Radiation surveillance in and around cyclotron facility

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ABSTRACT
The cyclotron is the most widely used particle accelerator for producing medically important radio nuclides. Many medical centers in India have installed compact medical cyclotrons for on-site production of short-lived positron-emitting radio nuclides such as $^{18}$F, $^{13}$N, and $^{11}$C. A mandatory requirement for cyclotron installation is radiation control permit from Atomic Energy Regulatory Board. Cyclotron radiation survey is an integral part of the overall radiation safety in the cyclotron facility. Radiation surveillance in and around a newly installed cyclotron was performed using ionization chamber counter and Geiger Muller counter before, during and after operating the cyclotron. The readings were recorded at various locations where a high radiation field was expected. The results were recorded, tabulated and analyzed. The highest exposure level (0.93 $\mu$Sv) was found at the back wall of the radiochemistry lab facing the cyclotron vault. Reason for the high exposure of 0.93 $\mu$Sv/h: Synthesis of $^{18}$F-Fluoro-Deoxy-Glucose ($^{18}$F-FDG) was going in the synthesis module and activity ($^{18}$F) was present in the synthesis module when reading was taken. All other values were found to be below the recommended levels of exposure.

Keywords: Area survey, cyclotron, radiation surveillance

INTRODUCTION
The cyclotron is the most widely used particle accelerator for the production of Positron Emission Tomography (PET) radioisotopes (such as $^{18}$F, $^{13}$N, and $^{11}$C). An accelerator is a device that produces a well-defined, high-energy beam of charged particles with the high-beam intensity. This beam strikes the target and leads to the production of radionuclide. During routine cyclotron operation and target bombardment beam loss may occur when the de-focused or misdirected particle beam inadvertently strikes the internal wall of the beam tube, can produce high levels of prompt neutrons and gamma rays. The prompt fast neutrons slow down via multiple scattering events within the shielding and 10% are reflected back toward the cyclotron, thereby activating the various cyclotron components (including the beam tube, focus in g magnets, and ducts and piping). In addition, some prompt gamma and neutron radiations escape to the external environment through the shielding, producing direct external exposure. The neutrons, which penetrate the vault roof travel rather long distances and undergo multiple scattering events with nitrogen and oxygen in air, contributing to exposure via this “sky shine” radiation. With an adequate shielding; however, sky shine radiation can be reduced to negligibly low levels.

The major consideration in a cyclotron installation is the choice between a self-shielded and a vault-shielded device. A self-shielded cyclotron may also require a vault, though one with thinner walls than those of a non-self-shielded cyclotron. In the former, retractable shielding is integrated into the cyclotron unit; in the latter, shielding is separate, and is built into the structure housing the device.

Still during the routine operation of cyclotron, it is mandatory to measure the radiation levels in and around the cyclotron. This helps to keep the radiation exposure to a level of minimum and also helps the radiological safety officer (RSO) and medical physicist (MP) to identify the high radiation level around cyclotron. Routine cyclotron survey is an important part of overall radiation safety in the cyclotron facility. Facilities operating cyclotrons have radiological hazards that necessitate the implementation of an integrated radiation safety program.

This procedure should be routinely performed by the MP during the operation of the cyclotron. This helps MP/RSO to ensure the radiation safety of visitor, working staff, and radiation workers.

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RSO/MP can also tell whether the exposure is within the atomic energy regulatory board (AERB) permissible limit or not.\textsuperscript{13} It can prevent unjustifiable radiation exposure to occupational worker and patients. To measure the radiation levels, every Nuclear Medicine Department should have radiation monitors, such as Geiger Muller (GM) counter and ionization chamber based survey meters.\textsuperscript{14-16} Radiation monitors are instruments, which are designed to measure dose rate (in mSv/h), integrated dose (mSv) or contamination level (Bq/cm\textsuperscript{2}). The choice of instrument is governed by the nature and the level of radiation anticipated in the environment.\textsuperscript{17} The present study is designed to survey the radiation in and around cyclotron area during its operation and to locate the area having high radiation exposure and at what time during the running of the cyclotron. The readings were compared using GM based and ionization chamber based survey meter. The background values calculated according to public annual exposure (1 mSv/h) according to AERB gives us 1000 µSv/year \(\approx 365\) days. 3 µSv/day and a working time of 12 h give exposure level of 0.25 µSv/h.\textsuperscript{13}

**MATERIALS AND METHODS**

A new installed self-shielded cyclotron was area surveyed using GM and ionization chamber based survey meters. Radiation surveillance was performed before, during and after the cyclotron operation, using ionization chamber (INOVISION, USA) and GM counter (RAMGENE-1, ROTEM, USA) based detectors. The various areas in and around cyclotron are shown in the Figure 1. Readings were taken with Ionization based survey meter and GM counter based survey meter continuously for 30 days at eight different areas.

