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Design of Waste Management in Nuclear Medicine Isolation Room of Dr. Sardjito Central General Hospital

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Abstract. *The purpose of isolation room is to prevent radioactive contamination from the patient's metabolic processes. Because of that the radiation dose around the room and working area need to be limited. So that the value of the dose limits are not exceeded, the work area could be divided according to Perka Bapeten number 17 of 2012 Article 35. The working area can be divided into two parts: control region and supervision region. According to Perka Bapeten number 4 of 2013 Dose Limit Value (DLV) received in the control region has the potential to exceed 3/10 radiation workers DLV and the dose received in the supervision region has the potential of less than 3/10 radiation workers DLV and exceed people DLV. The isolation room is belong in the control region. The liquid waste from the isolation room is accommodated in the multi tank to delay it before being released to wastewater treatment plant. The isolation room needs ventilation using filters to prevent contamination via air circulation. The position of the preparation and radiopharmaceutical room and the waste storage room which is in the control region must be adjacent to the isolation room.*

Keywords: Isolation Room, Radioactive, Control Region, Supervision Region, DLV

Introduction

The use of radionuclides for health in the field of nuclear medicine has shown very rapid development. Radionuclides and radiopharmaceuticals are not only used for diagnostics but also for the treatment of various diseases. Nuclear medicine therapy is a therapy carried out by inserting an open radiation source into the patient's body for both diagnostic purposes and for therapeutic treatment. Examples of open radiation source radionuclides include Tc-99m, I-131, Sm-153, etc. Patients who have received radionuclide or radiopharmaceutical input will release radioactive substances from their bodies, either through sweat, urine, feces and so on. Therefore, to avoid the impact of radioactive substances on the environment, patients need to be quarantined in an isolation room. An isolation room in nuclear medicine is a special room in a nuclear medicine installation that is used to minimize contamination of radioactive substances so that they do not spread to the surrounding environment. Contamination can be in the form of solids, liquids, or air. Therefore, it is also important to design a radioactive waste management system in the isolation room, including its ventilation system, so that contamination can be minimized.

The regulations that form the basis of this research include the Regulation of the Head of the Nuclear Energy Regulatory Agency (BAPETEN) Number 17 of 2012 concerning Radiation Safety

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in Nuclear Medicine, and the Decree of the Minister of Health of the Republic of Indonesia Number 008 of 2009 concerning Nuclear Medicine Service Standards in Health Service Facilities. Law No. 10 of 1997, Article 23 paragraph 1 [1], which contains: collection, grouping, processing, transportation, temporary storage and permanent storage of radioactive waste, states that radioactive waste management is carried out by the implementing agency, in this case the National Nuclear Energy Agency (BATAN). BATAN with its facilities is able to manage liquid radioactive waste, used resin, solid waste, and used source waste originating from hospitals and industries. The BAPETEN has the task of supervising all nuclear energy utilization activities by implementing regulations, licensing and inspections. This agency was established by Presidential Decree No. 76 of 1998 based on Law No. 10 of 1997. For radioactive waste, BAPETEN regulates through PP No. 27 of 2002, concerning the management of radioactive waste [2]. The International Atomic Energy Agency (IAEA) is an international body whose duties include issuing guidelines on radioactive waste management for applications of radioactive substances in medicine, research and industry (IAEA-TECDOC-644 and 1000), one of the guidelines is that all radioisotopes used in nuclear medicine and especially those used for diagnostic and therapeutic purposes and whose half-lives are relatively short, must be managed independently (in-house waste management) and sent to a management location (centralized waste management). For long-lived waste, in this case the used source is managed by an agency that has been established in each country or sent to the supplier country if there is no agency authorized to manage them [3].

The implementation of risk-based company licensing is specifically regulates by Government Regulation (PP) Number 5 of 2021 of the Republic of Indonesia. Licensing is regulated for all business sectors, including the health sector. Hospitals with nuclear medicine services (including therapeutic nuclear medicine and in vivo diagnostic nuclear medicine) that require molecular imaging so that a risk-based approach (RBA) is applied are strictly regulated by the Ministry of Health in accordance with Number 14 of 2021 concerning business actor activity standards and health products [4].

