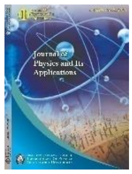
Journal of Physics and Its Applications

Journal homepage : https://ejournal2.undip.ac.id/index.php/jpa/index



Investigation of Radiation Protection Measures in Extracorporeal Shock Wave Lithotripsy Facilities: A Study Based on NCRP Report 147

Angelica Margaretha[1,*], Dwi Adhianto[1, 2], and Josua Timotius Manik[1]

[1] *Department of Physics, Matana University, Tangerang, Indonesia*
[2] *Departement of Radiology, Dr. Adjidarmo Hospital, Lebak, Indonesia*

**Corresponding author: angelica.margaretha@student.matanauniversity.ac.id*

A R T I C L E I N F O

Article history:
Received: 24 April 2024
Accepted: 22 May 2024
Available online: 31 May 2024

Keywords:
Fluoroscopy
ESWL
NCRP 147
Shielding

A B S T R A C T

Fluoroscopy, also referred to as the C-Arm, is a direct imaging modality used in interventional radiology. It is commonly used, particularly in Extracorporeal Shockwave Lithotripsy (ESWL) for kidney stone removal. The process of kidney stone destruction typically spans from 45 to 60 minutes. Continuous exposure to the radiation can lead to an accumulation of radiation dosage, potentially causing harmful effects. Radiation shielding is one of the most important factors for radiation protection in obtaining a license to construct a radiation room. Radiation shielding requires a minimum thickness to prevent exposure to radiation from escaping the room and posing a risk to the public. Measurements were conducted within the ESWL facility situated at XYZ private hospital, encompassing both internal and external locations, spanning across a total of 11 designated measurement points. The calculations were performed in accordance with the guidelines stated in NCRP Report No.147. The result obtained were 1.665; 1.681; 1.686; 1.109; and 1.716 mm for lead material thickness and 223.8; 225.9; 226.4; 153.2; and 230.2 mm for concrete material thickness. The hospital walls were constructed using concrete with a thickness of 200 mm and were additionally covered with a 2 mm Pb coating. In conclusion, the lead installed meets NCRP standards, but the thickness of the concrete walls around the room still falls short of the requirements.

1. Introduction

Medical physics employs the principles and techniques of physics within the medical domain, encompassing disease prevention, diagnosis, and treatment. It comprises three main specializations: radio-diagnostic and interventional, radiotherapy, and nuclear medicine. Medical physics significantly contributes to hospital functions, particularly in radiology, radiotherapy, and nuclear medicine facilities. To mitigate radiation-related risks, medical physicists conduct quality assurance assessments on radiation-emitting equipment, ensuring that the benefits of radiation are maximized while potential risks are minimized through proper usage.

One commonly visited facility by the public is the radiology center, where a variety of radiation equipment is housed, including conventional radio-diagnostics, mammography, X-rays, CT scans, fluoroscopy, and others. The employment of radiation in disease diagnosis can entail adverse effects arising from radiation doses exceeding recommended thresholds. Regular monitoring of these procedures is essential to mitigate potential harm, such as tube leakage or the dispersion of radiation doses beyond acceptable limits into the surrounding environment. Notably, the extent of radiation exposure to the body escalates in tandem with the duration of fluoroscopy utilization. [1]. Extended periods of exposure correlate directly with escalated levels of radiation impacting the body.

Utilizing radiation for disease diagnosis can occasionally result in detrimental consequences stemming from elevated radiation doses. Consequently, regular monitoring of imaging apparatus is imperative to avert potential hazards like tube leakage and the dissemination of radiation doses surpassing safety thresholds to the nearby environment. Notably, the duration of fluoroscopy employment correlates with heightened levels of radiation exposure for patients. Fluoroscopy, also referred to as the C-Arm, is a direct imaging modality used in interventional radiology. It is commonly used, particularly in Extracorporeal Shockwave Lithotripsy (ESWL) for kidney stone removal [2][3]. The process of kidney stone destruction typically spans from 45 to 60 minutes. Continuous exposure to the radiation can lead to an accumulation of radiation dosage, potentially causing harmful effects. Enhancing radiation protection involves implementing several measures, including shielding for fluoroscopy or C-Arm equipment, providing protective aprons for staff, employing dose monitoring tools like TLDs, and incorporating room shielding [4][5]. Establishing effective radiation shielding stands as a critical aspect in maintaining safety during interventional radio-diagnostics. It's mandatory for all hospitals to integrate radiation shielding into their interventional radio-diagnostic setups, aimed at safeguarding individuals from radiation exposure and averting adverse health effects [4]. The design of shielding in a room can vary based on factors like room dimensions, construction materials (e.g., concrete or lead), and the arrangement of radio-diagnostic equipment. Hospital-installed radiation shields must meet minimum thickness requirements to adequately contain radiation within the room [7]. These efforts are directed towards shielding the local community from excessive radiation exposure, thereby mitigating potential severe health risks.

