Monitoring of radiation levels in medical cyclotron facility measured by a comprehensive computerized monitoring system

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The medical cyclotron facility at Institute of Nuclear Medicine and Allied Sciences, Delhi, has an unshielded bunker type medical cyclotron (16.5 MeV) for the production of positron emitting radionuclides namely $^{18}$F, $^{15}$O, $^{13}$N and $^{11}$C. The pharmaceuticals labeled with these radioisotopes are used for positron emission tomography (PET) imaging. The medical cyclotron facility has an associated radiochemistry facility that contains chemistry modules housed in adequately shielded hot cells meant for the synthesis of the pharmaceuticals labeled with these positron emitters. The facility also has a beam extension room. The radiation levels were measured in the facility at different locations namely cyclotron vault, control console, radiochemistry laboratory, beam extension room and the stack using a comprehensive computerized monitoring system. The radiation levels were observed to be well within the prescribed limits.

Keywords: Medical cyclotron facility, PET, Radiation level

1 Introduction

Positron emission tomography has emerged as a major tool for non-invasive diagnostic purposes. The technique makes use of radiopharmaceuticals labeled with positron emitting isotopes. These radiopharmaceuticals are administered to the patient and the image is taken under a PET scanner. The isotopes used for PET imaging are short-lived and hence need an on-site medical cyclotron with an associated radiochemistry laboratory for the production and synthesis of PET pharmaceuticals. The production of short lived PET radiopharmaceuticals involves handling of radioactive gases and radiochemical multi-step reactions. This involves trapping of radioactive liquids and gases and as a result generation of radioactive by-products. Thus, a reliable waste gas decay system and continuous monitoring of radiation levels in real time are mandatory for both radiation safety and production purposes. The radiation levels measured using a comprehensive computerized monitoring system during the production of $^{18}$F and synthesis of $^{18}$F labeled fluoro deoxyglucose (FDG) are presented here.

2 Experimental Details

The facility consists of a medical cyclotron (PETtrace System, M/s GE Medical Systems) which accelerates negatively charged hydrogen ions ($H^-\ )$ to 16.5 MeV or negatively charged deuterium ions ($D^-\ )$ to 8.4 MeV energy. The total extracted beam current on the target is at least 80 $\mu$A for protons and at least 60 $\mu$A for deuterons. The cyclotron system is complete with magnet, radiofrequency, ion source, beam extraction, beam diagnostic and vacuum systems. Also included in the cyclotron system are: the control system, cooling water system and power supply system. The cyclotron is housed in a vault in the ground floor in one end of the building away from public domain.

The radiochemistry laboratory contains chemistry modules housed in adequately shielded hot cells purchased from Comecer (Castelbolognese – Italy). The chemical synthesis is fully automatic, software controlled and is monitored through TV cameras. Dorothea dose dispensing system is connected directly to automatic production modules. It performs automatic filling and calibration of syringes with radiopharmaceuticals. The use of Dorothea considerably reduces the dose to the operator. Dorothea is pre-disposed for the use of tungsten shielded container that is used as a transport container for internal use. During synthesis, the radioactive gases from the synthesis modules are compressed in the waste gas system till it decays to background level and subsequently released to ventilation exhaust duct system.
Data on radiation monitoring was collected over a period of two years during the production of each batch of $^{18}$F-FDG. An on-line monitoring system ROTEM’s MediSmarts (Medical Survey Mapping Automatic Radiation Tracking System) was used to measure radiation levels at various locations in the medical cyclotron facility. It is a comprehensive, modular, real time online system that consists of a radiation monitoring system and a control system. The radiation monitoring system has three basic components: the detectors, data processing units (DPUs) and a computer containing software and communication network. The detectors and the DPUs constitute a monitoring channel that is in turn connected to a computer having software for analysis.

