Radiation Survey of Tc-99m Occupational Exposure in a Tertiary Hospital in the Philippines

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Abstract. Single Photon Emission Computed Tomography (SPECT) imaging procedures consist of the patient receiving a dose of a radiopharmaceutical, making the patient a radioactive source, thereby exposing the staff and adding to their occupational exposure. This study aimed to determine the highest radiation exposure that can be received by the technologist interacting in close proximity with patients undergoing Technetium – 99m imaging studies in the SPECT room of the hospital and evaluate the doses received whether they are within the limits set by the International Commission on Radiation Protection (ICRP). Four sets of measurements were then taken when the Tc – 99m source's setting is either inside or outside the phantom, along with either in between or outside the detector heads. The dose rates were taken at various distances from the source at 0.5 m intervals wherein 5 readings were taken at 5-second intervals. The annual effective dose was then computed for 5 mins of exposure and a daily average of 10 patients. The phantom and collimators – inside the detector heads – significantly attenuated the gamma radiation emitted by the source at $\alpha = 0.01$. The highest dose that could be received by a technologist is directly adjacent from the patient couch, with 24.86 mSv/yr and 27.61 mSv/yr for the right and left side of the patient couch, respectively, pertaining to when the technologist is preparing the patient before the scan. The dose is observed to decrease with the increase in distance to the source in an inverse square trend. The results imply that so long as the technologist keeps the time with the patient at a minimum, that he/she would not exceed the limit.

KEYWORDS: Occupational Exposure, Tc-99m, SPECT

1 INTRODUCTION

Over the past 25 years, low dose ionizing radiation has increasingly become more common due to medical radiation exposure [1]. One source is nuclear medicine and molecular imaging procedures, which has been a highly effective and painless method used in diagnosis, assessment, and treatment of various diseases. Health care providers are able to examine the molecular and physiological processes within the body through the administration of a radioactive tracer to the patient; moreover, nuclear medicine also encompasses radiotherapy, which is administering radiopharmaceuticals for therapeutic purposes [2]. Most studies focus on the radiation exposure of the patient, but little attention is given to the occupational exposure received by the medical staff [3]. In the hospital setting, usually, the occupational exposure is below the 20 mSv/yr limit, however, some interventions, like nuclear medicine, and cumulative exposure may expose personnel to higher doses [4]. A number of publications (BEIR, UNSCEAR, ICRP) have published studies related to nuclear medicine occupational exposure. However, a facility-specific measurement/estimation is still important to address problems commonly encountered in the nuclear medicine flow. Moreover, there are also fewer studies on the estimation of the possible ceiling dose that could be received by the said personnel.

The occupational exposure in nuclear medicine is due to the dose received from the patient injected with the radiotracer during different times in the procedure conducted for the specific patient [5]. In the study conducted by [5], it was noted that "exposure of radiation workers is therefore of particular importance since it represents one of the most important radiobiological models where the probability of response increases with the radiation dose" – the Linear No Threshold theory.

There have been cohort studies determining the effect of protracted exposure to low dose ionizing radiation to radiation workers based only on the radiation dose from records [6]. And there are only a few studies that focused on the occupational radiation dose received by the medical staff based on the dose received during the actual procedure, specifically with regards to Nuclear Medicine procedures [5, 7]. This study aimed to determine the highest radiation exposure that can be received by the technologist interacting in close proximity with patients undergoing Tc-99m imaging studies in the SPECT room of the hospital and evaluate the doses received whether they are within the limits set by the International

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Commission on Radiation Protection (ICRP). This study only used the gamma camera in the Nuclear Medicine department of the hospital. Only Tc-99m MDP was the radioactive source used since the study aims to simulate an imaging scan. A Sensortechnik und Elektronik Pockau GmbH or STEP OD-01 survey meter was utilized for the study which reads the occupational exposure received in μSv/h. The height of measurement was at chest level, specifically 1.2 m, and was kept uniform for all readings taken. Lastly, the source was placed inside and outside the phantom which then acted as a 'point' source for this study, hence actual nuclear medicine patients were not included in this study.

