OPERATIONAL HEALTH PHYSICS DURING MAINTENANCE OF A
RADIOISOTOPE PRODUCTION CYCLOTRON

Bhaskar Mukherjee* and Joseph Khachan
Department of Applied and Plasma Physics
University of Sydney, Australia

*Now with European XFEL Project, Deutsches Elektronen-Synchrotron (DESY)
Notkestrasse 85, D-22607 Hamburg, Germany

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For safe and reliable operation of commercial radioisotope production medical cyclotrons the implementation of preventative maintenance at regular intervals becomes mandatory.

During the long term operation of a medical cyclotron, numerous (radio) activated zones at various locations of the cyclotron facility producing high levels of gamma radiation are created.

These radioactive zones are caused by the parasitic neutrons produced during the bombardment of cyclotron targets with protons during the isotope production process.

Obviously, these activated cyclotron components impact on personnel radiation exposure of the radiation workers during routine cyclotron maintenance and repair processes.

As the principle of ALARA (As Low As Reasonably Achievable) constitutes the part and parcel of operational health physics, it becomes imperative to study the impact of the induced radioactivity of the activated species and the relevant coll down (decay) times on the personnel radiation exposure during cyclotron maintenance.

This report highlights the method for the prediction of personnel doses during various types of work in the cyclotron active (radiation environment) areas using the statistics of a long term routine health physics survey data.
A Cyclotron Radioisotope Production Facility

FIGURE 1: Cyclotron Facility Foot-print (highly active zones are marked in red)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Half Life</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{15}$O</td>
<td>2 min</td>
<td>PET</td>
</tr>
<tr>
<td>$^{13}$N</td>
<td>10 min</td>
<td>PET</td>
</tr>
<tr>
<td>$^{18}$F</td>
<td>110 min</td>
<td>PET</td>
</tr>
<tr>
<td>$^{123}$I</td>
<td>13.4 h</td>
<td>SPECT</td>
</tr>
<tr>
<td>$^{99m}$Tc</td>
<td>67 min</td>
<td>SPECT</td>
</tr>
<tr>
<td>$^{17}$Ga</td>
<td>78 h</td>
<td>SPECT</td>
</tr>
</tbody>
</table>

Radioisotope Production Plan

The 30 MeV $^3$H- (Negative Ion) Medical Cyclotron

Area Specifications
Major Medical Cyclotron Sub Systems

- Radiation Monitoring
- Hot Cells
- PET Target Station
- SPECT Target Station
- Delay Tanks
- Stack Effluent Monitors
Materials and Methods

(A) During routine weekly Health Physics survey the gamma dose rates at selected locations were evaluated using a hand held gamma monitor: (i) at contact and at 50cm from target stations T1, T2 and T3, (ii) at contact and at 50cm from collimators of target stations T2 and T3, (iii) at contact and at 50cm from Faraday Cup FC2 and (iv) at target vault entrance (E).

(B) At the same time the gamma dose rate at the entrance point (E) detected by the Geiger Counters GM1 and GM2 and assessed by the real time radiation monitoring system (Health Physics Watchdog) was recorded.

(C) The Gamma dose rates at selected locations were normalised to the average entrance point (E) dose rate assessed by the Geiger counters. The normalisation factors (k_i) were evaluated. The results are shown in the Table next.

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>D_G [mSv/h]</th>
<th>k_i</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Target vault entrance</td>
<td>2.4 \times 10^2</td>
<td>0.75</td>
</tr>
<tr>
<td>FC2</td>
<td>At Faraday Cup FC2</td>
<td>4.5 \times 10^2</td>
<td>1.4</td>
</tr>
<tr>
<td>P0</td>
<td>50cm from Faraday Cup</td>
<td>3.7 \times 10^2</td>
<td>1.2</td>
</tr>
<tr>
<td>T2</td>
<td>At contact with target T2</td>
<td>4.0 \times 10^4</td>
<td>125</td>
</tr>
<tr>
<td>P2</td>
<td>50 cm from target T2</td>
<td>3.4 \times 10^3</td>
<td>10.6</td>
</tr>
<tr>
<td>C2</td>
<td>Collimator of target T2</td>
<td>5.0 \times 10^4</td>
<td>156</td>
</tr>
<tr>
<td>T3</td>
<td>At contact with target T3</td>
<td>2.1 \times 10^4</td>
<td>65.6</td>
</tr>
<tr>
<td>P3</td>
<td>50 cm from target T3</td>
<td>1.1 \times 10^3</td>
<td>3.4</td>
</tr>
<tr>
<td>C3</td>
<td>Collimator of target T3</td>
<td>7.6 \times 10^3</td>
<td>23.8</td>
</tr>
</tbody>
</table>

FIGURE 2: Dosimetry locations in the target vault and principle of real-time radiation monitoring system.

