Target developments for extraction of actinides from thick ISOL targets followed by laser-induced molecular break-up and/or ionization.
# ESR3 – WP2 – D2.4

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<th>Start: M6</th>
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**Project title:** Target developments for extraction of actinides from thick ISOL targets followed by laser-induced molecular break-up and/or ionization. [WP2: Novel techniques and technologies for actinide research](#)

**Objectives:** Study and optimize the reaction conditions required to create volatile molecular species of refractory elements in general and actinides in particular. Develop a dissociation scheme for the provision of atomic species suitable for efficient laser ionization or in-source laser spectroscopy.

**Expected results:** Extraction of radiogenic actinide elements from an ISOL target and delivered in atomic form to the users. Determine the production yield and purity of the beams and report the new beam availability to the community.

**Planned secondment(s):** JGU (Christoph E. Düllmann) – M8-10 – working on the sample preparation to be used for the actinide molecular release studies; TRIUMF (Thomas Day Goodacre, Peter Kunz) – M15-17 – Extraction of actinides from thick targets at the ISAC facility. Participation in activities around radioactive ion beam development involving actinide beams and molecular beam extraction. Gaining experience in radioactive detection techniques used to assess the quantity and quality of the produced isotopes.

**Enrolment in Doctoral degree:** JGU in the Department of Chemistry under the supervision of Prof Christoph E. Düllmann
ESR3 – WP2 – D2.4

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Outline

• Motivation for molecular beams

• Optimization of reaction conditions

• Develop a dissociation / ionization scheme

• Determine production yield
**ISOLDE: Isotope Separation On Line**

**Beam Intensity**

\[ Beam\ Intensity = \sigma \cdot j \cdot N_t \cdot \varepsilon \]

- \( \sigma \) – Cross section [mb]
- \( j \) – Proton flux \([\text{cm}^{-2}]\)
- \( N_t \) – Nr of exposed atoms \([\text{dim}]\)
- \( \varepsilon \) – Efficiency [%]

**Extraction optics**

- Mass separator
- Proton

**1. Production**
- **4. Ionization**

**2. Diffusion**
- **5. Mass Separation**

**3. Effusion**
- **6. Transport**

**Target unit**

- 1.4GeV Protons
- Extraction optics

**Extraction electrode**

- Ion Source

**Ion Source**

- (pulsed) Protons

**Transfer line**

- Protons

**Target heating**

- (1 – 2kW), \(<\sim 10\% \text{ beam power}\)

**Adapted from**

- S. Rothe | LISA Kickoff CERN | ESR3 - Molecular Actinide Beams
boiling/melting points vs. ISOLDE Yields

Target materials operated at < 2200 C


actinides
Molecular Beams – Why?

• Beam purification
  • Shift the mass region to a higher mass to avoid isobaric contaminants. e.g. GeS, SnS, SeCO, LnO

• Beam extraction by *in-situ* volatilization
  • Elements with very low volatility are not released
  • Reactive elements can be chemically trapped

\[
^8\text{B} \quad \overset{\text{SF}_6 (g)}{\rightarrow} \quad ^8\text{BF}_3
\]

Boron
Low Volatility (m.p. 2076 °C) reactive with many metals

Boron trifluoride
gaseous even at RT very stable
Optimize reaction conditions

- target material
  - U vs. Th
  - Metal vs. Carbide vs. Oxide
- target microstructure
  - Investigate nano materials, stabilize nanostructure
- Reactive gas
  - (O, F, S, ...)
- Reaction conditions
  - Concentrations, temperatures
In-target production

Thorium vs Uranium

Release properties to be studied

Simulated results require validation

- ThC is a standard target material at ISOLDE
- Nano ThC possible with new nano lab
  - co-development with SCK*CEN possible

FLUKA Simulations: Joao Pedro Ramos
Study effects of reactive gas to actinide nano materials

Adopted from
João Pedro Ramos | 07/09/2017
MEDICIS-Promed Specialized Training on Radioisotope Production

S. Rothe | LISA Kickoff CERN | ESR3 - Molecular Actinide Beams
### Selected molecular sidebands

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What are the best sidebands for actinide release?  
1st experiments planned with irradiated targets at MEDICIS

U. Köster et al.  
NIMB 266 (2008), 4229  
EPJ-ST (2007), 285

Slide adapted from: Jochen Ballof | ISOLDE Workshop | 5.DEC.2017
Beyond Uranium

**Neptunium**

NpF₆

BP: 55°C

**Plutonium**

Study NpF₆ release

239Pu: 1E7 /s

UCₓ, 1.4GeV, Fluka
Pump stand (YPS1)
Offline 1 (YOL1)
Offline 2 (YOL2)

Frontend, Separator magnet

RFQ-CB

Studying molecular beam formation

Concept for a dedicated development unit for molecular beams

Study chemical reactions

- Injection of gases and vapor of solid samples into reaction volume
- Suppression by quartz and other materials

Parameters

- 2 gases, controllable flow rates
- 2 mass markers
- Controllable temperatures in reaction volume and chromatography column
- Materials for chromatography and
- Materials in reaction volume (target matrix)

- better understanding of molecule formation
- improve reliability of existing beams, tailor new beams
Studying molecular beam formation

Concept for a dedicated development unit for molecular beams

• Move residual gas analyzer to identify separated beam composition through molecular break up patterns
Studying molecular beam formation

Concept for a dedicated development unit for molecular beams

- Add **Multi Reflection Time of Flight (MR-ToF)** mass spectrometer: allows ISOBAR separation.
- Collaboration with MIRACLS experiment launched

**Example TOF spectrum on mass 46**

![TOF spectrum diagram](Image)

**Key Elements**

- **VADIS source**
- **Heated reaction volume**
- **Chromatography**
- **Solid Samples (mass markers)**
- **Gas 1**
- **Gas 2**
- **RGA**
- **Faraday Cup**
- **Magnet**
- **Scanner**
- **Faraday Cup**

**Diagram Notes**

- **Ti**, **Ca**, **Sc**, **K**
- **Curtesy: S.Malbrunot**

**Related Experiments**

- **Multi Reflection Time of Flight (MR-ToF)**
- **Collaboration with MIRACLS experiment**
First prototype for reaction chamber tested at YOL1

BaO + CF4 \rightarrow BaF2 + x \rightarrow BaF+

V. Samothrakis, M. Ballan, J. Ballof, D. Leimbach, B. Crepieux, S. Rothe et al.
Photocathode source

VADIS source at ambient temperature
Electron generation by laser, not thermal evaporation

Motivation
- Ionization of fragile molecules
- No decomposition on hot surfaces
- Diagnostic tool to measure ionization properties

Set up

Laser properties (PHARROS)
- Pulse length: 265 fs
- Power: 4.5 W
- Wavelength: 343 nm
- Rep. Rate: 50 kHz

First Results:
Mass spectrum of Mo(CO)$_6$ + Kr

Two operation modes found
- Photo cathode
  - Direct laser breakup
- Anode biased
  - Anode off
- Magnet 6A
  - Magnet off
- Krypton ionized
  - Krypton not ionized
- Mo(CO)$_3$ predominant
  - Mo(CO)$_5$ predominant

THE ISOLDE Yield station (YYS)

Proposal: install spare YYS2 at GLM
- Used for beam development
- Can be used in p.sharing mode with minimal impact to ISOLDE physics
- Opportunistic development, in-source laser spectroscopy
- Upgrade (LS3…): integrate MR-ToF-MS
THX