2 METHODOLOGY

2.1 Preparation of imaging room with predetermined measuring points

Prior to the day of radiation measurement, the researcher marked the points discussed below at each of the imaging rooms. Fig. 1 and 2 show a rough floor plan and the planned points where the measurements for occupational dose rates were taken. As seen in the figures, areas with little occupancy, like the walls far from the personnel desk have only two points of measurement, 0 m, and 0.5 m. On the other hand, the wall near the personnel desk has four points of measurement, from 0 m to 1.5 m at 0.5 m – intervals. Lastly, the angles 48° and 31°, with respect to the patient couch when the vial is in between and outside the detector heads, respectively. Measurements at these angles ranged from 0.5 m to 2.5 m at 0.5 m – intervals were taken to determine the dose rates the personnel could have received when he/she is seated at the desk for the course of the scan.

Figure 1: Facility diagram for SPECT imaging room when the Tc-99m vial is in between the detector heads

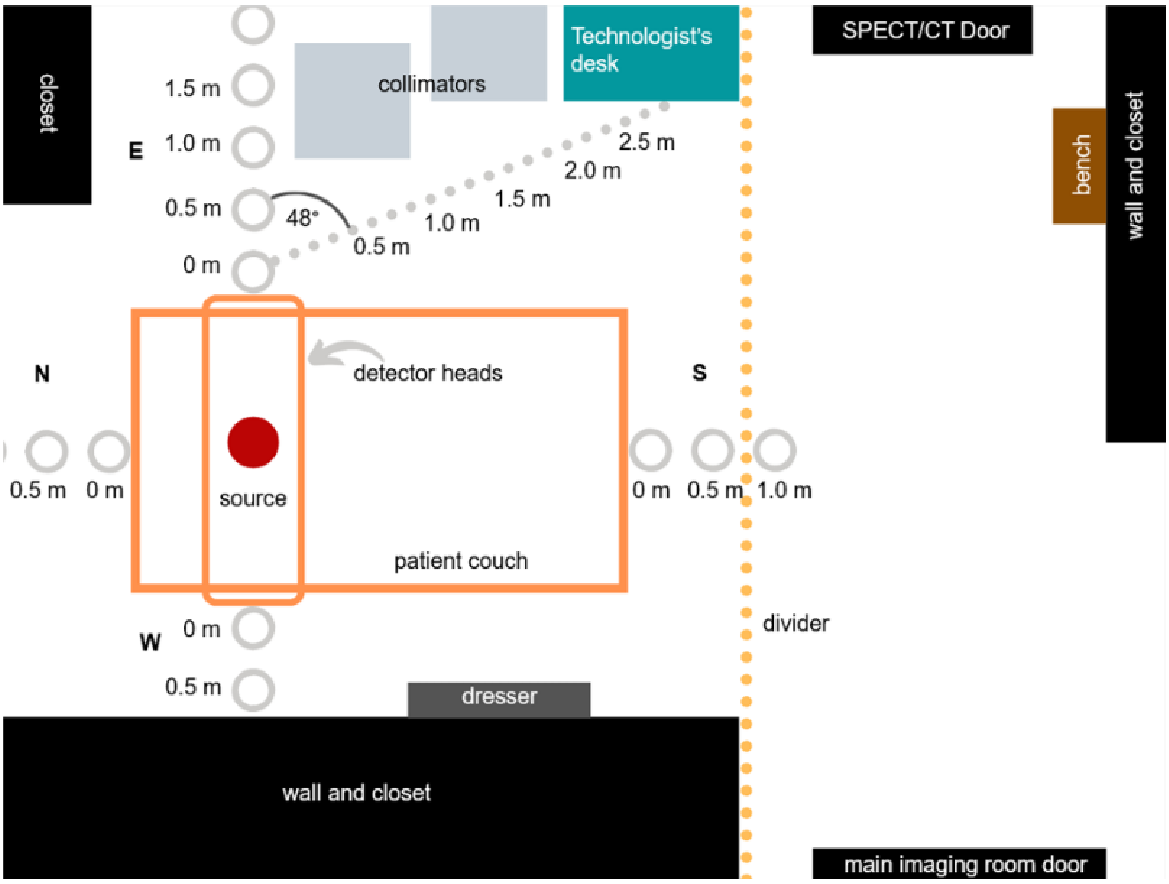

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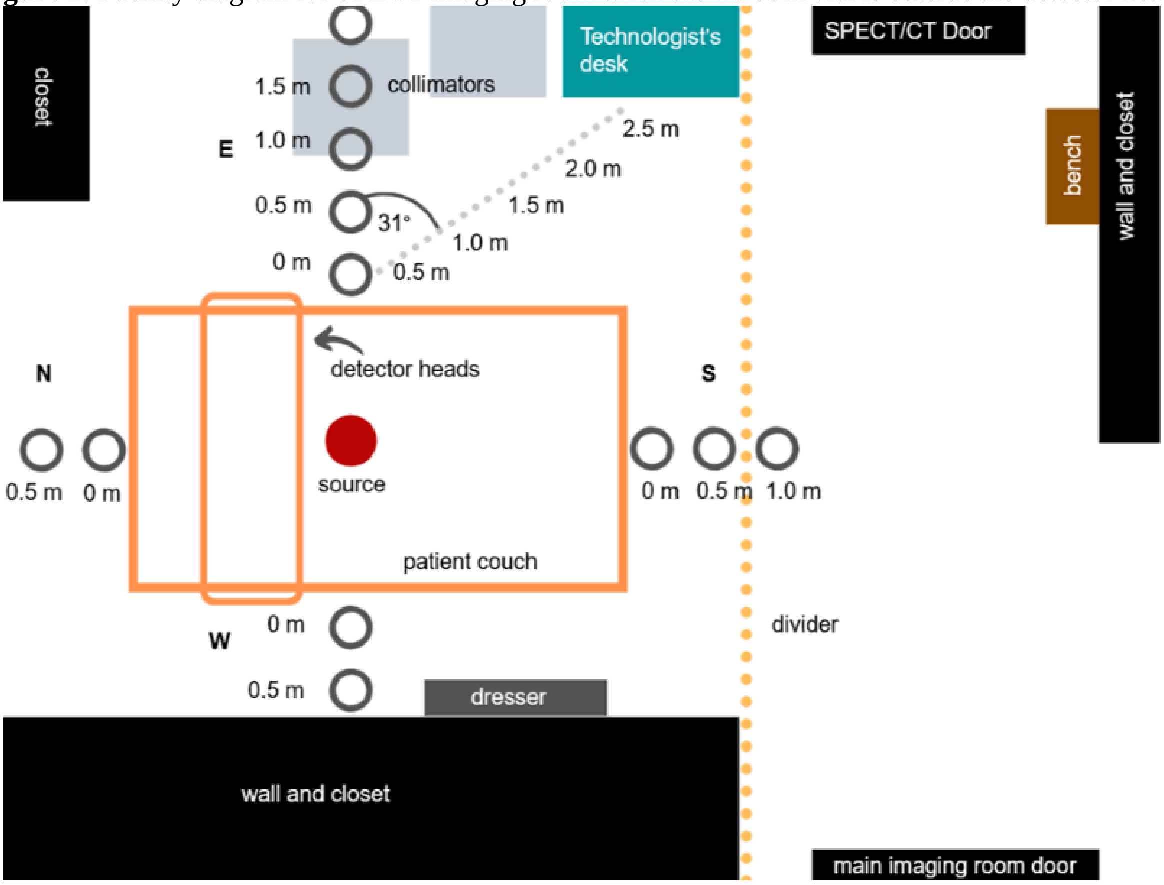
Figure 2: Facility diagram for SPECT imaging room when the Tc-99m vial is outside the detector heads



The background radiation level was then measured prior to the actual data gathering using the STEP OD-01 survey meter. This was subtracted to the measured dose rates to get the ambient occupational dose at the said points, which was then used in the calculation of annual dose estimates to the personnel [8].

Before placing the source to their designated locations on the patient couch of each machine, the initial activity of Tc-99m was taken using a dose calibrator. All the sources used in the study were above 740 MBq (20 mCi), which is the activity usually injected into the nuclear medicine facility's patients, given that the study focused on the worst-case scenarios. Moreover, the adult dose for bone scans ranges from 370 to 1110 MBq (10 to 30 mCi) [9].

