The evaluation the magnitude radiation exposure dose rate in digital radiography room design

Agung Dwiyanto1, Wahyu Setia Budi2, Gagoek Hardiman1
1Department of Architecture, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia.
2Department of Physics, Faculty of Sciences and Mathematics, Universitas Diponegoro, Semarang, Indonesia.

Corresponding e-mail: agungdwie@gmail.com

Abstract. This study discusses the dose rate in digital radiography room, built according to meet the provisions of KEMENKES No.1014 / Menkes / SK / XI / 2008 and Regulation of BAPETEN No. 8 / 2011. The provisions primary concern of radiation safety, not comfort, by considering the space design. There are five aspects to consider in designing the space: functionality, comfort, security, movement activities and aesthetics. However provisions only met three aspects of the design, which are a function, security and movement activity. Therefore, it is necessary to evaluate digital radiography room in terms of its ability to control external radiation exposure to be safe and comfortable.

The dose rate is measured by the range of primary and secondary radiation in the observation points by using Surveymeter. All data are obtained by the preliminary survey prior to the study. Furthermore, the review of digital radiography room is done based on architectural design theory. The dose rate for recommended improvement room is recalculated using the same method as the actual room with the help of computer modeling.

The result of dose rate calculation at the inner and outer part of digital radiography observation room shows that in-room dose for a week at each measuring point exceeds the allowable dose limit both for staff and public. During a week of observation, the outdoor dose at some measuring points exceeds the dose limit set by the KEMENKES No.1014 / Menkes / SK / XI / 2008 and Regulation BAPETEN No 8/2011. Meanwhile, the result of dose rate calculation in the inner and outer part of the improved digital radiography room can meet the applicable regulations better.

Keywords: dose rate, range of primary and secondary radiation

1. Introduction

In the hospital architectural design, radiology ward is a central point of interest needed by other wards to support their functions. Almost every medical treatment in a hospital is done based on test and observation result of radiology ward. This ward uses the lowest exposure radioactive radiation from x-ray ionizing equipment. Radiology ward consists of three main parts: diagnostics containing ultrasonic application, fluoroscopic, etc.; radiation therapy; and nuclear treatment [9].

Diagnostic radiology needs special and wide building with suitable shape and construction for its usage. Since diagnostic radiology uses ionize radiation, the ward design should consider the safety against radiation.

In designing diagnostic radiology ward, current design must refer to the ministry of health regulation number 1014/Menkes/SK/XI/2008 and the regulation of head of BAPETEN number 8 year 2011. Those regulations emphasize the safety aspect but do not consider other aspects of architectural spatial design theory. It is important to design a safe and comfortable digital radiography ward.
This study will evaluate the magnitude of dose rate in an existed ward built based on current regulations and compare the result with the suggested ward design built based on architectural aspect design. The research object is digital radiography ward in government hospital Semarang.

1.1. Theoretical background

1.1.1. Radiation and Protection

Radiation is the emission of energy from a source to its surrounding without certain medium. Radioactive radiation is not always dangerous for human and environment; it can be used for human advantages if used properly. The negative effect of radioactive radiation when hitting human body will cause genetic, somatic, teratogenic, stochastic, and non-stochastic effect. Those effects lead to congenital disease such as radio dermatitis, cataract, infertility, and acute radiation syndrome. The danger of radioactive radiation cannot be felt and seen directly and is able to penetrate many materials.

The danger of external radiation depends on its penetration power through a medium; the higher the power, the bigger the radiation threat. Radiations with high penetration power are gamma, x-ray, and neutron radiation, while alpha and beta radiation have lower penetration power.

The protection to external radiation can be done through these steps:

- **Time factor**
  Radiation dose is the amount of radiation absorbed by certain objects including human body. The value of dose is equal to the accumulation of radiation intensity in certain period of time. Thus, the longer a person exposed to radiation, the bigger the amount of radiation absorbed by the person.

- **Distance factor**
  The source of radiation emits radiation to every direction forming ball shape. So, the further a person from the sources (the core of the ball), the less radiation absorbed.

NCRP stated those x-ray shields are in two categories, source shield and structural shield. The source shield is usually provided by x-ray tube manufacturer in the form of \( \text{Pb} \) shield which is also tube housing. The structural shield is designed to dispel the effect of x-ray. Calculating the regulated thickness of the shield can be done physically.

