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Radiation Risks of Employees During the Production and Use of Radiopharmaceuticals in Medicine

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ABSTRACT: The study focuses on occupational radiation risks among 40 specialists working in nuclear medicine: 23 employees involved in the production of radiopharmaceuticals and 17 staff members of radioisotope departments at medical centers. Depending on their professional responsibilities, the participants were classified as process engineers, production laboratory assistants, incoming quality control laboratory assistants, dosimetrists, senior engineers, medical technicians, radiologists, or nurses. The assessment identified the main sources and pathways of potential occupational exposure. External exposure may occur during the handling of unsealed radioactive sources and during contact with patients following radiopharmaceutical administration. Internal exposure may result from the intake of radionuclides associated with radioactive contamination of workplace air, working surfaces, or personal protective equipment. The analysis was performed using data from the Radiological Research Laboratory of the Center for the Development of Professional Qualifications of Medical Workers. The findings emphasize that radiation safety in the production and clinical application of radiopharmaceuticals requires a comprehensive system of protective measures, including optimized work procedures, appropriate shielding, remote handling techniques, individual dosimetric monitoring, workplace contamination control, proper use of personal protective equipment, and regular staff training. Effective implementation of these measures can reduce occupational radiation risks while preserving the diagnostic and therapeutic benefits of nuclear medicine.

INTRODUCTION

A lot of time passed from the discovery of the phenomenon of radioactivity to its introduction into practice. The global development and use of nuclear technology, along with the increasing use of radioactive sources in industry and medicine, has led to an increase in occupational exposure [1,2]. One of the modern branches of clinical medicine is nuclear medicine, which is divided into diagnostic and therapeutic applications. Developments in nuclear medicine include the introduction of new

radiopharmaceuticals, the introduction of new technologies, and changes in research structures that may increase radiation risks [3].

In Uzbekistan, nuclear medicine is a priority area in oncology, and the successful development of this field largely depends on the production of radionuclides and radiopharmaceuticals by the Institute of Nuclear Physics (INP) of the Academy of Sciences of the Republic of Uzbekistan. The key advantage of radiopharmaceutical-based treatment is its localized and selective action, unlike chemotherapy [4].

Today in Uzbekistan, medical clinics use radioisotopes - technetium-99m, iodine-131, samarium-153, lutetium-177. Using gamma-ray-emitting technetium-99m, skeletal and cardiac muscles, liver, kidneys, spleen, etc. are visualized. Iodine-131 is widely used for the treatment and imaging of thyroid hyperfunction and cancer. Samarium-153 is used for the palliative treatment of metastatic bone cancer. Since 2023, the INP began to produce the drug "Lutetium-177", which is effective in the treatment of prostate cancer. At the same time, in the fourth and fifth doses, a therapeutic effect on metastases in other parts of the body was observed.

Knowledge about the formation of individual radiation doses and their patterns is important for the creation of scientifically based, safe working conditions and for the continuous optimization of the radiation protection system at facilities that pose a radiation hazard [5].

To ensure radiation safety of persons working with sources of ionizing radiation, Uzbekistan adopted Resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 613 “On a unified state system for monitoring and recording individual radiation doses” dated September 29, 2021. [6]. The individual dosimetry monitoring system (IDC) allows you to collect and analyze data on radiation exposure by gender, age, profession and time dynamics both at the facility level and at the regional level [7].

The Unified System is intended to ensure the systematic recording and monitoring of individual radiation doses, support the implementation of measures aimed at reducing radiation exposure, and provide an assessment of both individual and collective doses received by different population groups from all categories of ionizing radiation sources. Another important function of the system is the identification of individuals whose exposure levels exceed the established dose limits. In accordance with the Resolution, individual doses may be determined using several approaches: direct measurements obtained with personal dosimeters; dose assessment for members of the public; or retrospective evaluation based on biological, biochemical, and biophysical indicators of radiation exposure. At the same time, the reliability and comparability of the accumulated dosimetric information can only be confirmed through comparative analysis [8].

