OPERATIONAL HEALTH PHYSICS DURING THE MAINTENANCE OF A RADIOISOTOPE PRODUCTION CYCLOTRON

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Abstract

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 neutrons produced during the bombardment of the radioisotope producing target. Present report highlights the major operational health physics aspects, including (a) dose assessment of activated regions, (b) personnel dosimetry and (c) radioactive waste management during the maintenance of the 30 MeV, H^- ion medical cyclotron jointly operated by the Royal Prince Alfred Teaching Hospital (RPAH) of University of Sydney and National Medical Cyclotron (NMC), Australian Nuclear Science and Technology Organisation (ANSTO).

INTRODUCTION

Since July 1992 the NMC has been routinely producing short lived PET (Positron Emission Tomography) isotopes ^{18}F ($T_{1/2}$ = 110min), ^{15}O ($T_{1/2}$ = 2min) and ^{13}N ($T_{1/2}$ = 10min) and delivered to National PET centre at RPAH as well as longer lived SPECT (single Photon Emission Computer Tomography) isotopes ^{201}Tl ($T_{1/2}$ = 73 h), ^{67}Ga ($T_{1/2}$ = 78 h) and ^{123}I ($T_{1/2}$ = 13.4 h) for the Australian Nuclear Medicine Community.

Unlike the large overseas radioisotope production facilities each operating a battery of medical cyclotrons, THE NMC is quite unique in its operations, running a single 30 MeV, negative H^- ion cyclotron for both PET and SPECT radioisotope production. The facility is operated by about twenty personnel responsible for isotope production, quality control, cyclotron operation and maintenance and operational health physics.

It is evident that safe and flawless operation of a commercial medical cyclotron like the NMC is of paramount importance for guaranteed production and supply of life saving medical radioisotopes. A continuous, long-term operation of the cyclotron however, results in the accumulation of induced radioactivity in various critical cyclotron parts caused by neutrons produced in the cyclotron targets while bombarded with protons [1].

Obviously, these activated cyclotron components impacts on personal radiation exposure of the radiation-workers during the routine maintenance and repair procedures. Since the principle of ALARA (As Low As Reasonably Achievable) constitutes the part and parcel of the NMC operational health physics goals, it becomes imperative to study the impact of the induced radioactivity of the activated species and the relevant cool down (decay) times on the personal radiation exposure during the cyclotron maintenance [2].

This report highlights the method for the prediction of personal doses during various types of work in the cyclotron active areas (radiation environment) using the database of the routine weekly health physics survey data and experimentally estimated decay characteristics radiation field in the active environment. The schematic footprint of the NMC is depicted in Figure 1.

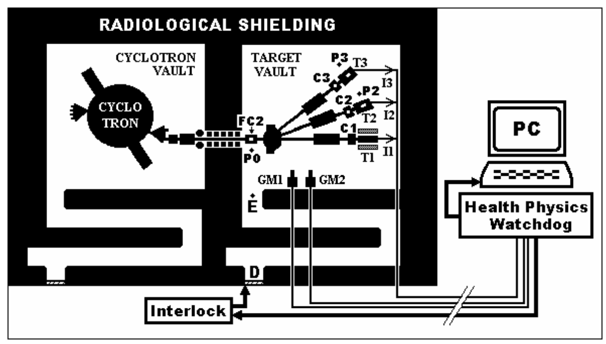

Figure 1: Footprint of the NMC Facility showing the high current SPECT (T1, T2, T3 radioisotope production target stations, collimators (C1, C2, C3) and Faraday Cup (FC2).

The gamma area monitors (GM1 and GM2) are connected to Health Physics Watchdog (HPWD) for real-time monitoring of gamma dose rates at vault entry point (E). The vault door (D) is regulated by the interlock system interfaced to HPWD. The dose measurement points are indicated as P0, P2, P3 and E. The proton currents at targets T1 (I1), T2 (I2) and T3 (I3) are recorded in real-time by the HPWD.

