การวัดปริมาณรังสีที่แพทย์และเจ้าหน้าที่ได้รับในรังสีร่วมรักษา ด้วยเครื่องวัดรังสีเทอร์โมลูมิเนสเซนท์โดสมิเตอร์

นายสรจรส อุณห์ศิริ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาฉายาเวชศาสตร์ ภาควิชารังสีวิทยา
คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2547

ISBN 974-17-6530-4

THERMOLUMINESCENT DOSIMETRY MEASUREMENT OF RADIATION DOSE TO MEDICAL STAFF IN INTERVENTIONAL RADIOLOGY

Mr. Sornjarod Oonsiri

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Medical Imaging
Department of Radiology
Faculty of Medicine
Chulalongkorn University
Academic Year 2004

ISBN 974-17-6530-4

Title	Thermoluminescent Dosimetry Measurement of Radiation Dose to Medical Staff in Interventional Radiology
By	Mr. Sornjarod Oonsiri
Field of study	Medical Imaging
Thesis advisor	Associate Professor Sivalee Suriyapee
Thesis co-advisor	Associate Professor Dr. Anchali Krisanachinda

---

Accepted by the Faculty of Medicine, Chulalongkorn University in partial fulfillment of the requirement for Master's Degree

…… Dean of the Faculty of Medicine
(Professor Pirom Kamol-ratanakul, M.D., M.Sc.)

THESIS COMMITTEE :

……..…..…… Chairman
(Associate Professor Sukalaya Lerdlum, M.D., M.Sc.)

……..…… Thesis Advisor
(Assistant Professor Sivalee Suriyapee, M.Eng.)

.

…… Thesis Co-Advisor
(Associate Professor Anchali Krisanachinda, Ph.D.)

……..…..…..…… Member
(Mrs. Weeranuch Kitsukjit, M.Sc.)

นายสรจรส อุณห์ศิริ : การวัดปริมาณรังสีที่แพทย์และเจ้าหน้าที่ได้รับในรังสีร่วมรักษาด้วยเครื่องวัดรังสีเทอร์โมลูมิเนสเซนท์โดสมิเตอร์. (THERMOLUMINESCENT DOSIMETRY MEASUREMENT OF RADIATION DOSE TO MEDICAL STAFF IN INTERVENTIONAL RADIOLOGY). อาจารย์ที่ปรึกษา : รศ. ศิวลี สุริยาปี, อาจารย์ที่ปรึกษาร่วม : รศ .ดร. อัญชลี กฤษณจินดา ; 70 หน้า ISBN 974-17-6530-4

การใช้รังสีร่วมรักษามีปริมาณเพิ่มมากขึ้น วิธีการนี้ต้องถ่ายภาพฟลูออโรสโคปี รวมกันแล้วนานเกือบครึ่งชั่วโมง เป็นเหตุให้แพทย์ผู้ทำการตรวจหรือรักษา รวมทั้งเจ้าหน้าที่ซึ่งเป็นผู้ช่วยแพทย์เสี่ยงต่อการได้รับรังสี รายงานนี้เป็นการวัดปริมาณรังสีที่แพทย์และเจ้าหน้าที่ได้รับ ในระหว่างการปฏิบัติงานทางรังสีร่วมรักษา โดยใช้เครื่องวัดรังสีชนิดเทอร์โมลูมิเนสเซนท์โดสมิเตอร์ รวมทั้งเป็นการหาความสัมพันธ์ระหว่างปริมาณรังสีที่แพทย์ได้รับกับปริมาณรังสีที่ผู้ป่วยได้รับซึ่งวัดได้โดยใช้เครื่องแดพมิเตอร์

