OCCUPATIONAL RISK ASSESSMENT AND DETERMINATION OF THE NEED FOR INTERNAL EXPOSURE MONITORING OF RADIATION WORKERS AT INSTITUT KANSER NEGARA

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ABSTRACT: Ionizing radiation exposure is divided into two categories that are external and internal exposure. The annual dose limit for the radiation workers is 20 mSv consists of internal and external exposure. Radiation workers in nuclear medicine are not only exposed to ionizing radiation externally but also internally. The widespread use of unsealed radioactive sources in nuclear medicine poses a potential for internal exposure of radiation workers in the field of nuclear medicine. External radiation monitoring using a dosimeter has been developed in Malaysia since 1985. However, assessment of the need for individual internal dose monitoring has not yet been developed in Malaysia. The purpose of this study is to assess occupational risk and to compare determination value of the need individual internal exposure monitoring of radiation workers in nuclear medicine department at Institut Kanser Negara (IKN). This study involves radiation workers at IKN by observation, survey forms and calculation of decision factor of the need for internal exposure monitoring based on IAEA dose criteria. The results show that the highest risk is during the use of radiopharmaceuticals for diagnosis and treatment of disease through inhalation process for lung scan as well as the preparation and oral administration to patient, especially radiopharmaceutical containing I-131 and I-124. In addition, a total of 12 out of 16 workers need internal monitoring involving biochemists, pharmacists, and technologists while physicist do not require internal monitoring. Overall, data obtained from this study is the first step in establishing a comprehensive internal exposure framework and promote to more effective and manageable radiation exposure monitoring.

KEYWORDS: *Internal exposure, decision factor, occupational risk, nuclear medicine*

1.0 INTRODUCTION

Humans can be exposed to external radiation or radionuclides that enter the body (internal exposure) [36]. The basic concept of internal exposure is when radioactive materials enter the body through several main routes, through respiration and wounds [34]. The method used to measure an individual's internal exposure is by directly measuring the radioactivity in the whole body or specific organs by measuring radioactivity through urine and fecal samples [10]. Radiation workers at nuclear medicine department are not only exposed to external ionizing radiation but also internal exposure. Nuclear medicine involves the use of unsealed radioactive materials for diagnosis and treatment of diseases, which can pose significant risks to radiation workers if not properly handled. The work routines of nuclear medicine workers cause them to be exposed to higher radiation doses when compared to other healthcare workers [37], [38]. The assessment of external radiation exposure using dosimeters has been developed in Malaysia since 1985. Currently, radiation worker exposure monitoring in Malaysia is done externally using Optically Stimulated Luminescence Dosimeters (OSLD). Previous studies on internal dosimetry using whole-body gamma counter on nuclear medicine workers from 2 nuclear medicine centres demonstrated no internal exposure found for all monitored radiation workers [1],[39] However, further research is needed to determine if this lack of internal exposure is consistent across all nuclear medicine facilities. Collecting data on the requirements for monitoring the internal dose of radiation workers is the initial step in developing a comprehensive internal exposure monitoring program for radiation workers. The data obtained are precious to authorities in implementing regulations related to routine internal dose exposure monitoring and indirectly assisting employers in ensuring workers' safety, health, and well-being in the workplace.

2.0 METHODOLOGIES

2.1 Sampling location

This study was conducted at the Nuclear Medicine Department of the Institut Kanser Negara (IKN), located in the Federal Territory of Putrajaya, adjacent to Putrajaya Hospital. This department provides diagnostic, therapeutic, Positron Emission Tomography-Computed Tomography (PET-CT) scanning, and cyclotron services. The department began its operations on October 14, 2013, offering radioiodine treatment for hyperthyroid patients and bone scans for external patients. IKN is categorized by the Ministry of Health Malaysia as Level 1 (Diagnostic, External Patient Therapy) and Internal Patient Therapy IKN [21].