2.2 Setup of Tc-99m vial for phantom and collimator setting

For this part of the methodology, there were two placements of the Tc-99m vial: alone and then contained inside the phantom. There were also two settings of the phantom with respect to the patient couch: in between and outside the detector heads. Therefore, there were four settings for the source: (A) inside the phantom, in between the detector heads, (B) inside the phantom, outside the detector heads, (C) outside the phantom, in between the detector heads, and (D) outside the phantom, outside the detector heads. This is to see the different doses that can be received from different source settings: setting A is when the patient is the radioactive source, is undergoing a scan with Tc-99m as the radiopharmaceutical used; setting B: looks into the effect of the collimators on the attenuation of the gamma rays during the scan alone; setting C: looks into the effect of the phantom and its attenuation of the gamma radiation coming from the Tc-99m source when compared to setting A; setting D is the unattenuated radioactive source which served as a basis for how much effective dose is attenuated by the factors mentioned. The radiation levels were then measured at the predetermined points discussed above.

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For each point in the facility, data were obtained at a height of 1.2 m which would be, close to the chest level of an adult given the demographic of the study [10]; moreover, the personal dosimeters are placed at the chest level of the nuclear medicine worker [11]. This was maintained during the study using a camera tripod. Five measurements were made per point as the repetitions for this study at 5-second intervals.

2.3 Dose calculations

The dose rate, D_r, was given by the survey meter, wherein the background radiation, B_r, was subtracted to this measured dose rate. After this, the dose reduction factor, R_t, in Equation (1) was taken for Tc-99m for patient setup before imaging and patient release which accounts for 5 minutes of interaction or exposure time of the technologist.

$$Reduction\ Factor\ (R_t) = 1.44 \times \frac{T_{1/2}}{t}\left[1 - e^{-\lambda t}\right] \qquad (1)$$

Equation (2) was used by [5] in determining the effective dose rate received by the radiation worker during a phase in a nuclear medicine procedure, where t is the exposure time – the time the personnel was in proximity with the source – was recorded during the interaction of the radiation technologist with the patient, and B_r is the background radiation measured. This is the effective dose received by the personnel and from one patient during one imaging session using Tc-99m as a radiotracer.

$$Effective\ Dose = (D_r - B_r) \cdot t \cdot R_t \qquad (2)$$

The annual effective dose was then taken using Equations (3) which was adopted from [8]. This was then compared to the ICRP 103 (2007) regulation for the occupational dose to ionizing radiation, which is 20 mSv per year, averaged over defined periods of five years, with no single year exceeding 50 mSv [12].

$$Annual\ Effective\ Dose = Effective\ Dose\ \cdot P \cdot OD\ \cdot 4\ weeks\ \cdot 12\ months \qquad (3)$$

Where:
P – the average number of patients per day using Tc-99m imaging studies
OD – number of operational days per week

2.4 Statistical Analysis

All data were represented as an average annual effective dose calculated using Equations 1 through 3. One – sample one-tailed student t-test was used to compare the average annual effective dose to 20 mSv/yr for occupational at $\alpha = 0.01$. The statistical analyses were carried out using Microsoft® Excel 365 ProPlus.

3 RESULTS AND DISCUSSION

Data collected at various points around the Tc – 99 m source were used to calculate the annual effective dose at each point for 5 min, for 10 patients per day, for 5 working days per week, and for each of the four source settings as discussed in the previous section. The average annual effective dose for each setting and time factor is then listed in Table 1. The exposure times used was based on the study of [5] for which most of the exposure times of the radiation technologists in their study – which scrutinized the various phases in a nuclear medicine study as to which contributed most to the occupational dose received by the personnel – did not exceed 6 min in most scenarios and was significantly short. Furthermore, according to the technologist interviewed for this study, at most the interaction could take up to 5 minutes if the patient is bedridden and must be adjusted on the patient couch before scanning.

