PERSONNEL DOSE MONITORING DURING FLUOROSCOPY-GUIDED INTERVENTIONAL (FGI) PROCEDURES AT INSTITUT KANSER NEGARA

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ABSTRACT

The number of fluoroscopy-guided interventional (FGI) procedures has significantly increased recently. The radiology department staff such as the interventional radiologists (IR), medical officers (MO), radiographers and nurses who are involved in FGI procedures are usually working in a controlled area and receive doses primarily from scattered radiation off the patient. This was a one-year observation study conducted at the Radiology Department, Institut Kanser Negara (IKN), Putrajaya. Each interventional radiology staff member was given two optically-stimulated luminescence (OSL) dosimeters, used to measure the dose of radiation they received. In this study, two types of OSL dosimeter (OSLD) were used: InLight® XA dosimeter and nanoDot® dosimeter. The effective doses received by the interventional radiology staff after performing 230 FGI procedures were estimated using single and double dosimetry algorithms. Assessment on the interchangeability of the effective dose algorithms shows that both Niklason and Boetticher algorithms strongly supported the absence of statistical significance in the estimated effective doses using the Bland-Altman analysis. The effective dose received by the IRs, MOs, radiographers and nurses with double OSLDs were 9.82, 7.91, 6.42 and 6.02 mSv, respectively. The estimated annual eye dose for IR was 18.32 mSv y^{-1} and is below the recommended dose limit (20 mSv y^{-1}). Due to the IR's position on the left side of the patient, the right eye shows a lower dose than the left one. Radiation scattered throughout the FGI room shows the left anterior oblique 90° tube angulation has the highest single peak distribution (28.65 mSv h^{-1}). The single peak distributions for the standard anteroposterior, left anterior oblique 45° and right anterior oblique 45° imaging were 13.32, 22.99 and 17.40 mSv h^{-1}, respectively. Knowledge pertaining to radiation exposure levels is integral in order to avoid adverse risks, particularly amongst staff. It is highly recommended that interventional radiology staff use double OSLDs during FGI procedures in order to determine the occupational dose accurately.

ABSTRAK

Bilangan prosedur intervensional berpandu fluoroskopi (FGI) telah meningkat dengan ketara baru-baru ini. Staf jabatan radiologi seperti pakar radiologi intervensional (IR), pegawai perubatan (MO), jururadiografi dan jururawat yang terlibat dalam prosedur FGI biasanya bekerja dalam kawasan kawalan dan menerima dos terutamanya dari sinaran terserak daripada pesakit. Ini adalah cerapan kajian selama satu tahun yang dijalankan di Jabatan Radiologi, Institut Kanser Negara (IKN), Putrajaya. Setiap staf radiologi intervensional dibekalkan dengan dua dosimeter perdarkilau terangsang secara optik (OSL) digunakan untuk mengukur dos sinaran yang diterima oleh mereka. Dalam kajian ini, dua jenis dosimeter OSL (OSLD) telah digunakan: dosimeter InLight® XA dan dosimeter nanoDot®. Dos efektif yang diterima oleh kakitangan radiologi intervensional selepas melakukan 230 prosedur FGI dianggarkan dengan menggunakan algoritma dosimeter tunggal dan berganda. Penaksiran kesalingbolehtukaran antara algoritma dos efektif menunjukkan bahawa algoritma Niklason dan Boetticher sangat menyokong ketiadaan keertian statistik di dalam kedua-dua anggaran dos efektif dengan menggunakan analisis Bland-Altman. Dos efektif yang diterima oleh IR, MO, jururadiografi dan jururawat dengan memakai OSLD berganda masing-masing adalah 9.82, 7.91, 6.42 dan 6.02 mSv. Anggaran dos mata tahunan bagi IR ialah 18.32 mSv y^{-1} dan adalah di bawah had dos yang disyorkan (20 mSv y^{-1}). Disebabkan oleh posisi IR pada sebelah kiri pesakit, mata kanan menunjukkan dos yang lebih rendah daripada mata kiri. Sinaran terserak di seluruh bilik FGI menunjukkan tiub angulasi anterior kiri serong 90° mempunyai taburan puncak tunggal tertinggi (28.65 mSv h^{-1}). Taburan puncak tunggal untuk pengimejan anteroposterior piawai, anterior kiri serong 45° dan anterior kanan serong 45° menunjukkan 13.32, 22.99 dan 17.40 mSv h^{-1}. Ilmu yang berkaitan dengan tahap dedahan sinaran adalah penting untuk mengelakkan risiko mudarat, terutamanya di kalangan staf. Staf radiologi intervensional adalah sangat disarankan untuk menggunakan OSLD berganda semasa prosedur FGI bagi menentukan dos pekerjaan yang tepat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADRC	-	Automatic dose rate control
AELB	-	Atomic Energy Licensing Board
AK	-	Air kerma
ALARA	-	As low as reasonably achievable
AP	-	Standard anteroposterior
CA	-	Coronary angiography
CI	-	Confidence interval
CoV	-	Coefficient of variation
CT	-	Computed tomography
CW-OSL	-	Continuous-wave OSL
DAP	-	Dose area product
DNA	-	Deoxyribonucleic acid
DOSL	-	Delayed OSL
DSA	-	Digital subtraction angiography
FGI	-	Fluoroscopy-guided interventional
FT	-	Fluoroscopy time
HP	-	Home Position
HVL	-	Half value layer
IC	-	Interventional cardiologist
ICRP	-	International Commission on Radiological Protection
ICRU	-	International Commission on Radiations Units and Measurements
IMRT	-	Intensity-modulated radiation therapy
IORT	-	Intraoperative radiation therapy
IR	-	Interventional radiologist
IRPA	-	International Radiation Protection Association
ISO	-	International Organisation for Standardisation
LAO45	-	Left anterior oblique 45°
LAO90	-	Left anterior oblique 90°
LED	-	Light emitting diode

LM-OSL	-	Linear modulated OSL
LOA	-	Limits of agreement
MO	-	Medical officer
NCRP	-	National Council on Radiation Protection
NCS	-	Netherlands Commission on Radiation Dosimetry
ORAMED	-	Optimization of Radiation Protection for Medical Staff
OSL	-	Optically stimulated luminescence
OSLD	-	Optically stimulated luminescence dosimeter
PCI	-	Percutaneous coronary interventions
PED	-	Personal electronic dosimeter
PMMA	-	Polymethyl-methacrylate
PMT	-	Photomultiplier tube
POSL	-	Pulsed OSL
PVC	-	Polyvinyl chloride
RAO45	-	Right anterior oblique 45°
RPL	-	Radio-photoluminescence
RQR	-	Radiation Qualities in Radiography
SAR	-	Single aliquot regenerative dose
SD	-	Standard deviation
SID	-	Source image distance
SNR	-	Signal to noise ratio
SSDL	-	Secondary Standard Dosimetry Laboratory
TL	-	thermoluminescence
TLD	-	Thermoluminescence dosimeter
UTM	-	Universiti Teknologi Malaysia
UV	-	Ultraviolet
XRII	-	X ray image intensifier

LIST OF SYMBOLS

D	-	Absorbed dose
$d\bar{\varepsilon}$	-	Mean energy
dm	-	Mass
w_R	-	Radiation weighting factor
E	-	Effective dose
w_T	-	Tissue weighting factor
H_T	-	Tissue equivalent doses
Hp(10)	-	Deep dose
H_{under}		Hp(10) under protective lead apron
$H_{outside}$		Hp(10) outside the protective lead apron
Hp(0.07)		Shallow dose

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

A fluoroscopy-guided interventional (FGI) procedure is a process to guide small tools, such as catheters, using ionising radiation, through blood vessels or other paths in the body. FGI represents a significant advantage over invasive surgical procedures due to the minimal incisions required, the substantially reduced risk of infection, and shorter recovery time compared to surgical procedures. These interventions are used by a growing number of health workers in a wide range of medical fields. However, most of these experts have only moderate training in radiation disciplines or protective measures.

Borrego et al. (2019) reported that interventional radiologists performing FGI procedures have among the highest exposure levels to ionising radiation compared to other workers in the medical field. Although their occupational dose is within the United States' regulatory limit, they still require accurate and persistent dose monitoring. The finding shows that the improper placement of badges is one of the significant problems affecting the gathering of precise information from one-badge and two-badge monitoring protocols. The current eye dose limit recommended by the International Commission on Radiological Protection (ICRP) is being considered, due to the increase in cataract formation incidents related to radiation exposure.

Even though they are under dose monitoring, 15% of the workers performing FGI received a dose exceeding the annual eye dose limit (20 mSv), and their median for the annual eye dose was higher than the estimated mean dose among medical radiation workers in the United States (Borrego et al., 2019). Due to these findings, the dose received by interventional radiology staff who perform FGI procedures should be monitored continuously to evaluate short- and long-term ionising radiation exposure.

There are two main objectives of using ionising radiation in medicine: i) diagnostic and ii) therapeutic. Diagnosis is related to identifying the patient's disease or illness, whereas therapeutic is relating to the treatment of disease or illness. Regarding the ionising radiation fields in diagnostic radiology and radiation therapy, there are two main differences: photon energy and tissue dose. Diagnostic radiology uses X-ray beams with typical energies < 140 keV, whereas radiation therapy uses typical energy in the MeV range in the case of photon and electron beams. The primary purpose of diagnostic radiology is to produce a good quality image for clear understanding by the radiologist. Increasing the image quality increases the dose to the patient. This is of primary concern because the principle of using ionising radiation is to keep the patient's dose as low as possible without affecting image quality.

