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Hand Extremities and Effective Doses from Radiation Workers at the Nuclear Medicine Department, A. W. Sjahranie Hospital, Samarinda

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ABSTRACT

The use of radiopharmaceuticals in nuclear medicine increases the risk of radiation exposure for workers, particularly in the extremities and sensitive organs such as the lens of the eye and lungs. This study aims to determine the radiation dose received by three radio-pharmacists at the Nuclear Medicine Installation of RSUD A. W. Sjahranie Samarinda during the 2018–2023 period, and to compare the effective dose and hand extremity dose with the Dose Limit Values (NBD) set by ICRP and BAPETEN. The data were analysed using quantitative descriptive methods, based on readings from thermoluminescent dosimeters (TLD badge and ring dosimeter). The analysis included calculations of effective dose, extremity dose, mean values, and standard deviation. The results showed that Radio-pharmacist 2 had the highest effective dose to the eye lens (0,073 ± 0,02) mSv and lungs (0,18 ± 0.04) mSv, while Radio-pharmacist 3 had the highest hand extremity dose (33 ± 30,03) mSv. All doses recorded were below the Dose Limit Values (NBD) recommended by the ICRP, i.e., 20 mSv/year for internal organs and 500 mSv/year for extremities. The variation in dose among workers was influenced by the duration and technique of work, body positioning, and the effectiveness of protective equipment. This study highlights the importance of optimizing radiation protection and regularly monitoring individual doses to ensure the safety of nuclear medicine personnel.

I. Introduction

Nuclear medicine is a branch of medical science that utilizes open radioactive substances, in the form of radioisotopes, for diagnostic, therapeutic, and biomedical research purposes [1]. The use of radioisotopes has become a primary choice due to several advantages, including a biological half-life that is compatible with human activity and metabolism, ease of administration, and relatively economical production costs. Commonly used radioisotopes include Iodine-131 (I-131) and Technetium-99m (Tc-99m), which are the most widely employed in nuclear medicine [2].

In practice, these radioisotopes are introduced into the patient's body along with a carrier compound, which then travels to the target organ through the metabolic system. Administration can be carried out via oral ingestion, injection, or inhalation, thereby enabling the acquisition of valuable diagnostic information, precise targeted therapy, or innovative biomedical research. However, with the increasing use of radioisotopes, concerns have arisen regarding radiation exposure to nuclear medicine workers [1].

Radiation exposure from various isotopes poses an increased risk to nuclear medicine personnel because they are directly involved in the preparation and administration of radiopharmaceuticals to patients, often in close proximity during both diagnostic and therapeutic procedures. These tasks include generator elution, radioactive labelling, dilution, and dose dispensing into vials or syringes. Due to this proximity to the radiation source, workers are at higher risk of exposure to certain body parts such as fingers, wrists, eye lenses, and the chest. To prevent exceeding the recommended exposure limits, radiation dose assessments are carried out periodically, either monthly or annually [3].

According to the International Commission on Radiation Units and Measurements (ICRU), several fundamental quantities and units are used in radiation dose measurements. Two of the most important quantities in dosimetry are the equivalent dose and the effective dose. The equivalent dose represents the absorbed radiation dose adjusted for the type of radiation, directly correlating with potential biological effects. Meanwhile, the effective dose quantifies the overall risk by considering the varying sensitivities of different organs to radiation [4]. Radiation doses received by workers are measured as effective doses for the whole body and equivalent doses for extremities and the lens of the eye. Internationally, the recommended operational quantities for occupational radiation monitoring are Hp(10) for the whole body and Hp(0.07) for extremities [2].

The scope of dose limits for public exposure focuses on doses resulting from specific practices. Doses requiring intervention as the sole protective action are excluded from these limits. Potential exposures such as radionuclide emissions from facilities, including naturally occurring ones—are considered practices and must comply with dose limits. Conversely, situations such as radon in homes and outdoors, as well as naturally existing radioactive materials in the environment, are handled through intervention measures and are not subject to public exposure limits. For public exposure, the limit recommended by the International Commission on Radiological Protection (ICRP) is 1 mSv per year, with flexibility allowing higher doses in a single year provided the five-year average does not exceed 1 mSv per year [5].

