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ESTABLISHMENT OF A NEW NUCLEAR MEDICINE FACILITY: FUNDAMENTAL STRUCTURE AND THEIR SHIELDING

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ABSTRACT

This work was an attempt to propose a model to set up for newly establishment of Nuclear Medicine facility. Medical physicist should establish a major guideline to set up a model of a new nuclear medicine facility; draw the fundamental structure and calculate the corresponding shielding. The various layouts such as the diagnostic (In-Vivo and In-Vitro) and therapeutic layouts of fundamental structure were been made on the primacies as controlled, supervised and non-supervised area according to radiation exposure rate. Some shielding calculations of various facilities such as the diagnostic and therapeutic facility have to provide on instrumentation and radiation safety with the required layout according to maximum activity of radionuclide into the controlled area.

Keywords: Transmission factor, Monte Carlo calculation, imaging modalities, AAPM shielding calculation

1. INTRODUCTION

Nuclear medicine is a medical notability, uses radiopharmaceuticals through intravenous injection to human body as a tracer to assess bodily functions and to diagnose and treat disease. Positron Emission Tomography (PET)/Computed Tomography (CT) has become the best method in the diagnosis of tumor and cancer diseases. In PET/CT units, ionizing radiation emits from ^{18}F-FDG (Fluoro-deoxy-glucose). Radiation protection as well as save region is essential for PET/CT occupational workers. The present work tried to establish a new nuclear medicine facility where was been drawn a fundamental structure along with corresponding shielding.

This is a theoretical analysis to get the optimal solution for establishment of a new nuclear medicine facility designed based on the major components, such as; fundamental structures for premises with the assessment of radiation safety and their shielding for instrumentation of the facility. Firstly, definite site is selected by medical physicist for the diagnostic (In-Vivo and In-Vitro) and the therapeutic layouts and made or drawn the typical layouts for new establishment with ensuring the thickness for radiation safety according to ALARA (As low as reasonably achievable) concept. Secondly, the medical physicist calculates the corresponding shielding of various facilities over the providing on instrumentation and radiation safety with the required layout according to maximum activity of radionuclide into the controlled area. The importance of this theoretical analysis consists as the basic guideline for establishment of a new nuclear medicine facility.

To discuss some of works exhibit the possibility to establish the model of a new nuclear medicine facility. Using the guidelines of society of nuclear medicine [1], a concept found on the design guide of new nuclear medicine and diagnostic facility, which is established. A typical layout is designed on the principle of fundamental structure of nuclear medicine facility to install the having both gamma camera and PET/CT (Positron Emission Tomography/Computed Tomography) for a new nuclear medicine facility which was also being reviewed by us. The site planning and radiation safety of the PET/CT facility is described by this work. Some articles also reviewed where to realize the calculations and analysis of the radiation protection of PET/CT center about the structural shielding calculation and design for medical use of X - rays and gamma rays of energies up to 10 MeV in the following work of National Council on Radiation Protection and Measurements and NCRP Report No. 49 [2]. For the various fundamental structures, shielding are being assessed by a Monte Carlo calculation in the work "constant-potential diagnostic X-rays beams" and photon shielding for a positron emission tomography is also noted by this work.

This paper contains as follows: section 1 deals with introduction and section 2 focuses on the design of fundamental structure of new establishment of nuclear medicine facility. Section 3 contains mechanism and methodology of shielding calculation for uptake and imaging room, hot lab and therapy using the experience of American Association of Physicists in Medicine (AAPM) Task Group 108. Result and result discussion is evaluated in section 4. Thus, the conclusion place in last section that based on the result table.

2. DESIGN OF FUNDAMENTAL STRUCTURE

After site selection and determine the total area of the infrastructure of a new nuclear medicine facility according to the radiation safety ,this infrastructure classify into three types of area like as controlled, supervised and non-supervised area on the base of radiation exposure rate. These areas are drawn and denoted by different colors, which indicates for the following instruments such gamma camera, PET/CT or others, the supervised areas including dosing admitted room, post admin waiting room, storage room and decontaminated room is been placed near to the corresponded controlled area. The position of the non-supervised area of required facility usually sets up to one end of the infrastructure. Fume hood is to be installation into the "Hot lab", if required decontamination room is optional. The active toilet may use for personnel decontamination by providing a shower and washbasin. Radioactive waste storage room for PET facility is optional. The supervised area for working people and the non-supervised area for public in nuclear medicine facility safety were also been drawn. For therapeutic facility, patient's room (with specified design) and nurse station would also been mentioned or formed by medical physicist.

