Estimates of ISOL beam intensities for fast neutron induced fission fragments

P. Delahaye
Contributions M. Fadil, X. Ledoux
A flux of neutrons of \( \sim 10^{18} \text{ m}^{-2}\text{s}^{-1} \) is generated with a broad peak at around 14 MeV.
ISOL method
“Isotope Separation On Line”

• A primary beam impinges on a thick target / n converter
• Reaction products diffuse out of the target to an ion source
• After ionization and post-acceleration, the reaction products are separated

11 MeV deutons on Be target
10 kg UO2 (!)
A flux of neutrons of \(\sim 10^{18} \text{ m}^{-2}\text{s}^{-1}\) is generated with a broad peak at around 14 MeV.
SPIRAL 2 – phase 2 radioactive ion beams

- **Deuteron beam on neutron converter**
  - UCx target + ECRIS
  - UCx target + LIS
  - UCx target + Febiad
  - UCx target + SIS

- **Other beams / other targets**

Converter + target module

- 5 mA 40 MeV d
- Graphite wheel
- 200kW on converter
SPIRAL 2: Advanced RIB facility

Experiments with Radioactive Ion Beams at low cross section and with very exotic nuclei at a few MeV/nucleon

SPIRAL2 – ISOL facilities

SPIRAL2 – In flight facilities

High quality ISOL RIBs
- high intensity, optical quality and purity
SPIRAL 2 also includes light & heavy RIBs, intense stable beams

Multi beam capabilities
Months of beam time
World-class arrays and detectors

Courtesy H. Savajols
Comparison of neutron fluxes

• SPIRAL 2 neutron flux characteristics
  – Neutron spectrum a bit harder than IFMIF / Liquid Li target in DONES
    
    ![Graph of neutron flux](image)

    D. Ridikas et al, internal report, 2003, CEA Saclay
    
    Potentially $10^* \text{ more neutron/cm}^2\text{/s in } 10^* \text{ larger volume for IFMIF}

  – SPIRAL 2: Average flux on target:
    • **200 kW with large high density UCx targets** (10g/cm$^3$)
      – $10^{13}$ n/s/cm$^2$
      – $2.8 \times 10^{13}$ fissions / s
    • **50 kW with small normal density UCx targets** (3.5g/cm$^3$)
      – $2.5 \times 10^{12}$ n/s/cm$^2$
      – $2 \times 10^{12}$ fissions / s

    M. Fadil, B. Rannou et al, NIM B 266 (2008) 4318–4321
DONES. Neutron map in the Irradiation Cell (Horizontal Plane –z-axis position z=-220-)

**Remarks:**
- photofission/neutron induced fission is negligible
- Harder neutrons for SPIRAL 2 give more fissions
- First order estimates for DONES
DONES. Neutron map in the Irradiation Cell (Horizontal Plane –z-axis position z= -220-)

- X-Axis (cm)
- Y-Axis (cm)
- Neutron Fluence Rate [n/cm²s]

- Fusion irradition module
- Irradiacion cell inner walls
- Deuteron beam
- Presently empty space

- 3×10^{14} fissions /s
- Pf=12kW!
High power targets

• See for example ISAC high power targets

P. Bricault et al, NIM B 204(2003)319

Ta fins to be adapted to a SPIRAL 2 phase 2 –like target?

Or normal density target / nanostructured UCx targets (ACTILab)
* Pf~4kW, $10^{14}$ fissions/s
* Higher release efficiency for short lived isotopes
DONES. Neutron map in the Irradiation Cell (Horizontal Plane –z-axis position z=-220-)

- Neutron Fluence Rate [n/cm²s]
  - 10¹²
  - 10¹³
  - 10¹⁴

- X-Axis (cm)
  - 8.11e+011
  - 7.91e+014

- Y-Axis (cm)
  - Deuteron beam
  - Fusion irradiation module
  - Irradiacion cell inner walls
  - Presently empty space