Occupational exposure monitoring is one of the essential components of radiation protection for personnel. From the standpoint of radiological safety, its primary purpose is to verify that working conditions meet the established safety requirements and that radiation sources are used under appropriate control. Regular monitoring also makes it possible to identify patterns and changes in exposure levels among occupational groups involved in radiopharmaceutical production. The information obtained can be used to improve radiation protection strategies, support decision-making on preventive measures, and provide a reliable evidence base for epidemiological investigations and the assessment of occupational radiation risks.

To ensure adequate radiological protection, it is necessary to assess both the individual effective dose (E) resulting from external exposure and the equivalent doses received by specific organs and tissues. Since these protection quantities cannot be measured directly, radiation monitoring relies on operational quantities derived from the measurable physical characteristics of the radiation field. Operational dose measurements are therefore used as conservative surrogate estimates for regulatory control and for demonstrating compliance with radiation safety requirements [9].

For individual monitoring of external exposure, the operational quantity applied is the personal dose equivalent, (H_p(d)). The parameter (d), expressed in millimetres, represents the reference depth in tissue at which the dose equivalent is assessed. The selected depth and the positioning of the dosimeter on the worker’s body are determined by the protection quantity to be evaluated.

The aim of this study is to perform a differentiated assessment of radiation exposure levels among distinct occupational groups involved in the production and clinical use of radiopharmaceuticals.

MATERIALS AND METHODS

The study was carried out at the Radiological Research Laboratory of the Center for the Development of Professional Qualifications of Medical Workers. In this study, measurements were made of the personal dose equivalent (Hp(10)) recorded for various categories of personnel involved in the production of radiopharmaceuticals and their use in healthcare institutions. The study included 40 specialists working in the field of nuclear medicine: 23 employees involved in the production of radiopharmaceuticals and 17 employees of radioisotope departments of medical centers. Occupational exposure to X-ray and gamma radiation was monitored using DKG-RM1610 personal dosimeters. The measurement of personal dose equivalent from photon radiation was based on an integrated energy-compensated detector equipped with a Geiger–Müller counter. Within this detection system, incident photon quanta generate electrical pulses, which are subsequently processed to determine the recorded dose values.

The source dataset for this study comprised quarterly individual monitoring results for occupational radiation exposure among employees of the Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan and personnel of medical clinics. Based on their working conditions and professional responsibilities, the employees of the Institute of Nuclear Physics were classified into the following six occupational groups:

1) Process engineer;
2) Production laboratory technician;
3) Quality control laboratory assistant;
4) Dosimetry technician;
5) Senior engineer;
6) Laboratory technician.

Personnel employed in medical clinics equipped with radioisotope laboratories were divided into four occupational groups according to their working conditions and the nature of their radiation-related duties:

1) Radiologist;
2) Laboratory technician;
3) Nurse;
4) Dosimetrist.

To standardize the data, background dosimeter readings were subtracted.

The individual dosimetry monitoring (IDM) system is implemented through a sequence of interrelated stages:

Stage I involves the registration of the organization and the employees subject to occupational radiation monitoring.

Stage II includes the distribution of personal dosimeters, provision of radiation safety instructions, and appropriate training of personnel.

Stage III comprises the continuous collection of dosimetric information in accordance with the approved monitoring schedule.

Stage IV focuses on the automated processing and analysis of the obtained measurement results.

Stage V includes the preparation, finalization, and submission of the monitoring report.

Results and Discussion

For the initial assessment of potential differences in occupational radiation exposure among employees engaged in various stages of radiopharmaceutical production, individual dosimetry monitoring data obtained from the Research Laboratory were analyzed.

The mean daily equivalent dose values recorded for each of the six occupational groups were assessed over the fourth quarter of 2025 and the first quarter of 2026 (Figure 1). The analysis for both observation periods was based on data obtained from the same group of employees.