2.2 Risk Assessment

The risk assessment used 2 factors in the risk analysis, which are the likelihood or probability of an event occurring and the severity when that event occurs as shown in equation (1). The likelihood is estimated based on work experience, analysis, or measurements, and the range of likelihood scale varies from most likely to inconceivable as shown in Table 1 [9]. The severity level is based on the degree of severity concerning individual health, the environment, or property, and the severity range varies from negligible to extreme as shown in Table 2 [32]. Risk analysis is performed through a qualitative method by expressing the results in a risk matrix as shown in Figure 1, determining the risk level within a range from low to high. The relative risk value is used to prioritize actions that need to be taken to effectively manage workplace hazards. Hazards estimated as "High Risk" require immediate action to mitigate risks to life safety and/or the environment. Risk calculation using the following equation [9]:

$$\text{Relative Risk} = L \times S \qquad \ldots (1)$$

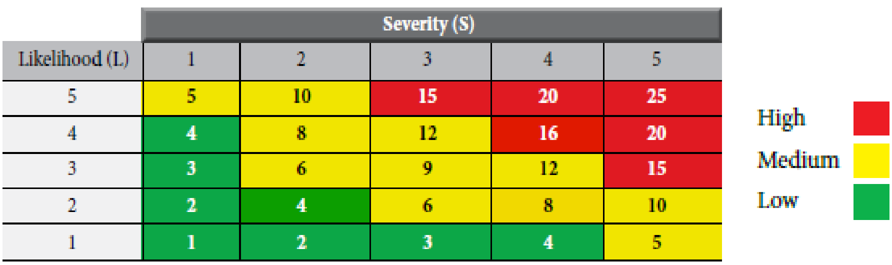
Where,
L = Likelihood of an event
S = Severity of an event

Table 1: Likelihood rating

LIKELIHOOD (L)	EXAMPLE	RATING
Most likely	The most likely result of the hazard / event being realized	5
Possible	Has a good chance of occurring and is not unusual	4
Conceivable	Might be occur at some time in future	3
Remote	Has not been known to occur after many years	2
Inconceivable	Is practically impossible and has never occurred	1

Table 2: Severity rating

SEVERITY (S)	EXAMPLE	RATING
Extreme	Fatal / dose > deterministic threshold	5
Major	Major Injury/ dose > legal limits / reportable to HSE	4
Moderate	Three-day injury / dose less than legal limits/ could exceed investigation levels	3
Minor	Minor injury / dose below investigation levels	2
Negligible	Slight chance injury / background radiation dose	1



	Severity (S)				
Likelihood (L)	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Figure 1: Risk matrix [9]

2.3 Survey Analysis

This study focuses on the factors of knowledge (K), attitudes (A), and practices (P). The study also involves a survey of radiation workers consists of 13 questions with a focus on demographic surveys such as gender, educational background, and work-related information while 16 questions using IAEA documents on safety culture surveys for license holders under the category of attitudes and behaviors [16]. The statistical analysis for survey testing is conducted using SPSS Cronbach's Alpha analysis. This analysis is used to measure internal consistency on a scale of 0 to 1 to assess the reliability of the conducted study [31]. A high reliability value indicates that the study's constructs have acceptable reliability [30] as shown in Table 3. Typically, this Cronbach's Alpha analysis is tested with a small number of respondents before being applied in a comprehensive study.

Table 3: Cronbach's Alpha score and reliability level [13]

CRONBACH'S ALPHA SCORE	RELIABILITY LEVEL
> 0.9	Excellent
> 0.8	Good
> 0.7	Acceptable
> 0.6	Questionable
> 0.5	Poor
< 0.5	Unacceptable

A descriptive analysis is used to analyze the obtained data, where frequency analysis (mode) is employed to determine demographic information and responses regarding safety in terms of worker behavior.

2.4 Determination of Internal Exposure Requirements

A total of 16 radiation workers who work with unsealed radioactive materials are considered in this determination assessment. This method is used to determine whether radiation workers at the Nuclear Medicine Department of IKN need to undergo internal exposure dose monitoring based on the calculation of dose criteria issued by the IAEA [15] as shown in Equation 2.

$$d_{j\_scenario} = \frac{A_j e(g)_{j,inh}\ f_{fs}\ f_{hs}\ f_{ps}}{0.001} \qquad \dots (2)$$

d_j	=	decision factor based on operation and radionuclide
A_j	=	cumulative activity of radionuclide *j* present in the workplace over the course of the year
$e(g)_{j.inh}$	=	dose coefficient (Sv/Bq) for inhalation of radionuclide, *j*
f_{fs}	=	physical form safety factor based on the physical and chemical properties of the material being handled
f_{hs}	=	handling safety factor
f_{ps}	=	protection safety factor
0.001	=	conversion factor from Sv to mSv