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Table 1: Average annual effective dose in mSv/yr computed for each of the Tc-99m vial settings for 5 minutes of exposure time with the source at various distances around the patient couch

Tc-99m Setting:		Inside phantom In between Detector Heads (A)	Inside Phantom Outside Detector Heads (B)	Outside Phantom In between Detector Heads (C)	Outside phantom Outside Detector Heads (D)
DIRECTION	Distance (m)	Average Annual Effective Dose (mSv/yr)			
E	0	10.61	23.11	15.70	24.86
	0.5	3.52	5.04	4.38	5.14
	1	2.09	2.06	1.84	1.90
	1.5	1.17	1.02	0.72	0.09
ϴ =	0.5	4.39	4.62	5.71	5.87
48° – In between the detector heads	1	1.66	1.87	2.33	2.27
31° – Outside the detector heads	1.5	1.06	1.07	0.72	1.03
	2	0.69	0.58	0.52	0.21
	2.5	0.48	0.35	0.25	0.71
N	0	1.39	0.43	0.94	0.40
	0.5	0.76	0.33	0.66	0.27
W	0	9.84	23.59	12.20	27.61
	0.5	3.08	5.85	3.81	6.00
S	0	0.40	1.03	0.37	1.15
	0.5	0.46	0.54	0.27	0.64
	1 – Open Divider	0.18	0.26	0.09	0.20
	1 – Closed Divider	0.17	0.29	0.10	0.26

At 0 m at point E in Table 1, the average annual effective dose is greater than the ICRP 103 standard of 20 mSv/yr averaged over 5 years but is still less than the 50 mSv maximum per year for the source setting, outside the detector heads. Using a one-sample t-test at $\alpha = 0.01$, the computed effective doses of 23.13 and 24.98 mSv/yr for settings B and D, respectively, are both significantly greater than 20 mSv/yr. At 0 m of point W, of settings C and D, the annual effective dose is also above 20 mSv/yr, however, the radiation technologist rarely stays in that area in general. Moreover, in the actual patient scan, there will be more attenuation due to the patient's body since the radioactive source is spread inside the body. Just by reducing the interaction time by half at the said points, the effective dose per year can be significantly lower than 20 mSv/yr at $\alpha = 0.01$, namely: 11.58 and 12.45 mSv/yr, respectively. Aside from those noted above, the rest of the average annual effective dose listed are significantly lower than 20 mSv/yr at $\alpha = 0.01$. Because time optimization is one of the important methods in radiation protection for nuclear medicine workers, the total time of exposure is crucial in the cumulative amount of radiation, which in turn is what actually counts in calculating the risk for the development of radiation-related conditions. One technique in reducing the dose received is to optimize the time of interaction with the radioactive source, therefore the exposure time has a positive correlation with the dose received by the nuclear medicine staff.

As seen in Table 1, the distance from the source has an inverse relationship with the dose rate measured. Increasing the distance decreases the intensity of the dose received. This is supported by [13], wherein their study expressed the intensity of the source having an inverse square relationship with the distance as seen in Equation (4), which is in line with the study's results. The said equation is valid for point sources, such as the Tc-99m vial used in this study. Therefore, increasing the distance is an immediately effective way of decreasing dose to the nuclear medicine staff.

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$$I_2 = I_1 \left[\frac{d_1}{d_2}\right]^2 \quad (4)$$

I_2 , I_1 intensity at d_2, d_1
d_2, d_1 distance to source

The initial activity per setting is also a contributor to the dose rate read by the survey meter. For settings A, B, C, and D, the initial activities are 892.44, 856.55, 916.12, and 827.32 MBq (24.12, 23.15, 24.76, and 22.36 mCi), respectively. The activity is directly correlated to the dose rate measured.

Compared to this study's literature supporting the methodology done, this is the only study that is not a clinical research that dealt with nuclear medicine. The approach is different in that a phantom was used to simulate an imaging scan using Tc-99m MDP. However, with the absence of a phantom that could simulate the whole body of a person during the source intake, the study used a thyroid phantom instead to make the source less of a point source.

