High-power target development for the next-generation of ISOL facilities

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Outlook

- Motivation for high-power target development
- Introduction to high-power targetry
- Short review of various high-power target concepts
- Summary & Outlook
Motivation for high-power target development

- **Exotic nuclei**: highly-interesting study laboratories, challenging the current nuclear-physics models

- **Difficulties** encountered in delivering beams of such exotic nuclei:
  - Extremely low production cross sections
  - Overwhelming production of unwanted species in the same beam-target interaction
  - Very short half lives of the nuclei of interest.

- Some of the “targetry” **solutions** to improve RIB production (yields & purity):
  - Use of different target materials (more favorable cross sections, favoring isotope release, etc.)
    - *see presentation by JP Ramos (Session 1)*
  - Optimize target configuration
  - Use different primary-beam energies
  - Use **higher beam-power on target** (higher driver-beam intensity)
Setting the ground

- **Low-power targets** require electric heating in order to reach the temperature regime specific to the evaporation of desired isotopes (e.g. ISOLDE targets)

- **High-power targets** are heated by the beam-power deposition and require heat removal during operation in order to prevent melting (e.g. ISAC targets)
  - Careful engineering design to ensure uniform temperature profile in the target and its container
  - Highly dependent on accelerator operation (continuity of the driver beam on target)
    - Beam interruptions affect the integrity of the target (target material & target container)
    - In the absence of electric heating, isotopes release stops during beam-off periods

- **Different challenges** for high-power targets when implemented at different beam energies:
  
  \[ W_{\text{beam}} = I_{\text{beam}} \times E_{\text{beam}} \]
  \[ W_{\text{dep}} = I_{\text{beam}} \times \Delta E \]
  
  \[ E_{\text{beam}} \downarrow, W_{\text{beam}} \downarrow \quad \text{but} \quad \Delta E \uparrow \Rightarrow \quad W_{\text{dep}} \uparrow \]

  The deposited-power density is (much) higher when targets are irradiated by low-energy beams \( \Rightarrow \) different target concepts needed

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Should one ever use low driver-beam energies?
- FLUKA simulations for isotopes production by a p-beam of various energies on a U-based ISOL target.

- Using various primary-beam energies one populates different regions of the nuclear chart.
Targets operating in “converter mode”

- Primary beam interacts with a converter => n
- Fission induced in the ISOL target by neutrons
- Limited number of reaction channels are open
  - Increased purity of the RIB
- Decoupling beam-power deposition from target heating
  - Avoiding temperature gradients in the fission target
  - Allows further increasing the driver-beam power (↑RIB yield)
- Fission target less prone to beam-interruptions issues:
  - Thermal stress (target material & container)
  - Suppression of isotopes release from the target
- Limited production of α-emitters (licensing limitation)

High-power targets: summary of various concepts

- High-energy high-power targets
  - Direct targets:
    - **ISAC** hp target
    - EURISOL 100-KW target concept: **LIEBE**
  - Converter targets:
    - p2n
    - EURISOL Multi Megawatt concept

- Low-energy high-power targets
  - Direct targets:
    - **SPES**
    - **ISOL@MYRRHA** phase 1
  - Converter targets:
    - **ARIEL**
    - SPIRAL2
TRIUMF high power target design (500 MeV)

- 20-mm diameter Ta target container

- Composite carbide target discs to enhance heat conduction within the target material and into target container

- 55 mm x 55 mm Ta fins for enhanced radiative cooling ($\varepsilon_{eq} \approx 0.9$)

- Capable of handling 17 kW deposited beam power

- Beam on actinide targets limited to 10 µA by licensing

High-power direct targets: LIEBE

- Molten-metal loop-type direct target (concept proposed in EURISOL-DS)
  - Decoupling production & release & heat removal
  - Thicker target (~200 g/cm²)
    - Higher in-target production
  - Dedicated release volume
    - Formation of small target-material droplets (~10 µm)
    - Faster diffusion = increased release efficiency
  - Dedicated heat exchanger
    - Better heat removal
    - Possibility to have a higher driver current

