Designing of sophisticated automatic lead shielding to reduce radiation dose of ^{99m}Tc

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In order to apply ALARA principle, a highly sophisticated automated lead shielding was designed to reduce radiation dose from ^{99m}Tc to the working staff in nuclear medicine/health centers. An automated IR sensor based radioactive container with movable lid was fabricated in order to reduce radiation exposure time. In case of existing radioactive storage containers, radiation protection aim was compromised due to heavy weight lid of containers used for the shielding purpose. In this research work lid of container was supported with electromechanical assembly and infrared sensors. Infrared sensors were adjusted as to facilitate automatic movement of lid. Timing for opening and closing of lid was optimized and adjusted as per requirement. The reduction of radiation dose per month for technologists with this designed shielding was calculated from 37.5 μSv to 1.3 μSv. Implementation of designed shielding in nuclear medicine center helped in achieving average percentage attenuation of 96.56%. Therefore the operating philosophy for maintaining the occupational doses as low as reasonably achievable was made possible with the help of this designed shielding.

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1. Introduction

All the nuclear medicine centers (NMC) in the world exercise some eminent radionuclide such as Mo^{99}, Tc^{99m}, I^{131}, Sr^{89}, P^{32} , Co^{57} etc for calibration, diagnostic use and therapeutic modalities as well as academic and research purposes [1-5]. Radiations emitted from these radio nuclides can interact with the human body and have several benefits if interact with the body for prescribed dose. These are very dangerous/hazards for workers if the exposure exceeds the permissible dose. Excess radiations have potential to cause both somatic and genetic effects including development of cancers and congenital anomalies. It is always possible that workers in nuclear medicine centers can be exposed to different forms of radiation [6-7]. Although all over the world most of the NMCs are regulated by the government regulatory bodies and took every possible step to prevent staff from radiation exposure, even then risk factor is very high due to technical barricades [8]. Most of the nuclear medicine centers are designed as to provide maximum safety from radiations to the working staff and common public. These centers are mostly divided into two parts for operational areas, controlled area and supervised area. Controlled area is known as hot lab where the radioisotopes are stored and their required dose is compounded, while the other area is used to administer the dose to the patients [9]. It is very important factor to manage every step from manufacturing, packing, compounding, transporting, administering to the waste management of radioactive materials in order to protect human from radiation. Radiation protection in hot lab is a very sensitive issue, especially for the manpowers and researchers of the hot lab who spent their maximum time in the hot lab for the preparation of radiopharmaceuticals [10].

There are three physical principles for radiation protection: (1) shielding (2) distance (3) time [11]. Objectives/Aims of excellent radiographic practice are to ensure that exposure of radiation having minimal harmful effects/invasiveness [12]. There are many types of equipment, containers and dresses used for radiation protection. Most of them are made up of lead because it is a good and economical heavy metal to attenuate gamma rays that are emitted from radioactive materials. To address waste management issue, various kind of containers have been used in NMC's including manually and mechanically operated containers which are made up of variable thickness of lead [13-17]. One of the anomalies observed in hot lab of NMC's was unshielded top of the waste storing container just due to heavy weight lead shielded lid which was very difficult to operate manually. Such containers considered as a prime cause to increase radiation exposure time. This problem was eradicated by fabricating a lead shielded lid which was automatically operated by electromechanical sensors. All designing details and reduction in radiation exposures are presented in this report.

2. Experimental

2.1 Materials and Methods

The current research experiment was performed in Punjab Institute of Nuclear Medicine Center (PINUM) cancer hospital situated in Faisalabad, Pakistan which can be considered as a good initiative for radiation protection study for future. The following points were considered for the designing of the present project.

1. To design a shielding system that has easy operation by using electromechanical assembly.
2. To avoid the surface contamination by the application of automated system operating by the use of IR sensors.
3. To reduce the operating time of the shielding system as a result reducing the radiation doses to the workers.
4. To shield the roof of the existing shielding system for the reduction of exposure level at working area. Ultimately reduction of the radiation doses to the workers.