MATERIALS AND METHODS

Health Physics Survey at Target Vault

In order to ensure a safe cyclotron operation and to minimise radiation exposure to NMC radiation workers, regular weekly radiation survey is carried out by health physics technicians. Three high-current targets for the production of SPECT radioisotopes are located in the Target Vault; hence, in this work we have put emphasis on the radiation levels in Target Vault (Figure 1).

During the weekly cyclotron maintenance, the gamma dose rates were evaluated using a hand-held gamma survey meter (Model: FAG F40F, Manufacturer: Thermo-

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Electron Inc. USA) during the cyclotron operation period 12-12-02 to 25-02-04 at the following spots: (a) At contact and at 50 cm from target station T2 and vault entrance point E (Figure 2a) (b) At contact with collimator of target station T2 and entrance point E (Figure 2b), (c) At contact and at 50 cm from target station T3 (Figure 2c), (d) At contact with the collimators of target stations T2 and T3 and (e) the entrance point E (Figure 2d).

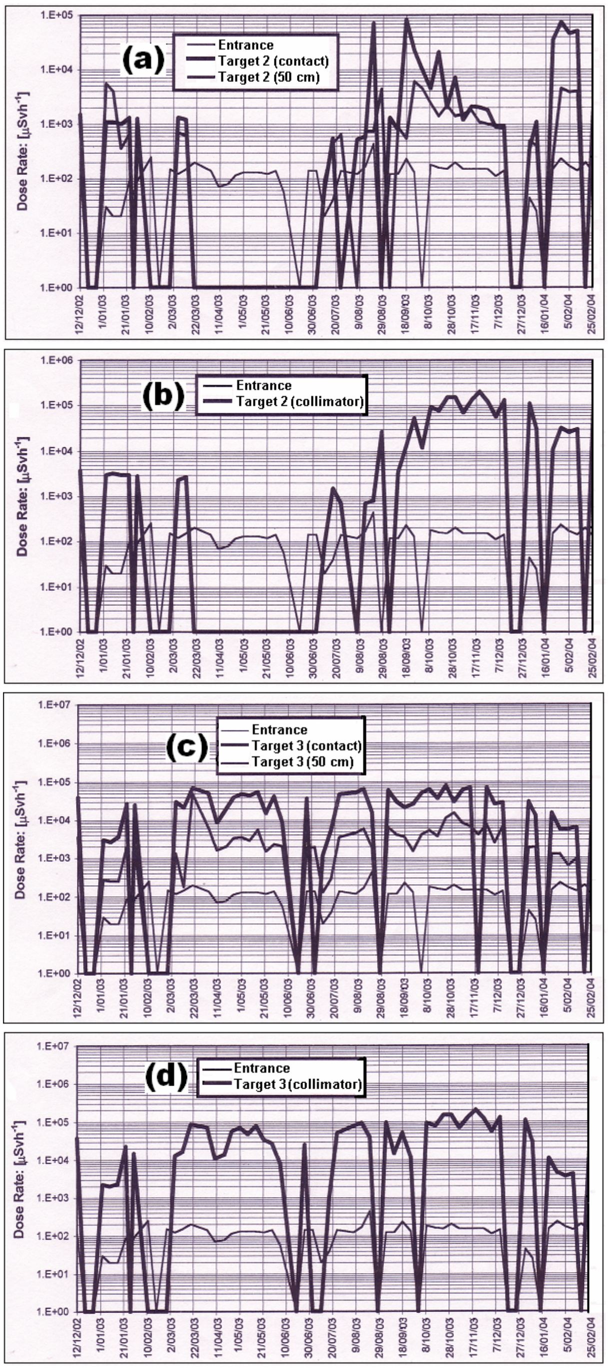

Figure 2: (a) Gamma dose rate assessed at target T2, (b) Gamma dose rate assessed at the collimator of target T2, (c) Gamma dose rate assessed at target T3, (d) Gamma dose rate assessed at the collimator of target T3.

The gamma doses prevailing near the selected locations in the target vault as shown in Figure 1, presented in Figures 2a-2d has been normalised with the average gamma area dose, evaluated with gamma monitors GM1 and GM2 interfaced to HPWD system and found to be 320 μSv.h^{-1} after a decay time of about 24 hours. The results are summarised in Table 1.