Two types of detectors namely PM-11 and GM-42 are used in these monitoring channels for radiation detection. The PM-11 monitoring channel is used to detect and report on low levels of radiation up to 50,000 cps. The PM-11 detector has sensitivity of approximately 28,000 cps/mR/h for an energy range of 350-700 keV. It has an accuracy of ± 10% within measuring range of 511 keV. The GM-42 monitoring channel is used to detect and report on higher levels of radiation from 0.02 mR/h to 1 R/h. The GM-42 detector has sensitivity of 17 cps/mR/h and has accuracy of ± 10% within measuring range of 0.05-1.3 MeV. The control system is based on a Programmable Logic Controller (PLC). The PLC generates warnings and alarms under abnormal conditions. A Human Machine Interface (HMI) software enables the intervention of authorized operators including automatic control. The HMI collects on line status of all the controlled parameters (radiation, pressure, humidity, doors contact, etc.) and displays the status and alarms messages.

The monitoring system has five number of installed gamma detectors (GM-42 and PM-11) and three neutron detectors (Ludlum Model 42-30). The GM-42 detectors use ZP1202 GM tube, M/s Centronic, UK and the PM-11 uses a high sensitivity NaI (Tl) scintillation detector. The GM-42 gamma detectors are used for monitoring in the cyclotron vault, radiochemistry laboratory, control console and the

![Layout of the medical cyclotron facility](image-url)
beam extension room whereas the PM-11 having NaI(Tl) scintillation detector is used for stack monitoring. The neutron monitors designed for detection of thermal and fast neutrons (0.025 eV to approximately 12 MeV) are installed in the cyclotron vault, control console and the beam extension room\textsuperscript{4,5}. The DPU processes the detector’s signal and transmits the calculated radiation data via RS-485 communication network to the computer.

Figure 1 shows the layout of the medical cyclotron facility showing the location of the cyclotron vault, control console, radiochemistry laboratory, beam extension room and the stack. Figure 2 shows the location of the installed gamma (GM-42 and PM-11) and neutron (Ludlum Model 42-30) radiation detectors in the medical cyclotron facility.

### 3 Results

The radiation levels measured inside the medical cyclotron facility were related to cyclotron operation. During production of $^{18}$F-FDG with an average operating current of 40 $\mu$A on the target, the gamma radiation level in the cyclotron vault measured by GM-42 detector at a distance of 1 m from the cyclotron was observed to be more than 10 mSv/h. However, the radiation level was reduced to less than 100 $\mu$Sv/h at 1 m from the cyclotron one hour after the end of the bombardment (EOB). The neutron radiation level at the same location was more than 1000 mSv/h but it reduced to nil as soon as the beam was off. The gamma radiation level on the door of the vault was measured to be in the range of 0.2-0.4 $\mu$Sv/h during beam on. It reduced to 0.1 $\mu$Sv/h after the end of the bombardment. No neutron radiation levels were detected by the neutron monitor located on the door of the vault during bombardment and hence also at EOB. The radiation level in the radiochemistry laboratory was measured by the GM-42 detector located at a distance of 2 m from the hot cells to be in the range of 0.1-0.5 $\mu$Sv/h during synthesis and it was reduced to 0.1 $\mu$Sv/h after the synthesis was over. The gamma radiation level in the beam extension room was measured to be 29.6 $\mu$Sv/h during irradiation and it was reduced to 0.1 $\mu$Sv/h during beam on.
after 45 min of the EOB. The maximum neutron radiation level observed in the beam extension room at the same location was 60 counts per sec (0.69 mSv/h) during irradiation. It was reduced to zero at the EOB. Under normal conditions of operation, the count rate on the stack monitor detected by PM-11 detector was observed to be in the range of 16-20 cps.

4 Conclusions

This comprehensive computerized monitoring system provides an effective solution for the control of various aspects of production and radiation safety in a medical cyclotron facility. The radiation levels measured by this monitoring system during the period of operation of two years of this facility were observed to be well below the permissible limits.

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References

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