RADIATION MONITORING AND PROTECTION

Radiation Surveillance in and around Cyclotron Facility in Nigeria

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Abstract

The cyclotron is an advanced particle accelerator that is mostly used to produce short-lived radionuclides or radioisotopes like ^{18}F, ^{13}N, and ^{11}C for Positron Emission Tomography (PET). A cyclotron accelerator produced a well-defined, high-energy, and intensely charged particle beam (Livingston, 1954) with radionuclides produced when this beam hits the object. The aim of this research is to conduct a thorough radiological surveillance of the cyclotron building at the African Medical Center of Excellence (AMCE) in Abuja, Nigeria. A calibrated Ranger Radiation Alert meter was used at twenty-nine (29) survey locations across the facility to conduct a radiation and contamination survey. The results obtained show that the least radiation levels were obtained at synthesizer, emergency and exit main entrance with values of 0.01 μSv/h, 0.02 μSv/h and 0.03 μSv/h respectively. While highest radiation levels were obtained at T3 and T7 with values of 5.39 μSv/h and 5.89 μSv/h respectively. Although, these values are high but do not exceed limit of 7.5 μSv/h in the controlled area (Cyclotron Vault and Hot Lab) prescribed in Nigeria Basic Ionising Radiation Regulations of 2025. The study concluded that there was no indication of contamination in all the areas surveyed and recommended that regular radiation monitoring should be carried out periodically.

Keywords: radiation; surveillance; cyclotron; Nigeria

1 Introduction

The cyclotron is an advanced particle accelerator that is mostly used to produce short-lived radionuclides or radioisotopes like ^{18}F, ^{13}N, and ^{11}C for Positron Emission Tomography (PET) (Phelps, 2004; Fowler and Wolf, 1986; Saha, 2005). A well-defined, high-energy, and intensely charged particle beam is produced by a cyclotron accelerator (Livingston, 1954) and radionuclides are produced when this beam hits the target. These radionuclides generated are essential for the production of radiopharmaceuticals used in PET/CT imaging (Zohra et al., 2020; Simeonova et al., 2021). This makes it possible to accurately visualize physiological processes for early cancer, neurological, and cardiac problem diagnosis, therapy planning, and monitoring (Becker et al., 2023; Zhang et al., 2025; Kim et al., 2025). A particle accelerator is a device that uses electromagnetic fields to accelerate charged particles, such as protons and/or electrons, to high speeds before the accelerated particles are used to bombard a material.

Radiation is produced by a nuclear reaction between high-energy protons that are accelerated by the cyclotron and materials like nitrogen gas and enriched water. The interaction produces secondary radiation in the form of gamma rays and fast neutrons in addition to the short-lived positron-emitting radioisotopes such as ^{18}F, ^{13}N, and ^{11}C. The misalignment of protons striking the cyclotron's internal components or the beamline walls can also result in beam losses by generating secondary radiation

and activating nearby materials. As a result of this, even when the beam is switched off, the active materials may still emit gamma radiation (Song and Cheong, 2025; Abuhoza et al., 2022; Matsumura et al., 2024). Additionally, when the cyclotron is operating, its structural components—such as collimators, magnets, and target holders—can be activated, resulting in the production of induced radioactive elements that, depending on their individual half-lives, emit ionizing radiation for a predetermined amount of time.

Furthermore, a major radiation risk or hazard in hot cell surroundings is gamma radiation from radiopharmaceuticals and volatile radioactive gases, such as ^{11}C-CO_2, ^{13}N-NH_3, and ^{18}F-labeled substances. Airborne pollution may arise from gas entrapment or ventilation failure. Neutron skyshine leakage and scattering in the environment, particularly through an insufficiently insulated roof, may raise the radiation levels outside the vault (Tang et al., 2016; Tripathy et al., 2014). Personnel radiation exposure, surface pollution, air activation, and the long-term production of low-level radioactive waste are additional concerns with the use of a cyclotron. However, it is recommended that the facility must have access controls, air filtration systems, engineered shielding, real-time radiation monitoring, and stringent safety regulations in order to lower these risks (O'Donnell et al., 2004; Kambali et al., 2016; Fujibuchi et al., 2017; Długosz-Lisiecka et al., 2021; Santos et al., 2020; Biegała et al., 2022). Because of the strong radiation fields generated during operation, adequate radiation protection is crucial for protecting workers, preventing environmental pollution, and meeting safety requirements (Kaur et al., 2012).