เครื่องวัดรังสีชนิดเทอร์โมลูมิเนสเซนท์โดสมิเตอร์ที่ใช้วัดจะได้รับการตรวจสอบคุณสมบัติที่สนองตอบต่อรังสี ได้แก่ ความไว พลังงาน ความสัมพันธ์ที่เป็นเส้นตรง และค่าปริมาณรังสีน้อยสุดที่สามารถวัดได้ รวมทั้งการวัดปรับเทียบปริมาณรังสีจากเครื่องโคบอลต์-60 ความถูกต้องของเครื่องมืออยู่ภายใน 14 % ในการศึกษาครั้งนี้ได้ทำการเก็บข้อมูลทั้งหมด 55 การตรวจ ซึ่งทำโดยแพทย์ ใน 3 ลักษณะการตรวจและการรักษา แพทย์จะถูกติดเครื่องวัดรังสีชนิดเทอร์โมลูมิเนสเซนท์โดสมิเตอร์ ทั้งหมด 8 ตำแหน่ง คือ ตาขวา ตาซ้าย ต่อมไทรอยด์ข้างในเสื้อตะกั่ว ต่อมไทรอยด์ข้างนอกเสื้อตะกั่ว ไหล่ซ้าย แขนซ้าย เอว และขาซ้าย ปริมาณรังสีที่ผู้ป่วยได้รับถูกวัดจากเครื่องแดพมิเตอร์ ซึ่งติดกับคอลลิเมเตอร์ของหลอดเอกซเรย์ และศึกษาความสัมพันธ์ของปริมาณรังสีที่แพทย์ได้รับกับปริมาณรังสีที่ผู้ป่วยได้รับ

ผลของการศึกษาในครั้งนี้แสดงว่า ปริมาณรังสีสูงสุดที่แขนซ้ายของแพทย์มีค่า 407 ไมโครซีเวิร์ด และปริมาณรังสีทั้งหมดที่แพทย์ได้รับอยู่ในช่วง 4 ถึง 1211 ไมโครซีเวิร์ต ต่อการตรวจและการรักษาในแต่ละครั้ง ส่วนเจ้าหน้าที่ที่เป็นผู้ช่วยได้รับรังสีประมาณครึ่งหนึ่งของแพทย์อัตราส่วนระหว่างปริมาณรังสีที่แพทย์ได้รับต่อปริมาณรังสีที่ผู้ป่วยได้รับ คือ 12.88, 22.58, 148.29 และ 100.46 ไมโครซีเวิร์ต ต่อ 10 เกรย์ตารางเซนติเมตร จากการตรวจ TOCE (Siemens Polystar), TOCE (Siemens Neurostar), PTBD (Siemens Polystar) และ ERCP (GE Advantx) ตามลำดับ เมื่อสร้างความสัมพันธ์ระหว่างปริมาณรังสีที่แขนของแพทย์ได้รับกับปริมาณรังสีที่ผู้ป่วยได้รับจะได้ความสัมพันธ์แบบเส้นตรง ซึ่งจะช่วยแพทย์ผู้ทำการได้ทราบถึงปริมาณรังสีพึงจะได้รับเพื่อจะได้หลีกเลี่ยงการได้รับรังสีปริมาณสูง

ภาควิชา รังสีวิทยา ลายมือชื่อนิสิต.....

สาขาวิชา ฉายาเวชศาสตร์ ลายมือชื่ออาจารย์ที่ปรึกษา.....

ปีการศึกษา 2547 ลายมือชื่ออาจารย์ที่ปรึกษาร่วม.....

4674798030 : MAJOR DIAGNOSTIC IMAGING

KEYWORDS : THERMOLUMINESCENT DOSIMETER / DOSE-AREA PRODUCT /
RADIATION DOSE / INTERVENTIONAL RADIOLOGY
SORNJAROD OONSIRI : THERMOLUMINESCENT DOSIMETRY MEASUREMENT OF RADIATION DOSE TO MEDICAL STAFF IN INTERVENTIONAL RADIOLOGY. THESIS ADVISOR : ASSOC. PROF. SIVALEE SURIYAPEE, THESIS CO-ADVISOR : ASSOC. PROF. DR. ANCHALI KRISANACHINDA. 70 pp. ISBN 974-17-6530-4

Radiological risk to medical staff in interventional radiology is a major concern in hospital, due to the rapidly increasing use of fluoroscopy. The purpose of this study is to determine the dose of medical staff in interventional radiology at different locations on the body using thermoluinescent dosimeter (TLD) as occupational dosimetry and to relate with patient dose using the dose-area product (DAP). Since thermoluminescent dosimeter does not provide a direct indication of absorbed dose, their response to radiation in the form of an emission of light has to be calibrated against a known standard absorbed dose.