The block diagram of the circuit used in the designed shielding system is represented in Fig. 1. The circuit description for sensing system and limit switches are shown in Fig. 2 and 3 respectively. The details of materials, equipment and design used to fabricate the automated lead shielding assembly for the attenuation of Gamma Radiation emitted from Tc^{-99m} is described in preceding sections. The overall view of the designed lead shielded container is depicted in pictures presented in Fig. 4.

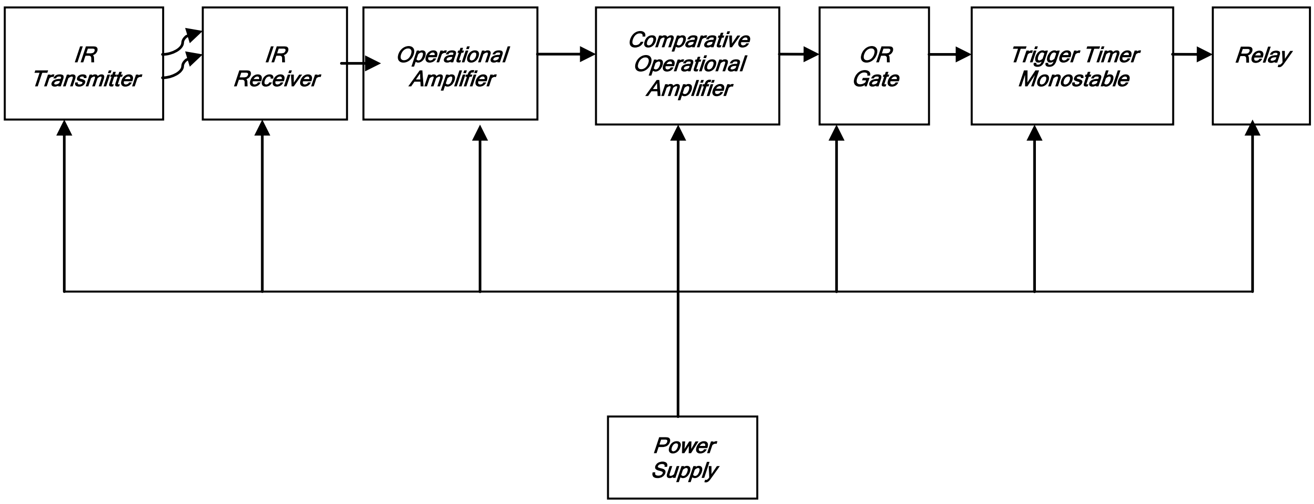

Fig 1. Block diagram of electronic circuit system.