The calculation of the final decision factor for each radiation worker is sum of all decision factor, *dj*, obtained for each radiation worker as shown in Equation 3.

$$D = \sum_{j} d_j \quad \dots (3)$$

D = final decision factor
d_j = decision factor based on operation and radionuclide

Calculations involving more than one type of radionuclide present in the workplace area, the determination to undergo individual internal exposure monitoring is based on the following criteria [15]:

i. For all radionuclides where the value of $d_j \geq 1$, radiation workers must undergo internal exposure monitoring.
ii. When the value of $D \geq 1$ and the value of $dj \geq 0.3$, radiation workers must undergo internal exposure monitoring.
iii. Internal exposure monitoring is not required if the value of dj is less than 0.1.

3.0 RESULTS AND DISCUSSION

3.1 Risk Assessment

This risk assessment is conducted through observation during the work processes at IKN, starting from the production process to the use of radiopharmaceuticals. Work scenarios are divided into two (2) categories: (i) the production and preparation of radiopharmaceuticals and (ii) the use of radiopharmaceuticals for the diagnosis and treatment of diseases as shown in Table 4 and Table 5. These work scenario categories are carried out based on different scopes of work to facilitate the identification of high-risk levels that need to be prioritized according to more specific work scenarios.

Table 4 : Scenario 1 - Production and preparation of radiopharmaceuticals

1. Identifying Hazards				2. Risk Analysis	
No.	**Work Activity**	**Hazards**	**Potential Consequence**	**Risk Value**	**Risk Level**
1	Distributing radiopharmaceutical vials automatically according to customer requirements	Exposure to external ionizing radiation	Short-term or long-term health effects	10	Moderate
		Spillage or vial breakage	Contamination with radioactive material	12	Moderate
		Ergonomics - object handling, fatigue, pressure, or workplace design errors	Muscle strain/backache	4	Low
2	Transferring containers containing radiopharmaceuticals from an automated machine to lead syringe	Exposure to external ionizing radiation	Short-term or long-term health effects	10	Moderate
		Syringe containing radiopharmaceuticals falls	Radioactive material leakage	6	Moderate
		Ergonomics - object handling, fatigue, pressure, or workplace design errors	Muscle strain/backache	4	Low
		Automated machine malfunctions and requires manual handling	Increased risk of hand extremity dosage	6	Moderate
3	Transferring vials to a dose calibrator for radiopharmaceutical activity measurement	Exposure to external ionizing radiation	Short-term or long-term health effects	10	Moderate
		Contamination on vials	Contamination with radioactive material	12	Moderate
		Spillage or vial breakage	Contamination with radioactive material	12	Moderate
		Ergonomics - object handling, fatigue, pressure, or workplace design errors	Muscle strain/backache	8	Moderate
4	Transportation of	Spillage or vial	Contamination	12	Moderate

	containers containing radiopharmaceuticals in lead containers using a trolley	breakage	with radioactive material		
		Ergonomics - object handling, fatigue, pressure, or workplace design errors	Muscle strain/backache	8	Moderate
5	Quality control - swab test for each vial before transportation process	Exposure to external ionizing radiation	Short-term or long-term health effects	10	Moderate
		Contamination on vials	Contamination with radioactive material	12	Moderate
		Ergonomics - object handling, fatigue, pressure, or workplace design errors	Muscle strain/backache	4	Low
6	Setting for radiopharmaceutical production	Gas usage	Gas leakage	10	Moderate
		Employee work rotation	Self-safety may be compromised	12	Moderate