The increasing use and complexity of FGI procedures implemented by public health bodies causes concern regarding the results of increased radiation exposure to interventional radiology staff and patients. Increased numbers of people have reported severe skin injuries. A significant increase in delayed effects such as lens injuries and cataracts, and possibly cancer, necessitates more information on radiation risks and on plans to control radiation exposure to patients and interventional radiology staff.

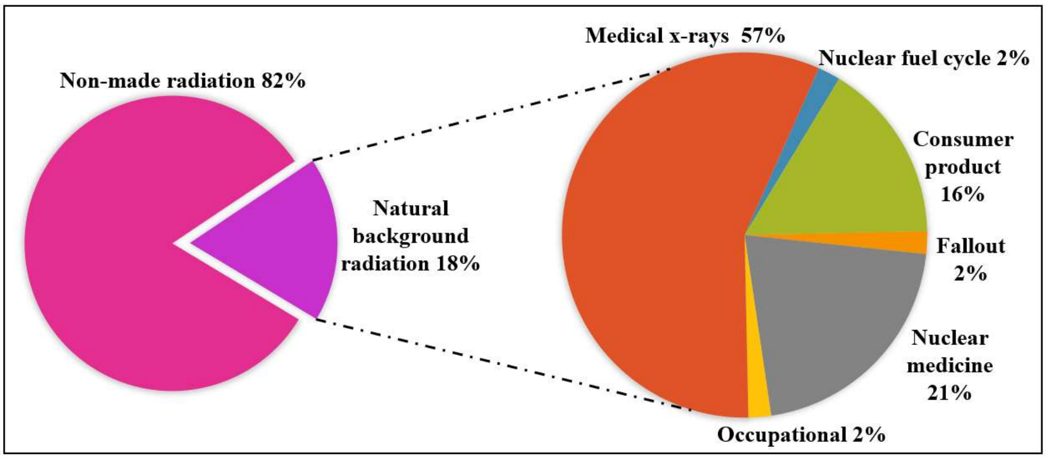

Figure 1.1 Energetic causes of cancer (Cantley et al., 2012)

Several risk factors closely associated with cancer risk are possible to avoid, but others are more difficult to escape; one of which is ionising radiation, said to energise cancer. Both natural and man-made sources emit ionising radiation, as shown in Figure 1.1. Annual exposure in the United States to ionising radiation composed of natural background radiation was 82%, and the remaining 18% comes from man-made sources. From the non-made radiation, 2% of cases of cancer are caused by an occupational dose. If awareness of risk continues to be low, this number will increase, even though its contribution to the total is minimal.

The earliest medical groups that were exposed to ionising radiation were interventional radiology staff. They represent a large proportion of the occupational groups exposed to non-made radiation. Yoshinaga et al. (2004) reported that more than 270 000 radiology staff employed before the 1950s, from eight cohorts, showed the evaluation of cancer risk continually increased due to high radiation exposure. An increased risk of leukaemia related to the duration of work in the early years, showed a clear relation to radiation exposure during that period. Nowadays, FGI procedures only take a short time due to hi-tech equipment and modern medical practices. Still, it is crucial to continue personnel monitoring among the interventional radiology staff.

The radiation beam in FGI procedures is targeted for a substantial length of time at a relatively small patch of skin. Of any portion of the patient's body, the highest radiation dose will be received by the skin area. It is enough to cause a sunburn-like injury, hair loss or, in rare cases, skin necrosis (Mettler et al., 2002). Threshold doses for potential radiation effects with a related time of onset were shown in Table 1.1.

Table 1.1 Potential effects of fluoroscopic exposures on the reaction skin and lens of the eye (Valentin, 2000)

Effect	Approximate threshold dose (Gy)	Time of onset
Early transient erythema	2	2 – 24 hours
Main erythema reaction	6	≈ 1.5 weeks
Temporary epilation	3	≈ 3 weeks
Permanent epilation	7	≈ 3 weeks

Effect	Approximate threshold dose (Gy)	Time of onset
Dry desquamation	14	≈ 4 weeks
Late erythema	15	8 – 10 weeks
Dermal necrosis	> 12	> 52 weeks
Skin cancer	None known	> 15 years
Lens opacity	> 1 – 2	> 5 years
Lens/cataract	> 5	> 5 years

The procedures most frequently reported for the highest doses are percutaneous transluminal coronary angioplasty (PTCA), radiofrequency cardiac ablation (RFA) procedures, transjugular intrahepatic portosystemic shunt (TIPS) procedures and embolisation procedures in the brain (Koenig et al., 2001). High doses received by the patient in the procedure, as mentioned earlier, influence the doses due to scattered radiation received by the interventional radiology staff (interventional radiologists, medical officers, radiographers and nurses). Most of the research in monitoring interventional radiology staff doses uses a thermoluminescence dosimeter (TLD), which requires challenging preparation and complex readouts (Reuven, 2001; Olko, 2010).

1.2 Problem statement

In current decades, for dose limitation determination, ICRP has categorised all diverse radiation effects into stochastic effects (with no threshold) or tissue reactions (previously called non-stochastic or deterministic effects, which do have a threshold). The purpose of effective dose limits is to reduce the risk of stochastic effects (heritable effects/cancer). It is based on detriment-adjusted nominal risk coefficients, assuming a linear-non-threshold dose response and a dose and dose rate effectiveness factor of 2. Otherwise, equivalent dose limits aim to avoid tissue reactions and are based on a threshold dose.

Injury to the skin (deterministic risk) is more likely to occur in adult patients during FGI procedures compared to children. The stochastic risk among children is more important, as it is four times greater for a child aged 10 years than the same KAP received by adults (IAEA, 2010). Interventional radiology staff also face the risk of stochastic effects. Nevertheless, skin reactions happen if the radiation personnel's hands are regularly in the primary beam.

The primary purposes of personnel monitoring are to assess whether staff in the radiation control area have exceeded the dose limits and, through regular review, to assess the effectiveness of strategies being used for optimisation. It must always be a reminder that monitoring does not reduce dose, but it will help in reducing personnel exposure. In the radiology department, personnel monitoring should be carried out for staff, including the interventional radiologists, medical officers, radiographers and nurses, who are generally exposed to radiation in the X-ray room. Cardiologists and other specialists who perform FGI procedures are also candidates for personnel monitoring. Personnel dosimeters are designed to estimate either the effective dose or an equivalent dose to an organ. There are many types of individual dosimeters, such as optically stimulated luminescence dosimeters (OSLD), TLDs, film badges and a variety of electronic devices.

A basic radiation monitor worn at the collar level and above the radioprotective attire provides a reasonable estimate of eye dose. Unprotected eyes receive approximately the dose indicated by such a monitor. The use of high-quality radioprotective glasses will decrease the eye dose to nearly 1/3 of the monitor reading. This is less than the nominal reduction of the radioprotective lenses. This is because radiation can be received by the eyes through spread around the glasses and scatter within the radiation personnel's head. Cardiologists, interventional radiologists and other medical doctors using fluoroscopy in the operating room are the individuals who remain near to the patient during the procedure. These individuals might be within a high scatter X-ray radiation area for certain hours every day during procedures.

For radiation protection of staff in FGI procedures, personnel dosimetry is one of the ten rules of radiation protection of staff in fluoroscopy that must be taken into consideration. During FGI procedures, interventional radiology staff have been recommended to use at least two dosimeters, with one inside the protective apron at chest level and the other outside the protective apron at neck level. Contrary to this recommendation, radiology staff in hospitals such as Institut Kanser Negara (IKN), Putrajaya, wear only one dosimeter placed inside the protective apron, which may not fully represent the personnel effective dose. Ideally, the effective dose should represent the stochastic health risk to the whole body, which is the probability of cancer induction and genetic effects resulting from low dose ionising radiation. At the same time, the dose report of interventional radiology staff provided by the Atomic Energy Licensing Board (AELB) only comprises the shallow dose or Hp(0.07) and deep dose or Hp(10).

Due to unsuitable protective equipment and improper operational measurement, the risk for eye lens injuries is increased. Current studies have recognised the correlation between eye lens dose and patient dose in terms of dose area product (DAP). This correlation has a factor for estimating eye lens dose without measurements. DAP may be useful as a replacement measure of eye lens dose to the operator if the eye lens dosimeter is unavailable. Typically, 1 Gy cm^2 to the patient resulted in an average of 10 μSv to the unprotected eyes of the primary radiation personnel, or 1 μSv when a protective, ceiling-suspended screen (without glass eyewear) is used.

The eye lens dose limit has already been reduced from 150 mSv y^{-1} to 20 mSv y^{-1} based on new regulations (ICRP, 2011). But for interventional radiology staff in the Institut Kanser Negara, Putrajaya, especially the radiologists, there exists no documented report regarding the eye lens dose. Hence, to prevent the risk of eye injuries during FGI procedures in IKN, it is imperative to design a mechanism that allows routine monitoring of eye lens dose, since there is no established protocol.