The distribution of daily equivalent dose values was fitted to a log-normal distribution, with the goodness of fit verified using the Kolmogorov–Smirnov test ($p < 0,05$). Subsequently, the dose data were logarithmically transformed to evaluate whether

the resulting log-transformed distributions followed a normal distribution. [10]. To identify potential differences in mean daily equivalent doses across the six occupational categories within each observation period, a one-way analysis of variance (ANOVA) was applied. The study design involved repeated monitoring of the same employees over two consecutive quarters. Since the initial dose values exhibited a log-normal pattern of distribution, logarithmic transformation was performed prior to the statistical analysis.

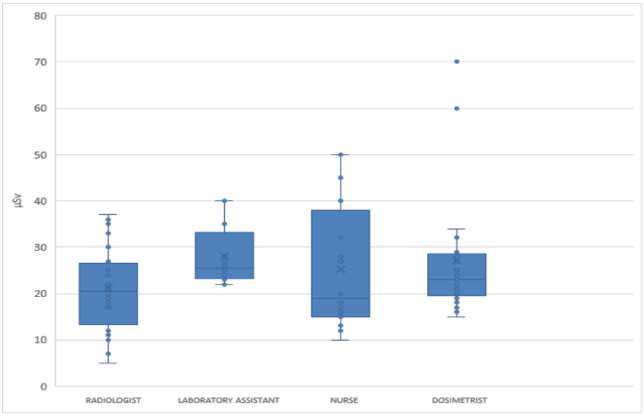


Fig. 1. Mean daily equivalent dose levels among occupational groups involved in radiopharmaceutical production.

The results of the analysis of variance (ANOVA) demonstrated that occupational group was associated with statistically significant differences in radiation exposure levels. The probability of observing such differences under the assumption that all six professional categories had comparable mean dose values during both quarterly periods was below 1% ($p < 0.01$). Accordingly, the null hypothesis was rejected in favor of the alternative hypothesis, confirming significant variation in mean equivalent doses among the occupational groups. Repeated-measures analysis of variance revealed statistically significant differences in daily occupational exposure levels among the professional groups ($p < 0.05$). The mean daily equivalent doses ranged from 0.007 to 0.052 mSv. According to Tukey's post hoc analysis, production laboratory technicians, laboratory assistants, senior engineers, and process engineers were exposed to significantly higher dose levels, ranging from 0.034 to 0.052 mSv, than dosimetry technicians and quality control laboratory personnel, whose mean daily doses ranged from 0.007 to 0.031 mSv. According to the Radiation Safety Standards and the Basic Sanitary Rules for Ensuring Radiation Safety, dated 5 January 2006, No. 0193-06, the permissible daily occupational exposure dose for Category A personnel is established at 0.036 mSv, based on a six-hour working day and the application of a safety factor of 2. The findings indicate that, on days when radiopharmaceuticals were produced, the mean daily equivalent dose exceeded this reference limit across all occupational groups. The highest daily occupational exposure values were observed among laboratory assistants and senior engineers, reaching up to 0.137 mSv. Nevertheless, owing to the shift-based work schedule, the average dose accumulated over a two-week working period remained within the permissible limits. Dose exceedances were primarily associated with days of intensive radiopharmaceutical production.

No statistically significant differences in occupational exposure levels were identified between the following pairs of professional groups: production laboratory technicians and laboratory assistants; process engineers and senior engineers; dosimetry technicians and incoming quality control laboratory personnel.

Despite differences in their assigned responsibilities, these findings suggest that employees within each pair were exposed under comparable working conditions. Therefore, the respective occupational subgroups may be combined in subsequent analyses of annual effective doses.

As illustrated in Figure 2, the mean monthly collective equivalent dose among personnel involved in radiopharmaceutical production varied between 4.7 and 8.0 mSv over the observation period from October 2025 through March 2026.

