The Cryogenic Stopping Cell of the IGISOL facility at ELI-NP

Paul Constantin

ELI-NP / IFIN-HH
High Power Laser System (HPLS)  
– built by Thales  
– 2 arms, 6 outputs  
– 2 x 0.1 PW, 10 Hz  
– 2 x 1 PW, 1 Hz  
– 2 x 10 PW, 0.1 Hz

Gamma Beam System (GBS)  
– built by EuroGammaS  
– spectral density $0.8-4 \times 10^4 \gamma/(s\cdot eV)$  
– narrow bandwidth 0.3-0.5%  
– energy range 0.2-19.5 MeV  
– linear polarization >99%
The ELI-NP Gamma Beam

\[ E_L = 2.4 \text{eV} \]

\[ T_e = 720 \text{MeV} \]

\[ E_\gamma < 19.5 \text{MeV} \]

\[ E_\gamma(\theta, T_e) = \frac{4\gamma_e^2 E_L}{(1 + \delta^2/4 + a_0^2/2) + \gamma_e^2 \theta^2} \]

\[ \gamma_e = 1 + T_e/m_e c^2 \]

\[ E_\gamma^{\text{max}} = 9.55 \text{eV} \cdot \gamma_e^2 \]
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Radioactive Ion Beams with the Gamma Beam

Beam energy range up to ~19 MeV covers the GDR: RIB via photofission in an actinide thick target

\[ ^{238}\text{U}(\gamma,f) \]

\[ J.T. \text{ Caldwell et al.,} \\
\text{Phys. Rev. C 21} \\
(1980) 1215 \]
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Refractory elements: light region Zr-Mo-Rh and heavy rare-earths region around Ce
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$^{238}\text{U target}$:
- thick because $\sigma(\gamma,f)\sim 1b$
- sliced in many thin foils: refractory, fast extraction
- tilted foils:
  (1) avoid hitting neighboring foils
  (2) increase $\gamma$ pathlength w/ increasing thickness
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2) RFQ (Radio Frequency Quadrupole)
3) MR ToF (Multiple Reflection Time of Flight)
IGISOL beamline: Exotic Neutron-Rich Isotopes

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Phase II
1) \( \beta \)-decay station: HPGe detectors, tape station
2) collinear laser spectroscopy station
Fission fragment release rates

**Geant4** photofission implementation
**Target** foils: 3μm UF₄ with 0.5μm graphite backing
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- Photofission rate
- Fragment release rate; Ziegler
- Fragment release rate; Schwietz

![Graph 1](image1.png)  
![Graph 2](image2.png)
**Fission fragment release rates**

**Geant4** photofission implementation

**Target** foils: 3μm UF₄ with 0.5μm graphite backing

For beam rate $10^{12}$γ/s: $4 \cdot 10^7$ frag/s
**Fragment Slowing Down in Gas**

*Geant4*: He, $T=70K$, $p=300$mbar ($\rho=0.206$mg/cm$^3$)  
$>95\%$ of fragments stop in 11.3cm $\rightarrow$ **width~24cm**
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**Space charge** = He⁺ cloud created by fragment (>90%) and e⁺/e⁻ (<10%) induced ionization of He gas

Above a certain **charge density rate Q**: field saturation, strong e-ion recombination, weak plasma.
**Fragment extraction – space charge effect**

**SIMION 8.1**: solve Poisson equation dynamically (PIC simulation) with ionic charge distribution from GEANT4 as input → **extraction efficiency** $\varepsilon$ and **time** $\tau$

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(a) $\rho=0.21 \text{ mg/cm}^3$