- 3x10¹³ fissions /s
- SPIRAL 2 phase 2
- Pf=3kW
Spiral 2: the oven for the UCx target

- $5 \times 10^{13}$ fission/s with 5 mA / 40 MeV deuteron.
- Coupled with ECRIS, LIS, FEBIAD or SIS ion source
- Temperature of 2000°C
- Working period: 3 months
- 19 series of 80 Ucx pellets (Ø 15; thickness 1mm)

A prototype in carbon
- Easier than Tantalum to reach more than 2000°C
- Lifetime lower due to high evaporation rate of carbon

$\sim 10^{13}$ fissions / s with nanostructured UCx

For optimized production, the converter must be as close as possible to the target.
DONES. Neutron map in the Irradiation Cell (Horizontal Plane –z-axis position z=-220-)

**Neutron Fluence Rate** [n/cm²s]

- **X-Axis (cm)**
  - 8.11e+011
  - 7.91e+014

- **Y-Axis (cm)**
  - 10^{12}
  - 10^{13}

- **Deuteron beam**
- **Fusion irradiation module**
- **Irradiacion cell inner walls**
- **2×10^{12} fissions /s**
- **SPIRAL 2 phase 2 day 1**
- **Pf=0.3kW**
Radioactive ion beam intensities

In target yields

\[ Y_{\text{target}} = Y_{1+} \times \varepsilon_{\text{release}} \times \varepsilon_{\text{ionisation}} \times \varepsilon_{\text{transport}} \]

On-line data: MCNPx, FISPACT

Data sources:
- > 10^{11} / 10^{13} fissions
- > 10^{10} / 10^{13} fissions
- > 10^{9} / 10^{13} fissions
- > 10^{8} / 10^{13} fissions

ISOLDE, Parnne data
Litterature (Kirchner)

1+ beam intensities (pps)
Radioactive ion beam intensities

\[ \gamma_{1^+} = \gamma_{\text{target}} \times \epsilon_{\text{release}} \times \epsilon_{\text{ionisation}} \times \epsilon_{\text{transport}} \]

- MCNPx
- FISPACT
- On-line data
- ISOLDE, Parnne data
- Literature (Kirchner)
- On-line data
- ISOLDE data

On the side of the irradiation cell

~SPIRAL 2 day 1
Radioactive ion beam intensities

\[ Y_{1^+} = Y_{\text{target}} \times \varepsilon_{\text{release}} \times \varepsilon_{\text{ionisation}} \times \varepsilon_{\text{transport}} \]

Close to the fusion irradiation module

\(~\text{SPIRAL 2 nominal}\)

- MCNPx
- FISPACT
- On-line data: ISOLDE, Parnne data
- Litterature (Kirchner)
- On-line data: ISOLDE data

\( ^{132}\text{Sn} \)

\( ^{78}\text{Ni} \)

Scaling factor = 5
Radioactive ion beam intensities

\[ Y_{1+} = Y_{\text{target}} \times \varepsilon_{\text{release}} \times \varepsilon_{\text{ionisation}} \times \varepsilon_{\text{transport}} \]

On-line data
- MCNPx
- FISPACT

ISOLDE, Parnne data
- Litterature (Kirchner)

On-line data
- ISOLDE data

In the fusion irradiation module

\~10 * SPIRAL 2 nominal

Intermediate step towards EURISOL
Comments on the ISOL target ion source

• Experience from ISOLDE, TRIUMF, SPIRAL, HRIBF, ALTO, ACTILab collaboration
  – Small integrated systems have to be preferred over large volumes
    • Higher release efficiencies due to shorter effusion times
    • Large volumes are only beneficial for long lived isotopes (ex $^{132}$Sn)
    • A target size like the one of SPIRAL 2 nominal is already large
  – NanoUCx materials developed in the frame of ACTILab
    • NanoUCx is a low density material presents generally (much) better yields than the standard (high) density Ucx
  – Improving intensities by orders of magnitude can be done by dedicated R&D
    • Grain size of targets: towards nanostructured materials
    • Molecular beams for refractory elements
    • Efficient ionization
      – Lasers, FEBIAD (+Lasers), ECR sources, Surface ionisation sources

