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Analysis of Radiation Dose Rate in the Working Area of Radioisotope and Radiopharmaceutical Technology Installation

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ABSTRACT

Radiation dose-rate monitoring is a routine but essential element of radiation protection in facilities that handle open radioactive sources. This study analyzed weekly area dose-rate monitoring data from the controlled area of the Radioisotope and Radiopharmaceutical Technology Installation (ITRR), National Research and Innovation Agency (BRIN), during September 2026. A quantitative descriptive design was used: dose rates were measured with a portable Radiagem 2000 survey meter at 21 locations over four consecutive weeks (84 readings), summarized descriptively, and tested with the Friedman test and a two-way analysis of variance on log-transformed data. Dose rates ranged from 0.05 to 4.15 µSv/hour (overall mean 0.57 µSv/hour; median 0.19 µSv/hour). The highest readings were recorded in Room C.106 in the third week (4.15 µSv/hour), Room C.107 in the first week (3.63 µSv/hour) and location 13.01.02 in the fourth week (3.40 µSv/hour). Dose rates differed significantly between locations (Friedman $\chi^2(20) = 62.02$, $p < 0.001$) but not between weeks ($\chi^2(3) = 2.85$, $p = 0.415$). All readings were below the 10 µSv/hour reference value on the monitoring from; however, five readings at three locations exceeded about 3 µSv/hour, the dose rate corresponding to 3/10 of the annual dose limit for radiation workers at 2,000 working hours per year. Radiological conditions are therefore governed mainly by location-specific factors, and Rooms C.106, C.107, and 13.01.02 should be prioritized for optimization and activity-linked monitoring under the ALARA principle.

Keywords: radiation dose rate, controlled area, radiopharmaceuticals, radioisotopes, radiation protection, occupational safety

Analisis Laju Dosis Radiasi di Ruang Daerah Kerja pada Instalasi Teknologi Radioisotop dan Radiofarmaka

ABSTRAK

Pemantauan laju dosis radiasi merupakan bagian rutin sekaligus penting dari proteksi radiasi di fasilitas yang menangani sumber radioaktif terbuka. Penelitian ini menganalisis data pemantauan laju dosis mingguan di daerah pengendalian Instalasi Radioisotop dan Radiofarmaka (ITRR), Badan Riset dan Inovasi Nasional (BRIN), selama September 2026. Penelitian menggunakan desain deskriptif kuantitatif: laju dosis diukur dengan surveimeter portabel Radiagem 2000 pada 21 lokasi selama empat minggu berturut-turut (84 pembacaan), dirangkum secara deskriptif, serta diuji dengan uji Friedman dan analisis varians dua arah pada data yang ditransformasi logaritma. Laju dosis berkisar 0,05-4,15 µSv/jam (rerata keseluruhan 0,57 µSv/jam; median 0,19 µSv/jam). Pembacaan tertinggi tercatat di Ruang C.106 pada minggu ketiga (4,15 µSv/jam), Ruang C.107 pada minggu pertama (3,63 µSv/jam), dan Lokasi 13.01.02 pada minggu keempat (3,40 µSv/jam). Laju dosis berbeda signifikan antar-lokasi (Friedman $\chi^2(20) = 62{,}02$; $p < 0{,}001$), tetapi tidak berbeda signifikan antar-minggu ($\chi^2(3) = 2{,}85$; $p = 0{,}415$). Seluruh pembacaan berada di bawah nilai acuan 10 µSv/jam pada formulir pemantuaan; namun lima pembacaan di tiga lokasi melampaui sekitar 3 µSv/jam, yaitu laju dosis yang setara dengan 3/10 nilai batas dosis tahunan pekerja radiasi untuk 2.000 jam kerja per tahun. Dengan demikian, kondisi radiologis terutama ditentukan oleh faktor spesifik lokasi, dan Ruang C.106, C.107, serta 13.01.02 perlu diprioritaskan untuk optimasi dan pemantuaan yang dikaitkan dengan kegiatan operasional sesuai prinsip ALARA.

***Kata kunci**: laju dosis radiasi, daerah pengendalian, radiofarmaka, radioisotop, proteksi radiasi, keselamatan kerja.*

INTRODUCTION

The Radioisotope and Radiopharmaceutical Technology Installation (ITRR) is one of the work units formerly under the National Nuclear Energy Agency BATAN and now under BRIN that utilizes radioisotopes for research, development, and oroduction in the field of radioisotopes and radiopharmaceuticals (Tresnawati et al., 2016). The working environment in such facilities has complex radiation exposure characteristics because it involves the use of open radioactive sources, the production of radionuclides, the operation of high-energy equipment, and the transfer of radioactive materials between workspaces (Vogt et al., 2024). Because each radionuclide has a different decay scheme, photon energy, and shielding requirement, radiation protection control cannot be generalized (Cember & Johnson, 2009; McCann et al., 2021).

The more activities involve radioactive sources, the greater the need for radiation protection to safeguard the public, workers, and the environment from ionizing radiation exposure. The protection framework is emphasized in Government Regulation Number 45 of 2023 concerning Ionizing Radiation Safety and Radioactive Material Security (Pemerintah Republik Indonesia, 2023) and is in line with international basic safety recommendations and standards (International Commission on Radiological Protection [ICRP], 2007; International Atomic Energy Agency [IAEA], 2014). This protection is necessary at various stages of operation, maintenance, and waste and emission management (Hao et al., 2024). Because exposure in facilities like this tends to be spatially and temporally heterogeneous influenced by the source location, the movement of

radioactive materials, shielding conditions, and the type of work being conducted monitoring the radiation dose rate is very important (Biegala et al., 2022; IAEA, 2018).