3. MECHANISM OF SHIELDING CALCULATION

In radiation exposure, all workers of nuclear medicine will have among the risk at during work, it can be reduced by three factors such increasing the distance from the source, minimizing the time of exposure and using the shielding of thickness. Distance often employed simply and effectively. Limiting the duration of an exposure is not always feasible, because a certain amount of time is usually required to perform a given task. Sometimes, though, practice runs beforehand without the source can reduce exposure times when an actual job is been carried out. While distance and time factors can employ advantageously in radiation exposure protection. Shielding alone can use to reduce exposure rates to desired levels. Therefore, it is important factor for radiation safety. However, the amount of employed shielding will depend on a balancing of practical necessities such as cast and the benefit expected. In this section, the safety of patients and radioactive workers is been ensured by the calculating shielding design of wall of fundamental layouts for in-vivo, in-vitro and therapy at the controlled area. In non-supervised area, the shielding is not more than needier supervised for safety. As the decay, energy of ^{18}F-FDG (Fluoro-deoxy-glucose), which is used in PET/CT, is maximum like 511keV than others radionuclide, only the shielding calculation of PET/CT is the need. PET facility has divided into two sections such as during the administration of dose is uptake room facility and the measurement of consideration is imaging room facility. Certain radionuclides decay by spontaneously converting a proton into a neutron [3] and simultaneously emit an energetic positron. In this paper, the values of broad beam transmission factors will be used for lead, concrete and iron that are based on consistent Monte Carlo calculations [4] performed by one of the authors Douglas Simpkin.

Table 1: Following table shows the broad beam transmission factors at 511 keV in lead, concrete and iron.

Thickness	Transmission Factors		
	Lead*	Concrete**	Iron
0	1.0000	1.0000	1.0000
1	0.8912	0.9583	0.7484
2	0.7873	0.9088	0.5325
3	0.6905	0.8519	0.3614
4	0.6021	0.7889	0.2353
5	0.5227	0.7218	0.1479
6	0.4522	0.6528	0.0905
7	0.3903	0.5842	0.0542
8	0.3362	0.5180	0.0319
9	0.2892	0.4558	0.0186
10	0.2485	0.3987	0.0107
12	0.1831	0.3008	0.0035
14	0.1347	0.2243	0.0011
16	0.0990	0.1662	0.0004
18	0.0728	0.1227	0.0001
20	0.0535	0.0904	
25	0.0247	0.0419	
30	0.0114	0.0194	
40	0.0024	0.0194	
50	0.0005	0.0009	

*Thickness is in mm for lead.

**Thickness is in cm for concrete and iron.

3.1 Methodology of Shielding Calculation and Thickness

In this paper, calculations of the shielding of PET/CT facility followed the experience of American Association of Physicists in Medicine Task Group 108.

3.1.1 Dose Calculation for Uptake room

Patients undergoing PET scans need to be kept in a quiet resting state prior to imaging to reduce uptake in the skeletal muscles. This uptake[5] time varies on types of scans, but it is usually in the range of 30–90 min. The total weekly dose $D(t_u)$ at a point (d) 0.5 meters from the patient chair in an uptake room during the uptake time (t_u) is 0.0166 h or 1 min for supervised area and1 h or 60 min for controlled room. The patients are administered, (A_0) 555 *MBq* of ^{18}F-FDG whose half-life is only 109 min. However, it emits positron. The energy of annihilation is 511 keV, there are 40 patients per week (N_w), occupancy factor (*T*) is 1and dose reduction factor (R_{t_u}) is 0.83[5].

$$D\ (t_u) = [0.092\ \mu Sv m^2/\ MBq\ h \times N_w \times A_0\ (MBq) \times t_u(h) \times R_{t_u}]\ /d^2 \quad (1)$$

Now the transmission factor (B_U) required is

$$B_U = \frac{P}{D\ (t_u)} = 10.9 \frac{P\ d^2}{T\ N_w A_0\ t_u\ R_{t_u}} \quad (2)$$

P is the weekly dose limit in μSv. In the any country, P= 20 μSv for supervised areas, corresponding to the 1mSv/ year limit to the general [5] public and P= 100 μSv for ALARA levels in controlled areas. Thus, for supervised areas,

$B_U = 0.178$

Using above table of broad beam transmission factors, shielding for uncontrolled or supervised area of PET/CT is the value 12 mm of lead or 17 cm of concrete. Now, for controlled areas,

$B_U = 0.014$

The shielding is required about 22 mm of lead or 25 cm of concrete.