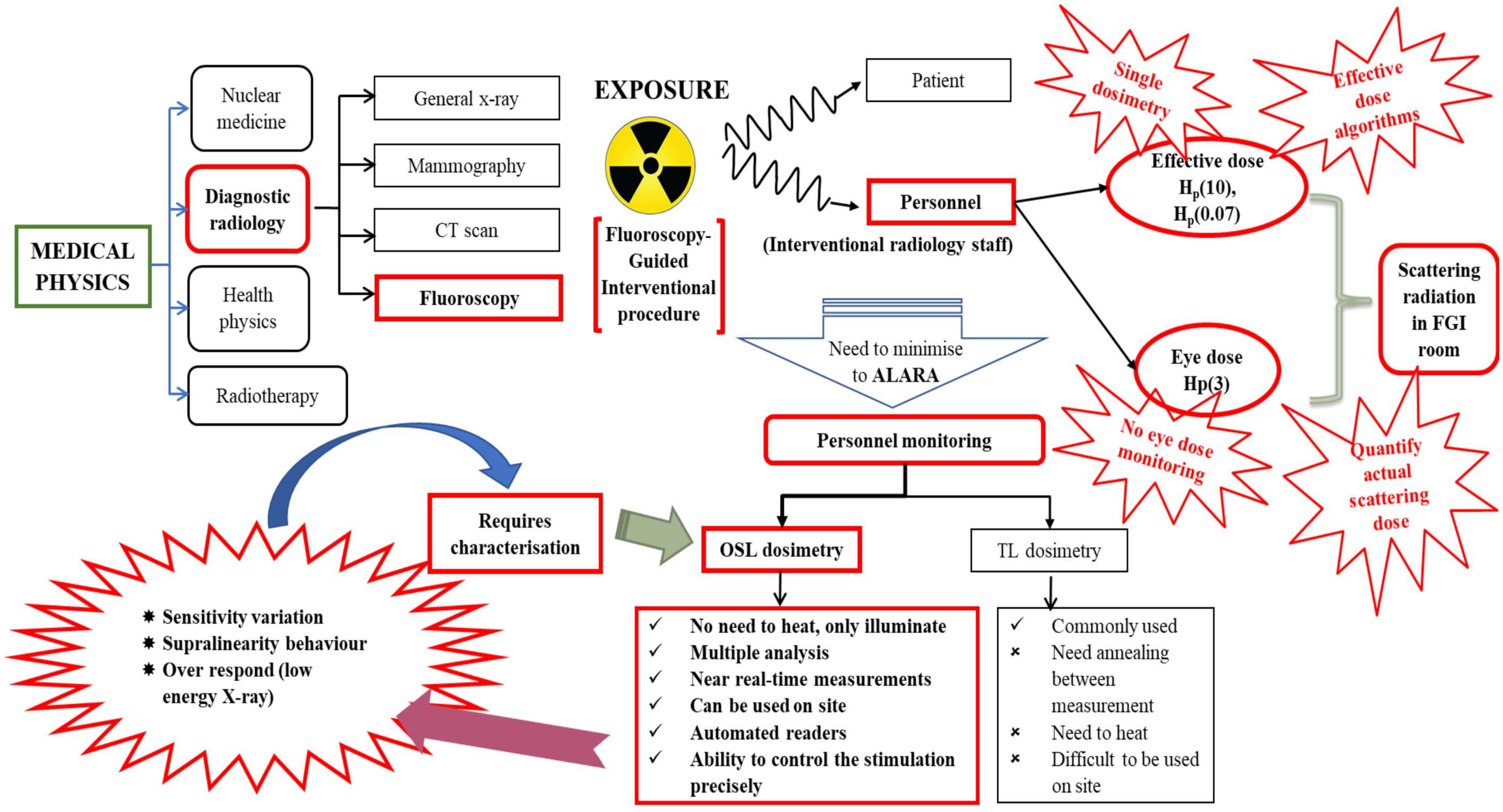

Figure 1.2 Overview of the problem statement

1.3 Aim and Objectives of the Study

This study aims to assess personnel monitoring during FGI procedures at Institut Kanser Negara, Putrajaya, using an optically stimulated luminescence (OSL) dosimetry system provided by Universiti Teknologi Malaysia (UTM). The objectives of this study are as follows:

i. To investigate the dosimetric characteristics of the OSL dosimetry system for personnel monitoring purposes, including sensitivity, dose-response and linearity, energy dependence and angular dependence for the energy range 40 to 150 kV for doses ranging from 1 to 10 mGy.

ii. To assess the interchangeability of the effective dose algorithms for interventional radiology staff during FGI procedures.

iii. To estimate the personnel effective dose for interventional radiology staff (interventional radiologists (IR), medical officers (MO), radiographers and nurses) during FGI procedures using single and double dosimetry.

iv. To determine the eye dose of the IR with and without protective lead glasses during FGI procedures.

v. To determine the actual radiation levels and the effects of scatter radiation on the FGI room, under various typical conditions of fluoroscopic imaging.

1.4 Scope of the Study

The current study was designed to assess personnel monitoring during FGI procedures among the staff involved in radiology at Institut Kanser Negara, Putrajaya. The use of the OSL dosimetry system supplied by Landauer Inc., provided by UTM, was to ensure the credibility of the system to give an accurate dose to improve awareness of risk among the interventional radiology staff.

The scope of the study is detailed as follows:

The InLight® XA and nanoDot® dosimeter is evaluated with different dosimetric characterisations, including sensitivity, dose-response and linearity, energy dependence and angular dependence for the energy range 40 to 150 kV, and different doses ranging from 1 to 10 mGy. The OSL dosimeters were irradiated to different energies under radiation qualities in radiography (RQR) conducted at the Secondary Standard Dosimetry Laboratory (SSDL), Agensi Nuklear Malaysia, and UTM.

The purpose of estimating the personnel effective dose using OSL dosimetry was to ensure the dose received by interventional radiology staff during FGI procedures does not exceed the annual limit for radiation workers i.e. 20 mSv in one year. This study also aims to gain more knowledge on the purpose of using single or double dosimetry during FGI procedures.

Malaysia's guidelines for occupational radiation protection uses the effective dose algorithm proposed by NCRP (Ministry of Health Malaysia, 2016b). Many researchers have created new effective dose algorithms based on FGI procedures for medical staff who work closely with the X-ray source. Assessment of the interchangeability of the algorithms that have strong mutual correlations to evaluate the effective dose of interventional radiology staff.

Most radiologists are not really concerned about the use of protective lead glasses during FGI procedures. The use of low dose radiation during FGI procedures may result in adverse effects on the eyes following continuous use and increased workload. The adverse long-term effect on unprotected eyes causes the interventional radiologist (IR) to develop cataracts (Rehani et al., 2011).

There are limitations to this study that could be addressed in future research. First, this study can be regarded as a pilot study focussing more on the general aspects of FGI procedures. All types of FGI procedures performed in IKN were taken as samples for calculation of dose workers. Priority in this study is on the number of dosimeters and not the procedure itself. Secondly, in the study presented here, the double dosimetry algorithm only involving the wearing of a thyroid collar is used for the estimation of the effective dose. This is due to all IKN staff being required to use a thyroid collar while performing FGI procedures.

1.5 Thesis Outline

This thesis is intended to give an extensive overview of personnel monitoring using the OSL dosimetry system during FGI procedures. The steps taken for realising the objectives were exclusively experimental, which involved the basic techniques of personnel monitoring and the OSL dosimetry system.

The thesis is sectioned into chapters, with Chapter 2 describing the use of OSL dosimetry in personnel monitoring during FGI procedures, as well as their previous and current status. Chapter 3 outlines the materials involved in carrying out this research and describes the methods used.

Chapter 4 is made up of the results and a discussion of the outlined objectives: (i) investigating the dosimetric characteristics of the OSL dosimetry system for personnel monitoring, (ii) estimating the personnel effective dose for interventional radiology staff during FGI procedures using single and double dosimetry, (iii) assessing the interchangeability of the effective dose algorithms for interventional radiology staff, (iv) determining the eye dose of the IR with and without protective lead glasses during FGI procedures, and (v) quantifying the actual radiation levels and the effects of scatter radiation on the FGI room, under various typical conditions of fluoroscopic imaging.

Chapter 5 consists of conclusions based on the results obtained. This chapter suggests some recommendations that might improve future studies involving personnel monitoring using OSL dosimetry systems with different modalities and procedures. It improves personnel awareness of medical radiation exposure results to keep the patient and personnel radiation dose as low as reasonably achievable (ALARA).

REFERENCES

Akselrod, M. S., Botter-Jensen, L. and McKeever, S. W. S. (2007) 'Optically stimulated luminescence and its use in medical dosimetry', *Radiation Measurements*, 41(1), S78–S99.

Akselrod, M. S., Kortov, V. S., Kravetsky, D. J. and Gotlib, V. I. (1990) 'Highly Sensitive Thermoluminescent Anion-Defect Alpha-Al_2O_3:C Single Crystal Detectors', *Radiation Protection Dosimetry*, 33(1–4), 119–122.

Akselrod, M. S., Larsen, N. A. and McKeever, S. W. S. (2000) 'Procedure for the distinction between static and dynamic radiation exposures of personal radiation badges using pulsed optically stimulated luminescence', *Radiation Measurements*, 32(3), 215–225.

Al-Abdulsalam, A. and Brindhaban, A. (2014) 'Occupational radiation exposure among the staff of departments of nuclear medicine and diagnostic radiology in Kuwait', *Medical Principles and Practice*, 23(2), 129–133.

