

**Higher quality**
### Targets for physics

<table>
<thead>
<tr>
<th>Thickness (µg/cm²)</th>
<th>Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 – 500</td>
<td>64Ni, 124Sn, 24Mg, 58,60,64Ni, 208Pb</td>
</tr>
<tr>
<td>1-2</td>
<td>64Zn, 82Se, 24Mg, 208Pb, 90Zr</td>
</tr>
<tr>
<td>8</td>
<td>208Pb / 90Zr</td>
</tr>
<tr>
<td>30</td>
<td>C substrate &amp; Qeq foils * 100s</td>
</tr>
</tbody>
</table>

#### Larger sizes

- New Z Target
- Larger quantity
- Higher quality

b.1 / Metallic targets for physics cases, Bi for radioisotopes ….

→ New evaporators: carbone (strippers, backings) & metals
b. New Challenges for targets → Updated Lab

Larger sizes  Larger quantity  New Z Target  Higher quality

b.2 / Lanthanides

\[ ^{238}\text{U} \]

Actinides → part 3 of this talk

- Targets @ S³ for commissioning + calibration + S3 LEB
- \(^{116}\text{Sn},^{144,148}\text{Sm},^{160,164}\text{Dy},^{60}\text{Ni},^{45}\text{Sc},^{170}\text{Er},^{174}\text{Yb},^{180}\text{Hf},^{160}\text{Gd},^{184,186}\text{W} & ^{181}\text{Ta} \]
- Ex P-process @Lyon: \(^{144,147,149,154}\text{Sm},^{155,158}\text{Gd},^{177,180}\text{Hf} \]
- Various Physics with \(^{238}\text{U} \) targets

→ New evaporator with EFe- heating method & R&D
→ New evaporator with sputtering method (\(^{238}\text{U} + \) monoisotopic materials, oxides, compounds…) & R&D

Project of collaboration with ORANO for \(^{238}\text{U} \) targets
CIME https://www.orano.group/cime/fr

GANIL Community Meeting, Caen, October 20th 2022
<table>
<thead>
<tr>
<th><strong>Physical Deposition</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resistance heating</strong></td>
</tr>
<tr>
<td>• The method is very simple, robust</td>
</tr>
<tr>
<td><strong>but</strong></td>
</tr>
<tr>
<td>• limited to the materials of the low melting point (not higher than 1600 - 1800 °C)</td>
</tr>
<tr>
<td>• and not alloying with the boat material.</td>
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<tr>
<td><strong>E-gun</strong></td>
</tr>
<tr>
<td>• The method is more complex, but extremely versatile.</td>
</tr>
<tr>
<td>• Can achieve temperatures in excess of 3000°C.</td>
</tr>
<tr>
<td>• Use evaporation cones or crucibles in a water cooled copper hearth.</td>
</tr>
<tr>
<td>• Typical emission voltage is 8-10 kV.</td>
</tr>
<tr>
<td><strong>but</strong></td>
</tr>
<tr>
<td>• Exposes substrates to secondary electron radiation.</td>
</tr>
<tr>
<td>• X-rays can also be generated by high voltage electron beam</td>
</tr>
<tr>
<td><strong>Sputtering</strong></td>
</tr>
<tr>
<td>• The method can be applied to the most of the materials except those which can degrade due to ionic bombardment</td>
</tr>
<tr>
<td>• This technology allows to release the deposited material at much lower temperature than evaporation.</td>
</tr>
<tr>
<td>• gives easy film thickness control via time, allows alloy deposition, no x-ray damage</td>
</tr>
<tr>
<td><strong>but</strong></td>
</tr>
<tr>
<td>• requires rather big surface of the sputtered material to avoid bombarding of the cathode material.</td>
</tr>
<tr>
<td>• There is as well big chance for the impurities incorporation due to low vacuum.</td>
</tr>
</tbody>
</table>