3.1.2 Dose Calculation for Imaging Room

If it takes the most conservative approach, where no shielding from the tomography assumed, then the calculation of shielding for the tomography room is used to the same formula as the uptake room calculation. However, it considers into account that the administrated activity is decreased during the uptake phase by the decay factor for ^{18}F-FDG at the uptake time is 1 h or 60 min, F_U is equal to exp (- 0.693 × 60/110) = 0.68 . The total weekly dose is equivalent to a point 3 meters from the patient during the PET imaging procedure. In most cases the patient will void prior to imaging, removing approximately 15% of the administered activity and thereby decreasing[5] the dose rate by 0.85.The average imaging time (t_I) is 30 min and the dose reduction factor for imaging (R_{t_I}) is 0.91.

$$D\ (t_I) = [0.092\ \mu Sv m^2/\ MBq\ h \times N_w \times A_0\ (MBq) \times 0.85 \times F_U \times t_I(h) \times R_{t_I}]\ /d^2 (m^2) \quad (3)$$

Now the transmission factor (B_I) required is

$$B_I = \frac{P}{D\ (t_I)} = 12.8 \frac{P\ d^2}{T\ N_w\ A_0\ F_u t_I\ R_{t_I}} \quad (4)$$

Thus, for supervised areas,

$B_I = 0.34$

Using above table of broad beam transmission factors, the shielding required by the value8 mm of lead or 11 cm of concrete for uncontrolled or supervised area of PET/CT. Now, for controlled areas,

$B_I = 0.0419$

The shielding is required about 30 mm of lead or 28 cm of concrete.

3.1.3 Dose Calculation for Gamma Camera

Now it is taken into account that the administrated activity is decreased during the imaging by the decay factor for Technetium-99m (^{99m}Tc) at the imaging time is 0.166 h or 10 min, F_U is equal to exp (- 0.693 × 10/360.6) = 0.98. The total weekly dose is equivalent to at a point 3 meters from the patient during the Gamma camera imaging procedure. The admitted by patients radioactivity dose which is of 9250*MBq* or 250 *mCi* of ^{99m}Tc, whose half-life is only 6.01 h or 360.6 min. However, since it emits γ ray, the energy of annihilation will 140 keV. There are 50 patients per week. In most cases, the patient will void prior to imaging, removing approximately 15% of the administered activity and thereby decreasing the dose rate by 0.85. The average imaging time is 10 min and the dose reduction factor for imaging is 0.99.The transmission factor required is 0.154. Using above table of broad beam transmission factors, shielding for controlled area of Gamma Camera is the value13 mm of lead or 16 cm of concrete.

3.1.4 Dose Calculation for Associate Area

Shielding requires only for Bone Mineral Densitometry (BMD) because it generates the radiation energies, as X-rays such as 70 keV and 120 keV, the thickness of walls of BMD is 3 mm limit to 5mm lead. Other regions can assume as a non- supervised such as ultra-sonograms are no need for the shielding because it is the elastic wave. No finite barrier thickness will eliminate the radiation dose outside the diagnostic room.

3.1.5 Dose Calculation for Hot Lab

The transmission factor is required for a controlled area of hot lab at a point 2 m from the center in a hot lab. Assume patients are administered 55500MBq or 300mCi of ^{18}F-FDG whose half-life is only 109 min, but it also emits positron. The energy of annihilation is 511 keV. There are 200 patients per week and the working time is 2 h or 120 min, occupancy factor (T) is 1 and the dose reduction factor is 0.7.The transmission factor (*B*) required is

$B = 0.00028$

The using broad beam transmitted factors table shielding requires about 52 mm or 5.2 cm of lead or 47 cm of concrete.