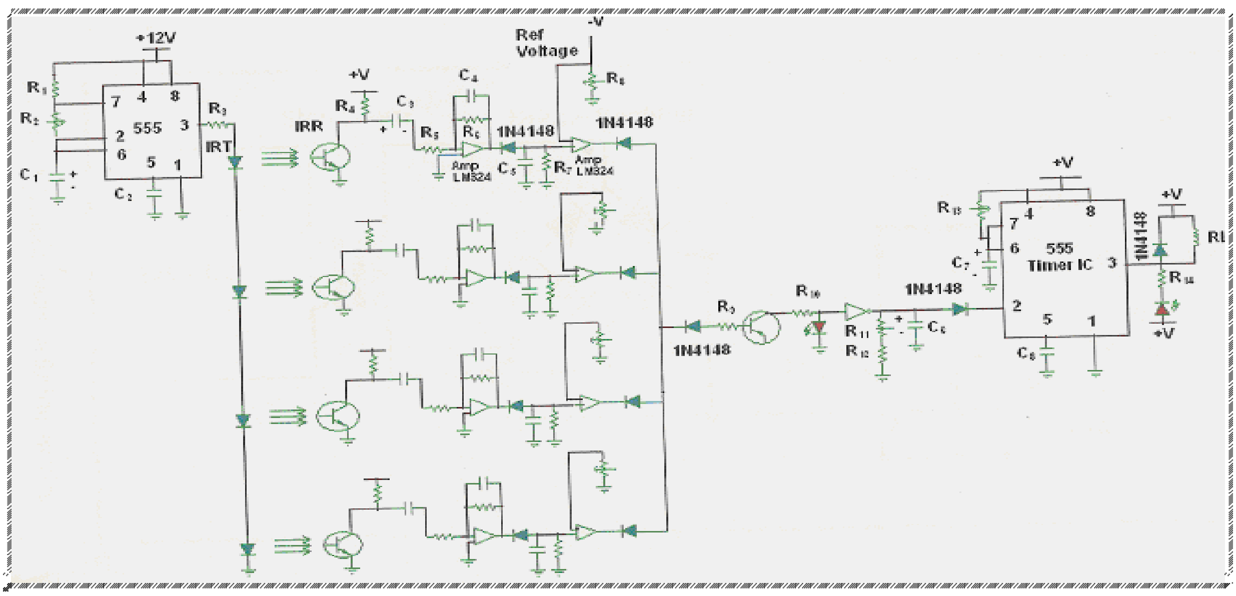

Fig 2. Circuit description for sensing system.

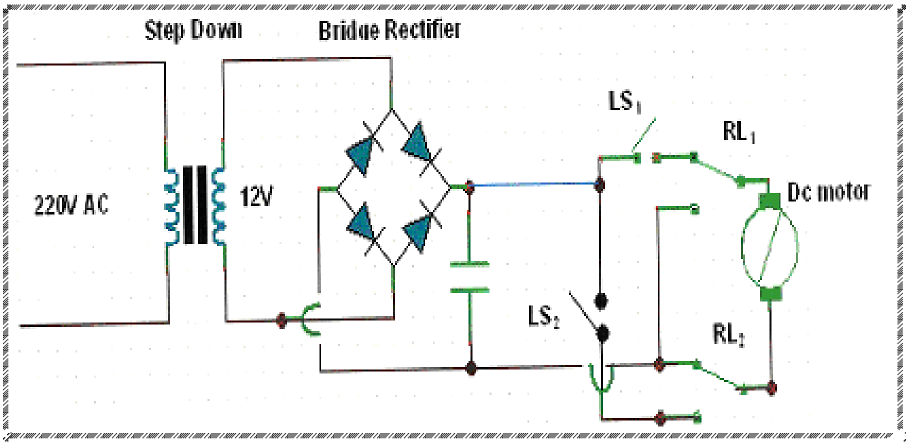

Fig 3. Circuit description for limit switches.

Fig. 4. (a) Shielding with open lid and sensors; (b) shielding with closed lid and wooden handle; (c) Top view with sensors and limit switches; (d) Back view of shielding; (e) Electrical Panel; (f) division of main shielding box.

Iron railings and screws were very gently used to join the walls of the outer assembly to avoid every possibility of radiation leakage, it is therefore avoided to use any iron nails and screw inside lead sheets. A wooden handle was fixed at the top corner of outer assembly for easy movement while four plastic black lockable wheels were used to avoid frequently movement of shielded assembly during operation. Two iron railings were used for support and movement of lid with flat gayer which was fitted at internal side. A round gayer located at shaft of the motor was used for coupling of flat gayer with DC motor. Its function is to control back and forth movement of lid by limiting switches (fig 3) after receiving signals from sensors. Pictures of newly designed shielding assembly are given in Fig 4. This assembly was then presented at PINUM cancer hospital to record the reduction in radiation exposure of residuals of ^{99m}Tc.

2.2 Lead sheets

For the lead sheet used in the project have thickness of 2 mm, absorbance and transmittance of gamma radiations of 140KeV energy was calculated using following shielding formula [14-16]

$$I(x) = I_0 e^{-\mu x} \quad (1)$$

Where I_0 and I are radiation intensities before and after shielding through thickness x, respectively, μ is the linear attenuation coefficient, x is the thickness of shielding material. According to this formula a 2 mm thick Lead sheet absorbs 99.7% of gamma radiations of 140KeV energy and transmits only 0.329% which offers good agreement with experimental data.