According to [5], it was determined that the capacity of the isolation room in the Nuclear Medicine Installation of Dr. Sardjito General Hospital is 4 people, and the size of the isolation room is 9.3 m × 4.8 m. The radioactive waste management technology at Dr. Cipto Mangunkusumo General Hospital (RSCM) has been studied by Veronica Tuka et al, by evaluating the radioactive waste management system at RSCM. From this study, it can be explained that the management of radioactive waste at RSCM has referred to the regulations made by BATAN, BAPETEN, the Ministry of Health and the Ministry of Environment [6].

Theoretical Background

Radiation is the emission and propagation of energy through matter or space in the form of electromagnetic waves or particles [7]. Radionuclides are isotopes of radioactive substances that can emit radiation. The production of radionuclides by activation process is carried out by shooting stable isotopes with neutrons in the reactor core. This process is commonly called neutron irradiation, while the material being irradiated is called a target. The neutrons that are shot will enter the target's atomic nucleus so that the number of neutrons in the target nucleus increases. This event can cause instability of the atomic nucleus so that it changes its properties to radioactive [8].

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Nuclear medicine is a specialist medical service activity that uses open radioactive sources from nuclear disintegration in the form of radionuclides or radiopharmaceuticals for diagnostic, therapeutic and clinical media research purposes. The level of activity present in the patient's body will gradually decrease due to physical decay and biological elimination experienced by the radiopharmaceutical. Radiation exposure is radiation received by humans or materials, whether intentionally or not, which comes from internal or external radiation [9].

The principle of radiation protection based on the Basic Safety Standard (BSS) consists of 3 elements; justification, optimization, and limitation [10].

Radionuclides present in the human body irradiate tissues for a period of time determined by their physical half-lives and biological retention in the body. Thus, they can deliver increasing doses to body tissues for months or years after administration. The need to regulate radionuclide exposure and the accumulation of radiation doses over long periods of time has led to the definition of the quantity bound dose. The bound dose of a radionuclide in the body is the total dose expected to be received over a specified period of time. The bound equivalent dose, $H_{T(\tau)}$, in a tissue or organ T is defined in Equation (1).

$$H_T(\tau) = \int_{t_0}^{t_0+\tau} H_T(\mathrm{t})\ \mathrm{dt} \tag{1}$$

where τ is the integration time after administration time t_0. Henceforth, the magnitude of the bound effective dose E(τ) is expressed in Equation (2) [11]:

$$\mathrm{E}(\tau) = \sum W_T\, H_T\ (\tau) \tag{2}$$

To meet the dose limitation, the International Commission on Radiological Protection (ICRP) recommends that the bound dose be determined in the year of exposure. For workers, the bound dose is usually evaluated for more than 50 years after exposure. The bound period of 50 years is a value considered by the ICRP as the worker's life expectancy calculated from his/her entry into work at a young age [10]. The bound effective dose from exposure to radionuclides is also used in determining the estimated dose to members of the public.

Radioactive waste is defined as residual or unused radioactive material, or material contaminated with a certain amount of radioactive material at a level or level of radioactivity that exceeds the established safety limit value. The storage of radioactive waste aims to isolate radioactivity from the environment around us for a certain period of time. Radioactive waste management activities include [12]:

a. collection/storage,
b. grouping,
c. processing,
d. transportation,
e. temporary and sustainable storage,
f. and/or disposal of radioactive waste.

The use of radioactive substances for medical activities, both diagnosis and therapy in hospitals and clinics, as well as the use of radioactive drugs (radiopharmaceuticals) produces radioactive waste that requires special handling.

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Three principles of radioactive waste processing [12]:

1. Dilution and dispersion. Especially for low and medium level liquid waste that has the property of being easily dissolved or dispersed in water. This can be done by:
   a. Adding liquid/solution to reduce its concentration
   b. Releasing liquid waste little by little over a long period of time
   c. Releasing liquid waste into large bodies of water such as oceans, rivers or lakes

2. Delay and decay. With suspension, radionuclides lose their radioactivity through decay. This applies to types of liquid, solid and gas waste, which have a short half-life.