3.1.6 Dose Calculation for Therapy

The thickness of wall of the therapy facility will depend on the area of the room, position of the bed and the occupancies all around. The transmission factor is required for a controlled area (therapy facility) at a point 4 m from the patient’s bed in the therapy facility. Suppose patients are administered 7400MBq or 200 mCi of Iodine-131 (^{131}I) whose radioactive energy is beta energy of 606 keV, effective half-life of beta energy of ^{131}Iis 7.6 days or 182 h. Here, there is one patient per bed per week, the working time is 7 days or168 h, occupancy factor (T) is 1(one) and the dose reduction factor is 0.74.The required transmission factor (B) is

B= 0.019

About 28 mm or 2.8 cm of lead or 30 cm of concrete shielding is required for therapy facility.

Some layouts (In-Vivo, In-Vitro, associated area, therapy, hot lab and radioactive waste management)have shown by the following figures with corresponding calculated value for the protection. All the walls of In-Vivo, In-Vitro, associated area, therapy, hot lab and radioactive waste management should be made of concrete only, the thickness of which will depend on the required workload. The shielding for In-Vivo is calculated only for PET facility because of the maximum radiation in PET/CT is needed for all facility. The walls of the required nuclear medicine facility (In-Vivo, In-Vitro, associated area) should be made of 11 cm concrete for imaging room and 15 cm concrete for uptake room. The thickness of hot lab and storage room should be made of 47 cm and 94 cm concrete wall respectively.

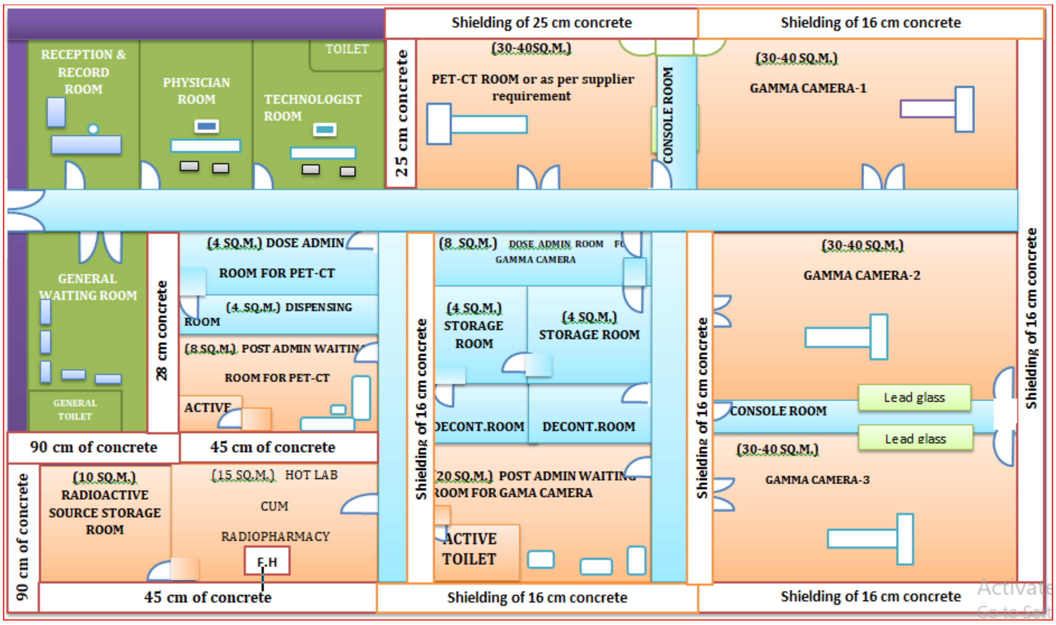

Fig.1: A typical layout for In-Vivo lab of a newly established nuclear medicine center both gamma camera imaging for diagnostic studies and PET/CT installation, total area = 180-200 sq.m.

	Control area
	Supervised area
	Non-supervised area
	Shielding with concrete or brick

Layout of hot lab is individually shown by the following figure.