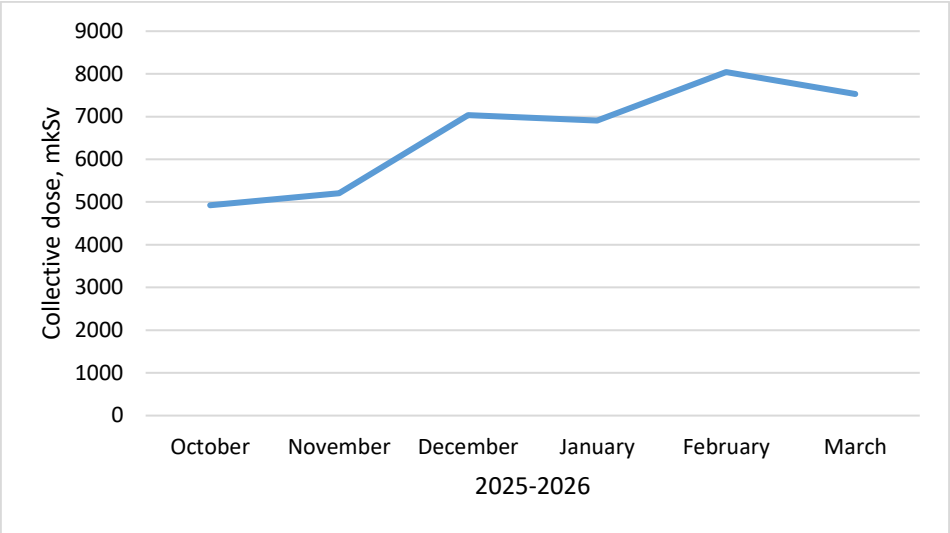


Fig. 2. Monthly mean equivalent dose values recorded among personnel engaged in radiopharmaceutical production during the period from October 2025 to March 2026.

The observation period from October 2025 to March 2026 was selected on the basis of several practical considerations:

- this interval corresponds to a period of relatively stable operation in medical institutions, with fewer staff members on annual leave, thereby supporting more consistent and uninterrupted data collection;

- during the autumn and winter months, demand for diagnostic and therapeutic procedures, including those involving radiopharmaceuticals, tends to increase;

- high summer temperatures may adversely affect the reliability of radiopharmaceutical production and transportation processes, particularly when short-lived radionuclides are involved;

- according to the production schedule, larger volumes of radiopharmaceutical output are planned for the autumn–winter season.

Figure 3 presents the maximum recorded values of the equivalent dose rate (EDR).

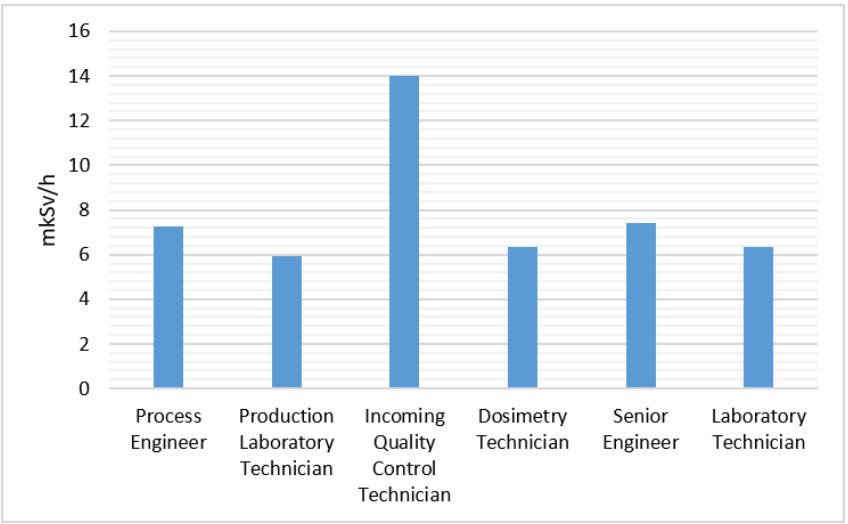


Fig. 3. Highest recorded equivalent dose values across different occupational categories during the period from October 2025 to March 2026.