Based on Table 4, almost all work activities and hazards are at a moderate level because most of the processes involved in the production and preparation of radiopharmaceuticals use automated systems. Adherence to existing regulations and Good Manufacturing Practice (GMP) procedures could further reduce the risk of existing hazards. The IKN facilities also undergo audits [19] and regulatory authorities to ensure that the work processes are in a controlled order. Other factors taken into consideration when determining the moderate risk level include the use of ionizing radiation detectors with warning systems, the use of contamination survey meters, the use of personal protective equipment (PPE) while performing tasks and also failure of quality control of radiopharmaceuticals products where repeated production processes increase the radiation exposure to the workers. Low-risk levels of ergonomic hazards refer to the use of automated equipment that reduces muscle strain and fatigue during the handling of radiopharmaceuticals. There are 2 work activities that have moderate risk levels for physical activities, that are the transport activity by carrying radiopharmaceuticals in lead containers using trolleys and the transfer of vials to the dosimetry calibrator. The risk levels are based on the handling of the lead containers that are lifted and placed on the calibration counter and trolleys. This ergonomic hazard can give rise to muscle tension or back pain [28]. The maximum weight that can be handled at foot level is 5 to 10 kg [33]. However, the lead containers used at IKN weigh as much as 14 kg, and this can directly have a long-term impact on the body posture of workers. Among the risk controls that can be implemented include using a trolley at the same height as the swab test counter and reducing repetitive operations through job rotation.

Table 5: Scenario 2 - The use of radiopharmaceuticals for diagnosis and treatment of diseases

1. Identifying Hazards				**2. Risk Analysis**	
No.	**Work Activity**	**Hazards**	**Potential Consequence**	**Risk Value**	**Risk Level**
1	Administration of doses via injection to patients	Exposure to ionizing radiation or radioactive substances	Short-term or long-term health effects	10	Moderate
		Dispersion of radioactive materials in the air and injection room area	Potential for external and internal exposure	6	Moderate
		Patients not following given instructions such as pulling their arm during injection	Contamination of radioactive substances from patient tubes or blood during injection	12	Moderate
		Ergonomics - object handling, fatigue, pressure, or workplace design errors	Muscle strain/backache	8	Moderate
2	Administration of doses via inhalation for lung scans	Exposure to ionizing radiation or radioactive substances	Short-term or long-term health effects	15	High
		Dispersion of radioactive materials in the air and common examination room areas	Potential for external and internal exposure	15	High
		Patients not	Contamination	15	High

		following given instructions such as pulling the mask cover during vapor release	of radioactive substances in the air		
		Ergonomics - object handling, fatigue, pressure, or workplace design errors	Muscle strain/backache	3	Low
3	Preparation and oral administration of doses to patients	Exposure to ionizing radiation or radioactive substances	Short-term or long-term health effects	15	High
		Spillage or leakage in containers containing radioactive liquids or solids	Contamination of radioactive substances in the room environment	15	High
		Patients vomiting after swallowing radioiodine	Contamination of radioactive substances in the room environment	9	Moderate
		Ergonomics - object handling, fatigue, pressure, or workplace design errors	Muscle strain/backache	8	Moderate

According to Table 5, activities such as the administration of doses via inhalation for lung scans and the preparation and administration of oral doses to patients have a high level of risk, particularly for exposure to ionizing radiation and when undesirable events occur. Both processes are carried out in open rooms and can potentially expose workers to internal exposure. The administration of injections to patients is also carried out in open rooms but the risk is at a moderate level due to the radiopharmaceuticals being placed in a lead-shielded syringe. Workers carrying out the injection process in nuclear medicine facilities should go through precaution procedures to prevent exposure [20]. Injection procedures also reduce the risk of internal exposure as the radiopharmaceutical liquid is injected directly into the tube into the patient's blood vessels. Spillage is considered as one of the hazards where there is a possibility of this happening due to inadequate control of radioactive material sources as well as from the reflex of patients such as withdrawing the arm during injections and removing the face mask during radiopharmaceuticals administration due to discomfort. The risk level for injection spillage is moderate where the radioactivity for each injection is less than 100 mCi (major spill category) [21] while the risk level for oral radio-pharmaceuticals administration spillage is high due to the radioactivity for each sample is exceeding 1 mCi and is categorised as a major spill if occurs [21]. Other than that, the vaporized and oral administration activity using volatile material such as radioiodine and technetium.

3.2 Survey Analysis

3.2.1 Respondent Demography

Table 6 shows the respondent demography based on the data received and majority of the respondents are male aged between 31 to 40 years old.