Although there are international recommendations for radiation protection, facility-specific information is crucial for assessing the efficacy of shielding, locating hotspots, and improving safety procedures in cyclotron facilities (Li et al., 2025). Due to the possibility of occupational exposure to cyclotron-generated radionuclides during regular operation and target processing activities, radiation protection in the cyclotron facility at this research building is essential. This analysis is one of the few in-depth investigations of radiation surveillance conducted following a facility fire. In order to support the development of the nation's radiation protection programs, it is crucial to record the radiation environment during installation, operation, and periodic intervals as PET imaging facilities continue to expand in developing countries. The aim of this study is to conduct a thorough radiological surveillance of the cyclotron building at the African Medical Center of Excellence (AMCE) in Abuja, Nigeria.

2 Materials and methods

2.1 Facility description

The AMCE's Cyclotron facility is the subject of this study and Figure 1 depicts the study facility's site plan. The survey locations for radiation and contamination measurements were taken within and outside the facility's layout (see Figure 1). To determine radiation before and after operation, measurements were taken both before and after the facility's operation. This will assist in determining contamination levels and confirming adherence to Nigerian radiation safety laws.

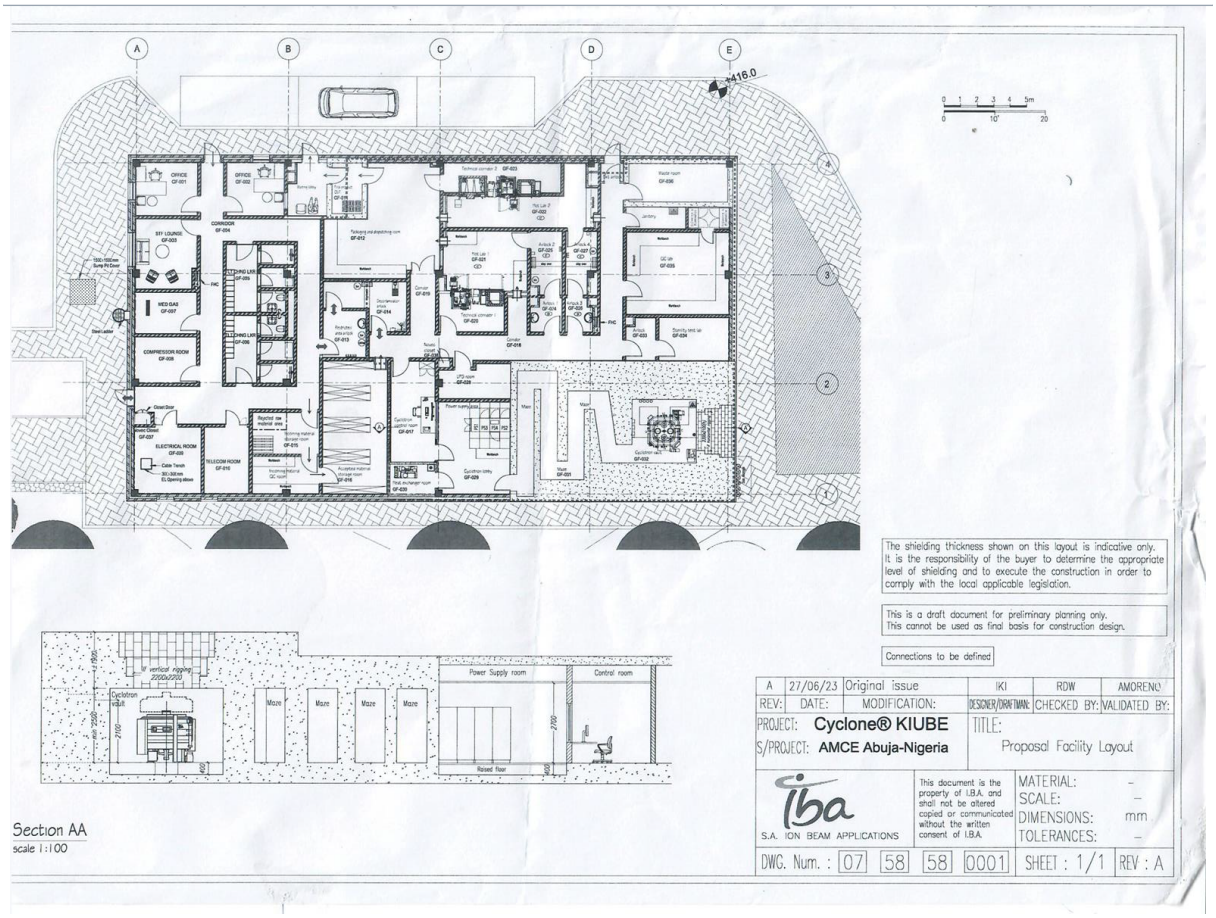


Figure 1. Layout of the study building

A calibrated Ranger Radiation Alert meter was used to conduct a radiation and contamination survey at twenty-nine (29) survey points across the plant, as indicated in Table 1. Additionally, the facility's suspected regions were examined for contamination.