Large volume targets limited to some applications for long-lived isotopes
The resulting intensities are quite often marginally a question of fissions / s!
Comments on the ISOL target ion source

- Required infrastructure
  - Hot cell
  - Target storage
  - Remote handling
  - Target front end
  - Beam lines, separators
    - 1 or 2 targets? Or more...?
  - Experimental areas
    - DESIR like?
    - Post-acceleration?
  - Radiation Shielding (target bunker, experimental areas)
  - Nuclear ventilation
  - Gas storage
  - Services
    - Power supplies
    - Cooling
    - Etc
  - Staff and offices
  - Etc

SPIRAL 2 phase 2 production building

The target and ion source is the tip of the iceberg!
Physics cases and instrumentation

See for example: Updated Physics and Instrumentation case for ISOL facilities and for EURISOL
ENSAR Final deliverable report

- process and nuclear structure far from stability

**DESIR – like facility**
Masses, T1/2, Beta decay spectroscopy Gamow strength Bn Spins, moments Charge radii ...

**Postaccelerated beam facility**
Coulomb excitation, transfer reactions DIC, FE Superdeformation and highly deformed states ...

A vast unknown territory to study
Towards EURISOL

Assuming E<=10-15AMeV/n

γ arrays, wide variety of detectors, active targets, spectrometers etc
Conclusions

• Preliminary considerations
  – High neutron flux at IFMIF/DONES gives interesting perspectives for RIB production using a SPIRAL 2 like target
    • Up to 10 times higher flux than from SPIRAL 2
  – More detailed studies needed for
    • The actual fission rate in the target
    • According to the possible target location
  – Using one or several targets at DONES require a developing a complex/advanced infrastructure
  – The physics cases should motivate the project
    • Defining instrumentation
    • Depending on the interest, post-acceleration may be envisaged at short or longer term

• Not considered but should be considered
  – Other targets (examples)
    • $^9\text{Be}(n,a)^6\text{He}$ (BeO target)
    • $^{11}\text{B}(n,a)^8\text{Li}$ (BN or $\text{B}_4\text{C}$ target)
Thanks a lot for your attention!
$^6\text{He from BeO target}$

Collaboration ISOLDE – GANIL
SOREQ – Weissman Institute

Small microstructure = quick diffusion

Proton beam on W converter

Neutron flux measurement with the activation foil method

FLUKA simulation results gives reasonable agreement
**6He from BeO target - results**

- **Record intensities for ISOLDE:** $3 \times 10^8$ /uC
  - Up to $4 \times 10^{11}$ pps for SPIRAL 2 (5mA d on converter)
  - (20% ionization in ECRIS)

- **Rapid diffusion and effusion!**

- **New opportunities for $\beta$–$\nu$ angular correlation measurements!**
  - Using LPCtrap or the double MOT at DESIR

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**6He release curve from BeO**

$t_{rise}$ is a characteristic of the effusion

(Ionisation in VADIS!)

**Released fraction**

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<th>Released fraction</th>
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<table>
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<th>t_{delay+0.5tcoll} (s)</th>
<th>betas/mscoll/smeas (s$^{-1}$)</th>
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</table>

|$t_{rise}$ is a characteristic of the effusion

(Ionisation in VADIS!)
Nano structured UCx targets

Generally higher yields than standard density targets

From ACTILab final report

Different structures according to density

Figure 14. Preliminary results of the ActILab nano-structured UCx (#52.5UC-Re) in comparison to conventional ISOLDE UCx targets. The references are mostly taken from the ISOLDE yield database, or in the case of 26Na from a measurement on target #410 UC-W, and for 88Rb from #301UC-Ta

Figure 6. SEM images. From left to right: compact structure of high-density UC, open structure containing UC$_2$ grains and carbon fibers, open structure containing UC$_2$ grains and graphite residual clusters (black blocks).