- LIEBE project
  - Develop and test a prototype of a molten-metal loop-type direct target
  - Offline and online tests at ISOLDE
  - Collaboration between 6 institutes: CEA, CERN, IPUL, PSI, SCK•CEN, SINP
  - Extraction of short-lived Hg isotopes

LIEBE main components

Proposed in EURISOL DS
High-power direct targets: LIEBE

LIEBE target currently under offline commissioning

- Liquid metal flow assessment
  - Cavitation limits checked at IPUL
  - Minimum flow for release optimization achieved (0.13 L/s)
- Target manipulation and installation tests
- Fully operational target now on test-stand with mass separator
  - Vacuum testing
  - Pump vibration monitoring (alignment, cavitation)
  - Thermal testing (check for cold zones)
  - Mass scans
- Vacuum leak issue
  - Deformation of the vacuum vessel due to thermal stress
    - Thermal radiation of hot ion-source (2000°C)
  - New vacuum vessel design solved the issue
High-energy high-power converter targets: p2n

- Match/improve ISAC yields while suppressing proton-rich isobaric components
- Overcome ISAC UCx beam intensity limitation due to alpha-emitters activity and radiotoxicity
- First high power p2n operation at full proton beam power:
  - ~7 kW deposited in 2 cm
  - Increase geometrical efficiency
  - Decoupling target heating and incoming proton beam current

Compilation of slides given at the courtesy of Luca Egoriti (TRIUMF), more details in poster 60: "High-power converters for RIB production"
High-energy high-power converter targets: p2n

Total beam power deposited = 7.5 kW
Max T = 2100 C

**Off-line tests**
- Current = 1500 A
- Temperature exceeding expectations
- Target failed after day
- Second prototype ongoing

**On-line operation** (20 shifts approved. Request for beamtime in Spring 2019)
- Extraction of several beams of different elements:
  - Neutron-rich nuclei → Sn, Cd and Zn to be maximized;
  - Main related isobaric contaminants → Lanthanides, Cs, Rb
- Laser Ion Source (LIS) operated for ionizing Sn, Cd, Zn
- ISAC yield station: Absolute yield of the reference isotope
- TITAN MR-TOF-MS: Isobaric beam composition
  - Characterize the contact resistance W – Cu alloy
  - Thermal simulation benchmarked
  - Torque on screws determined

- Total current = 1500 A
- UCx temperature >1800 C
- Total beam power deposited = 7.5 kW
- Max T = 2100 C

Expected ISABEUCx for 130Cd, 133In, 135Sn:

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<tr>
<th>ISOTOPE</th>
<th>ISABEUCx</th>
<th>p2n-a</th>
<th>p2n-a / ISABE</th>
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<tr>
<td>130Cd</td>
<td>6.42E+06</td>
<td>3.66E6</td>
<td>0.5</td>
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<tr>
<td>133In</td>
<td>9.19E+06</td>
<td>1.66E7</td>
<td>1.83</td>
</tr>
<tr>
<td>135Sn</td>
<td>1.70E+07</td>
<td>4.36E7</td>
<td>2.57</td>
</tr>
</tbody>
</table>

Expected ISABEUCx for 130Cs, 133Cs, 135Cs:

<table>
<thead>
<tr>
<th>CONTAMINANT</th>
<th>ISABEUCx</th>
<th>p2n-a</th>
<th>p2n-a / ISABE</th>
</tr>
</thead>
<tbody>
<tr>
<td>130Cs</td>
<td>3.10E+09</td>
<td>2.41E9</td>
<td>8E-2</td>
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<tr>
<td>133Cs</td>
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<td>1.15E9</td>
<td>8.37E-02</td>
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<tr>
<td>135Cs</td>
<td>9.14E+09</td>
<td>8.68E8</td>
<td>9.50E-02</td>
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</tbody>
</table>

Compilation of slides given at the courtesy of Luca Egoriti (TRIUMF), more details in poster 60: “High-power converters for RIB production”
High-energy high-power converter targets: p2n

- Complementary tests at ISOLDE

  ![Diagram](image)

  Converter will act as internal heat source

  - Normal shielding: several metal foils stacked
  - New shielding: Sigratherm material (1-cm thick)

  ![Image of test setup]