The following preparations were made before the survey process began. First, survey meter batteries were examined. A known radiation source was used to check the survey meter. In a region with minimal background radiation, the meter was set to zero. Prior to using the survey meter, the type and calibration due date for the radiation survey were noted. Before beginning the survey, active radiation dosimeters were worn. The radiation survey process involved a number of steps. In order to minimize exposure to the body, readings were obtained using a Radiation Alert survey meter that was held at arm's length, one meter above the ground for dose rate measurements, and ten centimeters above the surface for contamination measurements. The outcomes were recorded and tabulated. The recorded readings underwent appropriate statistical analysis (Currell and Dowman, 2009). Care was taken that survey does not take more than a few minutes.

3 Results and discussion

Table 1 displays the specifics of the exposure surrounding the cyclotron building using a calibrated Ranger Radiation Alert meter. The average background radiation was found to be 0.11 μSv/h prior to taking readings at the building locations (which served as the sample points). This was the measurement that served as the basis for the dose rate at each of the study's locations; that is, the

measurement from which the D_{MAXWBG} = MDR − BG (μSv/h) was derived for each of the study's locations.

With values of 0.01 μSv/h, 0.02 μSv/h, and 0.03 μSv/h, the recorded readings indicate that the synthesizer, emergency, and exit main entrance had the lowest radiation levels. At T3 and T7, the greatest radiation levels were recorded at 5.39 μSv/h and 5.89 μSv/h, respectively. Because the surrounding materials are neutron-activated and the area is under control, the outcomes at T3 and T7 are expected. These values, however, were below the Nigeria Basic Ionizing Radiation Regulations (2025) limit of 7.5 μSv/h in the controlled environment (Cyclotron Vault and Hot Lab). Overall, the facility's supervised areas—areas outside of the controlled areas—had dose rate data that were well within the recommended range. This means that workers in these areas are likely to be exposed to an effective dosage of more than 1 mSv annually or an equivalent dose of more than a tenth of the yearly dose limit specified in the Nigeria Basic Ionizing Radiation Regulations (2025).

Table 1. Survey locations and results of measurements

No.	Area	MDR before (μSv/h)	MDR after (μSv/h)	D_{MAXWBG} before (μSv/h)	D_{MAXWBG} after (μSv/h)
1	Average Background Radiation (BG)	0.111	0.112		
2	Main Entrance (ME)	0.14	0.14	0.03	0.03
3	Electrical Room (ER)	0.22	0.24	0.11	0.13
4	Decontamination Room (DR)	0.17	0.18	0.16	0.07
5	Cyclotron Control Room (CCR)	0.3	0.4	0.19	0.29
6	Cyclotron Room (CR)	0.21	0.23	0.10	0.12
7	Entrance to Cyclotron Vault (ECV)	0.33	0.38	0.22	0.27
8	Maze (MZ)	0.3	0.4	0.19	0.29
9	Target 7 (T7)	2.2	2.4	2.09	2.29
10	Target 3 (T3)	5.5	6.0	5.39	5.89
11	Packing and Despatch Room (PDR)	0.17	0.17	0.06	0.06
12	Corridor 1 (CD1)	0.15	0.15	0.04	0.04
13	Hot Lab 1 (HL 1)	0.23	0.24	0.12	0.13
14	Air lock system (ALS)	0.21	0.22	0.10	0.11
15	Synthesizer (SZ)	0.11	0.12	0.00	0.01
16	Chiller (CL)	0.18	0.2	0.07	0.09
17	Maintenance (MT)	0.19	0.22	0.08	0.11
18	Corridor 2 (CD2)	0.16	0.16	0.05	0.05
19	Hot Lab 2 (HL 2)	0.16	0.17	0.05	0.06
20	Sterility Room (SR)	0.19	0.24	0.08	0.13

No.	Area	MDR before (µSv/h)	MDR after (µSv/h)	D_{MAXWBG} before (µSv/h)	D_{MAXWBG} after (µSv/h)
21	Quality Control Lab (QC)	0.20	0.23	0.09	0.12
22	Waste Room (WR)	0.17	0.19	0.06	0.08
23	Emergency Exit (EE)	0.13	0.15	0.02	0.04
24	Outside (OS)	0.21	0.22	0.10	0.11
25	Office 1 (OF1)	0.16	0.17	0.05	0.06
26	Office 2 (OF2)	0.2	0.2	0.09	0.09
27	Staff Lounge (SL)	0.22	0.23	0.11	0.12
28	Male Changing Room (MCR)	0.23	0.23	0.12	0.12
29	Female Changing Room (FCR)	0.26	0.27	0.15	0.1625 TNOTE|Note: D_{MAXWBG} = MDR – BG. Source: Field survey, 2026.