TABLE 1: Dosimetry locations and the normalisation factors
Materials and Methods (contd.)

Long-term gamma dose rates assessed at the vault entry point (E), vicinity of target stations T2 and T3, collimators and Faraday Cup (FC2) during 12-12-02 to 25-02-04.

FIGURE 3
Radioactive Decay Analysis

The radioactive decay characteristics of activated species in the cyclotron components shall be well estimated for accurate gamma dose calculations.

The gamma dose rate at the target vault entrance point (E) was assessed in real-time after a 12 hours routine radioisotope production run using the Geiger counters (GM1 and GM 2) interfaced to Health Physics Watchdog (FIGURE 2). The decay curve is shown below (FIGURE 4).

DATA ANALYSIS

The decay curve was fitted with four (A, B, C, D) components using “least square” analysis (fitting error ~ ± 2%):

(A) \[ y = 65.0\exp(-0.693t/4) \implies \]

(B) \[ y = 20.0\exp(-0.693t/156) \implies \]

(C) \[ y = 6.0\exp(-0.693t/900) \implies \]

(D) \[ y = 9.0\exp(-0.693t/64224) \implies \]

As the fitting function the radioactive decay equation has been considered:

\[ D(t) = D_0 \exp[-t(\ln2 / T_{1/2})] \]

Where, t and \( T_{1/2} \) are the decay time (min) and half life (min) of the activation product of interest respectively.

FIGURE 4: The gamma dose rate assessed in real-time at target vault entrance plotted as a function of elapsed time (decay curve).
Results (dose calculations)

From the slope of the decay equations 1, 2, 3 and 4 we have estimated the half lives, and subsequently identified the induced radioactive species as: (A) $^{28}$Al ($T_{1/2} = 4$ min), (B) $^{56}$Mn ($T_{1/2} = 156$ min), (C) $^{24}$Na ($T_{1/2} = 900$ min), (D) $^{59}$Fe ($T_{1/2} = 64224$ min = 44.6 d).

The integrated job specific gamma dose at any cyclotron part of interest $D_i(t)$ after the elapsed time “t” was derived from equations (1) – (4) and dose normalisation factor $k_i$:

$$D_i(t) = D_{GM} \cdot k_i \cdot \left[ 65.0 \exp(-0.693t/4) + 20.0 \exp(-0.693t/156) + 6.0 \exp(-0.693t/900) + 9.0 \exp(-0.693t/64224) \right] \cdot T_i ;$$

Where, $T_i = \text{Work duration}$ (TABLE 3), $D_{GM} = \text{Geiger Counter reading} [\mu \text{Sv/h}]$. Results are summarised in TABLE 3.

**TABLE 3:** Summary of the dose calculation results highlighting the work description of the cyclotron maintenance worker, work duration, work location and personal radiation exposure after decay periods of 1, 7, 14 and 30 days.
Good Practice of Cyclotron Operational Health Physics

- Radiation dose monitoring
- Maintenance (dose sharing)
- L. L. Radioactive waste auditing
- Target repair using long wrenches
Summary and Conclusions

We have presented a method for the prediction of induced radioactivity and work specific personnel radiation exposure at a radioisotope production cyclotron facility.

A long term health physics survey data (FIGURE 3) was the basis of dose prediction.

The analysis of the radioactivity decay revealed that thermal neutron induced activity of $^{59}$Fe ($T_{1/2} = 44.6$ d) in cyclotron parts made of iron (i.e. beam lines, target station) is the main contributor of long term radiation exposure (TABLE 2).

Personnel radiation exposure during the execution of some specific work found to be quite high (TABLE 2). This could be reduced to ALARA level by (a) implementing local body shield, (b) using long wrenches for handling highly active parts, (c) Dose sharing among two or more adequately trained radiation workers (Good Practice of Cyclotron Operational Health Physics).

The operational health physics methods and techniques presented in this report are basically valid for the NMC/RPAH located in Sydney Australia and operating a 30 MeV H- ion medical cyclotron.

Evidently, these health physics procedures could be used as useful guidelines for any commercial medical cyclotron facility after suitable modifications.

THANK YOU
mukherjee@ieee.org
The generic chart showing the radiation production pathways of a high-current medical cyclotron and the nature of associated radiological exposure.