All thermoluminescent dosimeters were calibrated for the sensitivity, energy response, linearity and minimum detectable dose. Dose measurement accuracy of thermoluminescent dosimeter is within 14 % over the range of measurement. The study covered a sample of 55 procedures in three interventional radiology procedures with three x-ray machines. The radiologists wore eight thermoluminescent dosimeter chips next to eyes, thyroid under thyroid shield, thyroid outside thyroid shield, left shoulder, left forearm, gonad and left leg during procedure. In addition, direct reading for patient dosimetry from dose-area product which placed in front of the collimator of the x-ray tube was recorded to estimate the patient radiation dose.

The average dose to the primary radiologist shows maximum value at the left forearm which is 407 μSv. The range for all procedures and machines are 4 to 1211 μSv per procedure. The secondary radiologist who was far behind the primary radiologist received about half of the primary one. The range of dose-area product are 282 to 37937 cGy cm^2. A clear linear relationship is shown between the dose-area product reading and the dose to the radiologist. The ratio between the radiation dose of interventional radiologist and patient dose is 12.88, 22.58, 148.29 and 100.46 μSv per 10 Gy cm^2 for TOCE (Siemens Polystar), TOCE (Siemens Neurostar), PTBD (Siemens Polystar) and ERCP (GE Advantx), respectively. The estimation of personal dose can be done from the patient dose. This will help the radiologists to avoid the excess dose during their work.

Department Radiology Student's signature……..

Field of study Diagnostic Imaging Advisor's signature…….

Academic year 2004 Co-advisor's signature……

ACKNOWLEDGEMENTS

I would like to express gratitude and deepest appreciation to Associate Professor Sivalee Suriyapee, Chief Physicist at Division of Radiation Oncology, Department of Radiology, Faculty of Medicine, Chulalongkorn University, my major advisor for her guidance, invaluable advice, supervision, constructive comments and English language proof in this research. I am equally grateful to Associate Professor Anchali Krisanachinda, Head of Nuclear Medicine Division, Department of Radiology, Faculty of Medicine, Chulalongkorn University, my co-advisor for her help in the experiment, kind suggestion, constructive comments in the experiments and English language proof in this research.

I would like to deeply thank Associate Professor Somjai Wangsuphachart, Director of Department of Radiology, Faculty of Medicine, Chulalongkorn University for advice and comments in the research.

I would like to deeply thank to my thesis committee, Assistance Professor Sukalaya Lerdlum, Head of Diagnostic Division, Department of Radiology, Faculty of Medicine, Chulalongkorn University and Mrs. Weeranuch Kitsukjit for her kindness in examining the research methodology and provide suggestion for the improvement.

I would like to thank Associate Professor Peter Homolka, Physicist at Center for Biomedical Engineering and Physics, Vienna Medical University, for his help in the experiment, kind suggestion, constructive comments in the experiments and English language proof in this research

I am grateful to all teachers, lecturers and staff in Master Science Program in Medical Imaging, Faculty of Medicine, Chulalongkorn University for their kind support and supply the knowledge in Medical Imaging.

I would like to thank the staffs of Division of Interventional Radiology and radiation Oncology, Department of Radiology in allowing and helping me to collect the radiation dose that became the data of this research.

Finally, I am grateful to my family for their financial support, valuable encouragement, entirely care and understanding during the entire course of study.

Sornjarod Oonsiri

CONTENTS

CONTENTS (Continued)

CHAPTER **Page**

CONTENTS (Continued)

CHAPTER **Page**

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF ABBREVIATIONS

Abbreviation	Terms
Al_2O_3	Aluminum oxide
B	The back scatter factor
BG	The background
CA	The coronary angiography
$CaCO_3$	Calcium carbonate
CaF_2	Calcium fluoride
$CaSO_4$	Calcium sulphate
cc	Cubic centimeter
cGy	Centigray
cGy cm^2	Centigray centimeter square
^{60}Co	Cobalt-60
^{137}Cs	Cesium-137
$^{\circ}c$	Degree celcius
C/kg	Coulomb per kilogram
DAP	The dose-area product
D_w	The absorbed dose to water at point of measurement in a water phantom
E_{max}	The maximum energy
ECC	The element correction coefficient
ERCP	Endoscopic retrograde cholangiopancreatography
g	Fraction of energy of secondary charged particles that is lost to bremsstrahlung

LIST OF ABBREVIATIONS (continued)

