Solid Targetry for Compact Cyclotrons

Jožef Čomor

Vinča Institute of Nuclear Sciences
Belgrade, Serbia and Montenegro

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Outline

- Introduction
- Basic principles of solid targetry
- High power targets for large scale production of radioisotopes
- Solid targets for radioisotope production with compact cyclotrons
- COSTIS: Compact solid target irradiation system
- Conclusion
Introduction

- The production of useful amounts of radioisotopes started with Lawrence’s cyclotron and with solid targets in 1932...
Introduction (2)

- For a long time solid targetry was the main source of cyclotron produced medical radioisotopes, like:
  - $^{67}$Ga
  - $^{103}$Pd
  - $^{111}$In
  - $^{201}$TI
  - ...

Solid targetry is still the workhorse of radioisotope production technology development:

- Stacked foil technique for nuclear reaction cross section measurements
- Precise thick target yield measurements

Many promising isotopes are waiting for routine production based on solid targetry
Basic Principles of Solid Targetry

\[ Y = \frac{I \cdot N_a \cdot \rho}{Z \cdot e \cdot A} \cdot \left(1 - e^{-\lambda \cdot t}\right) \int_{E_o}^{E_i} \frac{\sigma(E)}{\frac{\partial E}{\partial X}} \, dE \]
Basic Principles of Solid Targetry (2)

![Graph showing cross-section vs. proton impact energy for different reactions](image)

- $^{203}\text{Tl}(p,3n)^{201}\text{Pb}$
- $^{205}\text{Tl}(p,5n)^{201}\text{Pb}$
- $^{203}\text{Tl}(p,4n)^{200}\text{Pb}$
- $^{203}\text{Tl}(p,2n)^{202m}\text{Pb}$
- $^{205}\text{Tl}(p,4n)^{202m}\text{Pb}$

Proton impact energy, MeV

Cross-section, barn
Basic Principles (3)

50 µm $^{203}$Tl, 28.5 MeV protons, 7° glancing angle

Energy distribution of transmitted protons

4.32% are backscattered!!!
High Power Targets for Large Scale Production of Radioisotopes

Silver substrate

High power target for $^{201}$Tl production (IBA, Belgium)

Aluminum or copper body
High Power Target Stations

Basic principle of rabbit transport systems
Target Irradiation Chamber for High Power Targets
High Power Target Stations in Operation

Solid target stations developed at TRIUMF, Canada
High Power Target Stations in Operation (2)

Solid target station developed by IBA, Belgium
The Potential of Compact Cyclotrons

- In a typical PET center the cyclotron is not in use in the afternoon and late evening.
- Counting only 10 h a day in this time window and 20 \( \mu \text{A} \) beam on target, one could make use of 200 \( \mu \text{A} \cdot \text{h} \) useful beam for daily RI production.
- Potential candidates for this evening production could be \( ^{124}\text{I} \), \( ^{123}\text{I} \), \( ^{94}\text{Tc} \), \( ^{86}\text{Y} \), \( ^{64}\text{Cu} \), etc…
The Potential of Compact Cyclotrons (2)

- An existing compact cyclotron installation provides:
  - Typically 15-18 MeV protons, 40-80 μA
  - He cooling loop
  - Water cooling loop
  - Compressed air supply
  - PLC based control system

- Certain space limitation
The Potential of Compact Cyclotrons (3)
The Potential of Compact Cyclotrons (3)

- What is missing for solid target irradiation on compact cyclotrons?
  - A compact target station that will comply to all space (and budget) limitations
  - A simple target transport system – there is no justification for a rabbit system
State of the Art

- The cyclotron producers are not addressing seriously this issue:
  - There is only limited interest on the PET cyclotron market for solid targetry
  - Until recently the four “classical” positron emitters provided sufficient base for research
- But now, the need is there for alternative positron emitters...
- And also at least one solution: COSTIS (COnpact Solid Target Irradiation System)
COSTIS: the Concept

- Custom made flange
- He cooling cavity
- Water jet
- Pneumo-mechanical parts
COSTIS: Operating principle
Heat Load of the TeO$_2$ Target: 20 μA Protons @ 15 MeV
Problems

- The heat conductivity of TeO$_2$ is very low: 30 mW·K$^{-1}$·cm$^{-1}$ (typical values for metals are 3-5 W·K$^{-1}$·cm$^{-1}$, i.e. 100× higher)
- The melting point of TeO$_2$ is 733 °C
- The vapor pressure of TeO$_2$ becomes significant above 600 °C
Solving the Problem

