Numerical optimization of radiation shielding of target used for production of $^{18}\text{F}$

_BgNs INTERNATIONAL CONFERENCE NUCLEAR ENERGY FOR THE PEOPLE_

10 - 13 September, 2018, Garden of Eden Resort, Sveti Vlas, Bulgaria

A. Demerdjiev, INRNE-BAS
Contents

› Introduction
  › INRNE cyclotron Physics Laboratory
  › Radiological characterization of the cyclotron vault - FLUKA
› Description of the model
  › Local target shielding
  › Modeling domain – simplified spherical geometry
› Results and discussion
  › Nuclides in inner concrete layer
› Summary
Introduction

TR24 Cyclotron parameters:
› ACSI, Vancouver, Canada
› Beam Energy: 15 – 24 MeV
› Beam Current: 400 µA
› Upgradeable to 1 mA

PET: $^{11}\text{C}$, $^{13}\text{N}$, $^{15}\text{O}$, $^{18}\text{F}$, $^{124}\text{I}$, $^{64}\text{Cu}$, $^{68}\text{Ge}$

SPECT: $^{123}\text{I}$, $^{111}\text{In}$, $^{67}\text{Ga}$, $^{57}\text{Co}$, $^{99m}\text{Tc}$

Cyclotron Physics laboratory current status:
› cyclotron successfully delivered - 12.01.2016
› cyclotron center building has to be build
› current research activity - numerical studies on the possibilities to produce various medical isotopes; radiological characterization of the setup.
Beamlines, targets and target stations for PET&SPECT radioisotopes

A. Demerdjie <Numerical optimization of radiation shielding of target used for production of 18F>
Radiological characterization

Evaluate internal hazards:

› Nuclides in target body
› Define nuclides expected to be produced over the operation time of the machine and the vault
› Check vault radiation specs w.r.t. neutrons and gamma rays
› Define cooling time - short lived nuclides (airborn $^{41}\text{Ar}$?)
› Check operators dose rate

Monte-Carlo approach
FLUKA used for simulations
Radiological characterization

› Emission and transport of secondary particles due to primary nuclear reaction
  › low energy neutron transport
  › takes into account the geometry of the impinging beam (e.g. point source)
› Assessment of the produced residual nuclei
› Possibility to score the same physics process at different irradiation & cooling times
  › buildup and decay of waste

› Not possible to include missing X-section libraries

Two-step approach to estimate fluence/waste within the vault

› Simulate target irradiation, assess secondary particles
  › \((p, n), (p, \gamma)\)
› Use secondary particles as source irradiating vault components
18F high-current liquid target

› Delivered 3.8 mL targets
› Check thick target yield in 18O(p, n)18F
› Pipe secondary particles to be used as source irradiating the vault
A proton beam (various $E$, fixed $I$) impinges on a simple target

**Thick target** – the reaction takes place with the volume of enriched water.

The lower the beam energy, the better the agreement:

- Real beam not gaussian in any plane, not point-like, no experimental data on phase space
- The FLUKA model is limited in terms of energy
Secondary particles – real target: density distribution

- beam orientation w.r.t. target
- rate of emission of secondaries

Fixed (E, I) beam
Secondary particles – real target: energy spectrum

100μA, 18 MeV: 3e10 n/(s.cm²)

400μA, 24 MeV: 2.5e11 n/(s.cm²)

*15 μA, 17 MeV

2.44e10 n/(s.cm²)

*Sadat-Eshkevar et al, Assessment of the staff absorbed dose related to cyclotron operation and service in the production of ¹⁸F radiopharmaceuticals, Nukleonika 2012; 57 (3):407-410

Neutron and gamma spectra for two different proton beam energies. The secondary particle count is scored in a 4-π volume surrounding the target.
Description of the volume

- Source of secondary particles → geometrical center
- Target material irradiation → one month, six hours daily, five days per week
- $^{18}$F-target, neutrons emitted → scored and written in files → neutron source irradiating the vault
- FLUKA → particle transport; nuclides’ activities
- Geometry:
  - At the center → sphere $R = 20$ cm (air)
  - Spherical shell with thickness of 250 cm:
    - Innermost layer 5 cm;
    - Second layer 25 cm;
    - Second and third shells → concrete with Portland cement

Two cases of chemical composition of the innermost layer: concrete with Portland cement, borated polyethylene.

Preliminary results

Worst case scenario: target and local shielding close to the vault walls
Results and discussion: Nuclides in the first 25 cm

After a month of cooling

› Nuclides in the first concrete layer for the two cases without (left) and with borated polyethylene local target shielding.
Results and discussion: Nuclides in concrete layer behind shielding

Activities in [Bq] of some of the nuclides generated in the first 25 cm thick layer behind the shielding. The borated polyethylene layer here has thickness of 5 cm.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>High-density concrete</th>
<th>Borated polyethylene</th>
<th>Parent nucleus</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{55}\text{Fe}$</td>
<td>$1.0\times10^6$</td>
<td>$9.4\times10^5$</td>
<td>$^{55}\text{Mn}$</td>
</tr>
<tr>
<td>$^{45}\text{Ca}$</td>
<td>$3.9\times10^6$</td>
<td>$3.9\times10^6$</td>
<td>$^{44}\text{Ca}$</td>
</tr>
<tr>
<td>$^{41}\text{Ca}$</td>
<td>472</td>
<td>491</td>
<td>$^{40}\text{Ca}$</td>
</tr>
<tr>
<td>$^{39}\text{Ar}$</td>
<td>3264</td>
<td>2164</td>
<td>$^{39}\text{K}$</td>
</tr>
<tr>
<td>$^{37}\text{Ar}$</td>
<td>$1.5\times10^6$</td>
<td>$7.5\times10^6$</td>
<td>$^{40}\text{Ca}$</td>
</tr>
</tbody>
</table>

Independently from the chemical composition of the innermost shielding, the two cases show similar levels of activities for the nuclides seen.
Using Monte-Carlo simulations the distribution of radionuclides outside of a local target shielding within a layer of 25 cm of a vault is obtained.

Preliminary results showing considering the activity of long-living nuclides a layer of 5 cm is preferable over no shielded high-density concrete but it is not sufficient.

Possible next steps are: changing the concrete recipe with one containing marble (e.g. reduced content of Si); studying the effect of changing the position of the borated polyethylene layer within the vault wall; and optimizing the thickness of the local shielding.
Thank you for the attention!

G. Asova, N. Goutev, D. Tonev