During the study period, the highest equivalent dose rate (EDR) was recorded among incoming quality control technicians, reaching 13.9 μSv/h. Process engineers and senior engineers demonstrated EDR values ranging from 7.0 to 7.8 μSv/h, whereas production laboratory technicians, dosimetry technicians, and laboratory assistants had lower recorded levels, ranging from 5.8 to 6.4 μSv/h.

Figure 4 illustrates the mean daily equivalent doses recorded among personnel working in nuclear medicine departments where short-lived radionuclides, including technetium-99m, samarium-153, and iodine-131, are used. Based on the nature of their professional duties, the monitored employees were classified into four occupational groups: radiologists, laboratory assistants, nurses, and dosimetry technicians.

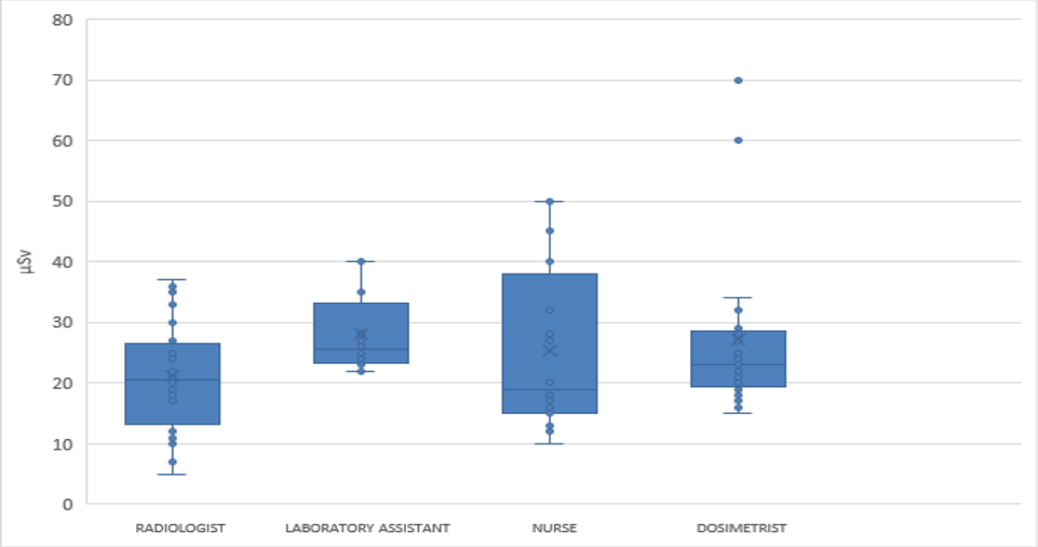


Figure 4. Mean daily equivalent dose values among staff of nuclear medicine departments operating radioisotope laboratories in medical clinics.

A comparison of occupational groups within nuclear medicine departments demonstrated that nurses and laboratory assistants received the highest exposure doses. This finding may be attributed to their longer duration of direct work with open radioactive sources during routine clinical procedures. In contrast, lower dose values were recorded among radiologists and dosimetry technicians, whose duties do not generally involve direct handling of radiopharmaceuticals. Nevertheless, all measured exposure levels remained below the regulatory limits established by Sanitary Rules and Norms № 0193-06. Therefore, the associated radiation risks may be classified as low.

CONCLUSION

The present study provided a comprehensive comparative assessment of individual occupational radiation exposure among personnel involved in both the production of radiopharmaceuticals and their clinical application in medical facilities. Despite the increased production demand observed during the evaluated period, the annual effective doses recorded for all monitored employees remained below the regulatory limit of 20 mSv.

The comparative assessment revealed that the highest exposure levels were recorded among personnel directly engaged in handling open radioactive sources, particularly during manual procedures and the synthesis of short-lived radionuclides. These findings highlight the importance of strengthening radiation protection measures at the most exposure-critical stages of the technological process. The findings obtained in this study emphasize the need for continuous individual dosimetry monitoring, further refinement of working procedures, and broader implementation of automated technologies and engineering protective controls. These measures are essential for improving radiation safety and maintaining compliance with established hygienic requirements.

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