3. Concentration and containment. Most of the radioactivity caused by radioactive waste must be separated/isolated from the human environment. This applies to radionuclides that have a medium to high half-life. Waste must be contained for a long time.

Radioactive waste classification depends on the content of radioactive material contained in the radioactive waste. Radioactive waste is classified into [13]:

1. Exempt waste (EW): Waste that meets the criteria for a permit, exemption or exemption from regulatory control for radiation protection purposes.

2. Very short lived waste (VSLW): Waste that can be stored to decay and then removed from regulatory control in accordance with arrangements approved by the regulatory body. This waste includes waste containing very short-lived radionuclides that are often used for research and medical purposes.

3. Very low level waste (VLLW): Waste that does not meet the criteria for EW, but that does not require high levels of containment and isolation, therefore, is suitable for near-surface disposal with limited regulatory control. This waste includes soil and debris with low activity or has very limited concentrations of long half-lived radionuclides.

4. Low level waste (LLW): Waste that is above the safe level, but with a limited amount of long-lived radionuclides that require strong isolation and containment for a period of up to several hundred years and is suitable for artificial disposal near the surface. This waste includes a very wide range of short-lived radionuclides with higher activity and also long-lived radionuclides, but with low activity.

5. Intermediate level waste (ILW): Waste that because of its content, especially long-lived radionuclides, requires greater containment and isolation than can be provided by near-surface disposal and therefore requires disposal from more than ten meters.

6. High level waste (HLW): Waste with a level of activity high enough to generate significant heat from radioactive decay processes or waste with large amounts of long-lived radionuclides that need to be considered in the design of disposal facilities. Disposal in deep soil in areas with stable geological formations several hundred meters below the surface.

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Waste produced from nuclear medicine isolation rooms is classified as very short lived waste or has a short lifespan so it only needs to be stored in a temporary storage area before being disposed of as ordinary waste.

Based on the results of statistical tests from 5 samples of nuclear medicine facilities in Indonesia conducted by Anita Nur Mayani et al, nuclear medicine facilities in Indonesia have not met the aspect of the room that meets the requirements and does not meet the construction aspects relating to safety [14].

Materials and Methods

This research was conducted at the Nuclear Medicine Installation of Dr. Sardjito Central General Hospital located at Jl. Kesehatan No.1 Sekip Yogyakarta. This study aims to redesign the waste management system of an existing isolation room in the nuclear medicine installation of Dr. Sardjito General Hospital which will be renovated. Designing a waste management system in a nuclear medicine isolation room installation must consider the condition of the room and analyze the needs and activities in the isolation room. This design refers to Perka BAPETEN No.17 of 2012.

Based on the results of the research that has been conducted at the Nuclear Medicine Installation of Abdoel Wahab Sjahranie Hospital for the period 2018-2020, it was concluded that the largest number of patients who have undergone diagnostics and therapy based on gender is female, based on patient origin is from Samarinda, based on patient age is 26-58 years [15].

In the working area of the Nuclear Medicine installation at Abdoel Wahab Sjahranie Hospital also has been conducted an analysis of radiation dose rate by using surveymeter Inspector Sn.46685. The measurement results data were varied, indicating that the rate of radiation exposure in the working area of a nuclear medicine installation ranged from 0.09-21.56 Sv per hour. The radiation exposure rate obtained was mostly below 10 Sv/hour, including the gamma camera room, post injection room, injection room, decontamination room and hotlab room. The waste room has relatively high measurement because it exceeds 10 Sv/hour [16]. In MRCCC Siloam Hospital Semanggi, Jakarta, has been analyzed the level of nuclear contamination and radiation exposure rate. The results of measurement obtained levels of nuclear contamination dose in various rooms installation of nuclear medicine is from 0.16 to 243Bq/cm^2 and were classified as low to high levels of contamination. While the results of measurements of the radiation exposure rate is from 0.026 to 1.693μSv/h, which is classified as below the allowable dose value level. [17]

This research method is a simulation using Hurricane software and Microsoft Excel for calculation.

Simulation Methods, Conditions and Parameters

The tools maintenance system and its management that should be present consist of: 1) laboratory hygiene, 2) preventive maintenance, and 3) corrective maintenance and repair [18].