Based on BAPETEN Regulation No. 4 of 2013 Article 1 (4), radiation protection is an action taken to reduce the harmful effects of radiation exposure (BAPETEN, 2013). Radiation protection includes the application of safety principles and procedures to control radiation exposure so that harmful health effects can be prevented, while considering the benefits of radiation exposure and keeping the dose as low as reasonably achievable according to the optimization principle, or ALARA (ICRP, 2007). One form of protection is the measurement of radiation dose rates in work areas that are potentially exposed to radioactive substances (Alatas et al., 2015). The dose limit values (DLV) according to BAPETEN Regulation No. 4 of 2013 for each category of exposed persons are presented in Table 1.

Table 1. Dose Limit Values for radiation workers, Apprentice/trainee, and the public

Application	***Annual Dose (mSv)***		
	Radiation Workers	***Apprentice/trainees***	***Public***
Effective Dose	*20 mSv*	*6 mSv*	*1 mSv*
Equivalent Dose for the lens of the eye	*20 mSv*	*50 mSv*	*15 mSv*
Equivalent Dose for the skin	*500 mSv*	*150 mSv*	*50 mSv*
Equivalent Dose for hands or feet	*500 mSv*	*150 mSv*	-

The use of radioisotopes and radiopharmaceuticals is developing in various research and production activities, and these activities have the potential to expose workers to radiation. Biegala and Jakubowska (2020) showed the presence of neutron and photon radiation exposure among workers involved in cyclotron operation and the production of radiopharmaceuticals, indicating that radiopharmaceutical production must strictly adhere to safety and radiation protection requirements. Covens et al. (2007) even placed nuclear medicine and the handling of radiopharmaceuticals among the critical applications in individual dose monitoring.

External dose-rate monitoring and surface-contamination monitoring answer different questions. Handling open sources may contaminate surfaces, equipment, and clothing, but an elevated ambient dose-rate reading alone cannot establish surface contamination, because the reading also reflects shielded sources, stored materials, waste, and work in progress nearby. Contamination must be confirmed with suitable methods, such as direct surface monitoring with a contamination monitor or indirect wipe (smear) testing (IAEA, 2018). Workplaces that use open sources nevertheless require radiation measuring instruments to minimize radiation risk and facilitate monitoring (Putri et al., 2023). Putri et al. (2023) reported area exposure rates of 0.09-21.56 µSv/hour in a hospital nuclear medicine installation, with only the waste room exceeding 10 µSv/hour, whereas Nisa et al. (2017), who assessed surface contamination and exposure rate separately, reported exposure rate of 0.022-1.404 µSv/hour in the controlled area, below 10 µSv/hour.

Radiation exposure conditions also vary with activity and work location. Biegala and Jakubowska (2020) found different exposure levels between workers operating cyclotrons and those in the radiopharmaceutical production area, and Klappa et al. (2025) showed that worker exposure varies with the type of work performed. A multicenter European study reported that hand doses of workers handling ^{18}F- and ^{99m}Tc-labelled radiopharmaceuticals depend strongly on the task, especially preparation and dispensing (Carnicer et al., 2011; Sans Merce et al., 2011). Struelens et al. (2024) showed that the contribution of each radionuclide (^{68}Ga, ^{177}Lu, and ^{131}I) to staff exposure varies significantly, while Wrzesien and Albiniak (2023) estimated that fingertip doses of radiochemists during ^{68}Ga-DOTATATE production could exceed the annual hand dose limit in the worst-case scenario. These findings emphasize that workplace monitoring must cover every area and type of activity.

One form such monitoring is the measurement of dose rates in the work area. Pairodsantikul et al. (20240 assessed area radiation doses at various locations of a cyclotron and PET center, and Biswasarma et al. (2025) reported a dose rate of about 2.3 μSv/hour in the hot cell during ^{18}F-FDG synthesis, with post-operation dose rates that remained above initial conditions. Dang et al. (2026) characterized exposure and the distribution of radiological hazards for workers in cyclotron-based ^{18}F radiopharmaceutical production. Riveira-Martin et al. (2023) assessed the exposure of nuclear medicine staff administering [^{177}Lu] Lu-DOTA-TATE with active and passive dosimetry, and Marshall et al. (2024) evaluated environmental radiation exposure and occupational effective dose during ^{99m}Tc-MDP bone scintigraphy. According to BAPETEN Regulation No.4 of 2013, work areas are divided into two categories (BAPETEN, 2013):

1. Controlled area: *a* controlled area is a work area that requires protective measures and specific safety provisions to control normal exposure or prevent the spread of contamination during normal working conditions, and to prevent or limit potential exposure. An area is designated as a controlled if there is a potential for exposure exceeding 3/10 of the radiation- worker DLV (6 mSv/year for an effective-dose DLV of 20 mSv/year) or if there is a potential for contamination.
2. Supervised area: a work area outside the controlled area that requires a review of occupational exposure but does not require specific protective measures or safety provisions. It is designated when the potential exposure is more than the DLV for members of the public (1 mSv/year), but less than 3/10 of the radiation-worker DLV, and the area is free from contamination.