Alejo, L., Koren, C., Corredoira, E., Sanchez, F., Bayón, J., Serrada, A. and Guibelalde, E. (2017) 'Eye lens dose correlations with personal dose equivalent and patient exposure in paediatric interventional cardiology performed with a fluoroscopic biplane system', *Physica Medica*, 36, 81–90.

Alvarez, P., Kry, S. F., Stingo, F. and Followill, D. (2017) 'TLD and OSLD dosimetry systems for remote audits of radiotherapy external beam calibration', *Radiation Measurements*, 106, 412–415.

Antonov-Romanovsky V. V., Keirim-Marcus I. D., Poroshina M. S., and Trapeznikova Z. A. (1955) Dosimetry of Ionizing radiation with the aid of infrared sensitive phosphors. *Conference Academy Sccience, USSR, Peaceful Uses of Atomic Energy*. July 1995. Moscow: USAEC, 239 - 249.

Aznar, M. C., Hemdal, B., Medin, J., Marckmann, C. J., Andersen, C. E., Bøtter-Jensen, L., Andersson, I. and Mattsson, S. (2005) 'In vivo absorbed dose measurements in mammography using a new real-time luminescence technique', *British Journal of Radiology*, 78(928), 328–334.

Aznar, M. C., Andersen, C. E., Bøtter-Jensen, L., Bäck, S. Å. J., Mattsson, S., Kjær-Kristoffersen, F. and Medin, J. (2004) 'Real-time optical-fibre luminescence dosimetry for radiotherapy: physical characteristics and applications in photon beams', *Physics in Medicine and Biology*, 49(9), 1655–1669.

Baechler, S., Gardon, M., Bochud, F., Sans-Merce, M., Trueb, P. and Verdun, F. R. (2006) Personnel dosimetry in fluoroscopy. *Second European IRPA congress on radiation protection - Radiation protection: from knowledge to action*. 15 - 19 May 2006. Paris, France: (Vol. 38).

Bailiff, I. K., Sholom, S. and McKeever, S. W. S. (2016) 'Retrospective and emergency dosimetry in response to radiological incidents and nuclear mass-casualty events: A review', *Radiation Measurement*, 94, 83-139.

Balaguru, D., Rodriguez, M., Leon, S., Wagner, L. K., Beasley, C. W., Sultzer, A. and Numan, M. T. (2018) 'Comparison of skin dose measurement using nanoDot® dosimeter and machine readings of radiation dose during cardiac catheterization in children', *Annals of Pediatric Cardiology*, 11(1), 12-16.

Balter, S., Zanzonico, P., Reiss, G. R. and Moses, J. W. (2011) 'Radiation is not the only risk', *American Journal of Roentgenology*, 196(4), 762–767.

Bland, J. M. and Altman, D. G. (1986) 'Statistical methods for assessing agreement between two methods of clinical measurement', *The Lancet*, 327(846), 307–310.

Boal, T. J. and Pinak, M. (2013) 'Dose limits to the lens of the eyes: International Basic Safety Standards and related guidance', *Annals of the ICRP*, 112–117.

BØtter-Jensen, L. (1997) 'Luminescence techniques: instrumentation and methods', *Radiation Measurements*, 27(5), 749–768.

Bøtter-Jensen, L., McKeever, S. W. S. and Wintle, A. G. (2003) *Optically stimulated luminescence dosimetry*. Netherlands: Elsevier.

Brenner, D. J. and Hall, E. J. (2007) 'Computed tomography--an increasing source of radiation exposure', *New England Journal of Medicine*, 357(22), 2277–2284.

Brun, A., Mor, R. A., Bourrelly, M., Dalivoust, G., Gazazian, G., Boufercha, R., Lehucher-Michel, M. P. and Sari-Minodier, I. (2017) 'Radiation protection for surgeons and anesthetists: practices and knowledge before and after training', *Journal of Radiological Protection*, 38(1), 175–188.

Cantley, L. C., Dalton, W. S., DuBois, R. N., Finn, O. J., Futreal, P. A., Golub, T. R., Lozano, G., Maris, J. M., Nelson, W. G., Sawyers, C. L., Schreiber, S. L., Spitz, M. R. and Steeg, P. S. (2012) 'AACR Cancer Progress Report 2012', *Clinical Cancer Research: An Official Journal of the American Association for Cancer Research*, *Nov 1:18*(21 Suppl).

Carinou, E., Ferrari, P., Koukorava, C., Krim, S. and Struelens, L. (2011) 'Monte Carlo calculations on extremity and eye lens dosimetry for medical staff at interventional radiology procedures', *Radiation Protection Dosimetry*, 144(1–4), 492–496.

Cember, H. and Johnson, T. E. (2009) *Introduction to Health physics: Fourth Edition.* United States: McGraw-Hill.

Chaudhari, S. (2014) 'Eye lens dose estimation during interventional radiology and its impact on the existing radiation protection and safety program: In the context with new International Commission on Radiological Protection guidelines' *Radiation Protection and Environment*, 37(2), 101–105.

Chida, K., Morishima, Y., Masuyama, H., Chiba, H., Katahira, Y., Inaba, Y., Mori, I., Maruoka, S., Takahashi, S., Kohzuki, M. and Zuguchi, M. (2009). 'Effect of radiation monitoring method and formula differences on estimated physician dose during percutaneous coronary intervention', *Acta Radiologica*, 50(2), 170–173.

Chida, K., Kaga, Y., Haga, Y., Kataoka, N., Kumasaka, E., Meguro, T. and Zuguchi, M. (2013) 'Occupational dose in interventional radiology procedures', *American Journal of Roentgenology*, 200(1), 138–141.

Ciraj-Bjelac, O., Antic, V., Selakovic, J., Bozovic, P., Arandjic, D. and Pavlovic, S. (2016) 'Eye lens exposure to medical staff performing electrophysiology procedures: Dose assessment and correlation to patient dose', *Radiation Protection Dosimetry*, 172(4), 475–482.

Ciraj-Bjelac, O., Rehani, M. M., Sim, K. H., Liew, H. B., Vano, E. and Kleiman, N. J. (2010) 'Risk for radiation-induced cataract for staff in interventional cardiology: Is there reason for concern?', *Catheterization and Cardiovascular Interventions*, 76(6), 826–834.

Clerinx, P., Buls, N., Bosmans, H. and De Mey, J. (2008) 'Double-dosimetry algorithm for workers in interventional radiology', *Radiation Protection Dosimetry*, 129(1–3), 321–327.

Cook, S., Togni, M., Walpoth, N., Maier, W., Muehlberger, V., Legrand, V., Milicic, D., Zambartas, C., Zelisko, M., Madsen, J. K., van Buuren, F., Lòpez-Palop, R., Peeba, M., Koskenkorva, J., Vanhanen, H., Lablanche, J., Lazaris, I., Géza, F., Eyjolfsson, K., Kearney, P., Piscione, F., Erglis, A., Navickas, R., Beissel, J., Channam, R., Koch, K., Deleanu, D., Melberg, T., Witkowski, A., Pereira, H., Reho, I., Fridrich, V., Zorman, D., Nilsson, T., Oezmen, F., Ludman, P. M., Meier, B. (2006) 'Percutaneous coronary interventions in Europe 1992-2003', *Journal of EuroPCR,* 1(4), 374–379.

Dagal, A. (2011) 'Radiation safety for anesthesiologists', *Current Opinion in Anaesthesiology*, 24(4), 445–450.

Dalah, E. Z., Mahdi, O., Elshami, W., Abuzaid, M. M., David, L. R., Mira, O. A., Obaideen, A., Elmahdi, H. M., Bradley, D. A. (2018) 'Occupational doses to cardiologists performing fluoroscopically-guided procedures', *Radiation Physics and Chemistry*, 153, 21–26.

Dauer, L. T., Thornton, R. H., Hay, J. L., Balter, R., Williamson, M. J. and Germain, J. S. (2011) 'Fears, feelings and facts: Interactively communicating benefits and risks of medical radiation with patients', *American Journal of Roentgenology*, 196(4), 756–761.

Degiorgio, S., Gerasia, R., Liotta, F., Maruzzelli, L., Cortis, K., Miraglia, R. and Luca, A. (2018) 'Radiation Doses to Operators in Hepatobiliary Interventional Procedures', *CardioVascular and Interventional Radiology*, 41(5), 772–780.

Ding, G. X., and Malcolm, A. W. (2013) 'An optically stimulated luminescence dosimeter for measuring patient exposure from imaging guidance procedures', *Physics in Medicine and Biology,* 58(17), 5885.

Dixon, R. L. and Ballard, A. C. (2007) 'Experimental validation of a versatile system of CT dosimetry using a conventional ion chamber: Beyond CTDI 100', *Med. Phys*, 34(34), 1272–1280.

Doğan, N. Ö. (2018) 'Bland-Altman analysis: A paradigm to understand correlation and agreement', *Turkish Journal of Emergency Medicine*, 18(4), 139–141.

Domienik, J., Brodecki, M., Carinou, E., Donadille, L., Jankowski, J., Koukorava, C., Krim, S., Nikodemova, D., Ruiz-Lopez, N., Sans-Merce, M., Struelens, L. and Vanhavere, F. (2011) 'Extremity and eye lens doses in interventional radiology and cardiology: Final results of the ORAMED project', *Radiation Measurements*, 144(1-4), 442-447.