Courtesy A. Stolarz
b. New Challenges for targets → Updated Lab

New Z Target

Larger sizes  Larger quantity

Destructive/non destructive
Locally or over the surface

Thicknness

Thickness uniformity

Surface morphology

Surface roughness

TARGET

Isotopic abundances

Identification of impurities

Energy loss
Precise analytical balance
Spectrophotometry

*Low geometry α-particle (LGA)
*Radiographic Imaging (RI)

Rutherford Back Scattering (RBS)
Electron attenuation
PhotoElectron Spectroscopy (XPS)
Energy Dispersive X-Ray Spectroscopy (EDS)
Particle Induced X-ray Emission (PIXE)
Particle Induced γ-ray Emission (PIGE)

Thermal Ionization Mass Spectroscopy (TIMS)

Neutron Activation Analysis (NAA)

Echantillon de la solution lors de sa préparation

During irradiation

b. New Challenges for targets → Updated Lab

Larger sizes  Larger quantity  New Z Target  Higher quality

- LGA
- T
- Neutrons
- EDS
- X-ray
- XPS
- MeV Ions
- RBS / EBS
- RI
- NAA
- NAA
- E_{out} - E_{in}
- X-ray PIXE
- N_{out}/N_{in}, E_{out}

GANIL Community Meeting, Caen, October 20th 2022
b. New Challenges for targets → Updated Lab

Larger sizes  Larger quantity  New Z Target  Higher quality

Reliability, Reproducibility

→ Chemical composition of targets: XRF analyzer in the target lab

→ Optimization of parameters (I, V, time, powders…) for each targets for each common and new technic
→ Development of backings and understanding their impact on fabrication process and under irradiation
→ Characterization (homogeniety, contaminants…) of targets at each step of the fabrication process and systematic for its delivery
→ Evaluating performance under realistic beam radiation
→ Feedback from experimenters
→ Understanding the involved physical, chemical, material processes
2. GANIL Target Activities:
2.c Investigation of external potentials (F. Perocheau*)

- Larger sizes
- Larger quantity
- New Z Target
- Higher quality

First Contacts with industries or CNRS laboratories, expertise in thin layer (optical & metallic treatments, sputtering technics)
- Lab. Matériaux Avancés, Lyon (Ta)
- HEF, Diamond Like Carbons-H (stripers, backings)
- KERDRY (Sn, Ni, W)
- PlasmaQuest (Ta, Ni)
d. 1st Conclusion – **Project « Target Lab »**

- Larger sizes
- Larger quantity
- New Z Target
- Higher quality

New equipment to be installed & take in charge of each technic/evaporator

+ ✓ R&D
✓ Targets management (from its fabrication to its use)

+ Manpower: GF, CDD, PD, + xxx ???
  + collaborations with experts

TARGET = multidisciplinary domain
3. Actinide Activities
   a. Requirements
   b. Project « Actinide Targets »
3. Actinide Activities a. Requirements

Cibles minces : surface utile de diamètre 30 mm, épaisseur 150-200 µg/cm² (80 – 100 nm pour l’uranium) sur support très fin : Ni de 250 nm ou plastique 220 nm

D. Doré

À compléter avec cibles épaisses et autres demandes d’isotopes

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3. Actinide Activities  a. Requirements

- Targets @ S3, > 2025 Experiments

Planning des expériences avec les isotopes (1-4Act) selon disponibilité cible** et contexte Scientifique international

- $^{226}$Ra*, $^{232}$Th, $^{238}$U, $^{237}$Np, $^{243}$Am*, $^{248}$Cm*, $^{239/242/244}$Pu*

$0.3$ - $0.5$ mg/cm$^2$; 1 roue $\approx$ 12 cibles de $\approx$ 3 cm$^2$ $\approx$ 25 mg $\approx 10^2$ $-$ $10^8$ Bq < 1 GBq

$^{238}$U: 1 roue $\approx$ 18 cibles de $\approx$ 22 cm$^2$ $\approx$ 200 mg

Pureté isotopique $\approx$ 97% (ou <, importance de la connaissance pour activité totale autorisée et analyse des données)

*Autres isotopes ORANO à considérer pour adapter programme scientifique, ** contraintes ASN, activité…
3. Actinide Activities  b. Project « Actinide Targets »

1/ ORNL, (Dubna), ORANO ?