2. Method

The research employed a quantitative observational methodology, employing direct measurement and testing to gather data. The tools and materials utilized included fluoroscopy (C-arm), a length measuring meter for room dimensions, a survey-meter to gauge radiation levels, an acrylic phantom, and the blueprint of the ESWL room [8]. The radiogram brand survey-meter, in Fig.1, is utilized for assessing both indoor and outdoor exposure rates. Employing acrylic with a thickness of 20 cm, as illustrated in Fig.2, serves as a means to simulate real-world conditions, thereby enhancing the precision of radiation dispersion measurements. Fig. 3 showcases the digital meter employed for measuring room dimensions and distances between walls and radiation sources. Fig. 4 displays the utilization of a C-Arm for ESWL, functioning as a modality for radiation emission, facilitating the measurement of radiation exposure rates.

Fig. 1: Survey meter radiogram


Fig. 2: acrylic with 20 cm thickness


Fig. 3: digital meters


Fig. 4: C-Arm for ESWL.

The subsequent step involved creating a schematic diagram detailing various aspects of the ESWL room, encompassing its dimensions, the positioning of the control room, the type and thickness of protective materials utilized, the gantry's location, the distance between the gantry and measurement points, and the overall space surrounding the ESWL room. A total of 11 measurement points were designated, with six situated indoors within the ESWL room and five outdoors. All measurements were slated to be taken at a distance of 30 cm from the wall, except for points F and D. At point F, measurements were to be conducted 30 cm from the shielding, while at point D, measurements were to be taken 30 cm from the examination table. Exposure rate assessments were conducted at points A, C, D, E, and F within the ESWL room, whereas radiation shielding measurements were undertaken at points B, G, H, I, J, and K. The determination of the requisite radiation shielding thickness adhered to the guidelines outlined in NCRP report no. 147 and entailed several calculations [7-8].

a. The air kerma from unshielded secondary radiation

$$K_{sec}(0) = \frac{K_{sec}^{1} \cdot N}{d_{sec}^{2}} \quad (1)$$

K_{sec}^{1}: the secondary air kerma
N: number of patients per week
d_{sec}^{2}: distance from source to calculation point (m)

b. Transmission barrier

$$B_{sec}(x_{barrier}) = \left(\frac{P}{T}\right)\frac{d_{sec}^{2}}{K_{sec}^{1}.N} \quad (2)$$

P: weekly shield design objectives

T: occupancy factor

The occupancy factor serves as a constant parameter utilized in determining radiation shielding requirements for the ESWL room. A value of 1 is assigned to the occupancy factor, as the calculation primarily centers on the equipment control room and its immediate vicinity. Another unchanging factor is the shielding design objective value per week, set at 0.1 mGy/week for the controlled area and 0.02 mGy/week for the uncontrolled area.

c. Barrier thickness

$$x_{barrier} = \frac{1}{\alpha\gamma} ln \left[\frac{\left(\frac{N.T.K_{sec}^{1}}{Pd_{sec}^{2}}\right)^{\gamma} + \frac{\beta}{\alpha}}{1+\frac{\beta}{\alpha}}\right] \quad (3)$$

α, β, γ: Transmission coefficient of radiation shielding wall material.

The value of the transmission coefficient used for lead and concrete materials are shown in Table 1.

Table 1: Parameter of x-ray transmission coefficient

All Barrier	Transmission Coefficient		
	α (mm^{-1})	β (mm^{-1})	γ
Lead	2.322	1.291 x 10^{-1}	7.575 x 10^{-1}
Concrete	3.630 x 10^{-2}	9.360 x 10^{-2}	5.955 x 10^{-1}

The acquired data underwent calculation and analysis in accordance with the guidelines outlined in the National Council on Radiation Protection (NCRP) Report No. 147, which offers recommendations for structural shielding design within medical x-ray imaging facilities. Subsequently, these calculations were juxtaposed with the wall thickness implemented in the ESWL room at the hospital and the exposure test values recorded within the room.