Of the several designs that have been made on previous studies, designs that use concrete materials are the most effective and economical. It takes the thickness of the concrete wall to limit the dose rate of radiation workers and the general public by 33 cm and 43 cm [19].

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As a shielding material, glass with boro-tellurite material has a high density, ranging from 3.172 to 6.64 g/cm3 and an HVL value of 1.0 to 2.988 cm, and an MFP of 1.456 to 4.311 cm in testing the characteristics of gamma radiation protection materials with an energy of 662 keV [20].

According to Perka Bapeten No.17 of 2012 Article 35, efforts to ensure that the dose limit value is not exceeded require the division of work areas into 2 classifications, namely: control areas and supervision areas.

1. Control Area

The isolation room is part of the control area where this room also has the potential for contamination of radioactive substances caused by the patient's body metabolism after being given radionuclides such as I-131. The items used in this isolation room are: 4 patient beds, tables, TVs for patient entertainment, 2 toilets, intercoms as a means of communication to radiation protection officers, AC, CCTV as a monitoring tool in the isolation room. **Figure 1** shows isolation room before renovation.

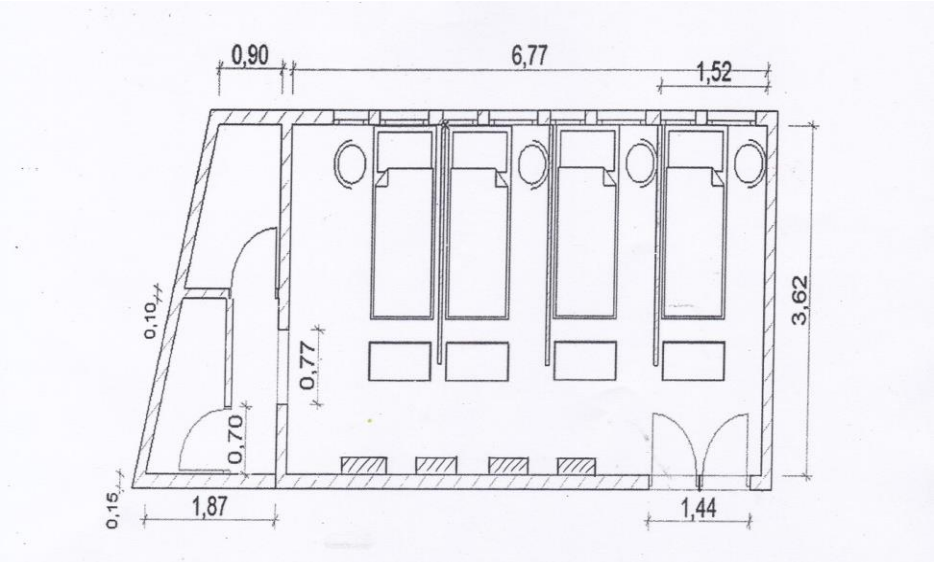

Figure 1. Isolation room before renovation

In order to prevent exceeding the dose limit for radiation workers and members of the public, facilities must be created in this control area, including:

a. Radiation signs.
b. Clear boundaries between the control area and the supervision area.
c. Visitor assistance procedures.
d. Safety procedures and instructions at the entrance and required locations.
e. Skin and clothing contamination monitoring equipment.
f. Storage for contaminated clothing and radiation protection equipment.
g. Decontamination facilities.
h. Radiation protective equipment at the entrance and exit.
i. Storage for personal equipment.

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2. Supervision Area

This area is an area outside the control area where there is no possibility of radioactive contamination. In order to prevent exceeding the dose limit for radiation workers and members of the public, facilities must be created in this supervision area, including:

a. Radiation signs
b. Clear boundaries between the supervision area and the control area
c. Monitoring equipment for visitors entering the supervision area

The rooms in the Nuclear Medicine Installation that are included in the supervision area include: sample examination room for in vitro diagnostics, diagnostic patient imaging room with gamma camera, decontamination room, temporary storage room for solid radioactive waste. **Figure 2** shows control and supervision area at the Nuclear Medicine Installation of Dr. Sardjito General Hospital.