Duller, G. A. T. and Bøtter-Jensen, L. (1993) 'Luminescence from potassium feldspars stimulated by infrared and green light', *Radiation Protection Dosimetry*. 47(1-4), 683-688.

Duller, G. A. T., Bøtter-Jensen, L., Kohsiek, P. and Murray, A. S. (1999) 'A high-sensitivity optically stimulated luminescence scanning system for measurement of single sand-sized grains', *Radiation Protection Dosimetry*, 84(1–4), 325–330.

Eagan, J. T. and Jones, C. T. (2011) 'Cutaneous cancers in an interventional cardiologist: A cautionary tale', *Journal of Interventional Cardiology*, 24(1), 49–55.

Efstathopoulos, E. P., Pantos, I., Andreou, M., Gkatzis, A., Carinou, E., Koukorava, C., Kelekis, N. L. and Brountzos, E. (2011) 'Occupational radiation doses to the extremities and the eyes in interventional radiology and cardiology procedures', *British Journal of Radiology*, 84(997), 70–77.

Endo, A., Katoh, T., Kobayashi, I., Joshi, R., Sur, J., and Okano, T. (2012) 'Characterization of optically stimulated luminescence dosemeters to measure organ doses in diagnostic radiology', *Dentomaxillofacial Radiology*, 41(3), 211–216.

Faulkner, K. and Marshall, N. W. (1993) 'The relationship of effective dose to personnel and monitor reading for simulated fluoroscopic irradiation conditions', *Health Physics*, 64(5), 502–508.

Fletcher, D. W., Miller, D. L., Balter, S. and Taylor, M. A. (2002) 'Comparison of four techniques to estimate radiation dose to skin during angiographic and interventional radiology procedures', *Journal of Vascular and Interventional Radiology*, 13(4), 391–397.

Franken, Y. and Huyskens, C. J. (2002) Guidance on the use of protective lead aprons in medical radiology protection efficiency and correction factors for personal dosimetry. *6th European ALARA Network Workshop. Occupational Exposure Optimisation in the Medical Field and Radiopharmaceutical Industry*. 23-25 October. Madrid, Spain. 135–139.

Gagna, G., Gauron, C., Amabile, J.C. and Laroche, P. (2011) 'Radiation exposure to operating room staff during prostate brachytherapy using iodine-125 seeds', *Radioprotection*, 46(2), 189-208.

Gertz, E. W., Wisneski, J. A., Gould, R. G. and Akin, J. R. (1982) 'Improved radiation protection for physicians performing cardiac catheterization', *The American Journal of Cardiology*, 50(6), 1283–1286.

Gislason-Lee, A. J., Hoornaert, B., Cowen, A. R. and Davies, A. G. (2014) Understanding automated dose control in dynamic X-ray imaging. *European Congress of Radiology.* 28 March - 1 April 2013. Vienna, Australia. 1689–

1699.

Gonzales, C. A. B. and Morales, A. A. (2015) Assessment of patient and staff doses in interventional cerebral angiography using OSL. *World Congress on Medical Physics and Biomedical Engineering*. 7-12 June. Toronto, Canada. 778–782.

Gualdrini, G., Mariotti, F., Wach, S., Bilski, P., Denoziere, M., Daures, J., Bordy, J. M., Ferrari, P., Monteventi, F. and Fantuzzi, E. (2011) 'Eye lens dosimetry: Task 2 within the oramed project', *Radiation Protection Dosimetry*, 144(1–4), 473–477.

Guide, I. S. (1999) 'Assessment of Occupational Exposure Due to External Sources of Radiation', *IAEA Safety Standards Series*, *No. RS-G-1*(18).

Haga, Y., Chida, K., Kaga, Y., Sota, M., Meguro, T. and Zuguchi, M. (2017) 'Occupational eye dose in interventional cardiology procedures', *Scientific Reports*, 7(569).

Hanu-Cernat, D. E., Duarte, R., Raphael, J. H., Mutagi, H., Kapur, S. and Senthil, L. (2012) 'Type of Interventional Pain Procedure, Body Weight, and Presence of Spinal Pathology are Determinants of the Level of Radiation Exposure for Fluoroscopically Guided Pain Procedures', *Pain Practice*, 12(6), 434–439.

Haqqani, O. P., Agarwal, P. K., Halin, N. M. and Iafrati, M. D. (2013) 'Defining the radiation "scatter cloud" in the interventional suite', *Journal of Vascular Surgery*, 58(5), 1339–1345.

Hardell, L., Mild, K. H., Påhlson, A. and Hallquist, A. (2001) 'Ionizing radiation, cellular telephones and the risk for brain tumours', *European Journal of Cancer Prevention: The Official Journal of the European Cancer Prevention Organisation (ECP)*, 10(6), 523–529.

Hayashi, N., Sakai, T., Kitagawa, M., Inagaki, R., Yamamoto, T., Fukushima, T. and Ishii, Y. (1998) 'Radiation Exposure to Interventional Radiologists During Manual-Injection Digital Subtraction Angiography', *CardioVascular and Interventional Radiology*, 21(3), 240–243.

Hayes, R.B., O'Mara, R.P. and Hooper, D.A. (2019) 'Initial TL/OSL/EPR considerations for commercial diatomaceous earth in retrospective dosimetry and dating', Radiation Protection Dosimetry, 185(3), 310-319.

Hellawell, G. O., Mutch, S. J., Thevendran, G., Wells, E. and Morgan, R. J. (2005) 'Radiation exposure and the urologist: what are the risks?', *The Journal of Urology*, 174(3), 948–952.

Higgins, A. (2015) 'Measurement of occupational doses of ionising radiation to the lens of the eyes of interventional radiologists', *Journal of Radiological Protection*, 36(1), 74–92.

Hu, B., Wang, Y., and Zealey, W. (2009) 'Performance of Al2O3:C optically stimulated luminescence dosimeters for clinical radiation therapy applications', *Australian Physical & Engineering in Medicine, 32*(4), 226–232.

Huntley, D. J., Godfrey-Smith, D. I. and Thewalt, M. L. W. (1985) 'Optical dating of sediments', *Nature*, 313(5998), 105–107.

Huyskens, C. J., Franken, Y. and Hummel, W. A. (1994) 'Guidance on personal dosimetry for occupational exposure in interventional radiology', *Journal of Radiation Protection*, 14(3), 229–234.

IAEA (2010) Patien dose optimization in fluoroscopy guided interventional procedures (IAEA -TECDOC-1641). Vienna: International Atomic Energy Agency.

ICRP (2000) Managing patient dose in computed tomography. ICRP Publication 87. *Annals of the ICRP,* 30(4).

ICRP (2007) The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. *Annals of the ICRP,* 37(2-4).

ICRP (2012) Compendium of Dose Coefficients Based on ICRP Publication 60. ICRP Publication 119. *Annals of the ICRP 41*(Suppl).

International Radiation Protection Association (2017) IRPA guidance on implementation of eye dose monitoring and eye protection of workers. Avaiable on http://www.irpa.net/members/54696/%7B2CC34E11-1808-4469-AD03-EC3764BAB6B8%7D/IRPA%20guidance%20on%20implementation%20of%20eye%20dose%20monitoring%20-%202017.pdf

Jacob, S., Donadille, L., Maccia, C., Bar, O., Boveda, S., Laurier, D. and Bernier, M. O. (2013) 'Eye lens radiation exposure to interventional cardiologists: A retrospective assessment of cumulative doses', *Radiation Protection Dosimetry*, 153(3), 282–293.

Jarvinen, H., Buls, N., Clerinx, P., Jansen, J., Miljanic, S., Nikodemova, D., Ranogajec-Komor, M. and D’Errico, F. (2008) 'Overview of double dosimetry procedures for the determination of the effective dose to interventional radiology operators', *Radiation Protection Dosimetry*, 129(1–3), 333–339.

Jarvinen, H., Buls, N., Clerinx, P., Miljanic, S., Nikodemova, D., Ranogajec-komor, M., Struelens, L. and d'Errico, F. (2008) 'Comparison of double dosimetry algorithms for estimating the effective dose in occupational dosimetry of interventional radiology staff', *Radiation Protection Dosimetry*, 131(1), 80–86.

Jerrold, T. B., J. Anthony, S., Edwin, M. LeidhodDT, J. and John, M. B. (2002). The Essential Physics of Medical Imaging (2nd Edition).pdf. In *ESSENTIAL PHYSICS OF MEDICAL IMAGING* (p. 17). https://doi.org/ISBN: 978-0-7817-8057-5.

Jursinic, P. A. (2007) 'Characterization of optically stimulated luminescent dosimeters, OSLDs, for clinical dosimetric measurements', *Medical Physics*, 34(12), 4594–4604.

Jursinic, P.A. (2010) 'Changes in optically stimulated luminescent dosimeter (OSLD) dosimetric characteristics with accumulated dose', *Medical Physics*, 37(1), 132-140.

Kawaguchi, A., Matsunaga, Y., Suzuki, S., and Chida, K. (2017) 'Energy dependence and angular dependence of an optically stimulated luminescence dosimeter in the mammography energy range', *Journal of Applied Clinical Medical Physics*, *18*(2), 191–196.