3. Result and Discussion

Exposure rate measurements and radiation shielding calculations were performed within the ESWL facility at XYZ Hospital. These calculations were guided by NCRP Report No. 147, which outlines the structural shielding requirements for medical X-ray imaging facilities. Employing a meter, we measured the dimensions of the ESWL room and determined the distance between the C-Arm tube and each side wall. Multiple measurement points were established within the ESWL room to ensure accurate installation of radiation shielding [9].

Fig. 5: ESWL room at XYZ Hospital

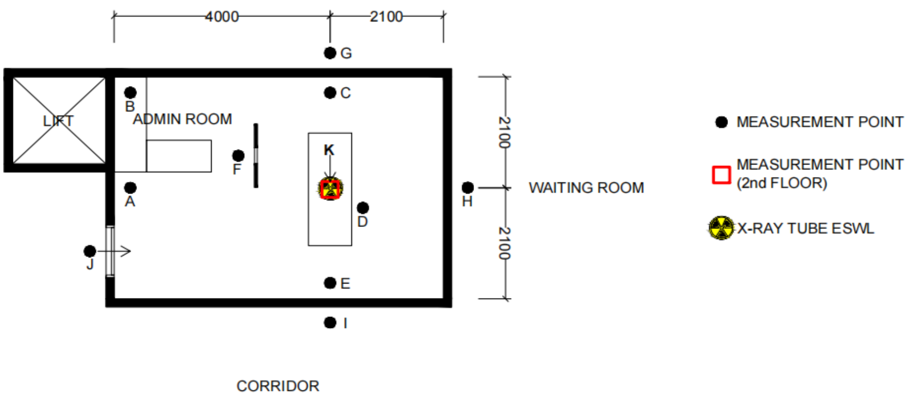


Fig. 6: Floor plan of ESWL room at XYZ Hospital

Table 2: Radiation shielding calculation results for lead according to NCRP report no.147

Measurement Point	d_{sec}^2 (m)	$K_{sec}(0)$	B_{sec} ($x_{barrier}$)	$x_{barrier}$ (mm)			
				Lead		Concrete	
				NCRP	Installed	*NCRP*	Installed
G	2.12	1.0235	0.01954	1.665	2	223.8	200
H	2.08	1.0632	0.01881	1.681	2	225.9	200
I	2.07	1.0735	0.01863	1.686	2	226.4	200
J	4.06	0.2790	0.07167	1.109	2	153.2	-
K	2	1.15	0.01739	1.716	-	230.2	300

The dimensions of the ESWL room at XYZ Hospital measure 6.1 m x 4.2 m x 2.87 m, meeting the safety standards set forth by both NCRP and IAEA [10]. Given the need for accommodating multiple pieces of equipment and personnel required for patient care, the ESWL room necessitates a spacious layout [10]. Based on blueprint form the hospital, the walls of the ESWL room constructed with 200 mm thick concrete walls supplemented by 2 mm thick lead lining, as well as a door fortified with 2 mm thick lead, the room is designed to minimize radiation exposure. However, it's notable that the floor lacks any lead material, as the room is situated on the lowest level of the hospital.

The aforementioned computations are grounded in data sourced from NCRP Report No. 147 and direct analytical findings. Specifically focusing on the outdoor locale mentioned earlier, the calculation aims to estimate the necessary thickness at 0.02, an occupancy factor of 1, and a secondary air kerma (K_sec^1) value of 0.46. The transmission coefficients α, β, and γ vary depending on the material utilized; for lead, they are 2.322 mm^{-1}, 0.1291 mm^{-1}, and 0.7575, respectively, while for concrete, they are 0.0363 mm^{-1}, 0.0936 mm^{-1}, and 0.5955, respectively [8]. of radiation shielding. Within this calculation, key parameters from NCRP Report No. 147 are employed, including the shield design objective set Initial measurement data used for the calculations include the distance from the radiation source to the room wall and an average of 10 patients per week. Upon determining the requisite thickness of the radiation shield, this data will inform the appropriate thickness. The required thickness of lead material for radiation protection on each side of the ESWL room is as follows: 1.665 mm, 1.681 mm, 1.686 mm, 1.109 mm, and 1.716 mm. Notably, the installed lead material thickness of 2 mm Pb remains within safe limits. Conversely, the calculated required thicknesses for concrete materials are 223.8 mm, 225.9 mm, 226.4 mm, 153.2 mm, and 230.2 mm, exceeding the installed concrete thickness of 200 mm. Given that measurement point J is positioned in front of a lead door, only the door thickness needs consideration