Area dose-rate monitoring at ITRR is a regulatory routine, so its scientific vales lies not in the act of measuring but in what the accumulated record reveal. Most published workplace studies of radiopharmaceutical production concern single-product cyclotron/PET facilities dominated by ^{18}F (Biswara et al., 2025; Dang et al., 2026; Pairodsantikul et al., 2024) or the personal and extremity doses of nuclear medicine staff (Camicer et al., 2011; Riveira-Martin et al., 2023; Struelens et al., 2024). Fewer reports describe multi-radionuclide research and production facilities, in which different rooms handle ^{125}I, ^{131}I, ^{99m}Tc, ^{153}Sm, ^{177}Lu, and ^{18}F in separate campaigns, and Indonesian studies have mainly reported single surveys in hospital nuclear medicine installation (Nisa et al., 2017; Putri et al., 2023). In addition, routine monitoring records are rarely analyzed statistically to separate persistent location-related differences from short-term

week-to-week fluctuations, although this distinction determines whether optimization should target specific rooms or general operational practice.

This study therefore aims to (1) describe the distribution of area dose rate at 21 controlled-area locations of ITRR during four weeks of September 2026; (2) test whether dose rates differ significantly between locations and between weeks; and (3) assess the readings against the 10 μSv/hour reference value on the monitoring form and the 3 μSv/hour criterion corresponding to 3/10 of the radiation-worker DLV. The results provide an empirical baseline for the facility and show how routine monitoring records can be used to priorities ALARA optimization.

METHOD

Research design and setting

This study used a quantitative descriptive with an observational approach based on routine area monitoring. A similar approach based on routine area monitoring. A similar approach based on direct workplace measurement has been used to describe radiation conditions in nuclear medicine facilities (Elshami et al., 2022; Hossain et al., 2024). The research was conducted in September 2026v at 21 controlled-area locations of the Radioisotope and Radiopharmaceutical Technology Installation. Directorate of Nuclear Facility Management, BRIN B.J. Habibie Science and Technology Area (KST BJ Habibie), over four consecutive weeks. The 21 locations are the fixed monitoring points listed on the facility's routine monitoring form.

Research design and setting

Dose rates were measured with a portable Canberra Radiagem 2000 survey meter, model (ref. 76687, serial no.1807) with an energy-compensated Geiger Muller detector was used to measure dose rates. With reported measurement range of 0,01 μSv/hour to 100 mSv/hour and a manufacturer-stated accuracy of ± 15%, the device measures the ambient dose equivalent rate, H*(10), for gamma and X-ray radiation in the photon energy range of 40 keV to 1.25 MeV ± 45º). DPFK BRIN (certificate no. 232964/LT/LDSS/11/2025) with a calibration factor of 1.02, and its recalibration due date is 22 November 2026, so it was within its calibration validity during the September 2026 measurements. In order to guarantee traceable measurements and comparability with reference values for occupational radiation monitoring, portable survey meters are typically calibrated in terms of H*(10) (IAEA, 2000; ICRP, 2021; Knoll, 2010). Micro sieverts per hour (μSv/hour) are used to express dose rates.

Measuring procedure

Three times a week, on Mondays, Wednesdays, and Thursdays, between 9.00 and 11.00 Western Indonesian Time (WIB), radiation dose rate measurements were carried out. The survey meter was examined as needed. In the supervision room, background radiation was measured independently and reported without being subtracted from the workplace measurements were carried out at specific monitoring locations in accordance with the structure of the facility, including, when appropriate, places close to fume hoods. Individual readings were taken at 10 second intervals at each monitoring site. The weekly maximum dosage rate was determined by

taking the highest reading from the measurements taken at each location during each weekly monitoring period. Following four weeks of observation, each location's four weekly maximum values were used to compute the maximum, mean, and standard deviation. When available, details about ongoing operations and the radionuclides being handled were documented. Figure 1 summarizes the measurement process.