![Figure 1. Rendering the Rate of Radiation Dose](source: NCRP, Report No.49 Bethesda, 1976)

The x-ray instrument emits x-ray pulse (primary pulse) directed to patient (M) in the distance dsca. That pulse penetrates the patient then weakened by the primary shield. The radiation leakage and primary pulse that hit the patient cause radiation scattering. X-ray tube leakage radiation and scattered radiation will be weakened by secondary shield. Clearer picture of radiation can be seen in figure:

![Figure 2. Exposure in x-ray ward](source: NCRP, Report No.49 Bethesda, 1976)
(a) Primary radiation from focal spot.
(b) Leakage radiation from x-ray tube.
(c) Scattered radiation from the patient.

1.2. Attenuation
Attenuation is the disappearance of foton from x-ray pulse after penetrating the matter caused by absorbance and scattering on primary foton [2]. The process of x-ray radiation weakening in a certain shield material is exponential based on equation (1).

\[ I = I_0 e^{-\mu x} \]

where \( I \) is radiation intensity after penetration, \( I_0 \) is the intensity before penetration, \( \mu \) is coefficient of linear absorbent of material (cm\(^{-1}\) or m\(^{-1}\)), and \( x \) is the thickness of material (cm or m) [3].

Kara, U in his journal A Study on Radiation in Operating Room in Suleyman Demirel University (2016) stated that the minimum radiation safety is the most important thing considering the long term effect of radiation.

Rostamzadeh in his journal Evaluation of the Level of Protection in Radiology Departments of Kermanshah, Iran (2015) stated that the awareness of medical staff in using equipment and applying radiation protection procedure is very low.

1.3. Spatial Design in Architecture
Many experts in spatial and building design argued that there are no fixed rules in terms of designing since everything depends on the types, functions, and kinds of space. However, there are five fixed aspects that should present and be considered in designing a space or a building. These five aspects are connected to each other to make optimal result as seen in table:

**Table 1.** Basic aspects in space and building design

| ESTETIC | SAFETY | COMFORT | FUNCTION | TRAFFIC |
|---------|--------|---------|----------|---------|
| Harmony | power/strong rules | Sense | Detail | Enclosure achievement efficiency |
| Scale | View | display element truth | pressure | traffic |
| color balance | Light/shade lighting | vitality | volume | |
| layout | | | character identity | |
| Simplicity | | | | |
| Rhythm | | | | |
| Similarity | | | | |
| Continuity | | | | |
| Unity | | | | |
| Formality contrast | | | | |
| Performer | | | | |

**Table 2.** The relationship among basic aspects of design

2. Methods
2.1. Time and Place for Data Collection
Data are collected from June to August, 2015 in government hospital Semarang at digital radiography room of radiology ward.
2.2. Tool and Material

The researcher uses surveymetergamma tool to detect rate of radiation dose in digital radiography room and uses measuring band to measure the range of primary and secondary radiation of focal spot (0.3 meters outside the shield). The material of the shield is the composition of wall and door of the room as shown in the figure.

![Figure 3. The composition of wall and door of the room](image)

2.3. Research Procedure

Generally, this research consists of four steps. First, the initial survey conducted before the research. Second, the measurement of dose rate measured inside and outside the room. Third, complete data collection which is shown in the research diagram.

3. Discussion

3.1. The Measurement of Radiation Exposure Dose Rate in Existing Digital Radiography Room

The position of measurement of dose rate inside and outside the digital radiography room is shown on figure

![Figure 4. Measuring point positions for dose rate measurement in digital radiography room government Hospital](image)
### Table 3. The Calculation of Exposure Dose Rate

| POSITION | MEASUREMENT POINT | DISTANCE (M) | EXPOSURE DOSE RATE (mSv/week) |
|----------|-------------------|--------------|-------------------------------|
| INDOOR   | A                 | 1.45         | 0.47                          |
|          | B                 | 2            | 0.19                          |
|          | C                 | 1.71         | 0.43                          |
|          | D                 | 2.2          | 2.97                          |
|          | E                 | 5.9          | 1.02                          |
|          | F                 | 4.7          | 2.08                          |
|          | G                 | 1.6          | 0.0251                        |
| OUTDOOR  | H                 | 2.15         | 0.0410                        |
|          | I                 | 1.77         | 0.056                         |
|          | J                 | 0.35         | 0.0055                        |
|          | K                 | 6.05         | 0.0259                        |
|          | L                 | 4.74         | 0.0328                        |