2/ Specific Infrastructure, radiochemistry skills
R&D @ ORNL, Uni Mainz, PSI, JRC Geel
ORANO ?

3/ AEL Exploitation

4/ Recovery
3. Actinide Activities  b. Project « Actinide Targets »

1/ ORNL, (Dubna): reactor ORANO ? « wastes » ?

Available Rare / Radioactive

| 89 | Ac | 90 | Th | 91 | Pa | 92 | U | 93 | Np | 94 | Pu | 95 | Am | 96 | Cm | 97 | Bk | 98 | Cf | 99 | Es | 100 | Fm |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

Méthodes de surveillance

Déchet ?

Stockage ?

Traitement ?

Evaporation 238U, 232Th met, ED GSI (TASCA) Target Wheel unit

Radiochimie Purification (ou DoD)

* A voir si montage/démontage faits sur site de fabrication et/ou gestion matière actinide
3. Actinide Activities

b. Project « Actinide Targets »

1/ ORNL, (Dubna), ORANO ?

2/ Specific Infrastructure, radiochemistry skills
   R&D @ ORNL, Uni Mainz, PSI, JRC Geel
   Production @ ORANO* ?

R&D on MP mecanism and kinetic,
MP parameters (U, I, solvent...),
Nature & thickness of backings
Innovative technics

✓ Constraints:
  ➢ limited availability
  ➢ high specific activity
  ➢ backing: material, thickness, roughness
  ➢ high chemical purity
  ➢ large surface/numerous
  ➢ fragile for transportation
  ➢ little expertise in the world

✓ Methods:
  ➢ high yield
  ➢ reliability/reproducibility
  ➢ control of dimensions and thickness

✓ Complementary developments:
  ➢ backings (material + thickness)*
  ➢ characterization techniques

* Electro-precipitation
  Drop-on-Demand
  intermetallic targets

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GANIL Community Meeting, Caen, October 20th 2022
3. Actinide Activities  
b. Project « Actinide Targets »

✓ GAGE Project for NFS
Authorized targets at NFS

- stables
- radioactives
- actinides (uniquement dans salle 33 ⇔ Neutrons)
  • cibles encapsulées
  • cibles minces de faible activité
  • cibles minces de forte activité (EDMS-I035121)

Liste des actinides autorisées
RGE :

\[ 233U, 235U, 237Np, 239Pu, 241Am, 242mAm, 245Cm, 234U, 236U, 240Pu, 242Pu, 244Pu, 246Cm, 247Cm, 248Cm, 231Pa, 241Pu, 249Cf, 251Cf \]

Caractéristiques:
Mince 150 µg/cm² ⇔ pour que les fragments sortent
Irradiée par des neutrons ⇔ pas de dépôt d'énergie

Risques:
- contamination en cas de chute
- irradiation selon activité

∞ Confinement obligatoire

Courtesy E. Dessay
Objectif pour la physique :
Réaliser des expériences avec des cibles minces radioactives (≈100µg/cm²)

Projet BAGE@NFS
Créer un dispositif expérimental de type BaG pour le transfert de cibles minces d'actinides de forte activité compatible avec les détecteurs utilisables dans la salle 33 de NFS

Activité « actinides »
Réceptionner, préparer, transporter et installer les cibles d'actinides