1. Toilet room inside the isolation room
2. Public toilet room
3. Patient isolation room
4. Warehouse
5. Radiopharmaceutical storage and preparation room
6. Decontamination room
7. Gamma camera location
8. Temporary storage place for solid nuclear waste

Figure 2. Control and supervision area at the Nuclear Medicine Installation of Dr. Sardjito General Hospital

Based on the Regulation of the Head of Bapeten No. 17 of 2012 [9], the temporary storage room for radioactive waste must be:

a. Locked and ventilated.
b. Installed with radiation signs.
c. Available with appropriate containers to separate waste based on its type.

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Results and Discussion

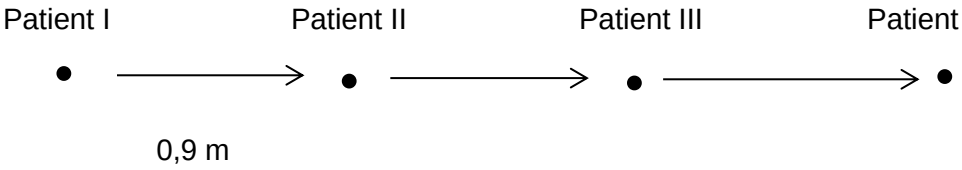
Determination of optimum isolation room management

This capacity is the number of patients who can be treated in an isolation room. This capacity is also the main thing that must be known to determine the size of an isolation room in the Nuclear Medicine Installation. How to calculate the number of patients in an isolation room written in Equation (3).

$$\frac{number\ of\ patients\ in\ a\ month \times isolation\ time}{1\ month} = \frac{16 \times 5}{22} = 3{,}63 \quad (3)$$

The number above is the capacity of the isolation room with the calculation results that can be rounded up to 4.

To calculate the radiation dose in the isolation room, data on the activity of the radionuclide given to the patient is needed. The radionuclide used is I-131 while the administration of Tc-99m does not need to be isolated. The specific gamma constant for I-131 is 59 µSv m2 GBq-1h-1. The patient is considered a radiation source because the radionuclide has been injected into the patient's body.



×	0,9 m	1,8 m	2,7 m
0,9 m	×	0,9 m	1,8 m
1,8 m	0,9 m	×	0,9 m
2,7 m	1,8 m	0,9 m	×

The distance between patients is 0.9 m. The formula for finding the radiation dose is: H = αΓ/(r×r) The radionuclide activity on the first day is 150 mCi α = 150 × 37 × 10-3 = 5.55 GBq At a distance of 0.9 m the radiation dose H0.9= 5.55 GBq × 59 µSv m2 GBq-1hour-1 0.9 m × 0.9 m = 404.2µSv hour-1 At a distance of 1.8 m radiation dose H1.8 =5.55 GBq × 59 µSv m2 GBq -1hour-1 1.8 m × 1.8 m = 101.1 µSv hour-1 At a distance of 2.7 m the radiation dose of H2.7 = 5.55 GBq × 59 µSv m2 GBq-1hr-1 2.7 m × 2.7 m = 44.9µSv hr-1

The maximum permissible dose (D) based on articles 33 and 34 of Bapeten Regulation No. 17 of 2012 for radiation workers is 20mSv/year and the general public is 1mSv/year. With the estimate that 1 year consists of 50 weeks then:

For radiation workers: D = 20mSv/year × 1 year/week = 20/50 mSv/week = 0.4 mSv/week

For public: D = 1mSv/year × 1 year/week = 1/50 mSv/week = 0.02 mSv/week

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In Bapeten Regulation No. 4 of 2013 Article 27 radiation exposure received in the control area has the potential to exceed 3/10 of the NBD of radiation workers, then 3/10 × 20mSv = 6mSv. So the radiation exposure in this area has the potential for NBD above 6mSv. In Perka Bapeten No.4 of 2013 Article 29 NBD received in the supervision area exceeds the NBD of community members and is less than 3/10 of the NBD of radiation workers, then 3/10 × 20mSv = 6mSv. So the NBD in this area is between 1mSv < NBD < 6mSv.