Table 3: Radiation shielding calculation results for lead according to NCRP report no.147

Measurement Point	Distance from the Source *(m)*	Background (μSv/h)	Average Exposure Rate (μSv/h)
A	3.7	0.01	11.39
B	3.46	0.01	0.043
C	1.82	0.01	73.42
D	0.85	0.01	72.19
E	1.77	0.01	64.96
F	1.95	0.01	0.007
G	2.12	0.01	0.013
H	2.08	0.01	0.037
I	2.07	0.01	0.037
J	4.06	0.01	0.097
K	2	0.01	0.027

Exposure rates are measured inside and outside the ESWL room to determine radiation exposure for workers and the public. In addition, it is important to take measurements outdoors to determine if there is any leakage inside the ESWL room [11]. Exposure rate measurements were taken inside and outside the ESWL room using a radiogram brand survey meter at 11 points. Measurements were taken three times per point to obtain the average value. Before measuring the exposure rate at each point, the background exposure rate was measured, which is the value of the exposure rate before exposure to the C-Arm aircraft and the result was 0.01 μSv/h. The actual exposure rate is calculated by subtracting the background exposure rate result from the result displayed on the survey meter. There are six measurement points within the room with varying distances from the source. Meanwhile, there are 5 measurement points outside the room, including one for the room above the ESWL room. Each measurement were taken from a distance of 30 cm away from the wall.

The result of the measurements obtained will be compared to the exposure rate limit value that workers and the public can receive based on BAPETEN regulation No.4 of 2013. The exposure limit value for workers is 1.5 μSv/h, and for the public, it is 0.15 μSv/h [12][13]. The measurement findings at points G, H, I, J, and K indicate radiation exposure rates below the prescribed limits of 0.013, 0.037, 0.037, 0.097, and 0.027 μSv/hour, respectively. Additional exposure rate measurements using the C-Arm modality were conducted in a distinct area, specifically the Cathlab room. Simanjuntak, et al documented that within the Cathlab room, with a measurement distance of 30 cm from the wall, exposure rate readings ranged approximately between 0.1-0.2 μSv/hour, surpassing the exposure rate findings obtained in the ESWL room [14]. Various factors may contribute to these differing exposure outcomes, including disparities in room dimensions between the ESWL and Cathlab rooms, as well as variations in the thickness of radiation shielding utilized. The Cathlab room exhibits insufficient radiation shielding thickness, resulting in elevated exposure rate measurements, whereas the ESWL room's shielding thickness aligns with standards. Conversely, findings from Dian, et al suggest that the radiation exposure rate in the Cathlab room hovers around 0.01-0.03 μSv/hour, akin to measurement outcomes in intervention rooms like the ESWL room [15]. This convergence could be attributed to both rooms meeting the standard radiation shielding thickness, thereby averting leakage.

4. Conclusions

The lead-based radiation shield implemented at XYZ Hospital adheres to the prescribed minimum thickness stipulated in NCRP Report No. 147. Calculations indicate that the determined thickness of the radiation shield falls below the installed thickness of 2 mm Pb. Conversely, within the hospital's concrete structure, the radiation shield encircling the designated room measures 200 mm in thickness. However, this falls short of meeting the minimum requirement outlined in NCRP Report No. 147. Nevertheless, the upper portion of the room's concrete structure satisfies the specified minimum thickness requirement. Despite this discrepancy, the ESWL room at XYZ Hospital remains in compliance with radiation protection standards, thanks to the adequate lead thickness that prevents radiation leakage, mitigating potential risks to the community. This is substantiated by exposure rate calculations conducted around the ESWL room, which consistently register below the BAPETEN-set limit of 0.15 μSv/h for community exposure. However, it's noted that the exposure rate within the ESWL room exceeds the BAPETEN-set limit of 1.5 μSv/h for workers. Consequently, heightened vigilance is warranted for workers, such as nurses and doctors, involved in procedures [16]. It's recommended that these workers wear double aprons during treatments to minimize bodily exposure [17]. It's observed that radiation exposure within a room escalates as the measuring device approaches the radiation source, in line with Bhanot and Hameed assertion that closer proximity to the radiation source corresponds to increased direct and scattered radiation exposure [1].