Table 6 :Analysis of the demographic of survey respondents

Demography	Total	Percentage
Gender		
Male	9	56
Female	7	44
Age		
31-40 years old	13	81
41-50 years old	3	19

Gender and age is one of the aspect that are normally discussed when comes to occupational risk. Female possible to have high risk compared to male in terms of death by receiving same amount dose of ionizing radiation [26], [27]. Relatively female have more reproductive cells compared to male, thus female exposed much more hazard of ionizing radiation due to the reproductive cells radiosensitivity [25]. The International Commission on Radiological Protection (ICRP) also identified differences in radiation risk between males and females, even though ICRP follows a gender-neutral radiation protection policy. In 1990, the ICRP decided that there was no need to differentiate between genders when it comes to controlling occupational radiation exposure. In 2007, the ICRP released specific cancer risk data by gender as a reference, but it is not applicable for general radiation protection purposes [18]. Radiation protection should prioritize workers who are confirmed to be pregnant, and fetuses should receive radiation protection similar to the general public [18]. Individuals of older age are sensitive to ionizing radiation, where the ability to repair or replace damaged cells due to ionizing radiation decreases [22]. Various other factors also need to be considered when examining the relationship between gender and age with occupational risk, such as a family history of cancer and the individual's lifestyle.

3.2.2 Respondent Education Background and Knowledge

The level of education and work experience is one of the elements considered to assess knowledge about the job to be performed. Theoretical and practical exposure is provided during higher education, while work experience is more related to individual experience. According to Table 7, the majority of respondents have education at the degree level, more than 10 years of work experience, and have attended at least one (1) radiation safety and protection course held internally within the past year. The survey results also indicate that all respondents with a diploma level of education are in the role of technologists, while other positions require either a degree or master's level of education.

Table 7 Analysis of educational level and work experience

Item	Total	Percentage
Education Level		
Diploma	5	31
Degree	7	44
Masters/PhD	4	25
Work experience		
1-3 years	1	6
3-6 years	1	6
6-9 years	5	32
More than 10 years	9	56
Number of trainings on radiation safety and protection in a year		
1 course	12	74
2 course	2	13
More than 3 course	2	13
Level of training		
In-house	16	100

The study on knowledge and awareness of radiation protection indicates a correlation between work experience (years) and awareness of the hazards of radiation effects [24], [29]. However, specific research through surveys and observations needs to be conducted to assess the knowledge gap regarding radiation protection among IKN workers.

3.2.3 Workers' Behavioral Practices

Based on Figure 2, the majority of workers express positive opinions (agree and strongly agree) regarding the actions taken. However, a minority of workers also provide neutral opinions on the following items:

i. I put in extra effort to improve the safety of the workplace
ii. I voluntarily carry out tasks or activities that help improve safety
iii. I use all the necessary safety equipment to do my job