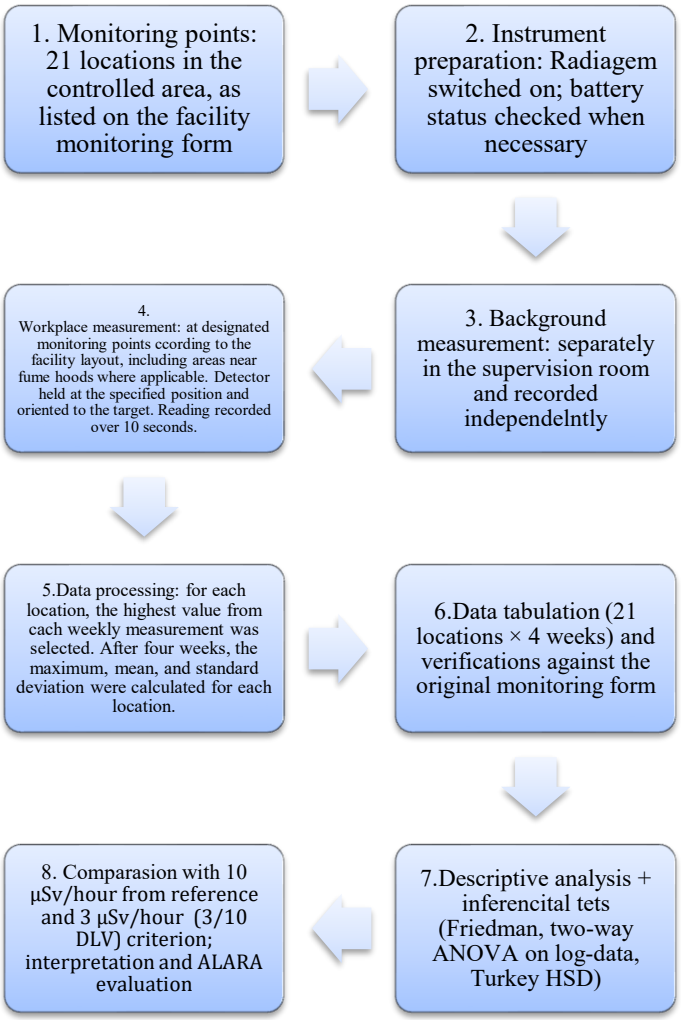


Figure 1. Measurement and analysis procedure

Data analysis

The data comprises the dose-rate values of the 21 locations over four monitoring weeks (21 locations × 4 = 84 readings), organized by location code and measurement week and verified against the original monitoring forms. Descriptive statistics (mean, standard deviation, median, minimum, maximum, and coefficient of variation) were computed per location and per week. Because each location was measured once per week (a repeated measures design without replication), differences between weeks were tasted with the Friedman test using locations as blocks, and differences between locations with the Friedman test using weeks as blocks; Kendall's W was reported as the effect size. As a parametric check, a two-way analysis of variance without replication (factor: location and week) was applied to $\log_{10}$ transformed dose rates, because dose

rates were strongly skewed. Normality of the residuals was checked with the Shapiro-Wilk test and avidity with Tukey's one-degree-of-freedom test, and pairwise, differences between locations were examined with Tukey's honestly, significant difference (HSD) test on the log scale, The significance level was, $\alpha = 0.05$, and the analysis was performed in Python (SciPy) To assess, radiological significance, dose, rates were converted to annual dose estimates using the conservative assumption of 2,000 working hours per year. The results are presented in tables. and figures.

RESULT AND DISCUSSION

Result of radiation dose rate monitoring

Dose-rate in the ITRR controlled area in September 2026 was conducted over four weeks. The measurement results at each location are presented in Table 2.

Table 2. Weekly dose rates (µSv/hour) at each controlled area location, September 2026

No	*Location (room code)*	*Week I*	*Week II*	*Week III*	*Week IV*	*Maximum*	*Mean*	*SD*
1	***C.101***	*0.27*	*0.23*	*0.19*	*0.37*	*0.37*	*0.27*	*0.08*
2	***C.102***	*0.13*	*0.19*	*0.18*	*0.07*	*0.19*	*0.14*	*0.06*
3	***C.103***	*0.73*	*0.53*	*0.56*	*0.46*	*0.73*	*0.57*	*0.11*
4	***C.106***	*2.59*	*0.46*	*4.15*	*0.30*	*4.15*	*1.88*	*1.84*
5	***C.107***	*3.63*	*1.81*	*3.11*	*2.85*	*3.63*	*2.85*	*0.77*
6	***C.110***	*0.18*	*0.19*	*0.07*	*0.08*	*0.19*	*0.13*	*0.06*
7	***C.129***	*0.05*	*0.11*	*0.14*	*0.06*	*0.14*	*0.09*	*0.04*
8	***C.133***	*0.08*	*0.13*	*0.08*	*0.07*	*0.13*	*0.09*	*0.03*
9	***C.136***	*0.12*	*0.19*	*0.32*	*0.06*	*0.32*	*0.17*	*0.11*
10	***Senyawa Bertanda***	*0.36*	*0.05*	*0.06*	*0.09*	*0.36*	*0.14*	*0.15*
11	***13.01.02***	*2.81*	*2.59*	*3.24*	*3.40*	*3.40*	*3.01*	*0.37*
12	***13.01.06***	*0.07*	*0.27*	*0.21*	*0.09*	*0.27*	*0.16*	*0.10*
13	***13.01.07A***	*0.10*	*0.09*	*0.20*	*0.12*	*0.20*	*0.13*	*0.05*
14	***13.01.08***	*0.14*	*0.31*	*0.38*	*0.41*	*0.41*	*0.31*	*0.12*
15	***13.01.09***	*0.28*	*0.34*	*0.22*	*0.26*	*0.34*	*0.28*	*0.05*
16	***13.01.11***	*0.19*	*0.12*	*0.08*	*0.11*	*0.19*	*0.13*	*0.05*
17	***13.01.12***	*0.29*	*0.30*	*0.47*	*0.40*	*0.47*	*0.36*	*0.09*
18	***13.01.13A***	*0.15*	*0.15*	*0.15*	*0.09*	*0.15*	*0.13*	*0.03*
19	***13.01.16/17***	*0.52*	*1.88*	*0.52*	*0.53*	*1.88*	*0.86*	*0.68*
20	***13.01.18***	*0.08*	*0.14*	*0.09*	*0.08*	*0.14*	*0.10*	*0.03*
21	***13.01.21***	*0.28*	*0.11*	*0.23*	*0.10*	*0.28*	*0.18*	*0.09*

Analysis of changes in radiation dose rate

Across the 84 readings, dose rates ranged from 0.05 to 4.15 µSv/hour, with an overall mean of 0.57 µSv/hour (SD 0.96) and median of 0.19 µSv/hour, 67 of the 84 readings (80%) were below 0.5 µSv/hour. The distribution is therefore strongly right skewed, and the overall mean is raised by a few locations. The highest four-week means were found at 13.01.02 (3.01 µSv/hour), C.107 (2.85 µSv/hour, and C. 106 (1.88 µSv/hour), whereas 12 of the 21 locations, including C.129, C.133, C.110, and 13.01.18 had means below 0.20 µSv/hour (Table 2; Figure 2).