Courtesy E. Dessay
Actinide « EIP » at NFS

6 EIP n°6: Systèmes de confinement des cibles d’actinides (hors faisceau)

<table>
<thead>
<tr>
<th>EIP n°6</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIP n°6a</td>
<td>Dispositif expérimental NFS de type « BâG »</td>
</tr>
<tr>
<td>EIP n°6b</td>
<td>BâG (x 2) cibles actinides (local 057)</td>
</tr>
<tr>
<td>EIP n°6c</td>
<td>Conteneur DPTE</td>
</tr>
<tr>
<td>EIP n°6d</td>
<td>Systèmes de transfert (chariot de transfert et mousse absorbante du chariot de transfert)</td>
</tr>
<tr>
<td>EIP n°6e</td>
<td>Capsule de conditionnement des cibles épaisse d’actinides</td>
</tr>
<tr>
<td>EIP n°6f</td>
<td>Armoire d’entreposage des cibles d’actinides</td>
</tr>
</tbody>
</table>

Tableau 31 : Composition de l’EIP n°6

Courtesy E. Dessay
3. Actinide Activities  b. Project « Actinide Targets »

- Design, fabrication of S3 actinide station
- Instrumentation for control of targets during irradiation and after
- Process of mounting, dismounting
- Art 26

TASCA model or not ?
French expertise @ ORANO ?
3. Actinide Activities  b. Project « Actinide Targets »

- Processes
  - Dismounting
  - Decontamination
  - Waste & targets management
  - Recovery of material

Radiochemistry skills

French expertise @ ORANO ?
4. Collaborations
Collaborations

- CIMAP: MEB, EDS,… - damage process, Thermal Spike model ….
- GSI: training & some « small » targets
- INTDS network: Training, « recipes/tricks », share of knowledge/know-how
- ORNL: material supply + actinides
- Uni Mainz (Actinide), proposal for studying performance of MP targets under realistic beam
- IPHC, backings developments
- ORANO, under discussion, 1st step with $^{238}$U

+ Catania, JYFL
The goal of the subtask is to gather, at a European level, the community of “nuclear target makers” having specific expertise in the field of target manufacturing and characterization, both for nuclear and applied physics purposes. Different research areas and applications, indeed, require high quality targets, ranging from fundamental physics (nuclear reaction studies, nuclear data measurements, etc.), passing through specific targets for strippers and neutron converters, up to the development of (usually) isotope-enriched targets for high quality standard medical radioisotope production. Target preparation is often a crucial step on the path towards the achievements of nuclear physics experimental results, or specific final nuclear “products.”

Specific activities
- Study of existing and novel materials
- Improvement of current and development of novel fabrication techniques
- Characterization procedures
- Sharing of knowledge.

Outcome:
Database, publicly available, containing the information about the preparation and the characteristics of available targets and those newly developed in various laboratories within this subtask. The first version of the database will be ready after the first year of the project and will be continuously updated during the duration of the project.
- 1 year Postdoctoral Researcher in Nuclear Targets within EURO-LABS project at GANIL
- + 1 application within Winning Normandy
- Master 2 internship 2023, « GEANT4 simulation of the interaction of a 15-30-kV-electron gun with thin nuclear physics Target »
5. conclusions
Conclusions – Take Home

→ Improve the capability of GANIL to make target (**manpower & equipment**)
   → “target” infrastructure = Project
   new equipment soon to cover the highest demand and new requests
Room for improvements in the quality of targets
R&D on fabrication, characterization pre-/during-/post-irradiation unavoidable
Time consuming, specific know-hows → complementary skills

When you plan an experiment:
1/ Define the properties of your future target: What is needed - absolutely necessary - for a successful measurement? What (material or chemical composition) is excluded?
   *element/isotope / thickness / dimensions / supported or not, if yes what can be considered as support / purity /chemical form (pure / compound)*

2 / Discuss your plans with the target maker: Target preparation people can do sometimes more for you than you believe. However, sometimes they can do less than you wish…

It is always a question of communication and of raising the relevant problems at a very early
Conclusions – Take Home

→ Improve the capability of GANIL to make target (manpower & equipment)
  → “target” infrastructure = Project

→ Settle collaboration with other target makers (GSI, Uni Mainz, ORANO, …)

→ Secure the supply chain for rare elements – to be analysed for targets

→ Actinide target development → Full project

- Liquid, Gas, cryogenic Targets
- Stations

Thanks for your attention