Kaira, A. (2017) 'Decoding the Bland-Altman Plt: Basic Review', *Journal of the Practice of Cardiovascular Sciences*, 3, 36–38.

Kerns, J. R., Kry, S. F., Sahoo, N., Followill, D. S., and Ibbott, G. S. (2011) 'Angular dependence of the nanoDot OSL dosimeter, *Medical Physics, 38*(7), 3955–3962.

Kim, K. P. and Miller, D. L. (2009) 'Minimising radiation exposure to physicians performing fluoroscopically guided cardiac catheterisation procedures: A review', *Radiation Protection Dosimetry*, 133(4), 227–233.

Kim, K. P., Miller, D. L., Gonzalez, A. B. de, Balter, S., Kleinerman, R. A., Ostroumova, E., Simon, S. L. and Linet, M. S. (2012) 'Occupational radiation doses to operators performing fluoroscopically-guided procedures', *Health Physics*, 103(1), 80.

Kim J. Y., Park, S. K., Kim, Y. L., Suh, T. S., Shin, J. W., Oh, K. Y., Nam, S. H., Kim, J. E., Min, B. I., Jo, S. M. and Oh, W. Y. (2014) 'Feasibility Study of an Optically-Stimulated Luminescent Nanodot Dosimeter (OSLnD) in High-energy Photon Beams', *Journal of the Korean Physical Society*, 65(7), 1159-

1163.

Koenig, T. R., Wolff, D., Mettler, F. A. and Wagner, L. K. (2001) 'Skin injuries from fluoroscopically guided procedures: Part I, characteristics of radiation injury', *American Journal of Roentgenology*, 177(1), 3–11.

Kong, Y., Gao, L., Zhuo, W. and Qian, A. (2013) 'A survey on radiation exposure of primary operators from interventional X-ray procedures', *Radiation Measurements*, *55*, 43–45.

Koukorava, C., Carinou, E., Ferrari, P., Krim, S. and Struelens, L. (2011) 'Study of the parameters affecting operator doses in interventional radiology using Monte Carlo simulations', *Radiation Measurements*, 46(11), 1216–1222.

Kry, S. F., Alvarez, P., Cygler, J. E., DeWerd, L.A., Howell, R. M., Meeks, S., O'Daniel, J., Reft, C., Sawakuchi, G., Yukihara, E.G. and Mihailidis, D. (2020) 'AAPM TG 191: Clinical use of luminescent dosimeters: TLDs and OSLDs', *Medical Physics*, 47(2), e19-e51.

Kuipers, G. and Velders, X. L. (2009) 'Effective dose to staff from interventional procedures: esimations from single and double dosimetry', *Radiation Protection Dosimetry*, 136(2), 95–100.

Kumari, G., Kumar, P., Wadhwa, P., Aron, M., Gupta, N. P. and Dogra, P. N. (2006) 'Radiation exposure to the patient and operating room personnel during percutaneous nephrolithotomy', *International Urology and Nephrology*, 38(2), 207–210.

Kuon, E., Dahm, J. B., Empen, K., Robinson, D. M., Reuter, G. and Wucherer, M. (2004) 'Identification of less-irradiating tube angulations in invasive cardiology', *Journal of the American College of Cardiology*, 44(7), 1420–1428.

Landauer (2012) *Landauer: microStar User Manual*.

Landauer (2015). nanoDot and microSTARii: Frequently Asked Questions. http://www.landauer.com/uploadedFiles/About_Us/microSTARii FAQ.pdf.

Le Heron, J., Padovani, R., Smith, I. and Czarwinski, R. (2010) 'Radiation protection of medical staff', *European Journal of Radiology*, 76(1), 20–23.

Limacher, M. C., Douglas, P. S., Germano, G., Laskey, W. K., Lindsay, B. D., McKetty, M. H., Moore, M. E., Park, J. K., Prigent, F. M. and Walsh, M. N. (1998) 'ACC expert consensus document. Radiation safety in the practice of cardiology. American College of Cardiology', *J Am Coll Cardiol*, 31(4), 892–913.

Linet, M. S., Kim, K. P., Miller, D. L., Kleinerman, R. A., Simon, S. L. and Berrington de Gonzalez, A. (2014) 'Historical Review of Cancer Risks in Medical Radiation Workers', *Radiation Research*, *174*(6), 793–808.

Løberg, M., Lousdal, M. L., Bretthauer, M., and Kalager, M. (2015) 'Benefits and harms of mammography screening', *Breast Cancer Research*, 17(1), 1–12.

Lonnroth, N., Hirvonen-Kari, M., Timonen, M., Savolainen, S. and Kortesniemi, M. (2012) 'Transition in occupational radiation exposure monitoring methods in diagnostic and interventional radiology', *Radiat. Prot. Dosim.*, 151(1), 58–66.

Maeder, M., Rocca, H. P. B.-L., Wolber, T., Ammann, P., Rowlli, H., Rohne, F. and Rickli, H. (2006) 'Impact of a lead glass screen on scatter radiation to eyes and hands in interventional cardiologists', *Catheterization and Cardiovascular Interventions*, 67(1), 18–23.

Magee, J. S., Martin, C. J., Sandblom, V., Carter, M. J., Almén, A., Cederblad, Å., Jonasson, P. and Lundh, C. (2014) 'Derivation and application of dose reduction factors for protective eyewear worn in interventional radiology and cardiology', *Journal of Radiological Protection*, *34*(4), 811–823.

Malone, J., Guleria, R., Craven, C., Horton, P., Jarvinen, H., Mayo, J., O'Reilly, G., Picano, E., Remedios, D., Le Heron, J., Rehani, M. M., Holmberg, O. and Czarwinski, R. (2012) 'Justification of diagnostic medical exposures: some practical issues. Report of an International Atomic Energy Agency Consultation', *British Journal of Radiology*, 85, 523–538.

Manchikanti, L., Cash, K. A., Moss, T. L. and Pampati, V. (2002) 'Radiation exposure to the physician in interventional pain management', *Pain Physician*, 5(4), 385–393.

Markey, B. G., Colyott, L. E. and McKeever, S. W. S. (1995) 'Time-resolved optically stimulated luminescence from α-Al_2O_3:C', *Radiation Measurements*, 24(4), 457–463.

Matsubara, K., Lertsuwunseri, V., Srimahachota, S., Krisanachinda, A., Tulvatana, W., Khambhiphant, B., Sudchai, W. and Rehani, M. M. (2017) 'Eye lens dosimetry and the study on radiation cataract in interventional cardiologists', *Physica Medica*, 44, 232–235.

McEwan, A. C. (1999) 'Assessment of occupational exposure in New Zealand from personal monitoring records', *Radiation Protection in Australasia*, 17(2), 60–66.

McKeever, S. W. S., Moscovitch, M. and Townsend P. D. (1995) *Thermoluminescence Dosimetry Materials: Properties and Uses*. United Kingdom: Nuclear Technology Publishing.

McKeever, S. W. S., Akselrod, M. S. and Markey, B. G. (1996) 'Pulsed Optically Stimulated Luminescence Dosimetry Using Alpha-Al_2O_3:C', *Radiation Protection Dosimetry*, 65(1–4), 267–272.

McKeever, S. W. S. and Moscovitch, M. (2003) 'On the advantages and disadvantages of optically stimulated luminescence dosimetry', *Radiation Protection Dosimetry*, 104(3), 263–270.

McKeever, S. W. S. (2001) 'Optically stimulated luminescence dosimetry', *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 184(1), 29–54.

Meeks, S. L., Paulino, A. C., Pennington, E. C., Simon, J. H., Skwarchuk, M. W. and Buatti, J. M. (2002) 'In vivo determination of extra-target doses received from serial tomotherapy', *Radiotherapy and Oncology*, 63(2), 217–222.

Mendes, M. and Pala, A. (2003) 'Type I error rate and power of three normality tests', *Pakistan Journal of Information and Technology*, 2(2), 135–139.

Mettler, F. A., Huda, W., Yoshizumi, T. T. and Mahesh, M. (2008) 'Effective Doses in Radiology and Diagnostic Nuclear Medicine: A Catalog', *Radiology*, 248(1), 254–263.

Mettler, F. A., Koenig, T. R., Wagner, L. K. and Kelsey, C. A. (2002) 'Radiation Injuries after Fluoroscopic Procedures', *Seminars in Ultrasound CT and MRI,* 23(5), 428–442.

Meye, P.O., Schandorf, C. and Ndong R.O. (2018) ‘Reader quality control tests, dose algorithm comparison, and signal depletion of optically stimulated luminescence dosimetry systems used for individual monitoring: A case of the dosimetry system of the national individual monitoring service in Gabon’, *Radiation Protection and Environment*, 41(2), 88-93.

Miljanic, S., Bordy, J.M., d'Errico, F., Harrison, R. and Olko, P. (2014) ‘Out-of-field dose measurements in radiotherapy - An overview of activity of EURADOS Working Group 9: Radiation protection in medicine’, *Radiation Measurements*, 71, 270-275.

Miller, D. L. (2008) 'Overview of contemporary interventional fluoroscopy procedures', *Health Physics*, 95(5), 638–644.