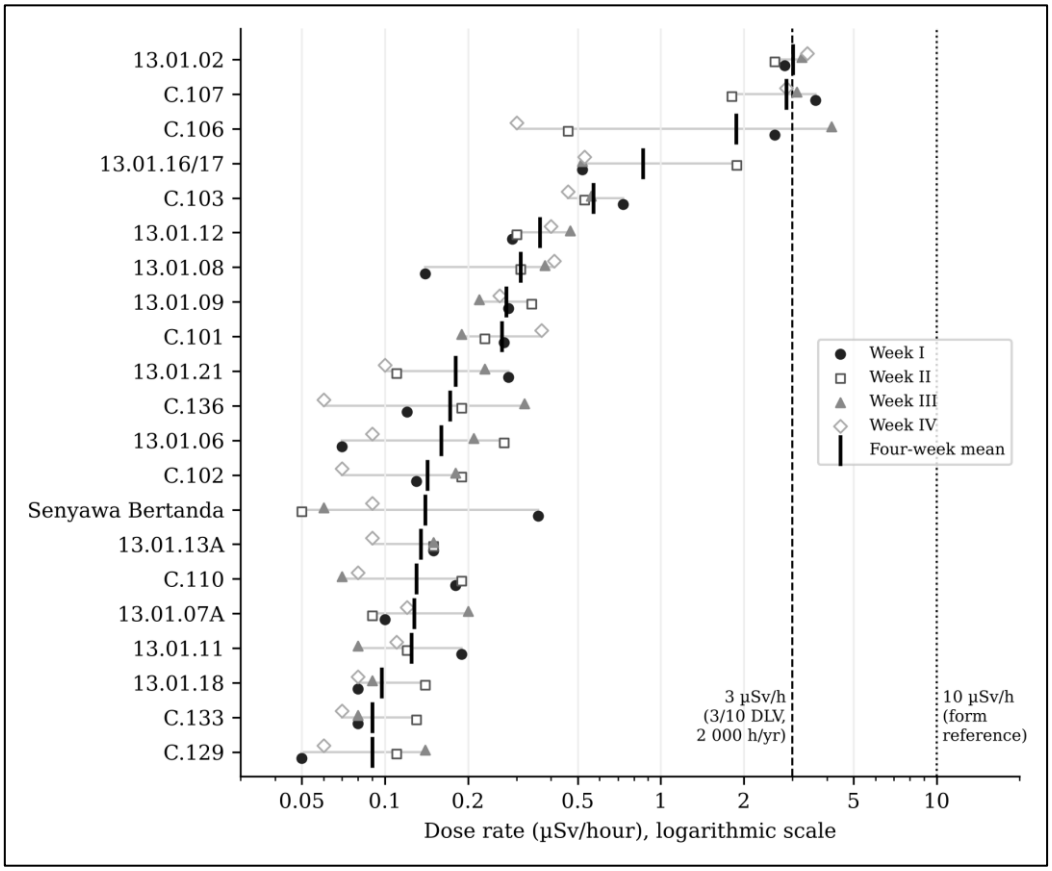


Figure 2. Weekly dose and four-week means at the 21 locations, ordered by mean (logarithm scale). The dashed line marks 3 µSv/hour from reference

Table 3. Dose rate statistic by measurement week (µSv/hour)

Period	*Mean*	*SD*	*Median*	*Minimum*	*Maximum (location)*
Week I	*0.62*	*1.03*	*0.19*	*0.05*	*3.63 (C.107)*
Week II	*0.49*	*0.70*	*0.19*	*0.05*	*2.59 (13.01.02)*
Week III	*0.70*	*1.20*	*0.21*	*0.06*	*4.15 (C.106)*
Week IV	*0.48*	*0.90*	*0.11*	*0.06*	*3.40 (13.01.02*
Overall	***0.57***	***0.96***	***0.19***	***0.05***	***4.15 (C.106)***

The highest weekly mean occurred in the third week (0.70 µSv/hour), and the lowest occurred in the fourth week (0.48 µSv/hour). However, the weekly medians were similar (0.11 - 0.21 µSv/hour), which indicates that the differences between weekly means are driven by a few high readings rather than by a facility-wide shift.

Inferential analysis

The results of the inferential tests are summarized in Table 4. Both the non-parametric and the parametric tests agree location had a large and significant effect on dose rate, whereas measurement week did not. Tukey's HSD showed that 13.01.02 and C.107 differed significantly from 18 and 17 of the other 20 locations, respectively, and C.106 from 14, while the three highest locations did not differ significantly from one another. The apparent changes between weeks should therefore be interpreted as location-specific fluctuations rather than systematic temporal trends. Because each cell is a single reading without replicates, the location x week interaction cannot be tested formally assessed. The manufacturer-stated instrument accuary of (± 15%) should be considered when interpreting individual weekly peaks.

Table 4. Results of inferential tests on the dose-rate data

Test	*Factor (blocks)*	*Statistic*	*p-value*	*Effect size*
Friedman	*Week (21 location)*	$\chi^2(3) = 2.85$	*0.415*	*W=0.05*
Friedman	*Location (4 weeks)*	$\chi^2(20) = 62.02$	*<0.001*	*W=0.78*
Two-way ANNOVA, log_{10} data	*Location*	*F (20,60) = 17.91*	*<0.001*	*partial η^2 = 0.86*
Two-way ANNOVA, log_{10} data	*Week*	*F (3,60) = 2,08*	*0.112*	*partial η^2 = 0.09*
Tukey additivity test	*Location x week*	*F (1,59) = 0,03*	*0.873*	-
Shapiro-Wilk (ANNOVA residuals)	-	*W = 0.998*	*0.641*	-