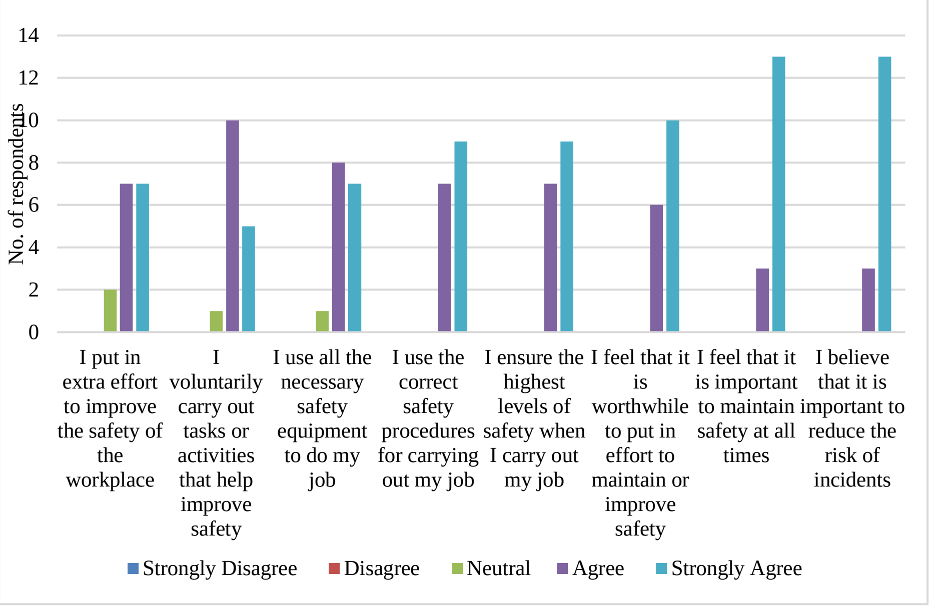


Figure 2: Survey findings on workers' opinions regarding safety aspects

Based on the items mentioned above, respondents who have more experience, specifically 6-9 years and more than 10 years, tend to choose the neutral option. Factors influencing this response may include the individual's perspective or experience, and the selection of a neutral response does not lean towards agreeing or disagreeing. Respondents who choose the neutral option can be divided into 2 groups: those who genuinely hold a neutral opinion on the statement and those who lack sufficient knowledge or opinion on the statement [23]. This information does not significantly impact the study findings as it represents a minority opinion. In the medical field, ionizing radiation has become an unavoidable tool for the diagnosis and treatment of diseases, along its increased usage has led to both patients and healthcare professionals being exposed to radiation [12].Worker's awareness of the importance of safety aspects in the workplace helps reduce the likelihood of accidents occurring in the workplace [4].

Based on Figure 3, the frequency of workers' behaviours is also considered in this study as an added value to risk assessment. The majority of workers respond with often and very often, indicating a high awareness of safety among colleagues.

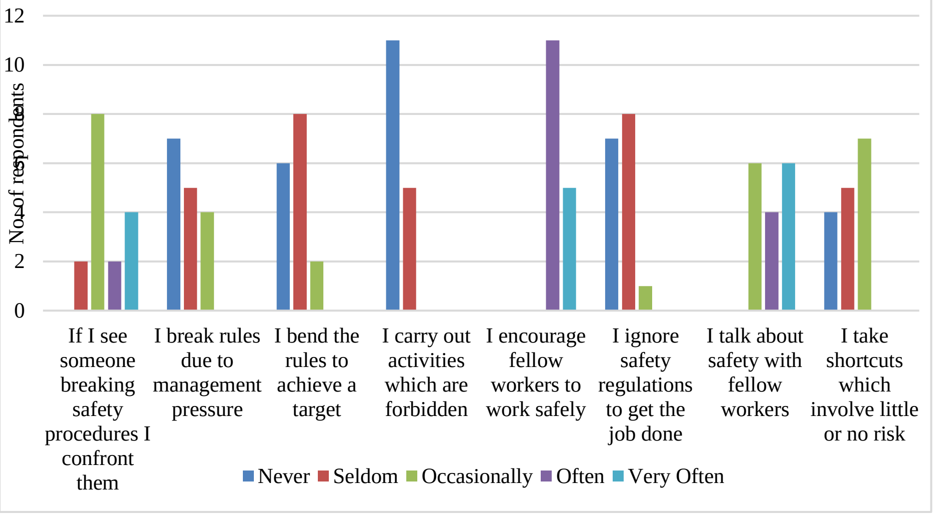


Figure 3: Survey findings on worker's behaviour

However, there are some points to emphasize, as there is a majority response indicating a frequency scale of seldom and occasionally for the following items:

i. If I see someone breaking safety procedures, I confront them
ii. I bend the rules to achieve a target

iii. I ignore safety regulations to get the job done
iv. I take shortcuts which involve little or no risk

Human factor is frequently tends to be one of the causes that can lead to an accidents in the workplace. The concept of human error is often associated solely with individual mistakes, but this issue also needs to be viewed from a new perspective, where individual assessments and actions are based on circumstances [7]. Workers in the healthcare sector provide critical services not only to identify problems but also to help identify the issue behind the problems, whether intentionally or unintentionally [14]. Work procedures need to be updated from time to time, considering the suitability of the work to reduce risks in the workplace.

In addition, there are occasionally and seldom responses, although they are not the majority response, for the following items:

i. I bend the rules to achieve a target

Among the things that can be associated with management pressure and regulatory violations are the pursuit of performance goals, attempts to save one's job and that of others, supervisory pressure, and requests from individuals who support or invest in the organization [11]. Management in any organization is a crucial element where employers in every organization should be responsible for ensuring the safety of every worker, especially when they carrying out their task. It is one of the general obligations of employers under the Occupational Safety and Health Act 1994 (Act 514), where employers are required to provide a safe workplace for their employees and others involved [9]. Therefore, employees and management need to apply the concept of good communication and continuously aim to improve the Occupational Safety and Health Management System (OSHMS). Management needs to design safety behaviour programs that facilitate the safety communication process, safety systems, and training. Employees who perceive that safety communication, safety systems, and training are positive or good are more likely to comply with safety regulations and procedures and voluntarily participate in safety activities [2].