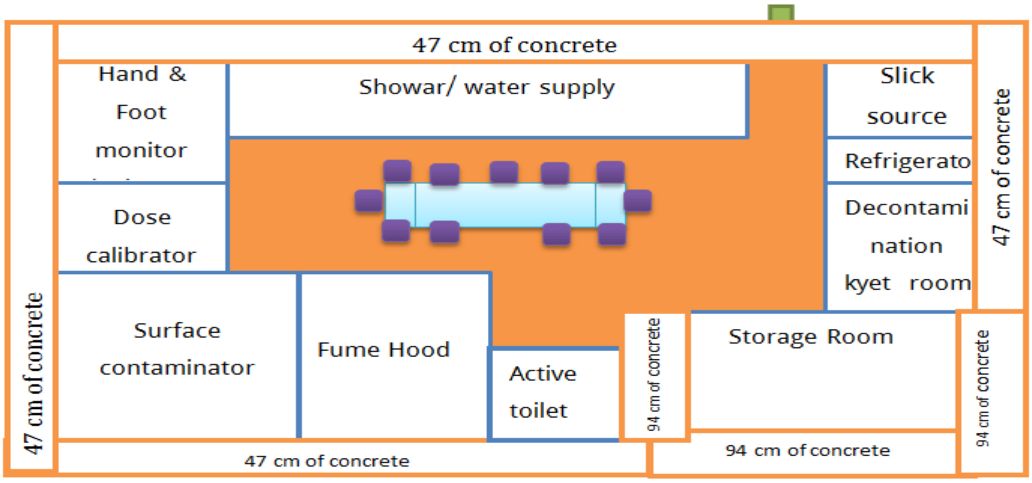

Fig. 2: A typical layout for hot lab of a newly established nuclear medicine center with 47 cm concrete walls and having storage room with 94 cm concrete, total area=25-30sq.m.

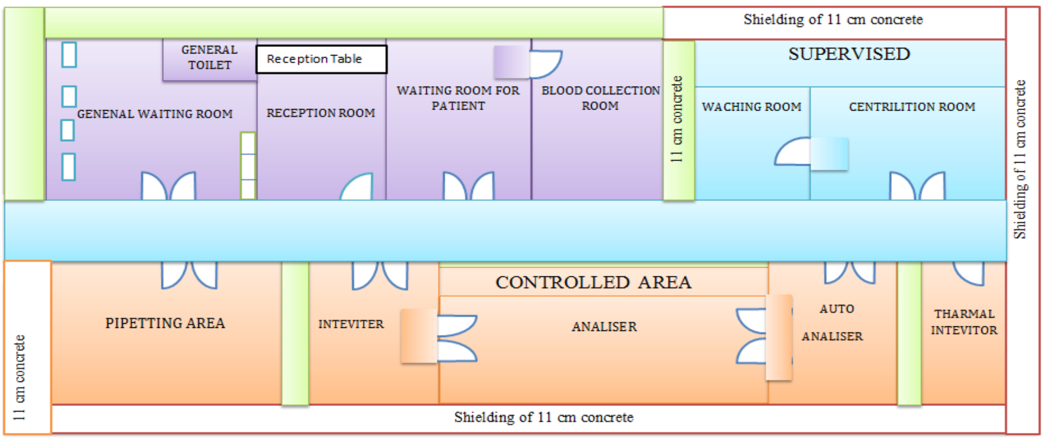

Fig. 3: A typical layout for In-Vitro lab of nuclear medicine center with 11 cm concrete walls because the maximum radiation safety is being considered, total area = 150-160 sq.m.

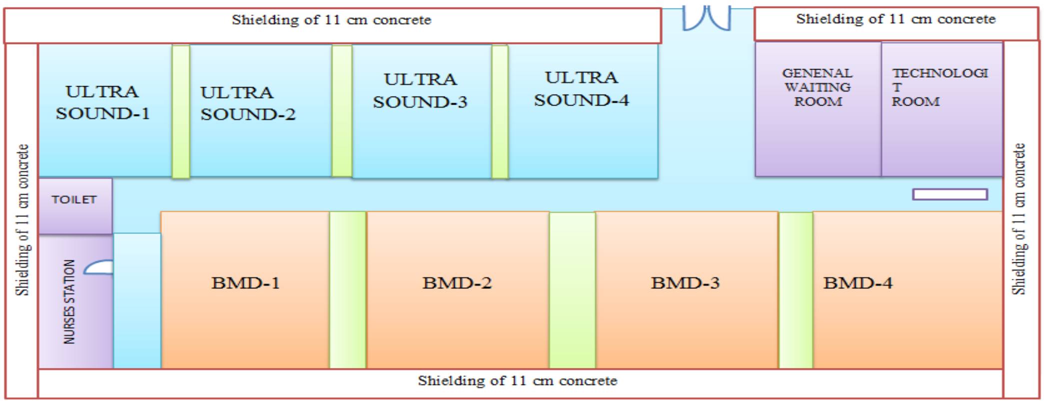

Fig. 4: A typical layout for associated area of a newly established nuclear medicine center with 11 cm concrete walls because the maximum radiation safety is considered, total area = 150-160 sq.m.