Radiation dose monitoring is performed using dosimeters, devices that measure the amount of radiation absorbed by an individual over a given period. In radiation protection, dosimeters are essential for monitoring exposure among workers directly involved with ionizing radiation sources in medical, industrial, and research settings. Passive Thermoluminescent Dosimeters (TLDs) are commonly used for whole-body monitoring, while ring dosimeters are used for extremity monitoring. TLDs can detect various types of radiation, including X-rays, gamma rays, and beta particles. Radiation exposure levels depend on factors such as individual roles within the department, workload, effectiveness of protective measures, and personal work practices [6].

The basic principle of a TLD is based on the interaction between radiation and the detector crystal: when radiation strikes the crystal, electrons move from the valence band to the conduction band, becoming trapped in energy states created by impurities in the crystal lattice. During dose reading, the crystal is heated, providing enough energy for the trapped electrons to return to the conduction band and subsequently recombine with the valence band, emitting light in the process. The intensity of this emitted light is proportional to the absorbed radiation dose [7].

The ring dosimeter model used—TLD DTX-RAD 707H-2 (Thermo Fisher Scientific, Oakwood Village, USA)—is based on a detector made of 7 mg/cm², 2 mm diameter ^{7LiF}:Mg,Cu,P, enabling Hp(0.07) measurements for photons and beta particles in the range of 0.2 mSv to 10 Sv. The ring dosimeter is worn at the base of the finger, over the TLD glove and under a standard nitrile glove, with the detector facing the palm side. This monitoring ensures that doses remain below the Dose Limit Value (DLV) set for radiation workers [3].

Radiation protection is a primary concern in healthcare, aiming to limit exposure levels and minimize potential risks to medical personnel. The As Low as Reasonably Achievable (ALARA) principle is applied to ensure that all reasonable measures are taken to keep exposures as low as possible.

ALARA emphasizes three core strategies: reducing exposure time, increasing distance from the source, and using shielding effectively [8].

Several studies have investigated occupational radiation exposure in nuclear medicine. McCann et al. assessed extremity radiation doses during preparation, distribution, and administration of ^{68}Ga labelled radiopharmaceuticals in PET departments across Europe. Workers in eight centres wore ring dosimeters for all ^{68}Ga related tasks over at least one month. The median normalized ring dose for ^{68}Ga procedures was 0.25 mSv GBq^{-1}. Based on this average ratio, 94% of monitored workers were estimated to receive annual fingertip doses below the dose limit (150 mSv) [9].

Similarly, Ahmed et al measured staff radiation exposure during sentinel lymph node scintigraphy at Liaquat National Hospital (LNH), Karachi, using Optically Stimulated Luminescence Dosimeters (OSLDs) and active portable dosimeters. The estimated effective dose per patient was approximately 0.0026 mSv (OSLD) and 0.0024 mSv (portable dosimeter). Based on annual dose limits, a worker could theoretically manage up to 7,765 patients per year. Nevertheless, strict adherence to ALARA and universal precautions is still required [10].

Erdemir et al evaluated extremity radiation exposure among medical staff in PET/CT units in Turkish hospitals, using both OSL and TLD ring dosimeters. The mean annual effective dose for all workers was 14.5 mSv, with wide variability among individuals, underscoring the need for proper workplace assessment and safety practices [11].

Based on the studies conducted by McCann et al, Ahmed et al and Erdemir et al, although most dose values remain below the established limits, there is a potential for considerable variation in radiation exposure among workers and across procedures. Therefore, the present study aims to analyze the effective dose and extremity dose received by radiation workers in the Nuclear Medicine Installation of A.W. Sjahranie Regional General Hospital, Samarinda, over the past six years, using thermoluminescent dosimeters (TLDs) for dose monitoring. This study is essential to evaluate whether the doses received comply with radiation safety standards set by the International Commission on Radiological Protection (ICRP) and the Nuclear Energy Regulatory Agency of Indonesia (BAPETEN).