Source: Field survey, 2026

Bar charts and line graphs were also used to plot some figures so that the results could be easily seen, read or understood. First, the dose rates obtained from the survey were plotted directly from the survey meter before and after the procedure. Figure 2 shows that the readings at T3 and T7 were noticeably high. Figure 3 shows the dose rate after the average background radiation has been subtracted from the readings obtained from the survey meter. The measurements at T3 and T7 were quite high, much like in Figure 2. A line graph of the results from Table 1 is shown in Figure 4. Like Figures 2 and 3, there are notable high values at T3 and T7, whereas the remaining measurements show a somewhat straight line.

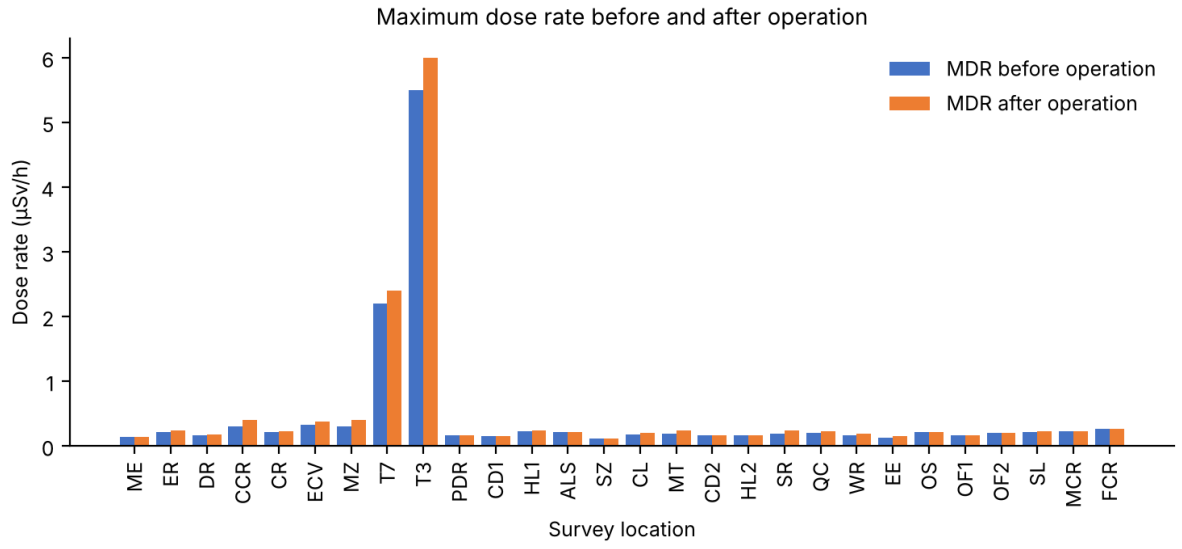


Figure 2. Dose rate obtained before and after operation

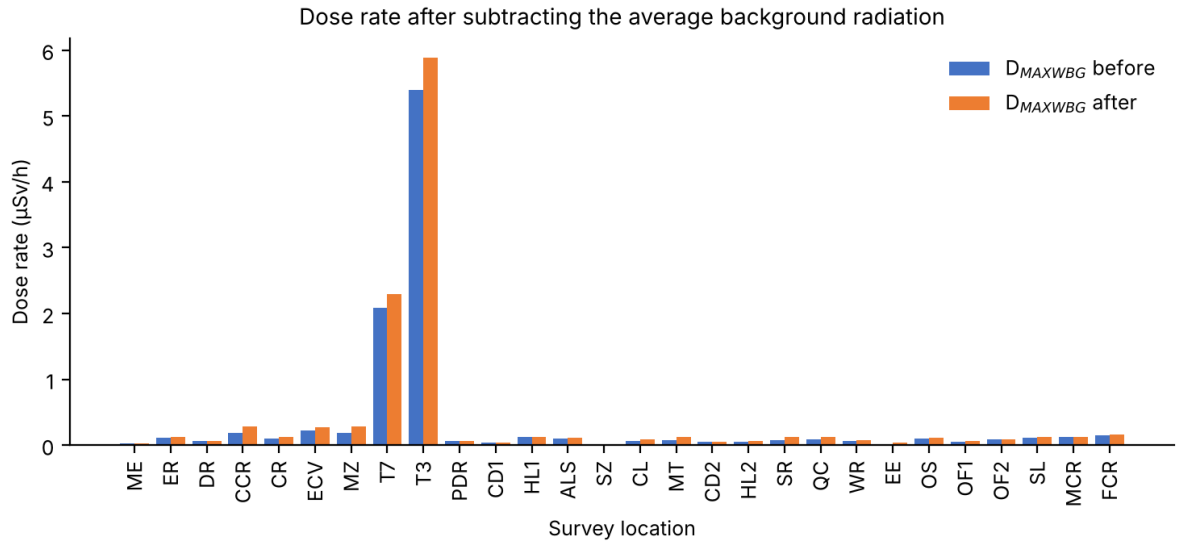


Figure 3. Dose rate after subtraction of the average background radiation

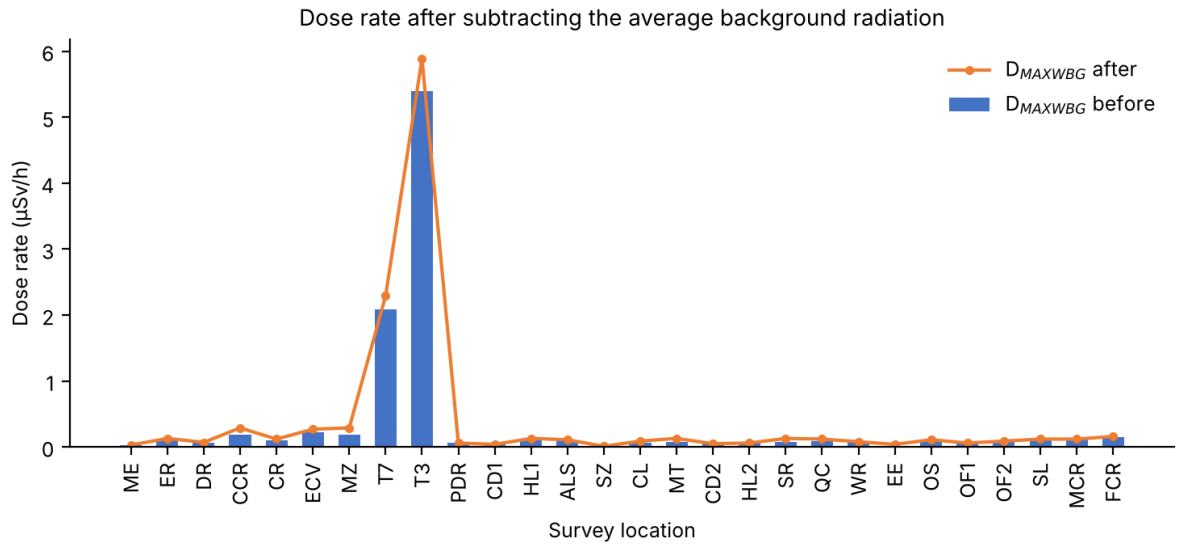


Figure 4. Line graph of the dose rate after subtraction of the average background radiation

4 Conclusion

The study's findings demonstrate that, even after the occurrence of a fire incident, all of the numbers are below the permissible threshold of exposure. According to the Nigeria Radiation Basic Safety Regulation 2025, all values are below the recommended levels of exposure for both controlled and supervised areas. This indicates that the exposure levels both inside and outside the shield are minimal, indicating that there was no radiation leakage within or outside the facility. Furthermore, none of the assessed regions showed any signs of contamination. Additionally, this thorough radiation surveillance of the Cyclotron building shows that contemporary medical cyclotron operations may be carried out safely while preserving environmental and occupational protection. Higher dose rates were produced at the source by localized operational operations; nevertheless, operator doses were kept low in accordance with ALARA principles through the efficient use of decay periods, remote handling, shielding, and procedural controls. The effectiveness of waste management

and ventilation systems in reducing airborne radioactivity was verified by ongoing monitoring of stack airflow and gamma emissions. All things considered, the facility's integrated approach—which includes shielding design, operational workflow, ventilation, and radioactive waste management—offers a solid and useful framework for safe cyclotron operation, providing helpful direction for the construction and commissioning of new PET radiopharmaceutical production facilities. The results of this study offer one of the first thorough radiation surveillance datasets for a PET cyclotron facility in Nigeria, providing a useful resource for safe operational planning, radiation protection, and facility design validation in developing radiopharmaceutical production facilities. It was however, recommended that regular radiation measurements should be carried out at periodic intervals to ensure that radiation exposure are within limits.

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