2.3 Electrical instruments

12V DC Motor with 6A current was used for the movement of heavy shielded lid of this shielding assembly (Fig. 5) and four infrared sensors were used to control the movements of the system remotely. These sensors were fitted on a strip by grooving on the upper side of the collars of this shielding assembly (shown in Fig. 4). The electric power supply and electrical connections were connected by insulated copper wires. A Combi board was used for the outer assembly of the shielding.

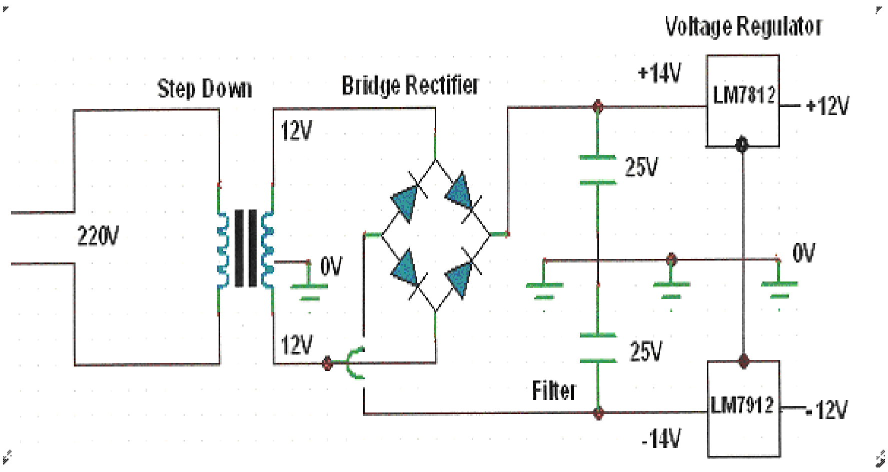

Fig. 5. Circuit description for 12V power supply.

2.4 Calculations for attenuation coefficient

Tc^{99m} is one of the common used isotopes in nuclear medicine centers that emit gamma ray of 140keV. In addition, by using lead as shielding material the necessary calculation i.e. attenuation coefficient for gamma ray has been carried out with the help of following formula.

$$x = x_1 + \left[\frac{y - y_1}{y_2 - y_1}\right](x_2 - x_1) \quad (2)$$

Where x = μ = attenuation coefficient for gamma ray of 140keV energy. $x_1 = \mu_1$ = attenuation coefficient for gamma ray of 100keV (0.1MeV) energy is equal to 59.7 cm^{-1}, $x_2 = \mu_2$ = attenuation coefficient for gamma ray of 150keV (0.15MeV) energy is equal to 2.8 cm^{-1}, $y_1 = E_1$ = 0.1MeV, $y_2 = E_2$ = 0.15MeV, y = E = 0.140 MeV [9]. So we have μ = 50.7 + [(0.140 – 0.1) / (0.15-0.1)] (20.8 – 59.7) = 28.58 cm^{-1}. The optimization of the weight was also considered in addition to the attenuation of the radiation by lead in the designing of shielding. The percentage of attenuated radiations is 99.67 and percentage of transmitted radiations is 0.329 calculated using formulas from equation (1).

2.5 Specifications of shielding

The Dimensions of the shielding system are given in Table 1.

The storage capacity of this Pb shielded radioactive container was 30*30*43 cm^3 which was enough for two weeks storage of radioactive waste (^{99m} Tc) generated at hot lab-I of PINUM. There was a control box adjacent to storage area for installation of electrical panel.

Table 1. Dimensions of the shielding system.

Storage portion	
Length	30cm
Width	30cm
Height	43cm
Control box	
Length	17cm
Width	30cm
Height	43cm
Collar	
Length	47cm
Width	3.6cm
Height	28.5cm

2.6 Operational details

A 220V AC current supply was stepped down to 12V using step down transformer then it was covered into DC current with the help of bridge rectifier afterward it was filtered by the electrolyte capacitors. Moreover, this filtered power supply was then regulated by IC regulators LM7812 and LM7912 circuit description for 12V power supply is sketched in Fig. 5. A power supplies of +12V and -12V DC were used to control circuit while +12V at a rate of 5Amps was used to drive DC motor.