II. Method

In this study, the first stage of radiation dose data collection was carried out on the fingertips of radiation workers using a ring TLD dosimeter, and whole-body radiation dose data using a pocket TLD dosimeter for the period 2018–2023. The research objects were 3 radiopharmaceutical workers with the target tissues being the lungs, the lens of the eye, and the hands. The collected data were then processed to determine the equivalent dose using the Equation.

$$H_{T,R} = W_R \, D_{T,R} \tag{1}$$

where $H_{T,R}$ is the equivalent dose in tissue or organ T from radiation type R, W_R is the radiation weighting factor for radiation type R, and $D_{T,R}$ is the absorbed dose in tissue or organ T from radiation R [4].

Next, determine the effective dose value, which is the sensitivity dose of the body's organs and tissues to radiation. The equation used is:

$$H_E = W_T H_T \tag{2}$$

where H_E is the effective dose, W_T is the tissue weighting factor for organ or tissue T, and H_T is the equivalent dose in organ or tissue T [4] .

The dose values were accumulated every three months over the six-year data collection period (2018–2023), along with their standard deviations. The analyzed dose results were then presented visually in the form of graphs.

III. Results and Discussion

The results of the effective dose calculations are presented in Table 1 and Table 2.

Table 1. Effective dose of the eye lenses

Year	Effective Dose Radiopharmacist (LM) 1 (mSv)	Effective Dose Radiopharmacist (LM) 2 (mSv)	Effective Dose Radiopharmacist (LM) 3 (mSv))
2018	0,053	0,060	0
2019	0,063	0,104	0
2020	0,045	0,083	0,029
2021	0,050	0,079	0,056
2022	0,052	0,053	0,062
2023	0,038	0,059	0,056
Mean ± SD	**0,05 ± 0,01**	**0,073 ± 0,02**	**0,034 ± 0,03**

Table 2. Effective dose of the lungs

Year	Effective Dose Radiopharmacist (PP) 1 (mSv)	Effective Dose Radiopharmacist (PP) 2 (mSv)	Effective Dose Radiopharmacist (PP) 3 (mSv)
2018	0,126	0,145	0
2019	0,151	0,249	0
2020	0,108	0,199	0,07
2021	0,121	0,189	0,134
2022	0,126	0,126	0,149
2023	0,091	0,141	0,135
Mean ± SD	**0,12 ± 0,02**	**0,18 ± 0,046**	**0,08 ± 0,068**

Table 3. Hand extremity dose values

Year	Hand Extremity Dose of Radiopharmacist E1 (mSv)	Hand Extremity Dose of Radiopharmacist E2 (mSv)	Hand Extremity Dose of Radiopharmacist E3 (mSv)
2018	20,710	12,740	0
2019	35,250	7,350	0
2020	33,290	8,520	45,450
2021	13,520	22,790	74,680
2022	34,420	38,790	52,530
2023	21,560	25,660	25,370
Mean ± SD	26,458 ± 9,07	19,308 ± 12,12	33 ± 30,03

Differences in the average effective dose were observed for the three Ophthalmic Lens (LM) radiopharmaceuticals, with Radiopharmaceutical 2 exhibiting the highest effective dose, with an average value of (0.073 ± 0.02) mSv. Meanwhile, Radiopharmaceutical 1 produced an average effective dose of (0.05 ± 0.01) mSv. Radiopharmaceutical 3 had the lowest average effective dose, at (0.034 ± 0.03) mSv. This is due to Radiopharmaceutical 2's higher activity level or longer production time, which increases exposure to the ocular lens. Radiopharmaceutical 3, on the other hand, had the lowest dose due to its shorter production time and lower production time, resulting in lower radiation exposure.

As shown in Table 2, the difference in average effective doses across the three Lung Radiopharmaceuticals (PP) is that Radiopharmaceutical 2 exhibits the highest effective dose, with an average value of (0.18 ± 0.046) mSv. Meanwhile, Radiopharmaceutical 3 has the lowest average effective dose, at (0.08 ± 0.068) mSv, indicating relatively lower lung exposure. Radiopharmaceutical 1, on the other hand, falls between these two values, with an average effective dose of (0.12 ± 0.02) mSv. Radiopharmaceutical 2 experiences high activity levels and a long preparation time during its production. Meanwhile, Radiopharmaceutical 3 receives a lower dose due to its short production time and minimal activity, resulting in low lung radiation exposure.