Cyclotron facility was GE PET TRACER4.

Duration of the bombardment was average of 39 min/day.

Average of 1393 mCi/day activity of \(^{18}\text{F}\) produced was produced in cyclotron.

Synthesis module was GE TRACER lab MXFDG.

Before the procedure for survey was started, the following preparations were performed. Firstly batteries of survey meters were checked. The survey meter was checked with a known radiation source. The meter was set at zero in a low-background radiation area. The type, Department of Energy (DOE) property number and calibration due date on the radiation survey form was recorded before the use of the survey meter. The surveyor wears a dosimeter before starting the procedure.

Different steps were performed during the radiation survey procedure. Radiation survey was carried out in all the locations possible to cover according to the layout and was carried out using GM based survey meter and ionization chamber based survey meter, simultaneously. Survey meter was held at arm’s length, minimize exposure to the body. Radiation levels were monitored around PET trace4 self-shielded cyclotron (before bombardment, during bombardment, after bombardment) hot lab (HL) wall, console, vault door, vault wall (VW), outer wall, chiller side wall, quality control, room wall, and MP room. The results were recorded and tabulated. Appropriate statistical analysis was performed on the recorded readings.\textsuperscript{13,18} Care was taken that survey does not take more than a few minutes.

**RESULTS AND DISCUSSION**

The details of the exposure around cyclotron using both types of survey meters are shown in the Table 1. Highest exposure level found in the HL after the bombardment was (0.93 µSv/h and 0.65 µSv/h by ionization chamber and GM counter. This may be due to the on-going synthesis in the hot cell. However, the second highest value (0.22 µSv/h) was found at VW and chiller side using ionization counter during bombardment. As soon as the bombardment was over, the exposure rate reduced. The Figure 2 and 3 shows the average values before, during and after the bombardment using both ionization chamber and GM counter in µSv/h. Remaining values were within prescribed limit.

The graph [Figure 4] suggests positive correlation between the readings of GM counter and ionization chamber based survey meters, but is not in a perfectly linear correlation. The Spearman rank correlation coefficient between the readings of two survey meters is \((r) = 0.324\). Correlation ‘r’ value suggests that there is random variation between the readings of two survey meters.

The background values calculated according to Public Annual Exposure (1 mSv/h) according to AERB gives us 1000 µSv/year.
≈ 365 days. 3 µSv/day and a working time of 12 h give exposure level of 0.25 µSv/h. We have compared reading with 0.25 µSv/h at all the locations and found that the exposure is below this level at all the time during the run of the cyclotron. The high exposure level in the cyclotron area is only during the bombardment period of 40 min. During this time period a worker staying near the VW or HL will not receive on an average of more than 1 µSv dose daily and approximately, 300 µSv extra dose yearly. These values are thus well within the AERB annual limits.[13]

CONCLUSION

The radiation survey was successfully performed in and around the newly installed cyclotron. All the values are below recommended levels of exposure. This reflected that the exposure levels outside the shield are minimal, which means that there was no leakage of the radiation outside the vault and all the values are below the recommended levels of exposure. Positive linear correlation with random variation exists between the readings of two survey meters.

Table 1: The average exposure values with GM counter and ionization counter in µSv/h at various locations

|          | VD | VW | CO | OW | CS | HL | QC room wall | MP room |
|----------|----|----|----|----|----|----|--------------|---------|
| GM counter |    |    |    |    |    |    |              |         |
| Before    | 0.11 | 0.12 | 0.12 | 0.12 | 0.14 | 0.13 | 0.13 | 0.16 |
| During    | 0.17 | 0.26 | 0.16 | 0.14 | 0.18 | 0.16 | 0.14 | 0.14 |
| After     | 0.11 | 0.13 | 0.13 | 0.12 | 0.16 | 0.65 | 0.14 | 0.15 |
| IC counter |    |    |    |    |    |    |              |         |
| Before    | 0.14 | 0.12 | 0.11 | 0.16 | 0.16 | 0.14 | 0.15 | 0.12 |
| During    | 0.17 | 0.22 | 0.16 | 0.19 | 0.22 | 0.19 | 0.18 | 0.16 |
| After     | 0.18 | 0.18 | 0.17 | 0.19 | 0.21 | 0.93 | 0.23 | 0.21 |

GM: Geiger muller, IC: Ionization chamber, VD: Vault door, VW: Vault wall, CO: Console, OW: Outer wall, CS: Chiller site, HL: Hot lab, QC: Quality control, MP: Medical physicist

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