3.3 Determination of Necessity of Internal Exposure

The majority of respondents in this study are pharmacists, while the minority are others, namely biochemist as shown in Table 8. All these workers are involved in various production processes leading to the use of radiopharmaceuticals.

Table 8: List of occupation

Occupation	Total
Pharmacist	5
Physicist	4
Technologist	5
Others (Biochemist)	2

Based on Table 9, there are 12 workers including biochemists, pharmacists, and technologists, who have final decision values, D, exceeding 1 mSv means require individual internal exposure monitoring while four workers including physicists have D values below 1 mSv that do not require individual internal exposure monitoring. Only 1 worker, a pharmacist does not require internal exposure monitoring for the Ga-68 radionuclide due to the assessment value, D, for this radionuclide below 0.1 mSv. In general, 75% of the workers involved in this study need to undergo individual internal exposure monitoring. Similar studies conducted showed that 71.9% and 100% of the workers in their studies [5], [35], respectively, needed individual internal exposure monitoring.

Table 9 Determination value of the necessity among IKN workers

Worker	Radionuclide	Operation	d_j	D
Worker 1 (Biochemist)	F-18	Quality control	1.72	1.72
Worker 2 (Biochemist)	F-18	Quality control	2.03	2.03
Worker 3 (Pharmacist)	Tc-99m	Dose fractionation (syringe)	0.25	27172.30
	Tc-99m	Ventilation study	0.33	
	Tc-99m	Dose administration (injection)	0.30	
	I-131	Dose fractionation (syringe)	266.60	
	I-131	Dose administration (oral)	26901.16	
	I-124	Dose fractionation (syringe)	0.16	
	Lu-177	Dose fractionation (syringe)	3.11	

	Y-90	Dose fractionation	0.38	
Worker 4 (Pharmacist)	F-18	Dose fractionation (vial)	7.61	12.29
	F-18	Dose fractionation (syringe)	1.65	
	Ga-68	Dose fractionation (vial)	0.06	
	Ga-68	Dose fractionation (syringe)	0.06	
	F-18	Dose administration (injection)	2.91	
Worker 5 (Pharmacist)	I-131	Dose fractionation (syringe)	743.73	76685.46
	I-131	Dose administration (oral)	75240.00	
	Tc-99m	Dose fractionation (syringe)	0.34	
	Tc-99m	Ventilation study	0.31	
	I-124	Dose fractionation (syringe)	0.10	
	I-124	Dose administration (oral)	9.97	
	Lu-177	Dose fractionation (syringe)	7.81	
	Lu-177	Dose administration (injection)	683.21	
Worker 6 (Pharmacist)	F-18	Dose fractionation (vial)	6.25	1695.07
	F-18	Dose fractionation (syringe)	0.24	
	Ga-68	Dose fractionation (vial)	0.27	
	Ga-68	Dose fractionation (syringe)	0.04	
	I-131	Dose fractionation (syringe)	14.05	
	I-131	Dose administration (oral)	1674.21	
Worker 7 (Pharmacist)	I-131	Dose fractionation (syringe)	601.19	59888.86
	I-131	Dose administration (oral)	59280.34	
	Tc-99m	Dose fractionation (syringe)	0.33	
	Tc-99m	Ventilation study	0.14	
	Tc-99m	Dose administration (injection)	0.26	
	I-124	Dose administration (oral)	6.61	
Worker 8 (Technologist)	Tc-99m	Dose fractionation (syringe)	0.01	97.30
	Tc-99m	Dose administration (injection)	9.25	
	I-131	Dose administration (oral)	88.04	
Worker 9 (Technologist)	Tc-99m	Dose fractionation (syringe)	0.03	164.16
	Tc-99m	Dose administration (injection)	43.52	
	Tc-99m	Ventilation study	0.30	
	I-131	Dose administration (oral)	119.67	
	F-18	Dose administration (injection)	0.64	
Worker 10 (Technologist)	Tc-99m	Dose fractionation (syringe)	0.04	106.93
	Tc-99m	Dose administration (injection)	19.74	
	Tc-99m	Ventilation study	0.31	
	I-131	Dose administration (oral)	8.58	
	Lu-177	Dose administration (injection)	78.27	
Worker 11 (Technologist)	Tc-99m	Dose fractionation (syringe)	0.02	49.67
	Tc-99m	Dose administration (injection)	12.40	
	Y-90	Dose administration (injection)	37.25	
Worker 12 (Technologist)	Tc-99m	Dose fractionation (syringe)	0.01	94.37
	Tc-99m	Dose administration (injection)	14.26	
	Tc-99m	Ventilation study	0.48	
	F-18	Dose administration (injection)	1.51	
	Ga-68	Dose administration (injection)	0.41	
	Lu-177	Dose administration (injection)	77.72	