Table 1: Gamma dose equivalent rates D_G [μSv.h^{-1}] at critical locations in the target vault recorded with a Model FAG F40F gamma survey meter are presented. The ratio between the work location (Figure 1) and corresponding area gamma dose equivalent rate, evaluated with gamma area monitors GM1 and GM2 (320 μSv.h^{-1}) is given as k_i.

Location	Description	D_G	k_i
E	Target vault entrance	2.4×10^2	0.75
FC2	At Faraday Cup FC2	4.5×10^2	1.4
P0	50cm from Faraday Cup	3.7×10^2	1.2
T2	At contact with target T2	4.0×10^4	125
P2	50 cm from target T2	3.4×10^3	10.6
C2	Collimator of target T2	5.0×10^4	156
T3	At contact with target T3	2.1×10^4	65.6
P3	50 cm from target T3	1.1×10^3	3.4
C3	Collimator of target T3	7.6×10^3	23.8

Radiation Decay Analysis

It is evident that the decay characteristics of the radiation field (Gamma DE rate) in the target vault could not be explicitly assessed from the manually estimated work location dose data collected every Monday morning during health physics survey as summarised in Figures 2a-2d. Hence, the radiation cool down characteristics was determined experimentally as follows:

After completion of a 12 hours isotope production run at target station T3, the gamma area monitors GM1 and GM2 at the entrance of the target vault (Figure 1) was switched on immediately after the transfer of highly target shuttle to the neighbouring hot cell. The gamma dose equivalent rates were sampled every minute for 1450 minutes (24 h) by HPWD and plotted in Figure 3.

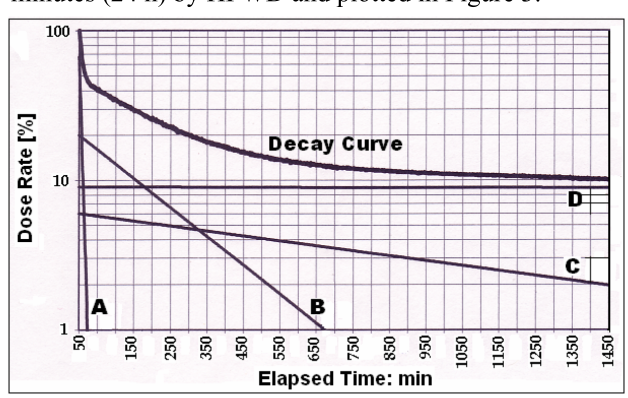

Figure 3: Normalised (%) gamma dose equivalent rate recorded with gamma area monitors is plotted as a function of elapsed time (decay curve). The decay curve was unfolded with four exponential functions (A), (B), (C) and (D), representing four major activation products.

The decay characteristics in Figure 2 strongly suggest that the radiation dose in target vault is originated from the gamma rays from four radioactive species. The individual components of radioactive decay curve were unfolded and presented as functions of elapsed time t:

$$\text{(A): } y = 65\exp(-0.693t/4) \quad (1)$$

$$\text{(B): } y = 20\exp(-0.693t/156) \quad (2)$$

$$\text{(C): } y = 6\exp(-0.693t/900) \quad (3)$$

$$\text{(B): } y = 9\exp(-0.693t/64224) \quad (4)$$

The net least-square fitting error of the component curves was ± 2%. Evidently, equations 1, 2, 3 and 4 are the special representations of radioactive decay equation:

$$D(t) = D_0 \exp(-t(\ln 2/T_{1/2})) \quad (5)$$

Where,

D_0 = initial gamma dose rate
D(t) = gamma dose after the decay period t
t = decay period
$T_{1/2}$ = half life radioactive species

By identifying the half lives as indicated in equations (1)-(4) we have identified the following radioactive species: ^{28}Al ($T_{1/2}$ = 4min), ^{56}Mn ($T_{1/2}$ = 156min), ^{24}Na ($T_{1/2}$ = 900min) and ^{59}Fe ($T_{1/2}$ = 64224 min = 44.6d).

