Crystalline Target for Radioisotope Production via Anti-Channeling

Outline

• Radionuclide productions in accelerators
• A benchmark for simulations: the GEKO project
• Searching for a crystalline target
• Validation in laboratory environment
Radioisotopes in Medicine

- Nuclear medicine uses radiation to provide diagnostic information about the functioning of a person's specific organs (SPECT, PET), or to treat them (Brachytherapy, target-therapy), especially for cancer. Diagnostic procedures using radioisotopes are now routine.

- Over 40 million nuclear medicine procedures are performed each year, and demand for radioisotopes is increasing at up to 5% annually.

- Radioisotopes for nuclear medicine are generated through various methods, i.e. particle accelerators, reactors facilities.
Accelerator produced radionuclides

Current scenario:
- Strong reduction of the production of Mo-99 (i.e. the parent daughter of TC-99m) in nuclear reactors

Advantages of accelerators:
- high specific activities can be obtained through charged particle induced reactions
- few radioisotopic impurities by selecting the energy window
- small amount of radioactive waste generated
- access to accelerators is much easier than to reactors

Major drawback:
- in some cases an enriched (and expensive) target material must be used
- The overall production cost is still 3 to 10 times with respect to nuclear reactors
Goal of TROPIC project

• **Aim:**
  • enhancement of the radio-isotopes production yield through cyclotron with minor modification of current instrumentations.

• **How:**
  • usage of microscopically ordered structures to force the particles to interact more frequently with nuclei.
History

• 2014/2015, collaboration with COMECER SpA:
  • Anti-channeling idea
  • “Exploiting Channeling of Charged Particles for the Enhancement of the Ni64->Cu64 Reaction Yield”, 7 June 2015, Society of Nuclear Medicine and Molecular Imaging Meeting 2015, Baltimore (US)

• 2016/2017, INFN-GeCO (Geant4 Crystal Objects) project:
  • Integration of channeling simulations into Geant4
  • Anti-channeling experiments at INFN-Legnaro Laboratories
    • “Crystalline targets for the enhancement of the nuclear interaction yield”, 15 November 2016, International Nuclear Target Development Society Meeting 2016, Cape Town (South Africa)
    • “Experimental measurement of the enhancement of the nuclear interaction yield with crystalline targets”, 13 June 2017, International Conference on Applications of Nuclear Techniques, Crete (Greece)

• 2017/2019, POR-FESR TROPIC project
  • Development of a target prototype for the production of radioisotopes for medical interest, to be tested in laboratory environment (TRL4) and in production environment (TRL5)
Radioisotope for medicine

- Radioactive isotopes used for diagnosis, therapy, or both (theragnostic)
- Lifetime of the order of biological processes (few hours/days)
- Possibility to fix them to a functional molecule
- To be produced with a good yield by using particles at energies available at commercial cyclotron (~15-20 MeV)

<table>
<thead>
<tr>
<th>Target</th>
<th>Initial Isotope</th>
<th>Final Isotope</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{89}$Y</td>
<td>$^{89}$Y</td>
<td>$^{89}$Zr</td>
</tr>
<tr>
<td>TeO$_2$</td>
<td>$^{124}$Te</td>
<td>$^{124}$I</td>
</tr>
<tr>
<td>TeO$_2$</td>
<td>$^{123}$Te</td>
<td>$^{123}$I</td>
</tr>
<tr>
<td>SrCO$_3$</td>
<td>$^{86}$Sr</td>
<td>$^{86}$Y</td>
</tr>
<tr>
<td>$^{64}$Ni</td>
<td>$^{64}$Ni</td>
<td>$^{64}$Cu</td>
</tr>
<tr>
<td>$^{61}$Ni</td>
<td>$^{61}$Ni</td>
<td>$^{61}$Cu</td>
</tr>
<tr>
<td>$^{111}$Cd</td>
<td>$^{111}$Cd</td>
<td>$^{111}$In</td>
</tr>
<tr>
<td>CaCO$_3$</td>
<td>$^{44}$Ca</td>
<td>$^{44}$Sc</td>
</tr>
<tr>
<td>$^{67}$Zn</td>
<td>$^{67}$Zn</td>
<td>$^{67}$Ga</td>
</tr>
<tr>
<td>$^{68}$Zn</td>
<td>$^{68}$Zn</td>
<td>$^{68}$Ga</td>
</tr>
</tbody>
</table>
How to deal with crystals?

- Isotopic purity needed to obtain a good yield of production without contaminants.
- A crystalline quality sufficiently high to observe the anti-channeling effect

Yttrium and Rhodium have only one isotope, they can be found as crystalline material, and are useful materials for nuclear medicine:

- Pros: No need to be enriched
- Cons: to be found as a pure monocrystal (expensive/not trivial)

First Y (2x2x0,5 mm) and Rh (3x3x0,5mm) already purchased, characterized and polished are the first candidates as a target.
Crystal Bulk Characterization @ ESRF ID11

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Photon energy</td>
<td>140 keV</td>
</tr>
<tr>
<td>divergence</td>
<td>Negligible</td>
</tr>
<tr>
<td>DE/E</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>Beam dimension</td>
<td>From 50x50 to 500x500 micron</td>
</tr>
</tbody>
</table>

Diagram:
- **DETECTOR or PHOTOGRAPHIC PLATE**
- Incident beam
- Diffracted beam
- Goniometer
- HCP (Hexagonal Closed Pack)
- FCC (Face-Centered Cubic)
- Rh (Rhenium)
Y (0001)

<table>
<thead>
<tr>
<th>Sample dimensions</th>
<th>2x2x0,5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traversed thickness</td>
<td>0,5 mm</td>
</tr>
</tbody>
</table>

Photographic plate

Horizontal direction

Vertical direction

Rocking curve on selected point

Counts

Angle [mrad]

Counts

Angle [mrad]
Rh (100)

Sample dimensions: 3x3x0.5 mm
Traversed thickness: 0.5 mm

Photographic plate

Rocking curve on selected point
Surface realignment and polishing

Surface Preparation Laboratory (Netherlands)

Yttrium as received  after 6 μm polishing  final result

Laue diffraction

Thursday, September 27, 2018
Channeling 2018
Surface realignment and polishing
Surface preparation laboratory (Netherlands)

Rhodium as received
after polishing

Laue diffraction
Alternative ionic/oxide crystals

- KBr
- YAG, YAlO$_3$, YVO$_4$
Crystal surface @ ESRF BM05

- Rh (100) - PRELIMINARY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Photon energy</td>
<td>20 keV</td>
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<tr>
<td>Divergence</td>
<td>Negligible</td>
</tr>
<tr>
<td>Beam dimension</td>
<td>10x10 mm</td>
</tr>
</tbody>
</table>
Crystal surface @ ESRF BM05

- KBr (110) - PRELIMINARY

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<td>Beam dimension</td>
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</table>
Tests with proton beam

• Experiments can be carried out in accelerators facilities

• The proposal for the TROPIC experiment at the Tandem accelerator of the INFN Legnaro National Laboratories, PD, Italy was accepted by the USIP. This represents the “validation in lab” (TRL4)
Setup scheme for laboratory validation at LNL Tandem

- **p^+ @ 10÷18 MeV**
- **Crystal (e.g. Y)**
- **Si detector**
- **Crystal support (Pl, Nb, Cu, Al, ...)**
- **Goniometer**
- **Ge detector**
Thank you for your attention!