Found in the studies of [5] and [7] some of the time points in which the highest doses were measured were during patient setup and patient release. In the study of [5] at varying distances with a liberal time for measurement, and they found that it was during the patient injection and the patient setup that made up the highest percentages of the total dose received during an individual imaging session, regardless of which nuclear medicine imaging procedure studied in their research, including a Tc-99m MDP bone scan and a Tc-99m sestamibi cardiac stress and rest test. The same was observed by [7], wherein they indicated that patient setup and patient release were two of the phases in which the nuclear medicine technologist received a relatively high dose. Also, the dose during the patient setup was higher due to longer exposure times from the technologist giving out instructions during imaging, hence this study's approach to computing for the annual effective dose at 5 minutes as per recommended by the technologist of the hospital [5, 7].

One of the major points discussed in the study was that time had a direct relationship with the annual effective dose while distance had an indirect relationship with it. According to [13], one of the determinants of radiation dose aside from shielding was time and distance. Shortening the exposure time would effectively reduce the radiation worker's occupational dose. Another determinant is the distance, and as mentioned above, the distance has an inverse-square relationship with intensity as illustrated in Equation (4).

Another observation made from the results of the study is that the phantoms have a much lower annual effective dose than the dose without the phantom. This is explained by [7] wherein they measured the patient-to-staff dose rate coefficient in their study. They found that the dose rates were significantly lower given that the patients are responsible for the photon absorption and self-attenuation, and accounts for the 48% reduction of the dose as compared to a point source. Given that the Phantocube® used for this study is made up of PMMA/acrylic and represents the human tissue, [7] explanation is accurate for this study's observation. Although the Phantocube® can simulate the average attenuation of human tissue, it would be more accurate if future studies would use anthropomorphic phantom simulating variation in human tissue and its shape.

In the paper of [13] titled "Strategies for Minimizing Occupational Radiation Exposure" said that since the cumulative long-term dose the medical staff might be exposed to requires careful monitoring as well as the use of protective equipment and techniques, the target annual effective dose should be kept below 10 mSv/yr. During the actual clinical practice, the activity prior to the scan might be lower than 740 MBq (20 mCi), therefore the results in this study are more than what might actually be received during the actual imaging procedure [13]. The results in this study may give an overestimation of the dose that can be actually received by the technologist in an actual clinical setting, given that aside from the initial activity of each setting being more than 740 MBq, there is also no tracer retention from the patient that is used in this study.

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Just like the study of [14], despite having significantly higher dose rates than the ICRP limit for some under the 5-minute exposure time, it would still be unlikely that a single operator would perform all 10 patients' bone scans for every workday, spending all of the 5 minutes of exposure time at the patient's side for the patient setup and patient release after the scan has completed. Therefore, the SPECT room and the stages involving the technologist under the bone scan imaging session of the hospital are acceptable in terms of radiation dose [14].

4 CONCLUSION

The highest doses were noticed when the source was outside the detector heads. The collimators inside the detector heads were observed to attenuate more of the radiation dose than the phantom. Distance and time were essential in reducing the radiation dose that was measured. Increasing the distance while lessening the exposure time gives the personnel a much lesser dose. And lastly, the activity of the source was also a factor in the dose that would be received by the radiation worker; reducing the activity would result in a decreased dose received by the personnel. The data in this study ensures that so long as the technologist keeps his/her time with the patient at a minimum, especially during patient setup, that he/she would not exceed the 20 mSv/yr.

The results can be used as a basis in designing a SPECT imaging room facility in other tertiary or public hospitals and in creating their radiation protection protocols. Lastly, the data can be used in simulation studies on how a phantom absorbs gamma rays from Technetium – 99m and compare them to other studies that use patients as their subjects in obtaining occupational doses, and use such results to design a phantom specific for bone scans for the use of future nuclear medicine researches.

If other researchers would choose to replicate this study, recommendations include measurement at different heights and getting the dose at the extremities like the fingers of the radiation technologists handling the source during the patient injection. The cumulative dose of one radiation technologist performing the whole bone scan procedure for one patient could also be included in future studies, so an accurate estimation of the annual effective dose of a radiation technologist working on a bone scan may be found. Lastly, the researcher suggests using patients instead of phantoms in the next studies for more accuracy, given that tracer kinetics and retention are also factors in nuclear medicine imaging studies.

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