Worker 13 (Physicist)	Tc-99m	Quality assurance	0.00	0.00
	F-18	Quality assurance (swab test)	0.00	
Worker 14 (Physicist)	Tc-99m	Quality assurance	0.00	0.00
	F-18	Quality assurance (swab test)	0.00	
Worker 15 (Physicist)	F-18	Quality assurance	0.00	0.14
	F-18	Quality assurance (swab test)	0.00	
	Tc-99m	Dose administration (injection)	0.14	
Worker 16 (Physicist)	Tc-99m	Quality assurance	0.00	0.00
	F-18	Quality assurance (swab test)	0.00	

The decision factors are based on variables such as inhalation dose coefficient for each radionuclide, the type of operation, cumulative annual radioactivity (mCi), and the protective measures used during operations. Pharmacists 3, 5, 6, and 7 have very high values of D from the iodine radiopharmaceutical source through the dose fractionation in the glovebox and the administration of I-131 doses orally in open areas. Although the determination values indicate values exceeding expectations, it still provides an indication that the potential for internal exposure is likely, and these workers require routine individual internal monitoring. The findings of this study are supported by a similar study where individual internal exposure monitoring should be included in the radiation protection plan for workers handling I-131 due to its high risk [6]. The same study has also been carried out in Chile and China, where workers handling I-131 and Tc-99m need to undergo individual internal exposure monitoring [3],[35]. Biochemists have the lowest decision factor. Biochemist also involved in RIA techniques [21], where this process only involves only external radiation exposure. The findings of this study also indicate that all physicist do not require individual internal exposure monitoring as they are not directly involved in the production, preparation, or administration of radiopharmaceuticals. Physicist involved with checking for any contamination on vials before it sent to customers or used by IKN. However, physicist also have the risk of individual internal exposure when there is any contamination during the calibration test. Additionally, the involvement of physicist in radiological emergency response and decontamination activities [17] at IKN could pose a risk of individual internal exposure. Therefore, physicist need to undergo immediate individual internal exposure monitoring when deemed necessary. Individual internal exposure monitoring is conducted through direct measurements using a thyroid counter (for workers handling I-131) and a whole-body counter for radionuclides emitting gamma radiation [1]. Indirect bioassay measurements using urine samples can also assess internal exposure with low activity. The results of individual internal exposure monitoring need to be recorded in the medical record book (Section B) LPTA/BM/5 [8]. The total external and internal exposure should not exceed 20 mSv per year for these workers.

4.0 CONCLUSIONS

High risk assessments occur during the use of radiopharmaceuticals for the diagnosis and treatment of diseases, especially in the administration of doses through vapor or inhalation for lung scans, as well as the preparation and oral administration of doses to patients, particularly for radiopharmaceuticals containing I-131 and I-124. The behavioral practices survey shows that employees at IKN are aware of safety consciousness in the workplace. However, there are occasionally and seldom responses to the rule violations, lapses in vigilance, and the choice of shortcuts involving minimal risks. Initiatives to improve work procedures in a simpler way may help reduce the likelihood of safety rule violations and work-related risks. The research findings indicating that a total of 12 workers, consisting of biochemists, pharmacists and technologists require individual internal exposure monitoring, while 4 physicist ar exempt. This situation is due to the varying risk levels associated with their roles and potential exposure to hazardous materials. Targeting monitoring efforts towards these at-risk individuals is crucial for effective occupational health and safety management.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ETHICAL APPROVAL

The Malaysian Research Ethics Committee and National Medical Research Registry approved this study under the protocol number NMRR ID-22-02767-DRO.

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