References

[1] Bhanot, R., & Hameed, Z. B. M. "ALARA in Urology: Steps to Minimize Radiation Exposure During All Parts of the Endourological Journey," Current Urology Report, 23, 255-259, (2022).

[2] Baralo, B., Samson, P., Hoenig, D., & Smith, A. "Percutaneous kidney stone surgery and radiation exposure: A review," Asian journal of urology, 7(1), 10-17, (2020).

[3] König, A. M., Etzel, R., Thomas, R. P., & Mahnken, A. H. "Personal radiation protection and corresponding dosimetry in interventional radiology: an overview and future developments," In RöFo-Fortschritte auf dem Gebiet der Röntgenstrahlen und der bildgebenden Verfahren, 191(6), 512-521, (2019).

[4] Kaatsch, H. L., Schneider, J., Brockmann, C., Brockmann, M. A., Overhoff, D., Becker, B. V., & Waldeck, S. "Radiation exposure during angiographic interventions in interventional radiology–risk and fate of advanced procedures," International journal of radiation biology, 98(5), (2022).

[5] Soison, J., & Usawachintachit, M. "Radiation safety and protection in urology," Insight Urology, 43(2), 140-9, (2022).

[6] Ayu, M. S. K. "Proteksi Radiasi Pada Pasien, Pekerja, dan Lingkungan di Dalam Instalasi Radiologi," Inst. Ilmu Kesehat. Str. Indones., (2020).

[7] Manik, J. W., & Hakim, L. "Analysis of Radiation Barrier Design in Peat Soil Using NCRP Method No. 147 at Murjani Regional Hospital," Journal of Social Research, 2(10), 3742-3749, (2023).

[8] National Council on radiation Protection and Measurement. "NCRP Report No.147: Structural

Shielding Design for Medical X-ray Imaging Facilities," Maryland: NCRP, (2004).
[9] Kim, C. G. "Measurement and Analysis of Environmental Radiation in The Extracorporeal Shock Wave Lithotripsy Laboratory," Journal of Survey in Fisheries Sciences, 10(4S), 462-471, (2023).
[10] International Atomic Energy Agency. "Radiation Protection and Safety in Medical Uses of Ionizing Radiation," International Atomic Energy Agency, (2016).
[11] Fitriani, E., & Wibowo, G. M. "Pengukuran Laju Paparan Radiasi Pada Ruang Pemeriksaan Msct 64 Slice," JRI (Jurnal Radiografer Indonesia), 1(2), 85-89, (2018).
[12] BAPETEN. "Peraturan Kepala Badan Nuklir Nomor 8 Tahun 2011 tentang Keselamatan Radiasi dalam Penggunaan Pesawat Sinar-x Radiologi Diagnostik dan Intervensional. Jakarta," (2011).
[13] BAPETEN. Peraturan Kepala Badan Pengawas Tenaga Nuklir Nomor 4 Tahun 2013 Tentang Proteksi Radiasi Dan Keselamatan Radiasi Dalam Pemanfaatan Tenaga Nuklir. Jakarta, (2013).
[14] Simanjuntak Josepa, Martua Damanik, & Elvita Rahmi Daulay. "Analisis penahan radiasi ruangan radiologi intervensi cathlab sebagai upaya proteksi keselamatan radiasi di RSUP H. Adam Malik Medan," Prosiding Seminar Si-INTAN, Vol 2, No. 1, pp 28-38, (2022).
[15] Dian, F., Poedjomartono, B., & Trikasjono, T. "Analisis Keselamatan Radiasi Tindakan Radiologi Intervensional dan Kateterisasi Jantung Vaskular di Cath-Lab Room RSUP Dr. Sardjito," J Radiol Indones, 1(1), 10-22, (2015).
[16] Savitri, Leily & Wawan Susanto. "Pengawasan Paparan Pekerja di Fasilitas Radiologi Intervensional," (Seminar Keselamatan Nuklir 2014 Makalah Penyaji Oral. Bidang Fasilitas Radiasi dan Zat Radioaktif), (2014).
[17] Dari, D. W., Wulandari, P. I., & Kusman, K. "Evaluasi Implementasi Proteksi Radiasi Di Ruang Radiologi Intervensi Instalasi Rir Rsup Prof. Dr. Igng Ngoerah," Humantech: Jurnal Ilmiah Multidisiplin Indonesia, 2(3), 604-619, (2023).