Variations were also identified in the hand extremity dose, as shown in Table 3. Radiopharmaceutical 3 showed a hand extremity dose with an average value of (33 ± 30.03) mSv, which indicates a greater level of exposure compared to other Radiopharmaceuticals. Meanwhile, Radiopharmaceutical 2 had an average hand extremity dose value of (19.308 ± 12.12) mSv, while Radiopharmaceutical 1 had an average hand extremity dose value of (26.458 ± 9.07) mSv. This dose difference can be caused by the way Radiopharmaceuticals are handled, and the duration of exposure where in Radiopharmaceutical 3 in the radiopharmaceutical production process with a longer duration and radiation close to the hands for a long time so that the radiation received is higher.Based on the data in Tables 1 and 2, a graph of the effective dose to the eye lens and lungs over a six-year period was generated and is presented in Figure 1 below.

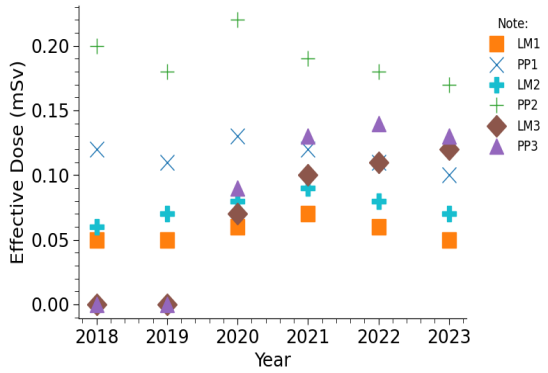

Fig 1. Effective dose to the eye lens and lungs

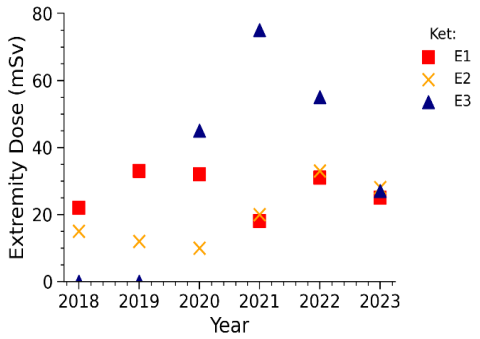

Fig 2. Hand extremity dose

Figure 1 illustrates the effective doses received by three radiopharmacy workers in the eye lens (LM) and lung (PP) organs from 2018 to 2023. In general, the effective dose to the eye lens (LM) remained relatively low, below 0,1 mSv, indicating adequate implementation of radiation protection in the ocular area. For Radiopharmacist 1 (LM1), the dose values were stable, ranging from 0,03 to 0,05 mSv. Radiopharmacist 2 (LM2) showed the highest doses among the three, with values of 0,104 mSv in 2019 and 0,083 mSv in 2020, suggesting direct exposure or work positioning closer to the radiation source. Meanwhile, Radiopharmacist 3 (LM3) exhibited a gradual increase in dose from 2020 to 2022, though still within safe limits.

For the lungs (PP), the effective doses received by the three radiopharmacy workers from 2018 to 2023 varied. Between 2018 and 2021, Radiopharmacist 2 (PP2) consistently received higher doses, indicating a higher risk of exposure compared to Radiopharmacist 1 and Radiopharmacist 3. In 2022, an increase in the effective lung dose was observed for Radiopharmacist 3 (PP3), exceeding that of the other two with a value of 0,15 mSv. This suggests that the worker in this category experienced increased exposure due to longer working durations when handling radiopharmaceutical materials.

Based on the data in Table 4, the graph of hand extremity doses over a six-year period is presented in Figure 2 below.

Hand extremity dose refers to radiation exposure measured at a skin depth of 7 mm, typically affecting the hands due to close contact with radioactive materials. In 2018, Radiopharmacist 1 (E1) and Radiopharmacist 2 (E2) received hand doses of 20,710 mSv and 12,740 mSv respectively, while Radiopharmacist 3 (E3) recorded no measurable exposure. These values suggest that E1 was more actively involved in procedures involving direct handling of radiopharmaceuticals, whereas E3 had no exposure-related activities that year.

In 2019, E1's dose increased significantly to 35,250 mSv, indicating a rise in workload and involvement in high-exposure tasks. In contrast, E2’s dose decreased to 7,350 mSv, reflecting a reduction in work activity or improved protection practices. By 2020, E3’s dose sharply increased to 45,450 mSv, surpassing both E1 (33.290 mSv) and E2 (8.520 mSv), signaling a shift in task distribution and exposure duration.