  Yield increase by factor of 6, reduction of % impurities

  To test online this year

Slide courtesy of Joao-Pedro Ramos (CERN), more detailed information on the poster 79
High-energy high-power converter targets: EURISOL multi-MW target

- 4-mA 1-GeV p-beam on a liquid-metal converter target surrounded by multiple fission targets allowing high in-target production yields (~10^{15} fissions/s/mA)

- Ambitious project proceeding through an intermediate step: EURISOL-DF
  - Realization of intermediate facilities: HIE-ISOLDE, SPES, SPIRAL2, ISOL@MYRRHA
  - Preparing the physics and technology for the (MW) EURISOL facility
Low-energy high-power direct targets: SPES

- 50 mm diameter target container
  - Larger surface area to radiatively cool the target (8 kW)

- Lower energy protons (40 MeV)
  - More intense heat deposition in the target material
  - 7 thin target discs optimally distributed over the length of the target to get a uniform temperature distribution
  - Radiative cooling from target discs to target container

- Integrated beam dump

*see presentation by A. Monetti (Session 2)
Low-energy high-power direct targets: ISOL@MYRRHA phase 1

- **MYRRHA**
  - MYRRHA phase 1: 100 MeV, 4 mA
  - ISOL@MYRRHA (PTF): 100 MeV, 500 µA
  - MYRRHA phase 2: 600 MeV, 4 mA
  - ISOL@MYRRHA (PTF): 600 MeV, 200 µA

- The proton target facility (PTF)
  - Upgradable to 600 MeV proton beams
  - ISOL system + spare irradiation pit

- Dedicated ISOL targets
  - Compact targets for the production of exotic/short-lived isotopes (physics)
  - Large high-power targets for the production of longer lived isotopes (applications)
Non-actinide targets for day-1 operation of ISOL@MYRRHA

- Startup of the ISOL system with non-actinide targets

- Proposal: titanium targets for production of Sc isotopes
  - Ti-carbide as target material ($T_{\text{melt}} = 3140^\circ\text{C}$)

- Target optimized for in-target production (part of PhD M. Ashford)
  - By variation of target material density (g/cm$^2$)
  - Limited to 10 kW deposited power (unfinned target container of $\varnothing 4$ cm, L=20 cm)
  - Limited to 300 µA beam current (beam window)

- 1D model for quick assessment of optimal target density (g/cm$^2$)
  - Followed by detailed FLUKA and ANSYS calculation
  - Optimal distribution of the discs to get uniform target temperature

Optimization of in-target production by 1D model
Low-energy high-power direct targets: ISOL@MYRRHA phase 1

- Two reference high-power target configurations
  - 10 kW / 300 μA: bare container (Ø4 cm, L=20 cm)
  - 25 kW / 500 μA: finned container (projected licensing limit)
  - Carbide target discs spread over the length of the target => uniform temperature profile (similar to SPES targets)
  - Proton-beam rastering

- 100 MeV is challenging for beam window design
  - Window 1: avoid proton beam line contamination (safety)
  - Window 2: avoid beam dump contamination (waste)
  - 100 MeV = high energy deposition in the windows
  - Large scattering when beam passes through target
Low-energy high-power converter targets: ARIEL

- 35-MeV >100-mA electron beam on a (e-γ) converter target
- Water-cooling and thermal design optimized for 100 kW electron beam power operation (experimentally validated up to 10 kW driver beam power equivalent)
- Production of radioisotopes in the ISOL actinide target by photo-fission

Concept detailed in the following presentation by Thomas Day Goodacre & poster 60: “High-power converters for RIB production”
Low-energy high-power converter targets: SPIRAL2

- 40-MeV up to 5-mA deuteron beam on a rotating graphite wheel (converter)
- Large U-base ISOL target behind the converter

Y. Huguet, The production module, SPIRAL 2 week 2011
Summary and Outlook

- The high-interest in exotic RIBs motivates development of next-generation ISOL facilities
  - Advance in high-power targetry
  - Advance in target materials
  - Development of high-intensity ion sources
  - ...

- Upcoming ISOL facilities implement high-power target technology at low driver-beam energies => innovative target concepts

- Current developments are paving the road towards the ultimate ISOL facility (in Europe):