Location-specific factors

The week-to-week variation is therefore best examined location by location, based on the function of each room and the radioisotopes recorded in the work-area inventory. Room C.106 (Iodination Preparation Laboratory), which recorded the maximum value of 4.15 µSv/hour in the third week, is associated with ^{125}I, ^{131}I, ^{99m}Tc, and ^{153}Sm.Its readings (2.59, 0.46, 4.15, and 0.30 µSv/hour, coefficient of variation 98%) form the most episodic pattern in the data set: high in weeks I and III and close to the facility median in weeks II and IV. A fixed source or long-lived contamination would produce a comparatively stable reading, so this pattern is more consistent with batch-wise handling of sources present on particular measurement days. The radionuclides concerned also differ strongly in half-life and photon energy: ^{99m}Tc (6.01 h; 140 keV) and ^{153}Sm (46.3 h; 103 keV) decay within hours to days, ^{131}I (8.02 d; principal photon 364 keV) is the most penetrating, and ^{125}I (59.4 d) emits only low-energy photons (about 27-35 keV) that are easily

shielded (Chember &Johnson, 2009). A reading in C.106 therefore reflects mainly which radionuclide, and how much activity, was being handled at time of measurement.

Room C.107 (Hot Cell) showed 3.63, 1.81, 3.11, and 2.85 µSv/hour from the first to the fourth week (coefficient of variation 27%), i.e., consistently elevated values. This room recorded the use of ^{131}I, ^{177}Lu, ^{99m}Tc, and ^{18}F. Among these, the 511 keV annihilation photons of ^{18}F (half-life 109.8 min) and the 364 keV photons of ^{131}I are the most penetrating, so the hot-cell shielding. The values in Room C.107 are comparable to the dose rate of about 2.3 µSv/hour reported in a hot cell during the values in Room C.107 are comparable to the dose rate of approximately 2.3 µSv/hour reported in the hot cell during ^{18}F-FDG synthesis by Bisawarsama et al. (2025). The remaining differences can be attributed to operational activities, the types and activities of radionuclides handled, source-handling conditions, measurement positions, and shielding systems (Carnicer et al., 2011; Struelens et al., 2024).

Locations 13.01.02, identified as the radioactive waste storage room, showed the most stable elevated pattern (2.81, 2.59. 3.24, and 3.40 µSv/hour, coefficient of variation 12%), suggesting a persistent radiation source, such as stored radioactive materials or waste, rather than short-term fluctuations. Location 13.01.16/17 showed a single peak in week II (1.88 µSv/hour) against about 0.52 µSv/hour in the other weeks, again an episodic pattern, whereas Room C.103 (Chemical Synthesis Laboratory-1; ^{131}I, ^{177}Lu, ^{99m}Tc) remained moderate and stable (0.46-0.73 µSv/hour), and 13.01.12 did not exceed 0.47 µSv/hour. Physically, such peaks do not require large changes in source activity: the transmitted intensity behind a shield falls as $I = I_0 \cdot 2^{-x/HVL}$, where the half-vales layer (HVL) increases with photon energy, and the dose rate from a point source falls with the square of the distance (Cember & Johnson, 2009). A change in the radionuclide handled, in the position of a source container, or in the shielding configuration can therefore change a fixed-point reading-several-fold. Recording operational conditions (the type and activity of radioisotopes handled and the activities taking place during measurement) and conducting regular monitoring need to be carried out systematically to evaluate changes in dose rates and support radiation safety in the workplace (IAEA, 2018).

Radiological significance

To assess the radiological significance of the results, the dose rate can be converted into an annual dose estimate with the conservative assumption that workers are present at a location for 2,000 working hours per year. With this assumption, the reference value of 10 µSv/hour is equivalent to 20 mSv/year, the effective-dose DLV for radiation workers, while 3/10 of the DLV (6 mSv/year) is equivalent to 3 µSv/hour. Five readings exceeded this level C.106 in week III (4.15), C.107 in weeks I and III (3.63 and 3.11), and 13.01.02 in weeks III and IV (3.24 and 3.40 µSv/hour) and the four-week mean at 13.01.02 (3.01 µSv/hour) was at the threshold. This is consistent with the designation of these locations as controlled areas under BAPETEN (2013). The locations with lower dose rates remain controlled areas because of the contamination potential associated with open sources, which was not measured in this study. The same 3 µSv/hour limit was used by Barenzani and Sugiarto (2017) as the controlled-area criterion in evaluating radiological monitoring at the BATAN Experimental Fuel Element Installation. This estimate is an upper limit because the time workers spend in each area is generally much shorter; the actual dose to workers must therefore be confirmed through personal dosimetry, and exposure

in the areas with the highest dose rates needs to be continuously optimized according to the ALARA principle (IAEA, 2018; ICRP, 2007).

This study has several limitations. The data cover one month and a single reading per location per week; operational activity, source inventory, and measurement geometry were not linked to each reading, and surface contamination was not measured. The findings should therefore be read as a description of area dose-rate conditions rather than as an assessment of individual worker doses or contamination.

CONCLUSION

Area dose rates in the ITRR controlled area during September 2026 ranged from 0.05 to 4.15 μSv/hour (overall mean 0.57 μSv/hour; median 0.19 μSv/hour). The highest value was recorded in Room C.106 in the third week (4.15 μSv/hour), followed by Room C.107 in the first week (3.63 μSv/hour) and location 13.01.02 in the fourth week (3.40 μSv/hour); the maxima at 13.01.16/17 (1.88 μSv/hour), C.103 (0.73 μSv/hour), and 13.01.12 in the fourth week (0.47 μSv/hour) were considerably lower. Dose rates differed significantly between locations but not between weeks, so radiological conditions are governed mainly by location-specific factors the radionuclides handled, their activity, and shielding rather than by a facility-wide temporal trend. All readings were below the 10 μSv/hour reference value on the monitoring form; however, five readings at C.106, C.107, and 13.01.02 exceeded about 3 μSv/hour (3/10 of the radiation-worker DLV at 2,000 working hours per year), which is consistent with their controlled-area designation and makes them priorities for optimization under the ALARA principle. Future monitoring should record the activity in progress, the radionuclide and activity handled, and the measurement geometry with each reading, include replicate readings and contamination surveys, and be compared with personal dosimetry so that the causes of dose-rate peaks can be established.