The year 2021 marked the highest recorded dose for E3, at 74,680 mSv, while E1 and E2 experienced dose reductions. This suggests that E3 took on more extended or higher-risk responsibilities in radiopharmaceutical handling. In 2022, although E3's dose decreased to 52,530 mSv, it remained higher than E1 (34,420 mSv) and E2 (38,790 mSv), indicating continued intense exposure.

By 2023, the hand extremity doses across all radiopharmacists became more evenly distributed and showed a general decrease. This trend could be attributed to improved safety protocols, redistribution of workload, or changes in radiopharmaceutical handling methods that reduced direct hand exposure.

The hand extremity dose is generally higher than the effective dose due to the hands being in closer proximity to the radiation source during the radiopharmaceutical production process. In contrast, effective doses to organs such as the lens of the eye and lungs are lower because these organs are located farther from the source of radiation.

Based on questionnaire data, Radiopharmacist 2 exhibited a relatively high effective dose but a low hand extremity dose. This is attributed to a shorter duration of exposure (1–2 hours per day) and a sworking posture that maintained some distance from the radiation source. On the other hand, Radiopharmacist 3 had a longer exposure duration (3 hours per day), leading to a higher hand extremity dose compared to their effective dose.

These findings are consistent with the time principle in radiation protection, which states that "the longer the duration of exposure to a radiation source, the greater the dose received by the worker." Similarly, the distance principle is also applicable, emphasizing that "the greater the distance from the radiation source, the lower the radiation dose received.

In the context of biological effects, the effective doses and hand extremity doses received by the three radiopharmacists have so far not reached levels that would result in observable biological

damage. However, subjective symptoms such as excessive fatigue, heaviness in the head, and headaches were reported by the radiopharmacists during radiopharmaceutical production. These symptoms are more likely attributed to heavy workloads and the physical strain associated with wearing heavy protective equipment rather than radiation exposure itself. These findings align with the dose measurements, which remained below the (NBD).

The use of Personal Protective Equipment (PPE) plays a significant role in minimizing radiation exposure, particularly to the hand extremities, lungs, and eyes. Gloves, for instance, serve as a barrier between the skin and radioactive surfaces or substances, making them highly effective in preventing direct contamination that could increase extremity doses. Therefore, the mandatory and consistent use of gloves by all three radiopharmacists during the preparation of radiopharmaceuticals contributed substantially to reducing radiation exposure. These practices are in accordance with responses gathered from the radiopharmacists' questionnaires. Previous researches that supports this research can be seen in Table 4.

Table 4. Previous research with this research

Researchers	Type of Exposure	Main Results
This research	Effective Dose and Extremities	Effective dose < 0.2 mSv; highest limb dose reached 33 mSv (Radiopharmacy 3)
N.A. Firli et al.[14]	Extremities	Extremity dose for Radiopharmaceuticals 14–24 mSv
A. Puspitasari et al . [15]	Effective Dose	Effective dose of Radiopharmacy workers 2.2 mSv
L. Cunha et al. [16]	Extremities	Radiopharmacy worker's extremity dose 38.8 mSv

Based on the results of several previous studies, the reported doses show a fairly wide range of values. From these comparisons, it can be concluded that this study aligns with previously reported research, particularly regarding the high radiation exposure to the extremities of radiopharmaceuticals. However, recent data indicates that the differences in doses are significantly influenced by the application of radiation protection, duration, and the working techniques used.

IV. Conclusion

Based on the data analysis from 2018 to 2023, it can be concluded that the radiation doses received by radiopharmacists varied across different organs. The average effective dose to the lens of the eye was (0,073 ± 0,02) mSv, to the lungs was (0,18 ± 0,04) mSv, and the dose to the hand extremities was significantly higher at (33 ± 30,03) mSv. This difference in dose values can be attributed to variations in work duration and proximity to the radiation source during radiopharmaceutical production. The extremity dose remains within safe limits, in accordance with the recommendations set by the International Commission on Radiological Protection (ICRP) and the Indonesian Nuclear Energy Regulatory Agency (BAPETEN).

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