Consequently, the integrated, job specific gamma dose at any cyclotron part of interest $D_i(t)$, after the elapsed time "t" was derived using equations (1)-(5) and the value of k_i from Table 1:

$$D_i(t) = D_{GM}\, k_i\, [(65\exp(-0.693t/4) + 20\exp(-0.693t/156) + 6\exp(-0.693t/900) + 9\exp(-0.693t/64224)]T_i \quad (6)$$

Where,

D_{GM} = Gamma dose rate detected by area monitors GM1 and GM2 (Figure 1)
T_i = time required to execute the ith job

The work specific radiation exposures to cyclotron maintenance personnel for the delay periods of 1, 7, 14 and 30 days, and the corresponding duration of the job at specific work locations (Table 1) are shown in Table 2.

Table 2: Work specific personnel radiation exposure of cyclotron maintenance personnel at the NMC.

Brief Description of the Jobs Performed by Cyclotron Maintenance workers in Target Vault (Figure 1)	k_i (Table 1)	T_i : Work Duration (Person min)	Work Location (Figure 1)	Personnel Radiation Exposure to Cyclotron Maintenance workers [mSv/person] after a delay period of:			
				1 d	7 d	14 d	30 d
Staying at Target Vault Entrance	0.75	1	E	0.01	0.01	0.00	0.00
Target 2 Collimator Removal	156	5	C2	7.07	5.25	4.71	3.67
Target 3 Collimator Removal	23.8	5	C3	1.08	0.80	0.72	0.56
Target 2 Collimator Replacement	156	5	C2	7.07	5.25	4.71	3.67
Target 3 Collimator Replacement	23.8	5	C3	1.08	0.80	0.72	0.56
Damaged VAT Valve Removal (Target 3)	65.6	10	T3	5.94	4.41	3.96	3.09
Target 2 Ram-Failure-Trouble Shooting	10.6	2	P2	0.19	0.14	0.13	0.10
Target 3 Ram-Failure-Trouble Shooting	3.4	2	P3	0.06	0.05	0.04	0.03
Target 2 Ram-Failure-Clean up Procedure	10.6	5	P2	0.48	0.36	0.32	0.25
Target 3 Ram-Failure-Clean up Procedure	3.4	5	P3	0.15	0.11	0.10	0.08
Target 2 Pump Replacement	156	5	P2	7.07	5.25	4.71	3.67
Target 3 Pump Replacement	23.8	2	P3	0.43	0.32	0.29	0.22
Damaged Faraday Cup Removal	1.4	5	FC2	0.06	0.05	0.04	0.03
Damaged Faraday Cup Replacement	1.4	10	FC2	0.13	0.09	0.08	0.07

SUMMARY AND CONCLUSIONS

We have presented a practical method for the prediction of induced radioactivity and work specific personnel radiation exposures at a radioisotope production cyclotron facility. The analysis of radioactive decay characteristics in the target vault revealed that the induced activity of ^{59}Fe ($T_{1/2}$ = 44.6 d) in cyclotron parts made of iron is the main contributor of long term radiation exposure.

Personnel radiation exposures during execution of some specific jobs are found be quite high (Table 2). This could be reduced to ALARA level by implementing: (a) Local body shield made of lead, (b) Long tongs for handling highly active components, (c) Job (dose burden) sharing with 2 or more adequately trained radiation workers.

The operational health physics methods and techniques presented in this paper were basically valid for the NMC located at Royal Prince Alfred Hospital in Sydney, Australia. Evidently, these health physics procedures could be used as useful guidelines for any commercial cyclotron facility after suitable modifications.

REFERENCES

[1] M. Barbier, Induced Radioactivity, North Holland, Amsterdam, New York, 1969.

[2] B. Mukherjee, Radiological Safety and Operational Health Physics of Medical Cyclotrons. In Proceedings of the 3rd International Conference on Isotopes (3ICI), Vancouver, Canada, 6-10 September 1999.