At the end, these regulated voltages were applied to four IR transmitters which are connected in series while IRR which are phototransistors will receive these signals. Whenever, there will be any obstruction between these IRT and IRR circuit (description of sensing system is given in Fig. 2) rely will be energized and will come in “switch on” mode to reverse DC motor power supply. As a result the motor will activate to open the lid. Block diagram of electronic circuit system is shown in Fig. 1.

3. Results and discussion

A shielding for radiation protection was designed and fabricated to eradicate a root cause of increased radiation exposure to the technical staff working at hot lab of nuclear medicine centers. The basic reason of this increased radiation exposure was time taking movement of very heavy lead shielded lid of radioactive storage container [18, 19]. As the lid of the radioactive container was frequently used due to which the sixth upper side of radioactive assembly remains unshielded for comparatively longer period of time. There are many examples where lid, cap or closures are manually operated at NMCs, [20] where dense radiation attenuation material likes Pb causes a delayed to shut the lid and increase exposure time and probability of cross contamination. In this research work, we have overcome these difficulties of movement of heavy lid of radioactive container by using electromechanical remote assembly which is speedy and time saving. The timing for opening and closing of lid was adjusted according to the requirement of work to facilitate technical workers (3 to 4 second) and also it could be adjustable according to need. The implementation of first principal (ALARA) [13] of radiation protection was assured while designing this system. In this system the lid can automatically open just at the time of placing a radioactive material and automatically close after the completion of procedure because of sensing mechanism.

Theoretically calculated percentage attenuation for 2mm thick lead is given in equation 1, which was 99.67%. The efficiency of this lead shielded assembly was analyzed by placing it at hot lab I of PINUM for three weeks and radiation exposure to the technologists was recorded. Average Percentage attenuation of the recorded data was calculated as 96.56% shown in equation 2. This difference between the theoretical and practical results was due to unlocking of the sixth side (lid) of shielding.

The technologists (who were continuously engaged with radioactive materials in hot lab) were monitored for the period of one week, in order to calculate mean exposure time for them (hours/day). Total time calculated for six days (one working week) was 12 hours and 37min so mean time per day is 2.1 hours. Radiation dose per hour to the technologists was calculated for three weeks given in Table 2. Furthermore, past three years radiation dosimetery record of PINUM (Fig. 6) was used for comparison and evaluation of this designed shielding. With the help of this data mean estimated radiation dose for technologists was calculate for per hour, per week, per month and per year without shielding as shown in Fig. 7. With the help of this record total dose for 36 months for hot lab -1 worker was calculated as 25.36 mSv. So mean dose per month of hot lab-1 workers = 25.36/36 = 0.75mSv. From Fig. 7 it is clear that total per month estimated dose reduction = 37.52–1.26= 36.26μSv= 0.03626mSv.

From these calculations, it is obvious that implementation of the designed shielding in nuclear medicine centers will help in achieving average percentage attenuation of 96.56%. Therefore the operating philosophy for maintaining the occupational doses as low as reasonably achievable will be made possible with the help of this designed shielding.

T-test was applied for statistical analysis of collected data; results are presented in Fig. 8 & 9.

