Radiation protection of a proton beamline at ELI

S. Bechet, A. Fajstavr, S. Rollet, R. Versaci, M. Zakova
Outline

- ELI-beamlines and ELIMAIA
- Radiation protection objectives
- Source terms
- Fluka simulations
- Prompt ambient dose equivalent in the experimental hall
- Induced activity
- Conclusions
ELI-beamlines and ELIMAIA

ELI-beamlines: User facility for short-pulse high power laser
ELIMAIA: Multidisciplinary Application for ion acceleration

Diagram showing ELIMAIA control room, corridor, and experimental hall.
Radiation protection objectives

**Prompt radiation**
- Only when the beam is on

**Induced activity**
- Also when the beam is off

**Ambient dose equivalent H*(10) [mSv]**

**Particles type and spectra**

**Radionuclides**

**Specific activity**

**General public limit: 1 mSv/year**

**Controlled area limit: 20 mSv/year**

**Legal maximum specific activity**
- Class 1: 0.3 Bq/g
- Class 2: 3 Bq/g
- Class 3: 30 Bq/g
- Class 4: 300 Bq/g
Source terms

**Korean experimental data**

![Energy spectrum graph](source_term_1)

<table>
<thead>
<tr>
<th>E [MeV]</th>
<th>dN/dE [MeVsr⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10¹⁰</td>
</tr>
<tr>
<td>10</td>
<td>10⁹</td>
</tr>
<tr>
<td>15</td>
<td>10⁸</td>
</tr>
<tr>
<td>20</td>
<td>10⁷</td>
</tr>
<tr>
<td>25</td>
<td>10⁶</td>
</tr>
<tr>
<td>30</td>
<td>10⁵</td>
</tr>
</tbody>
</table>

**PIC simulation data**

![Energy spectrum graph](source_term_2)

<table>
<thead>
<tr>
<th>E [MeV]</th>
<th>dN/dE [MeVsr⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
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<tr>
<td>20</td>
<td>10⁹</td>
</tr>
<tr>
<td>30</td>
<td>10⁸</td>
</tr>
<tr>
<td>40</td>
<td>10⁷</td>
</tr>
<tr>
<td>50</td>
<td>10⁶</td>
</tr>
<tr>
<td>60</td>
<td>10⁵</td>
</tr>
<tr>
<td>70</td>
<td>10⁴</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Korean case</th>
<th>PIC simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>#Primary/shot</td>
<td>7 10¹⁰ protons</td>
<td>2 10¹⁰ protons</td>
</tr>
<tr>
<td>Maximum energy</td>
<td>30 MeV</td>
<td>70 MeV</td>
</tr>
<tr>
<td>Divergence</td>
<td>25°</td>
<td>~10°</td>
</tr>
<tr>
<td># shot/day</td>
<td>300</td>
<td>2000</td>
</tr>
</tbody>
</table>
Simulation description

- Monte Carlo Simulation with FLUKA
- Source term:
  - Beam parameter (experimental data)
  - Input file from PIC simulation
- Geometry:
  - Complete description of the experimental chamber (EC)
  - Simple model for the target holder
  - Material used
    - AL6082 for aluminum
    - EN1.4306 for stainless steel
Prompt $H^*(10)$ in the experimental hall

Horizontal view at beam height

- Simulations configuration
  - $10^{10}$ primaries
  - Open doors in the geom model
  - Shot southward
  - Experimental chamber closed

- Observations
  - $> 1 \text{ mSv/year} \rightarrow$ no one allowed inside during the run
  - Effect of the 2 concrete columns visible
  - Concrete walls shield control room and other areas
  - Detailed radiation shape explained on the next slide

Korean data

PIC simulation

~31.5 m

~26 m

[ mSv/year ]
H*(10) in [mSv/year] - Horizontal view at beam height - ZOOM

- Back-scattering
- Shape depends on the geometrical structure of the experimental chamber
H*(10) in [mSv/year] - Horizontal view at beam height - statistical uncertainties

Less 10% → simulation reliable
H^*(10) due to induced radioactivity - PIC

Horizontal view at beam height – 1 year of operation for different cooling times

End of irradiation (EoI)  
After 1 hour  
After 1 day

After 1 week  
After 1 month  
After 1 year

[μSv/hour]

Preliminary

100 hours /man/year
Observations

- One order of magnitude difference between Korean and PIC due to energy differences
- Dose 1 year > dose 1 month > dose 1 day due to the nuclides build-up
- At the EoI, low dose → 100 – 1000 hours/year for one man
Main radionuclides in the target holder

1 year irradiation with PIC source term

<table>
<thead>
<tr>
<th>name</th>
<th>class</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr51</td>
<td>3</td>
<td>27.7 days</td>
</tr>
<tr>
<td>Mn56</td>
<td>1</td>
<td>2.58 h</td>
</tr>
<tr>
<td>Fe55</td>
<td>4</td>
<td>2.73 year</td>
</tr>
<tr>
<td>Co58</td>
<td>1</td>
<td>70.8 days</td>
</tr>
</tbody>
</table>

- Observations
  - Error of the order few %
  - Nothing above the most restrictive class
Main radionuclides in the steel structure
1 year irradiation with PIC source term

<table>
<thead>
<tr>
<th>name</th>
<th>class</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>F18</td>
<td>2</td>
<td>109.8 min</td>
</tr>
<tr>
<td>Na24</td>
<td>1</td>
<td>14.9 h</td>
</tr>
<tr>
<td>Mg23</td>
<td>unclassified</td>
<td>11.3 s</td>
</tr>
<tr>
<td>Al26m-1</td>
<td>1</td>
<td>6.3 s</td>
</tr>
<tr>
<td>Si27</td>
<td>unclassified</td>
<td>4.2 s</td>
</tr>
</tbody>
</table>

- Observations
  - Error of the order few %
  - Preliminary result : need a better normalization
  - High specific activity for F18, Mg23 and Si27 but they are short-lived nuclides
Conclusions

- Beam and geometry implemented in FLUKA
  → useful for next simulations with new configurations

- Prompt dose
  - > 1 mSv/year close to EC
    → no one allowed during the run in the experimental hall

- Induced activity
  - ≃ 1 μSv/h → ~ 1000 hours/man/year → “safe”
    - Some radionuclides have high specific activities but also short life-time → after one day no need for radioactive waste procedure

- Preliminary results not worrying for the radiation protection