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REFERENCES

Alatas. Z., Hidayati, S., Akhadi, M., Purba. M., Purwadi, D., Ariyanto, S., Winarno, H., Rismiyanto. Sofyatiningrum, E., Hendriyanto, H., Widyastono, H., Parmanto, E. M., & Syahril. (2015). *Buku Pintar Nuklir*. BATAN Press.

Antara, H., Perilaku, K., Dosis, D. A. N., Tresnawati, L., Denny, H. M., & Kurniawan, B. (2016). *PEKERJA DI PUSAT TEKNOLOGI RADIOISOTOP DAN RADIOFARMAKA (PTRR) BATAN SERPONG*. *4*.

Barenzani, N., & Sugiarto, A. D. (2017). Evaluasi hasil pemantauan radiologi di IEBE berdasar Perka BAPETEN Nomor 4 Tahun 2013. Dalam *Hasil-Hasil Penelitian EBN Tahun 2017*

(hlm. 333–340). Pusat Teknologi Bahan Bakar Nuklir–BATAN.

Biegala, M., & Jakubowska, T. (2020). Levels of exposure to ionizing radiation among the personnel engaged in cyclotron operation and the personnel engaged in the production of radiopharmaceuticals, based on radiation monitoring system. *Radiation Protection Dosimetry, 189*(1), 56-62. https://doi.org/10.1093/rpd/ncaa012

Biegała, M., Jakubowska, T., Wrzesień, M., & Albiniak, L. (2022). Exposure to ionizing radiation by service personnel working with cyclotrons used to produce radiopharmaceuticals in PET diagnostics. *International Journal of Occupational Medicine and Environmental Health*, 35(6), 753-760. https://doi.org/10.13075/ijomeh.1896.01992

Biswasarma, S. C., Azim, M. A. U., Podder, P., Uddin, M. J., Islam, S., Islam, M. S., Mehdi, H., Mia, M. S., Siddiqee, N. E. A., Kadir, M., Mamun, M., Hossan, M. E., Hossain, N., & Begum, F. (2025). Survey of radiation exposure during cyclotron operation for PET radiopharmaceutical production at NINMAS. *Bangladesh Journal of Nuclear Medicine, 28*(1), 68–74. https://doi.org/10.3329/bjnm.v28i1.79477

Carnicer, A., Sans-Merce, M., Baechler, S., Barth, I., Donadille, L., Ferrari, P., Fulop, M., Ginjaume, M., Gualdrini, G., Krim, S., Mariotti, F., Ortega, X., Rimpler, A., Ruiz, N., & Vanhavere, F. (2011). Hand exposure in diagnostic nuclear medicine with ^{18}F- and ^{99m}Tc-labelled radiopharmaceuticals – Results of the ORAMED project. *Radiation Measurements, 46*(11), 1277–1282. https://doi.org/10.1016/j.radmeas.2011.07.019

Cember, H., & Johnson, T. E. (2009). *Introduction to health physics* (4th ed.). McGraw-Hill Medical.

Covens, P., Berus, D., Buls, N., Clerinx, P., Vanhavere, F., & Struelens, L. (2007). Personal dose monitoring in hospitals: Global assessment, critical applications and future needs. *Radiation Protection Dosimetry, 124*(3), 250–259. https://doi.org/10.1093/rpd/ncm418

Dang, P., Feng, Z.-Y., Yang, X.-Y., Cao, X.-J., Tian, L., Shi, X., Shen, X., Qi, J., Zhong, E.-D., & Wang, J. (2026). Evaluation of exposure characteristics and radiological risks for cyclotron-based 18F radiopharmaceutical production workers in China.. *Applied radiation and isotopes : including data, instrumentation and methods for use in agriculture, industry and medicine, 230*, 112474 . https://doi.org/10.1016/j.apradiso.2026.112474

Elshami, W., Erdemir, R. U., Abuzaid, M. M., Cavli, B., Issa, B., & Tekin, H. (2022). Occupational radiation dose assessment for nuclear medicine workers in turkey: A comprehensive investigation. *Journal of King Saud University - Science*. https://doi.org/10.1016/j.jksus.2022.102005

Hao, Y., Wu, Z., Pu, Y., Zhou, Y., Qiu, R., Zhang, H., & Li, J. (2024). A Monte Carlo simulation dataset of radiation field parameters for a simple nuclear facility scenario. *Scientific Data*, 11, Article 1008. https://doi.org/10.1038/s41597-024-03799-8

Hossain, M. F., Chowdhury, M. S. A., Awal, M., Haque, M., Sarmin, S., Mamun, M. A. A., & Tarannum, N. (2024). Workplace Radiation Monitoring and Analysis: A Single Institution Based Study. *Bangladesh Journal of Nuclear Medicine*. https://doi.org/10.3329/bjnm.v27i1.71530

International Atomic Energy Agency. (2000). *Calibration of radiation protection monitoring instruments* (Safety Reports Series No. 16). IAEA.