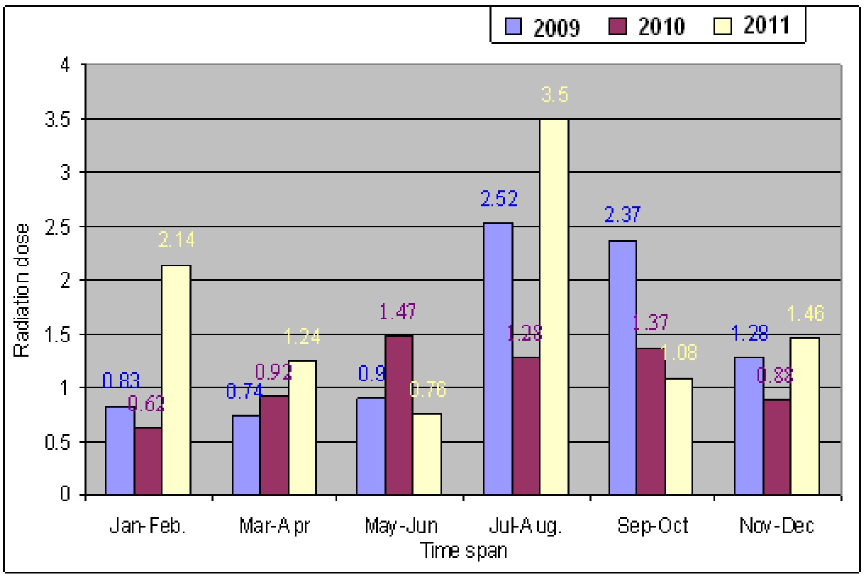

Fig. 6. Three years dosimetery record of PINUM hot lab -1 worker.

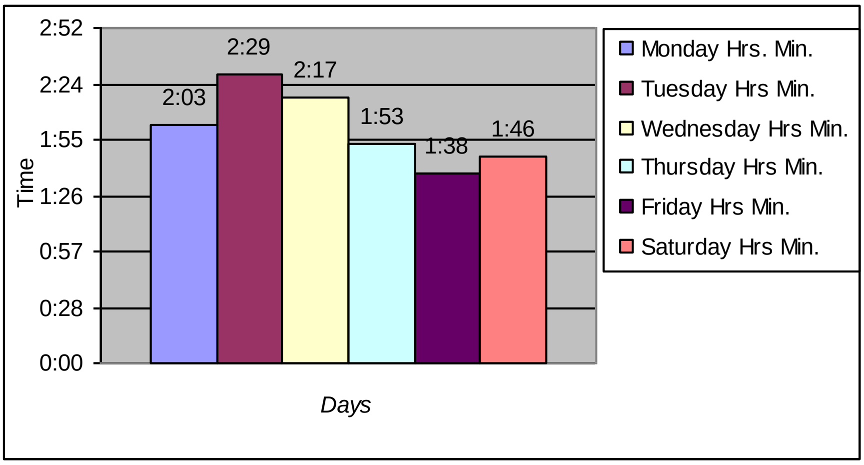

Fig. 7. Estimation of exposure time per day in hot lab-1for workers.

Table 2. Calculations for percentage attenuation.

Sr #	**Radioisotope**	**Radiation doses with out shielding I_0=µ.0Sv/h**	**Radiation doses after shielding I=µSv/h**	**I/I_0**	**% I/I_0**	**% attenuation**
	^{99m}Tc	0.96	0.031	0.032292	3.2292	96.7708
	^{99m}Tc	.87	0.0271	.031149	3.1149	96.8851
	^{99m}Tc	.78	0.024	.030769	3.0769	96.9231
	^{99m}Tc	.67	0.028	.041791	4.1791	95.8209
	^{99m}Tc	.53	0.021	.039623	3.9623	96.0377
	^{99m}Tc	.38	0.0116	.030526	3.0526	96.9474
	^{99m}Tc	.93	0.029	.031183	3.1183	96.8817
	^{99m}Tc	.84	0.027	.032143	3.2143	96.7857
	^{99m}Tc	.76	0.026	.034211	3.4211	96.5789
	^{99m}Tc	.65	0.022	.033846	3.3846	96.6154
	^{99m}Tc	.54	0.019	.035185	3.5185	96.4815
	^{99m}Tc	.40	0.017	.0425	4.25	95.75
	^{99m}Tc	.99	0.0299	0.030202	3.0202	96.9798
	^{99m}Tc	.86	0.0265	.030814	3.0814	96.9186
	^{99m}Tc	.74	0.0243	.032838	3.2838	96.7162
	^{99m}Tc	.61	0.0201	.032951	3.2951	96.7049
	^{99m}Tc	.50	0.0181	.0362	3.62	96.38
	^{99m}Tc	.36	0.015	.041667	4.1667	95.8333

Percentage attenuation =100- % I/I_0
Average value of Percentage attenuation = 96.56%.................. (a)
Value of percentage attenuation calculated with the formula is
% $I = I_0 e^{-\mu x}$ = 99.67%.. (b)
Difference = 3.11%.