The equipment that must be available for the isolation room must be in accordance with the Decree of the Minister of Health No. 008 of 2009. The Nuclear Medicine Installation at Dr. Sardjito General Hospital is included in the Main Nuclear Medicine Service classification. This service is in the form of an in vitro diagnostic service that can provide results in the form of imaging and also provides internal radiation therapy services, so it requires an isolation room. Table 1 shows Completeness of equipment in Nuclear Medicine, Dr. Sardjito General Hospital.

Table 1. Completeness of equipment in Nuclear Medicine, Dr. Sardjito General Hospital

	Equipment	Comlpeteness	Numbers	Availability
1	Radioactivity measuring instrument	-Printer -Can measure radioactivity in micro and millicurie units -Can measure Tc-99m and I-131 -Can measure beta-emitting radionuclides	1 unit	available
2	Radiation protection equipment	Surveymeter	1 unit	available
		Individual monitor (film badge or TLD)	According to the number of radiation workers	not available
3	Waste bin	1. General waste	As needed	Available
		2. B3 waste	As needed	Available
		3. Radioactive waste	As needed	Available

The position of the isolation room must be made close to the radiopharmaceutical preparation and storage room and the patient room after the radiopharmaceutical administration. This is done so that the patient's mobility after being given the radiopharmaceutical is not too far. The rooms included in the control area include: patient isolation room, toilet room in the patient isolation room, radiopharmaceutical preparation and storage room, patient room after the radiopharmaceutical administration. Outside this control area is the supervision area. The rooms included in this supervision area must be made close to the rooms included in the control area. Outside the supervision area is a public area where the possibility of radioactive contamination is very small. The public area is the area that is colored white. So, the location of the isolation room is made right next to the patient's room after the radiopharmaceutical administration. The layout of the

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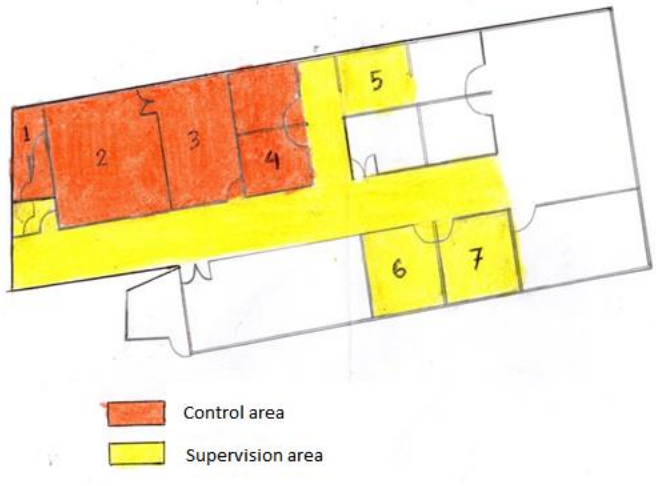
isolation room in the Nuclear Medicine Installation of Dr. Sardjito Hospital and determining the control area, supervision area, and public area are shown in **Figure 3**.



1. Toilet room in the patient isolation room
2. Isolation room
3. Patient room after radiopharmaceutical administration
4. Radiopharmaceutical preparation and storage room
5. Decontamination room
6. Temporary storage room for solid nuclear waste
7. Gamma camera room

Figure 3. New Nuclear Medicine Spatial Planning

RSUP Dr. Sardjito in nuclear medicine service activities, one of the most frequent is using radioisotope iodine-131 for thyroid disorder therapy. The selection of I-131 for the above therapy, based on several considerations including the high gamma radiation energy (E - 364 keV), and the price is relatively cheap. The half-life of I-131 is about 8 days and can be released from the patient's body through respiration and sweat, in addition to the main excretion through urine and feces. Given the increasing number of patients who require treatment with I-131, a good radioactive waste management system is needed, especially the management of liquid waste which is the most waste produced by the Nuclear Medicine Installation. This liquid waste is in the form of urine from patients undergoing treatment using I-131. Patients undergoing treatment using I-131 with a dose of ± 100 mCi, usually stay in the nuclear medicine isolation room for 5 days. During that time, the patient urinates and defecates in a special toilet in the isolation room, this waste enters and is collected in stacked tanks. The waste flow is made to flow from control tank 1 to control tank 2, then from control tank 2 to control tank 3, and then from control tank 3 to control tank 4. The location of these control tanks can be seen on the floor plan of the 1st floor of the Nuclear Medicine Installation of Dr. Sardjito General Hospital shows in **Figure 4**.