- Find the optimal geometry for coolant flow, while the flow rates are reasonable
- Use numerical modeling (SIMPLEST algorithm embodied in the PHOENICS computer code) instead of trial and error approach
Coolant flow in the central axes

He, m·s⁻¹

0.0
0.4
0.8
1.3
1.7
2.1
2.5
3.0
3.4
3.8
4.2
4.6
5.1
5.5
5.9

Water, m·s⁻¹

0.0
0.3
0.6
0.8
1.1
1.3
1.6
1.9
2.1
2.4
2.6
2.9
3.2
3.4
3.7
Maximum calculated temperatures in the target disk

Maximum temperature in a layer, °C

Depth in the target disk, mm

TeO₂

Pt
The prototype (1)
The prototype (2)

Actuators

He cooler

BNC connectors
The prototype (3)

Target guiding plate

4.6 kg total weight
Basic Technical Characteristics

- Dimensions: 16×34×27 (H×W×L, cm)
- 60 dm³/min He @ 2 bar and ≤ 25 °C
- 2×8 dm³/min cooling water @ 5 bar and ≤ 25 °C
- Independent beam current monitoring on the collimator and target
- Manual target loading
- Remote target unloading
Test Installation in Belgrade
COSTIS Installed on a GE PETtrace (Eastern Isotopes)
Routine Production of $^{124}$I in Richmond, Virginia, USA (Eastern Isotopes)

Beam on target, $\mu$A·h

EOB yield, mCi

16 MeV
20 $\mu$A beam on target
(320 W)
Dry Distillation Apparatus
Eastern Isotopes Inc. Distributes Iodine-124 to MD Anderson Cancer Center

LOUVAIN-LA-NEUVE, BELGIUM, June 21, 2004 – IBA (Ion Beam Applications S.A.: Reuters IOBA1.BR and Bloomberg IBAB.BB) announced today that its subsidiary Eastern Isotopes, Inc., has made its first delivery of Iodine 124 to MD Anderson Cancer Center, Houston, TX.

Iodine 124 is a PET isotope currently used for investigational purposes. Researchers are looking for new radiopharmaceuticals to expand the current PET imaging applications. Iodine 124 is an ideal option due to its relatively long half life and the ease of attaching it to peptide antibodies for oncology purposes and free fatty acids for cardiology purposes. In addition, Iodine 124 is also useful tool to assess thyroid dosimetry.

Eastern Isotopes is the first commercial radiopharmacy in the United States to manufacture and deliver this drug domestically. The PET chemistry expertise of our staff, along with our large capacity cyclotrons, has enabled Eastern Isotopes to step into this area of high demand in the PET community. The partnership with MD Anderson demonstrates Eastern Isotopes appreciation of the impact research PET isotopes will have on the advancement of healthcare. Eastern Isotopes efforts continue to make investigational isotopes available throughout the United States.
Possible applications

- $^{124}\text{I}$
  - $^{124}\text{Te}(p,n)^{124}\text{I}$
  - $^{124}\text{TeO}_2$

- $^{123}\text{I}$
  - $^{123}\text{Te}(p,n)^{123}\text{I}$
  - $^{123}\text{TeO}_2$

- $^{86}\text{Y}$
  - $^{86}\text{Sr}(p,n)^{86}\text{Y}$
  - $^{86}\text{SrCO}_3$

- $^{64}\text{Cu}$
  - $^{64}\text{Ni}(p,n)^{64}\text{Cu}$
  - $^{64}\text{Ni}$ (metallic)

- $^{94}\text{Tc}$
  - $^{94}\text{Mo}(p,n)^{94}\text{Mo}$
  - $^{94}\text{Mo}$ (metallic)

- ...
Conclusion

- Solid targetry is not restricted to large accelerator centers anymore.
- Small and medium scale radioisotope production is feasible with compact cyclotrons.
- The availability of versatile solid target systems is expected to boost the radiochemistry of “exotic” positron emitters.
Credits

- Gerd-Jürgen Beyer, HUG, Geneva
- Milan Rajčević and
- Đorđe Košutić, Vinča Institute of Nuclear Sciences, Laboratory of Physics, Belgrade
- Žarko Stevanović, Vinča Institute of nuclear Sciences, Laboratory of Thermal Engineering and Energy, Belgrade