International Atomic Energy Agency. (2014). *Radiation protection and safety of radiation sources: International basic safety standards* (IAEA Safety Standards Series No. GSR Part 3). IAEA. https://doi.org/10.61092/iaea.u2pu-60vm

International Atomic Energy Agency. (2018). *Occupational radiation protection* (IAEA Safety Standards Series No. GSG-7). IAEA.

International Commission on Radiological Protection. (2007). The 2007 recommendations of the International Commission on Radiological Protection (ICRP Publication 103). *Annals of the ICRP, 37*(2–4). https://doi.org/10.1016/j.icrp.2007.10.003

International Commission on Radiological Protection. (2021). Use of dose quantities in radiological protection (ICRP Publication 147). *Annals of the ICRP, 50*(1). https://doi.org/10.1177/0146645320911864

Klappa, K., Cegla, P., Cholewinski, W., & Mantaj, P. (2025). Assessment of the exposure to ionizing radiation of the Nuclear Medicine Department in the Greater Poland Cancer Centre in years 2008-2023. *Reports of Practical Oncology and Radiotherapy, 30*(2), 147-154. https:doi.org/10.5603/rpor.105027

Knoll, G. F. (2010). *Radiation detection and measurement* (4th ed.). John Wiley & Sons.

Marshall, S. K., Hayeeabdunromae, A., Noomad, N., Durawee, W., Sirieak, N., Karnkorn, P., & Keawtong, V. (2024). Evaluation of environmental radiation exposure and algorithms for determining the occupational effective dose during ^99mTc-MDP bone scintigraphy: A comprehensive analysis. *Applied Sciences*, 14(23), 11211. https://doi.org/10.3390/app142311211

McCann, A., Cournane, S., & Lucey, J. (2021). Assessment of occupational exposure from shielded and unshielded syringes for clinically relevant positron emission tomography (PET) isotopes—a Monte Carlo approach using EGSnrc. *Journal of Radiological Protection,* 41, 1060 - 1074. https://doi.org/10.1088/1361-6498/ac0df5

Nisa, U. L., Gunawan, G., Arifin, Z., Nuklir, K., Radiologi, I., & Semarang, R. K. 2017. Analisis Tingkat Kontaminasi Permukaan Daerah Kerja Dan Laju Paparan Radiasi Pada Instalasi Kedokteran Nuklir. *Youngster Physics Journal*, 6(1), 76–82.

Nuklir, B. P. T. (2013). Peraturan Kepala Badan Pengawas Tenaga Nuklir Nomor 4 Tahun 2013 tentang Proteksi dan Keselamatan Radiasi dalam Pemanfaatan Tenaga Nuklir. *Republik Indonesia*, 1-29.

Pairodsantikul, P., Wongsa, P., Sudchai, W., Wimlopas, N., Kongkhun, R., Fangnok, N., & Boonsingma, N. (2024). Assessment of area radiation dose for the National Cyclotron and PET Centre at Chulabhorn Hospital in Thailand. *Journal of Nuclear Medicine Technology*, 52(2), 152-157. https://doi.org/10.2967/jnmt.123.266159

Pemerintah Republik Indonesia. (2023). *Peraturan Pemerintah Nomor 45 Tahun 2023 tentang Keselamatan Radiasi Pengion dan Keamanan Zat Radioaktif* (Lembaran Negara Republik Indonesia Tahun 2023 Nomor 118).

Putri, A., Zurma, R., Putri, E. R., & Munir, R. (2023). Analisis Laju Paparan Radiasi Pada Daerah Kerja di Instalasi Kedokteran Nuklir RSUD Abdoel Wahab Sjaharine. *Progressive Physics Journal*. *4*, 270–275.

Riveira-Martin, M., Struelens, L., Munoz Iglesias, J., Schoonjans, W., Tabuenca, O., Nogueiras, J. M., Salvador Gomez, F. J., & Lopez Medina, A. (2023). Radiation exposure assessment of nuclear medicine staff administering [^177Lu]Lu-DOTA-TATE with active and passive dosimetry. *EJNMMI Physics*, 10, 70. https://doi.org/10.1186/s40658-023-00592-1

Sans Merce, M., Ruiz, N., Barth, I., Carnicer, A., Donadille, L., Ferrari, P., Fulop, M., Ginjaume, M., Gualdrini, G., Krim, S., Mariotti, F., Ortega, X., Rimpler, A., Vanhavere, F., Baechler,

S., & Struelens, L. (2011). Extremity exposure in nuclear medicine: Preliminary results of a European study. *Radiation Protection Dosimetry, 144*(1–4), 515–520. https://doi.org/10.1093/rpd/ncq574

Struelens, L., Aalbersberg, E., Beels, L., Cherbuin, N., D'Asseler, Y., De Monte, F., López Medina, A., Riveira-Martin, M., Schoonjans, W., Terwinghe, C., Van den Block, S., Vanhavere, F., Zaidi, H., & Schelfhout, V. (2024). How much do ^{68}Ga-, ^{177}Lu- and ^{131}I-based radiopharmaceuticals contribute to the global radiation exposure of nuclear medicine staff? *EJNMMI Physics, 11*(1), Article 95. https://doi.org/10.1186/s40658-024-00695-3

Vogt, J., Qeh, U., & Maringer, F. J. (2024). Development of the occupational exposure during the production and application of radiopharmaceuticals in Germany. Journal of Radiological Protection, 44(1), Article 011508. https://doi.org/10.1088/1361-6498/ad1fdd

Wrzesień, M., & Albiniak, Ł. (2023). Personal dose equivalent Hp (0.07) during ^{68}Ga-DOTA-TATE production procedures. *Radiation and Environmental Biophysics, 62*(1), 117–129. https://doi.org/10.1007/s00411-022-01015-y