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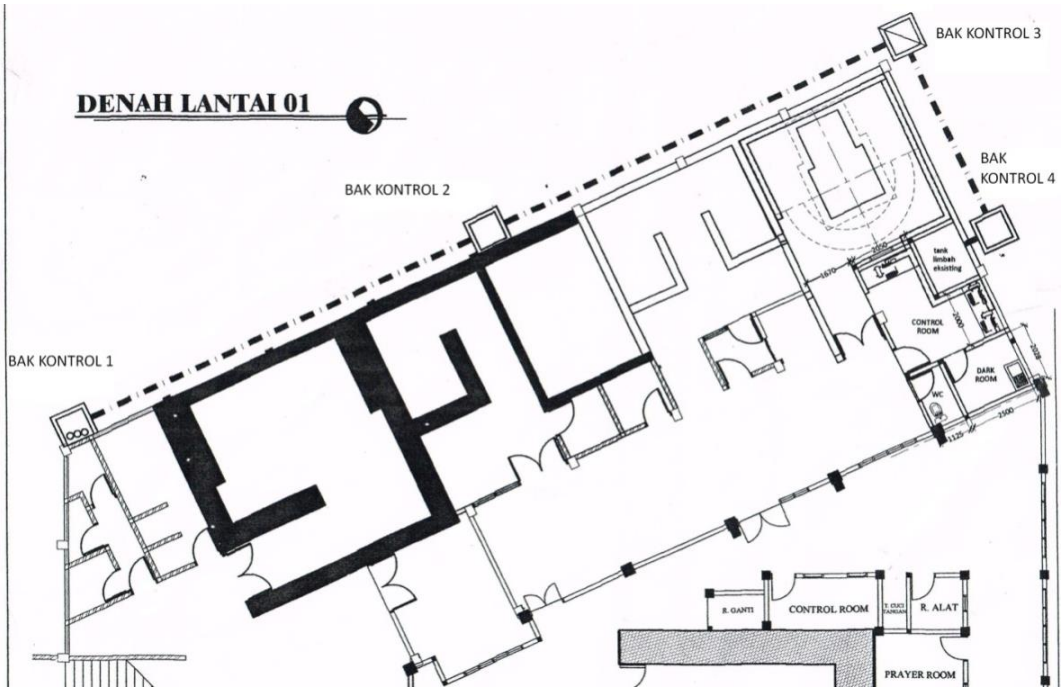

Figure 4. Position of control tanks in the Nuclear Medicine Installation of Dr. Sardjito General Hospital

The waste flow is designed in such a way that the previous waste liquid can flow into the next tank, while the latest waste liquid must be diluted with the previous waste liquid. Waste from control tank 4 can be forwarded to the Wastewater Treatment Plant after its activity is measured. The average I-131 activity in the control tank can be calculated using Equation (4).

$$A_{I-131} = \left[\frac{N_T - N_B}{E.Y}\right].V \text{ (Bq)} \quad (4)$$

$A_{I\text{-}131}$ = I-131 Activity
NT = Total Count
NB = Background Count
E = Gamma Spectrometry Detection Efficiency (cps/Bq)
Y = Gamma Energy Abundance of I-131 (0.812)
V = Volume

Based on IAEA-TECDOC-l000, the clearance level of radionuclide release into water bodies for I-131 is 1 x 107 Bq/year [3]. For solid radioactive waste such as used radiopharmaceutical bottles and injections, it is stored in a special warehouse until its activity decays. While for used source waste can be sent to BATAN or sent to the exporting country.

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Conclusions

The waste management system at the Nuclear Medicine Installation of Dr. Sardjito General Hospital meets the standards set by BAPETEN. However, there are several things that need to be improved. The air circulation in the isolation room need to be improved by ventilation with filters to reduce the risk of airborne contamination. In addition, the position of the radiopharmaceutical preparation and administration room and the waste storage room which are control areas, need to be brought closer to the isolation room so that can improve operational efficiency and safety for patients and workers

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