$E=100 \text{ V/cm}$

$\varepsilon = 89\% \quad \langle \tau \rangle = 6.8\text{ms}$

(b) $\rho=0.21 \text{ mg/cm}^3$

$E=40 \text{ V/cm}$

$\varepsilon = 67\% \quad \langle \tau \rangle = 17\text{ms}$
Fragment extraction – RF carpet transport

\[ V(t) = V_{DC} + V_{RF} \sin(2\pi \nu_{RF} t) \]

\[ E_{eff} = \frac{1}{2} \frac{m}{q} \frac{\mu_0^2 \rho_0^2 V_{RF}^2}{r_0^3} \]
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\( V_{DC} = 180\text{V} \), \( V_{RF} = 150\text{V} \), \( \nu_{RF} = 6\text{MHz} \), \( r_0 = 125\text{\mu m} \), \( \rho = 0.12\text{mg/cm}^3 \)

Optimal density \( \rho \): large for fragment stopping, small for carpet repulsion
Optimal \( U_{DC} \), \( U_{RF} \), \( \nu_{RF} \), \( r_0 \) for best \( \epsilon \) and \( \tau \rightarrow \epsilon > 90\% \) and \( \tau \approx 10\text{ms} \) are obtained
Current developments

Design of the main CSC components:
– target system
– gas recirculation and purification system
– cryogenic system
– electrode system (RF carpets) for ion drift
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A CSC demonstrator to test these systems:
– visualize and optimize gas flow
– test offline & online ion extraction
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CFD + heat transfer simulations (COMSOL)
→ gas jet optimization
Summary

- a two-phased IGISOL RIB facility will be built at ELI-NP

- its main characteristics are expected to be:
  - very low backgrounds (space charge)
  - high extraction efficiency (70-90%) and low extraction time (~25 ms)
  - very high mass selectivity ($\Delta m/m \sim 10^6$): isomeric beams
  - large range of measuring capabilities: mass, $\alpha/\beta/\gamma$ spectroscopy, nuclear moments and radii
  - emphasis on refractory isotopes

- the design of the gas cell is in final stages; a demonstrator cell will be ready next year
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Exotic nuclei selection and measurement

- Ions extracted from the CSC are formed into a RIB by the RFQ: cooling, bunching, mass selection (m/Δm~200), CID
- High resolution (m/Δm~10^6) mass selection and measurement by the MR-ToF
- β-decay station: β and γ decays and coincidences
Fragment Stopping in Target (I)


\[ S_{\text{ion}} = (\gamma Z)^2 S_p, \quad S_p = \text{proton stopping (Bethe-Bloch)} \]

\[ \gamma = q(1+s.c.) = \text{ion effective charge}, \quad q \equiv Q/Z, \quad \text{s.c.} = \text{screening correction (Brant-Kitagawa)} \]

\[ q \equiv Q/Z \sim 1 - \exp(-v/v_B^2 Z^{-2/3}) = \text{ion charge state (Bohr approx)} \]

\( \gamma \approx q \approx 1 \) for light ions (\( Z \sim 1 \)), high velocity (\( v >> v_B = 25 \text{ keV/u} \))

Significant for fission fragments: \( Z=30-60, \ KE \sim 0.3-1.5 \text{ MeV/u} \)

q(\( v, Z, Z_{\text{targ}} \)) measurement parameterizations:
1) Ziegler (1988): Geant4
2) Shima (1982): older, specific for slower heavy ions
3) Schiwietz (2001): newest (largest data set), differentiated for solid/gas targets

LOHENGRIN (ILL Grenoble): (\( n_{th}, f \)) of \( ^{235}\text{U}, ^{239,241}\text{Pu} \)

\( \langle Q \rangle = 20-22, \sigma_Q = 2.0-2.4 \)

Ziegler: \( \langle Q \rangle = 9.8, \sigma_Q = 3.0 \)

Shima: \( \langle Q \rangle = 16.5, \sigma_Q = 2.0 \)

Schiwietz: \( \langle Q \rangle = 17.3, \sigma_Q = 2.1 \)

Schiwietz&Shima:
- describe better data
- larger ionic charge
- stronger Z dependence
- smaller release efficiency
Release efficiency $\text{UF}_4$