Miller, D. L., Balter, S., Cole, P. E., Lu, H. T., Schueler, B. A., Geisinger, M., Berenstein, A., Albert, R., Georgia, J. D., Noonan, P. T., Cardella, J. F., George, J. S., Russell, E. J., Malisch, T. W., Vogelzang, R. L., Miller, G. L. and Anderson, J. (2003a) 'Radiation Doses in Interventional Radiology Procedures: The RAD-IR Study. Part I: Overall Measures of Dose', *Journal of Vascular and Interventional Radiology,* 14(6), 711–727.

Miller, D. L., Balter, S., Cole, P. E., Lu, H. T., Berenstein, A., Albert, R., Schueler, B. A., Georgia, J. D., Noonan, P. T., Russell, E. J., Malisch, T. W., Vogelzang, R. L., Geisinger, M., Cardella, J. F., George, J. S., Miller, G. L. and Anderson, J. (2003b) 'Radiation Doses in Interventional Radiology Procedures: The RAD-IR Study. Part II: Skin Dose', *Journal of Vascular and Interventional Radiology,* 14(8), 977–990.

Miller, D. L., Klein, L. W., Balter, S., Norbash, A., Haines, D., Fairobent, L. and Goldstein, J. A. (2010) 'Special Communication - Occupational Health Hazards in the Interventional Laboratory: Progress Report of the Multispecialty Occupational Health Group', *Journal of the American College of Radiology,* 7(9), 679-683.

Miller, D. L., Vano, E., Bartal, G., Balter, S., Dixon, R., Padovani, R., Schueler, B., Cardella, J. F. and De Baere, T. (2010) 'Special Communication - Occupational Radiation Protection in Interventional Radiology: A Joint Guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology', *Journal of Vascular and Interventional Radiology*, 21, 607-615.

Ministry of Health Malaysia. (2016a). *Guidance Document for Occupational Radiation Protection in Radiological Practice*.

Ministry of Health Malaysia. (2016b). *Guidelines for occupational radiation protection in medical interventional procedures*.

Mitchell, E. L. and Furey, P. (2011) 'Prevention of radiation injury from medical imaging', *Journal of Vascular Surgery*, 53(1), 22S-27S.

Moladoust, H., Ghazanfari-Tehran, M., Nikseresht, V., Nadim, T. and Rad, M. A. (2015) 'Comparison of Five Developed Algorithms to Estimate Staff Effective Dose in Interventional Cardiology: Are They Interchangeable?', *Journal of Medical Imaging and Health Informatics*, 5(3), 647–651.

Mora, P. and Acuña, M. (2011) 'Assessment of medical occupational radiation doses in Costa Rica', *Radiation Protection Dosimetry*, 147(1–2), 230–232.

Murray, A. S. and Wintle, A. G. (1998) 'Factors controlling the shape of the OSL decay curve in quartz', *Radiation Measurements*, 29(1), 65–79.

Musa, Y., Hashim, S., Karim, M. K. A., Bakar, K. A., Ang, W. C., and Salehhon, N. (2017) 'Response of optically stimulated luminescence dosimeters subjected to X-rays in diagnostic energy range', *Journal of Physics: Conference Series*, 851(1), 012001.

Nakamura, T., Suzuki, S., Takei, Y., Kobayashi, I., Pongnapang, N. and Kato, K. (2019) 'Simultaneous measurement of patient dose and distribution of indoor scattered radiation during digital breast tomosynthesis', *Radiography*, 25(1), 72-76.

Nass, J.S., Henderson, I.C. and Lashof, J.C. (2001) *Mammography and Beyond: Developing Technologies for the Early Detection of Breast Cancer*. Washington: National Academic Press.

National Council Research (2006) *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*. Washington, DC: The National Academies Press.

NCRP (1995). *Use of personal monitors to estimate effective dose equivalent and effective dose to workers for external exposure to low-let radiation: recommendations of the National Council on Radiation Protection and Measurements. NCRP report no.122*.

NCRP (2004). Recent Applications of the NCRP Public Dose Limit Recommendation for Ionizing Radiation. NCRP Statement No. 10, December 2004. *National Council on Radiation Protection and Measurements*, 1–7.

Niklason, L. T., Victoria Marx, M. and Chan, H. P. (1994) 'The estimation of occupational effective dose in diagnostic radiology with two dosimeters', *Health Physics*, 67(6), 611–615.

O'Connor, U., Walsh, C., Gallagher, A., Dowling, A., Guiney, M., Ryan, J. M., McEniff, N. and O'Reilly, G. (2015) 'Occupational radiation dose to eyes from interventional radiology procedures in light of the new eye lens dose limit from the International Commission on Radiological Protection', *The British Journal of Radiology*, *88*(1049), 1-7.

Obed, R. I., Ogbole, G. I., and Majolagbe, S. B. (2015) 'Comparison of the ICRP 60 and ICRP 103 Recommendations on the Determination of the Effective Dose from Abdominopelvic Computed Tomography', *International Journal of Medical Physics, Clinical Engineering and Radiation Oncology*, 4, 172–176.

Olko, P. (2010). Advantages and disadvantages of luminescence dosimetry. *Radiation Measurements*, *45*(3), 506–511.

Omar, A., Kadesjo, N., Palmgren, C., Marteinsdottir, M., Segerdahl, T. and Fransson, A. (2017) 'Assessment of the occupational eye lens dose for clinical staff in interventional radiology, cardiology and neuroradiology', *Journal of Radiological Protection*, 37(1), 145–159.

Oztuna, D., Elhan, A. H. and Tuccar, E. (2006) 'Investigation of four different normality tests in terms of type 1 error rate and power under different distributions', *Turkish Journal of Medical Sciences*, 36(3), 171–176.

Padovani, R., Foti, C. and Malisan, M. R. (2001) 'Staff dosimetry protocols in interventional radiology', *Radiation Protection Dosimetry*, 94(1–2), 193–196.

Padovani, R. and Rodella, C. A. (2001) 'Staff dosimetry in interventional cardiology', *Radiation Protection Dosimetry*, 94(1–2), 99–103.

Pallant, J. (2011) *SPSS Survival Manual 4th ed.* United States: McGraw-Hill.

Pantos, I., Koukorava, C., Nirgianaki, E., Carinou, E., Tzanalaridou, E., Efstathopoulos, E. P. and Katritsis, D. G. (2012) 'Radiation exposure of the operator during cardiac catheter ablation procedures', *Radiation Protection Dosimetry*, 150(3), 306–311.

Park, S. Y., Choi, C. H., Park, J. M., Chun, M., Han, J. H. and Kim, J. (2017) ‘Sensitivity and stability of optically stimulated luminescence dosimeters with filled deep electron/hole traps under pre-irradiation and bleaching conditions’, *Physics Medica*, 38, 81-87.

Patel, A. P., Gallacher, D., Dourado, R., Lyons, O., Smith, A., Zayed, H., Waltham, M., Sabharwal, T., Bell, R., Carrell, T., Taylor, P. and Modarai, B. (2013) 'Occupational radiation exposure during endovascular aortic procedures', *European Journal of Vascular and Endovascular Surgery*, 46(4), 424–430.

Peakheart, D., Rong, X., Yukihara, E. G., Klein, D., McKeever, S. W. S. and Ramji, F. (2006) 'TU-E-330D-03: Evaluation of An OSL Dosimetry System for CT Quality Assurance and Dose Optimization', *Medical Physics*, 33(6Part18), 2211–2211.

Perks, C. A., Le Roy, G. and Prugnaud, B. (2007) 'Introduction of the InLight monitoring service', *Radiation Protection Dosimetry*, 125(1-4), 220–223.

Ponmalar, R., Manickam, R., Ganesh, K. M., Saminathan, S., Raman, A. and Godson, H. F. (2017) 'Dosimetric characterization of optically stimulated luminescence dosimeter with therapeutic photon beams for use in clinical radiotherapy measurements', *Journal of Cancer Research and Therapeutics*, 13(2), 304-312.

Rehani, M. M., Ciraj-Bjelac, O., Vano, E., Miller, D. L., Walsh, S., Giordano, B. D. and Persliden, J. (2010) 'Radiological Protection in Fluoroscopically Guided Procedures Performed Outside the Imaging Department', *Annals of the ICRP*, 40(6), 5–6.

Rehani, M. M., Vano, E., Ciraj-Bjelac, O. and Kleiman, N. J. (2011) 'Radiation and cataract', *Radiation Protection Dosimetry*, 147(1–2), 300–304.

Reuven, C. H. E. N. (2001). Advantages and Disadvantages in the Utilisation of Thermoluminescence (Tl) and Optically Stimulated Luminescence (OSL) for Radiation Dosimetry. In IRPA Regional Congress on Radiation Protection in Central Europe Dubrovnik, Croatia.

Rosado, P. H. G., Nogueira, M. S., Squair, P. L. and Oliveira, M. C. (2007) Determination of the Mean Energy for Attenuated and Unattenuated IEC Diagnostic X-Ray Beams. *2007 International Nuclear Atlantic Conference* . 29 September - 5 Oktober. SP, Brazil.

Rosenstein, M. and Webster, E.W. (1994) 'Effective dose to personnel wearing protective aprons during fluoroscopy and interventional radiology', *Health Phys.*, 67(1), 88-9

Sadick, V., Reed, W., Collins, L., Sadick, N., Heard, R. and Robinson, J. (2010) 'Impact of biplane versus single-plane imaging on radiation dose, contrast load and procedural time in coronary angioplasty', *The British Journal of Radiology*, 85, 379 - 393.