3.2. Evaluation

The evaluation of NBD exposure dose rate for staff is effectively 20 mSv/year or equal to 0.4 mSv/week. Based on the Ministry of Health regulation number 1014/Menkes/SK/XI/2008, NBD for public is effectively 1 mSv/year (0.02 mSv/week).

The rate of radiation dose in the digital radiography room fulfills the principle of distance arrangement of radiation safety in which the rate of radiation dose inversely proportional to quadrate of distance. So, the bigger the range of radiation to a certain measurement point, the lower the measured dose rate will be. In terms of measurement, the rate of dose is different in point D and point F; point F has lower rate. This is because the radiation on measuring point F has been weakened when penetrating the patient and pre-shielding. Thus, the detection rate of the radiation dose on that measuring point is very low.

The measuring of dose rate outside the area of digital radiography room shows that point G has the highest rate because the rate of the dose before penetrating the shield on point A is also the highest one. Thus, the highest outdoor radiation is on point G. Then, the lowest rate of dose is found in point K since the rate of the dose before penetrating the shield on point E is the lowest. However, the increase of dose rate occurs in point L caused by the leakage through unlocked door.

A week dose in the room on each measuring point exceeds the dose tolerance for staff and public. However, the outdoor dose for staff on point I and J is under the dose tolerance regulated by Perka BAPETEN. Moreover, the dose on point G, K, and L also exceed the dose tolerance regulated by the Ministry of Health.

Considering the fact that patients, their families and relatives do not stay for a long time in measuring point G, and H, the rate of dose received by them on point G,H,K, and L is still under the dose tolerance.

Moreover, based on the dose received in every measuring point, point G as the only spot full of patients and their guardians has the dose above 0.02 mSv/week, while point K and L has the dose under 0.02 mSv/week. The point I and J, where the staff works, has the dose above 0.4 mSv/week. Point H, where the staff and public commonly interact, has the dose above 0.4 mSv/week.

3.3. Digital Radiography Room Based on Review (after completed based on iso-exposure and architectural spatial design aspects)

The measurement spots to calculate dose rate inside and outside the digital radiography room are planned similar to the existing measuring points with improved design. The design can be seen on figure.
The improvement/ the review result on existing room is based on iso-exposure as portrayed on the result of measurement of the dose rate on the initial research. The initial research result shows that measuring point G (USG room) and point H (public corridor) do not fulfill the regulated weekly tolerance level of exposure for staff and public. Both of the room also do not fulfill the aspect of spatial design in architecture which are the traffic aspect for patient and medical staff and the positioning aspect of radiography equipment inside the room.

By adding the width of the room and changing the position of the equipment, the dimension of the room becomes 6mx5m.

This way, the measurement of dose rate of radiation exposure on digital radiography room is improved. The improvement is in terms of the decrease of the exposure dose rate inside and outside the room. However, the weekly rate of dose inside the room is still above tolerance level which is 0.4 mSv/week. The weekly rate of dose on the outside is also still above tolerance level which is 0.02 mSv/week.

Eventhough the measurement of the radiation dose rate is relatively the same, the improved design of the digital radiography room has minimized the radiation exposure. The measurement in this room shows that its rate of radiation exposure dose is still under tolerance level considering the real condition on the field and the position of medical staff and public on exposed site. This can be seen on the table below:

| POSITION | MEASUREMENT POINT | EXPOSURE DISTANCE (m) | EXPOSURE RATE (uSv/week) | EXPOSURE RATE (uSv/week) |
|----------|-------------------|------------------------|---------------------------|---------------------------|
|          | A                 | 1.40                   | 1.67                      | 0.25                      |
|          | B                 | 1.60                   | 0.19                      | 0.01                      |
|          | C                 | 1.70                   | 0.42                      | 0.46                      |
|          | D                 | 1.80                   | 3.77                      | 4.41                      |
|          | E                 | 5.90                   | 1.11                      | 0.01                      |
|          | F                 | 4.70                   | 1.41                      | 0.01                      |
|          | G                 | 1.60                   | 0.01                      | 0.00                      |
|          | H                 | 2.19                   | 0.05                      | 0.05                      |
|          | I                 | 3.77                   | 0.01                      | 0.01                      |
|          | J                 | 5.90                   | 0.05                      | 0.05                      |
|          | K                 | 4.99                   | 0.03                      | 0.03                      |
|          | L                 | 4.70                   | 0.03                      | 0.03                      |

Table 4. The Result of Radiation Exposure Dose Rate Measurement in Recommended
4. Conclusion

Based on the result and explanation of this research, the conclusions are:

- The design of digital radiography room with five aspects of architectural design gives protection to the exposure of radiation and adds comfortability to the room.
- The position of medical supporting room should be parallel with the position of digital radiography equipment. It is minimal 2.3m behind the equipment.
- The position of the main door should be parallel with the radiation absorber panel.
- The corridor and waiting room should be positioned on the horizontal side toward digital radiography equipment.

5. References

[1] Akhadi Mukhlis, (2000). Dasar-dasar Proteksi Radiasi, Rineka Cipta, Jogjakarta.
[2] Badan Tenaga Nusional, Pedoman Proteksi Radiasi di Rumah Sakit, 1995
[3] Perka Bapeten nomor 8 tahun 2011 tentang, KESELAMATAN RADIASI DALAM PENGGUNAAN PESAWAT SINAR-X RADIOLOGI DIAGNOSTIK DAN INTERVENSIONAL
[4] Cember,H., dan E.J. Thomas, 2009, Introduction to Health Physics, Fourth Edition, The McGraw-Hill Companies, Inc., New York.
[5] Depkes RI, (1999), Standar Pelayanan Radiologi Rumah Sakit Umum Klas B,C dan D.
[6] Departemen Kesehatan RI, (1997) Pedoman Pemasangan Dinding Ruang Radiasi,
[7] Djoko Maryanto, (2008), Analisis Keselamatan Kerja Radiasi Pesawat Sinar-X di Unit Radiologi RSU Kota Jogjakarta, makalah Seminar Nasional IV SDM Teknologi Nuklir, Jogjakarta,
[8] Francis DK Ching,(2000), Arsitektur-Bentuk, Ruang dan Tatanan, Erlangga.
[9] Friedr,V, (1982), Standart Rumah Sakit-Bagian Radiologi, Braunschweig, Germany.
[10] Hendee,W.R., dan E.R. Ritnour, 2002, Medical Imaging, Fourth Edition, A JOHN WILEY & SONS, INC., New York.
[11] Kara,U (2016), ‘A Study on Radiation in Operating Room in Suleyman Demirel University’, Acta Physica Polonica, A., 2016, Vol. 130 Issue 1, p401-403. 3p
[12] Kementran Kesehatan RI, Pedoman Teknis Bangunan dan Prasarana Rumah Sakit 2013
[13] Permenkes RI No.780 tahun 2008 tentang Penyelenggaraan Pelayanan Radiologi di Rumah Sakit.
[14] Permenkes RI No.1014 tahun 2008 tentang Standar Pelayanan Radiologi Diagnostik di Sarana Pelayanan Kesehatan.
[15] Perpu No. 33 tahun 2007 tentang Keselamatan Radiasi Pengion dan Keamanan Sumber Radioaktif.
[16] Rostenberg Bill, FAIA, FACHA,(2006), The Architecture of Medical Imaging-Designing Healthcare Facilities for Advance Radiological Diagnostic and Therapeutic Techniques John Wiley, New Jersey,Canada.
[17] Rostamzadeh, Ayyob (2015),’ Evaluation of the Level of Protection in Radiology Departments of Kermanshah, Iran, Iranian Journal of Medical Physics, Summer2015, Vol. 12 Issue 3, p200-208. 9p
[18] Sukada, B. (2006). Kegagalan sebuah Karya Arsitektur; dapatkah diukur? Jakarta: Universitas Pelita Harapan-Lippo Karawaci