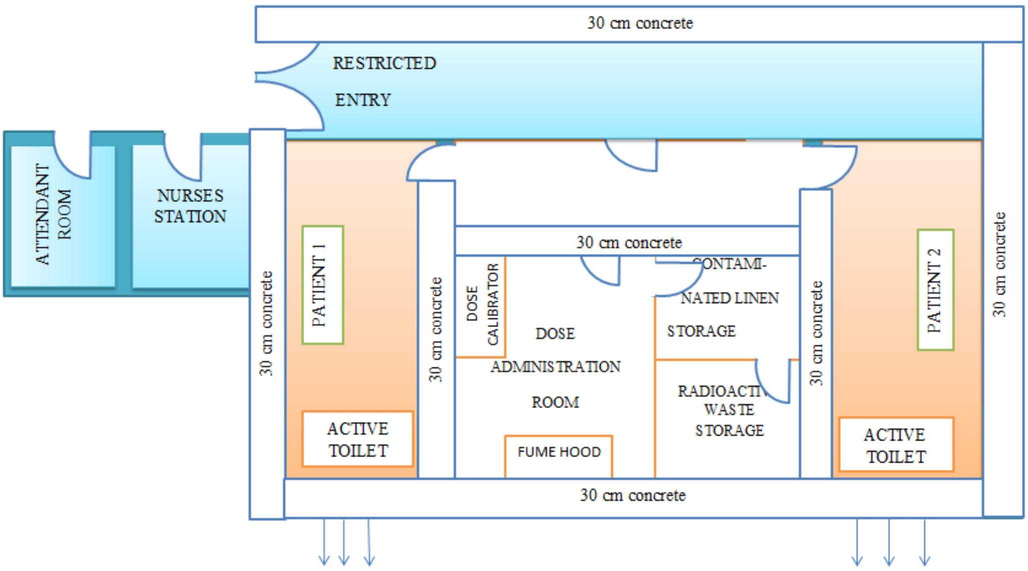

Fig.5: A typical layout for therapy of a newly established nuclear medicine facility plan for a 2-beds isolation ward for hospitalization of patients treated with large dose of ^{131}I.The thickness of walls of controlled area should be made of 30 cm concrete.

There is no significant different in the shielding barrier between two beds or more. The ducting line of the fume hood should been shown by the plan. Decontaminated room is optional. The active toilet may use for personnel decontamination by providing a shower and washbasin. In addition, the plumbing and ducting line from the isolation ward to the delay tank is to been shown clearly. It was also important to have clean pathways to carry the dose administrated patients to therapy room and if needed, to carry the patients for clinical assistances.

4. RESULTS

The following table shows the results of this article

<table>
<tr><td colspan="4">Facility</td><td>Shielding</td></tr>
<tr><td rowspan="5">In-Vivo</td><td rowspan="4">PET/CT</td><td rowspan="2">Uptake room</td><td>Uncontrolled area</td><td>12mm (Lead) or 17 cm (Concrete)</td></tr>
<tr><td>controlled area</td><td>22 mm (Lead) or 25 cm (Concrete)</td></tr>
<tr><td rowspan="2">Imaging room</td><td>Uncontrolled area</td><td>8mm (Lead) or 11 cm (Concrete)</td></tr>
<tr><td>controlled area</td><td>30mm (Lead) or 28 cm (Concrete)</td></tr>
<tr><td colspan="3">Gamma camera</td><td>13mm (Lead) or 16 cm (Concrete)</td></tr>
<tr><td colspan="4">In-Vitro</td><td>8mm (Lead) or 11 cm (Concrete)</td></tr>
<tr><td rowspan="2">Hot lab</td><td colspan="3">Active room</td><td>47 cm (Concrete)</td></tr>
<tr><td colspan="3">Storage room</td><td>94 cm (Concrete)</td></tr>
<tr><td colspan="4">Therapy</td><td>30 cm (Concrete)</td></tr>
</table>

5. CONCLUSION

To establish a new nuclear medicine facility, it is very important to proper calculation of shielding of fundamental areas and design layouts to carry out all nuclear medicine activities. Modeling of a new nuclear medicine establishment is been based on three vital components; which are as fundamental structure, instrumentation and required workers. In this paper, the first component's impotencies showed that is fundamental structure with shielding for various premises for a new nuclear medicine establishment.

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