Saez-Vergara, J.C. (2000) 'Recent developments of passive and active detectors used in the monitoring of external environmental radiation', Radiation Protection Dosimetry, 92(1-3), 83-88.

Sanchez, R. M., Vano, E., Fernandez, J. M., Pifarre, X., Ordiales, J. M., Rovira, J. J., Carrera, F., Goicolea, J. and FernAndez-Ortiz, A. (2016) 'Occupational eye lens doses in interventional cardiology. A multicentric study', *J Radiol Prot*, 36(1), 133–143.

Scarboro, S. B., Cody, D., Alvarez, P., Followill, D., Court, L., Stingo, F. C., Zhang, D., McNitt-Gray, M. and Kry, S. F. (2015) ‘Characterization of the nanoDot OSLD dosimeter in CT’, *Medical Physics*, 42(4), 1797–1807.

Schembri, V. and Heijmen, B. J. M. (2007) 'Optically stimulated luminescence (OSL) of carbon-doped aluminum oxide (Al_2O_3:C) for film dosimetry in radiotherapy', *Medical Physics,* 34(6Part1), 2113–2118.

Sherbini, S., and DeCicco, J. (2002) 'Estimation of the effective dose when protective aprons are used in medical procedures: A theoretical evaluation of several methods', *Health Physics*, 83(6), 861–870.

Shah, D. J., Sachs, R. K. and Wilson, D. J. (2012) 'Radiation-induced cancer: A modern view', *The British Journal of Radiology*, 85(1020), e1166–e1173.

Shore, R. E., Neriishi, K. and Nakashima, E. (2010) 'Epidemiological studies of cataract risk at low to moderate radiation doses: (not) seeing is believing', *Radiation Research*, 174(6), 889–894.

Silva, E. H. da, Struelens, L., Covens, P., Ueno, S., Ube, M., Vanhavere, F. and Buls, N. (2017) 'Where is the best position to place a dosemeter in order to assess the eye lens dose when lead glasses are used?', *Radiation Measurements*, 106, 257–261.

Sudchai, W. and Sa-Ngan-Sat, A. (2012) ‘Inlight optically stimulated luminescence for occupational monitoring service in Thailand’, *Progress in Nuclear Science and Technology*, 3, 94-96.

Szumska, A., Budzanowski, M. and Kopeć, R. (2017) 'Test of ring, eye lens and whole body dosemeters for the dose quantity Hp(3) to be used in interventional radiology', *Radiation Physics and Chemistry*, 140, 92–97.

Szumska, Agnieszka, Kopeć, R. and Budzanowski, M. (2016) 'Occupational doses of medical staff and their relation to patient exposure incurred in coronary angiography and intervention', *Radiation Measurements*, 84, 34–40.

Tchistiakova, E., Kim, A., Song, W. Y. and Pang, G. (2017) ‘MR-safe personal radiation dosimeters’, *Journal of Applied Clinical Medical Physics*, 18(4), 180–184.

Tien, C. J., Ebeling, R., Hiatt, J. R., Curran, B., and Sternick, E. (2012) 'Optically Stimulated Luminescent Dosimetry for High Dose Rate Brachytherapy', *Frontiers in Oncology*, 2(August), 1–8.

United Nations Scientific Committee on the Effects of Atomic Radiation. (2000) *Sources and Effects of Ionizing Radiation. UNSCEAR 2000 Report* (Vol. 2).

Valentin, J. (2000) 'Avoidance of radiation injuries from medical interventional procedures: ICRP Publication 85', *Annals of the ICRP*, 30(2), 7.

Vanhavere, F., Carinou, E., Gualdrini, G., Clairand, I., Merce, M. S., Ginjaume, M., Nikodemova, D., Jankowski, J., Bordy, J-M., Rimpler, A., Wach, S., Martin, P., Struelens, L., Krim, S., Koukorava, C., Ferrari, P., Mariotti, F., Fantuzzi, E., Donadille, L., Itie, C., Ruiz, N., Carnicer, A., Fulop, M., Domienik, J., Brodecki, M., Daures, J., Barth, I. and Bilski, P. (2012) *ORAMED: Optimization of Radiation Protection of Medical Staff. EURADOS Report 2012-02*. Braunschweig: European Radiation Dosimetry.

Vano, E., Gonzales, L., Guibelalde, E., Fernandez, J. M. and Ten, J. I. (1998) 'Radiation exposure to medical staff in interventional and cardiac radiology', *The British Journal of Radiology*, 71(849), 954–960.

Vano, E., Gonzalez, L., Ten, J. I., Fernandez, J. M., Guibelalde, E. and Macaya, C. (2001) 'Skin dose and dose-area product values for interventional cardiology procedures', *British Journal of Radiology*, 74(877), 48–55.

Vano, E, Fernandez, J. M., Resel, L. E., Moreno, J. and Sanchez, R. M. (2016) 'Staff lens doses in interventional urology. A comparison with interventional radiology, cardiology and vascular surgery values', *Journal of Radiological Protection*, 36(1), 37–48.

Vano, E., Kleiman, N. J., Duran, A., Rehani, M. M., Echeverri, D. and Cabrera, M. (2010) 'Radiation cataract risk in interventional cardiology personnel', *Radiation Research*, 174(4), 490–495.

Vano, E., Kleiman, N. J., Duran, A., Romano-Miller, M. and Rehani, M. M. (2013) 'Radiation-associated lens opacities in catheterization personnel: Results of a survey and direct assessments', *Journal of Vascular and Interventional Radiology*, 24(2), 197–204.

Viamonte, A., da Rosa, L. A. R., Buckley, L. A., Cherpak, A. and Cygler, J. E. (2008) 'Radiotherapy dosimetry using a commercial OSL system', *Medical Physics*, 35(4), 1261–1266.

Von Boetticher, H., Lachmund, J. and Hoffmann, W. (2010) 'An analytic approach to double dosimetry algorithms in occupational dosimetry using energy dependent organ dose conversion coefficients', *Health Physics*, 99(6), 800–805.

Wambersie, A. and Delhove, J. (1993) ‘Radioprotection in radiology, a controversial practice: how to wear the individual dosimeters?', *J Belge Radiol*. 76(6), 382-385.

Yoshinaga, S., Mabuchi, K., Sigurdson, A. J., Doody, M. M. and Ron, E. (2004) 'Cancer Risks among Radiologists and Radiologic Technologists: Review of Epidemiologic Studies', *Radiology*, 233(2), 313–321.

Yukihara, E. G. and McKeever, S. W. S. (2008) 'Optically stimulated luminescence (OSL) dosimetry in medicine', *Physics in Medicine and Biology*, 53, 351–379.

Yukihara, E. G., Yoshimura, E. M., Lindstrom, T. D., Ahmad, S., Taylor, K. K. and Mardirossian, G. (2005) 'High-precision dosimetry for radiotherapy using the optically stimulated luminescence technique and thin Al_2O_3:C dosimeters', *Physics in Medicine and Biology*, 50(23), 5619–5628.

Yukihara, E. G. and McKeever, S. W. S. (2006) 'Ionisation density dependence of the optically and thermally stimulated luminescence from Al_2O_3:C', *Radiation Protection Dosimetry*, 119(1–4), 206–217.

Yukihara, E. G., Gasparian, P. B. R., Sawakuchi, G. O., Ruan, C., Ahmad, S., Kalavagunta, C., Clause, W.J., Sahoo, N. and Titt, U. (2010) 'Medical applications of optically stimulated luminescence dosimeters (OSLDs)', *Radiation Measurements*, 45(3–6), 658–662.

Yusof, F.H., Ung N.M., Wong J.H.D., Jong W.L., Ath V., Phua V.C.E, Heng S.P. and Ng K.W. (2015) 'On the use of optically stimulated luminescent dosimeter for surface dose measurement during radiotherapy', *PLoS ONE*, 10(6)

LIST OF PUBLICATIONS

Journal with impact factor

1. Bohari, A., Hashim, S., Ghoshal, S. K. and Mohd Mustafa, S. N. (2019), 'Assessment on the interchangeability of personal effective dose algorithms in fluoroscopy-guided interventions using Bland-Altman analysis', *Radiation Protection Dosimetry*, 1–7. https://doi.org/10.1093/rpd/ncz051.
(Q4, IF=0.822)
2. Bohari, A., Hashim, S. and Mohd Mustafa, S. N. (2020) 'Scatter radiation in the fluoroscopy-guided interventional room', *Radiation Protection Dosimetry*, 1–6. https://doi.org/10.1093/rpd/ncz299.
(Q4, IF=0.822)
3. Bohari, A., Hashim, S., Ahmad, N. E., Ghoshal, S. K. and Mohd Mustafa, S. N. (2020) 'Fluoroscopy-guided intervention procedure norms for occupational eye radiation dose : An overall evaluation', *Radiation Physics and Chemistry*, 1–12. https://doi.org/10.1016/j.radphyschem.2020.108909.
(Q1, IF=1.984)

Indexed Journal

1. Bohari, A, Hashim, S. and Mustafa, S. N. M. (2019) 'Occupational radiation dose during fluoroscopy guided interventional procedures at Institut Kanser Negara', *Journal of Physics: Conference Series*, 1248, 012052. https://doi.org/10.1088/1742-6596/1248/1/012052