Table 3. Calculations for the statistical analysis of recorded data.

Sr#	Without shielding X_1	With shielding X_2	d= X_1 - X_2
1	0.96	0.031	0.929
2	.87	0.0271	0.8429
3	.78	0.024	0.756
4	.67	0.028	0.642
5	.53	0.021	0.509
6	.38	0.0116	0.3684
7	.93	0.029	0.901
8	.84	0.027	0.813
9	.76	0.026	0.734
10	.65	0.022	0.628
11	.54	0.019	0.521
12	.40	0.017	0.383
13	.99	0.0299	0.9601
14	.86	0.0265	0.8335
15	.74	0.0243	0.7157
16	.61	0.0201	0.5899
17	.50	0.0181	0.4819
18	.36	0.015	0.345
∑d			11.9534

Similarly work has been done by many researchers by applying different/manifold radiosensitive technique to avoid radiation exposure and bio distribution techniques [21, 22].

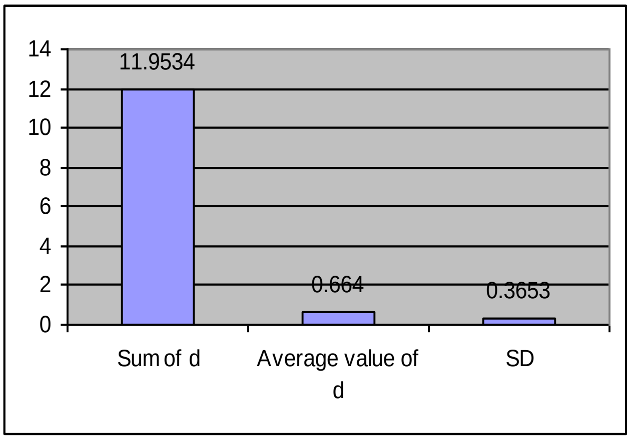

Fig. 8. Statistical results.

Formula used for calculating the standard deviation is

$$SD = \sqrt{\frac{\sum(X-\bar{d})}{N}}$$

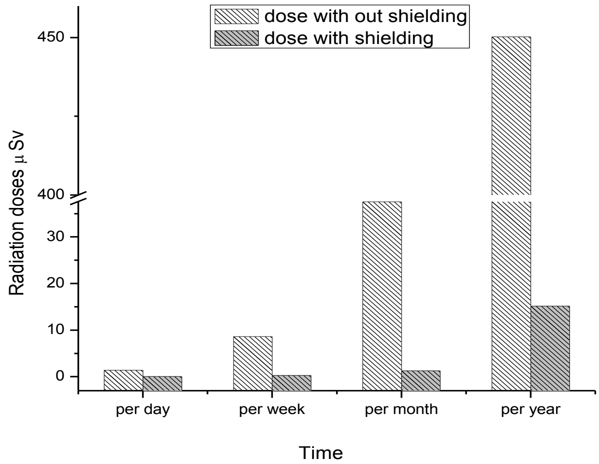

Fig. 9. Comparison of radiation dose without and with designed shielding.

4. Conclusion

Lead-lined storage container equipped with automated IR sensors lid has been fabricated that achieving average percentage attenuation 96.56% to working staff. Probabilities of cross contamination of radioactive sources in nuclear medicine center were minimized due to automated lead lid. The current shielding is more beneficial, sophisticated, safe, and efficient as compared to the manually operated shieldings fabricated earlier. This newly fabricated shielding has proven to be user friendly both for humans and environment. It is minimally invasive for workers in hot lab. Further studies are recommended by using different materials for different radiopharmaceuticals. More research work is also needed to commercialize this shielding for ^{99m}Tc in different sizes and shapes.

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