Abbreviation	Terms
GE	General Electric Company
Gy	Gray
Gy cm^2	Gray centimeter square
HVL	The half value layer
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
k_{air}	The kerma to air
keV	Kiloelectron volt
k_u	The radiation quality correction factor
kVp	Kilovoltage peak
k_w	The kerma to water
$Li_2B_4O_7$	Lithium borate
LiF	Lithium fluoride
m	Meter
mA	Milliampere
MDD	The minimum detectable dose
MeV	Megaelectron volt
mGy	Milligray
mGy/min	Milligray per minute

LIST OF ABBREVIATIONS (continued)

Abbreviation	Terms
mm	Millimeter
mm Al	Millimeter aluminium
M_u	The meter reading
MV	Megavolt
n	The neutron
nC	Nanocoulomb
$N_{D,w}$	Absorbed dose to water calibration factor
NE	Nuclear Enterprise
N_K	Air kerma calibration factor of an ionization chamber
N_x	Exposure calibration factor of an ionization chamber
^{60}Ni	Nickel-60
PC	The personal computer
PMT	The photomultiplier tube
PSDL	The primary standard dosimetry laboratory
PTBD	Percutaneous transhepatic biliary drainage
p_u	Factor to allow for of non-water equivalent of the ionization chamber, when in the user's beam.
Q_{ci}	The correction charge integral
Q_i	The charge integral value
r	The correlation coefficient
RCF	The reader calibration factor
SiO_2	Silicon oxide

LIST OF ABBREVIATIONS (continued)

Abbreviation	Terms
SSDL	The secondary standard dosimetry laboratory
Sv	Sievert
TLD	The thermoluminescent dosimeter
TOCE	Transarterial oily chemoembolisation
TTP	The time temperature profile
VC	The variation coefficient
W/e	The mean energy expended in air per ion pair formed and per electron charge
Z	The atom number
Z_{eff}	The effective atomic number
γ	The gamma-rays
ρ	The density
μ_{en} / ρ	Mass energy absorption coefficient
μ_{tr} / ρ	Mass energy transfer coefficient
μGy	Microgray
μSv	Microsievert

CHAPTER I

INTRODUCTION

In interventional radiology, the extensive use of x-rays results in an increased risk of radiation induced effects in medical staff. Two types of effect may occur, they are deterministic and stochastic effects. The risk for long-term stochastic effects (cancer, leukemia) may be assessed by effective dose. Radiologists who perform interventional procedures often have to stand close to the x-ray beam in order to carry out manipulations. As a result their eyes, shoulders, forearms, hands and legs, which will not be protected by conventional lead apron, may receive significant radiation doses from scattered x-rays. The radiation level below the couch is also high, because, with the C-arm under couch x-ray tube configuration commonly used, radiation is produced by scatter of the unattenuated primary beam from the bottom of the couch and from the patient.

Radiological risk to medical staff in interventional radiology is a topic of major concern in hospital occupational radiation protection, due to the rapidly increasing use of fluoroscopy. Furthermore, the fast development of interventional radiology in recent years has seldom, if ever, been matched by a parallel increase in the number of specialists. Thus, workloads supported by interventional radiology staff are often great. In addition, since fluoroscopic image quality can improve as radiation intensity increases, interventional radiology is prone to overexposure, both of the patient and staff. Various studies have been performed to optimize interventional radiology.

Optimization procedures can involve significant reductions in staff doses. However, some measures may detrimentally affect the radiation protection of staff in difficult situation. For example, manufacturers of interventional radiology x-ray equipment include elements to reduce doses to patients while keeping or improving the image quality, but some of these elements may entail an occupational dose increase if adjusted incorrectly or used improperly. Thus, the availability and regular use of protective tools such as aprons, glasses, gloves and screens, allows important dose savings. Image quality control must be carried out a regularly scheduled basis. Practices based on performing the procedure at the most suitable location with reference to the patient, with well collimated beams, using magnification only when strictly needed and low cine frame rates should be recognized as critical to radiation protection optimization strategies. A recent paper addressing staff radiation exposure in catheterization laboratories, stresses once again the importance of ability, good training and radiation protection awareness as key factors. Unfortunately, discomfort of staff when using protective tools and/or some of these measures may impair the image quality, thereby slowing down the procedure.

Interventional radiology includes invasive diagnostic procedures and therapeutic procedures that require radiological guidance such as interventional cardiology and interventional neuroradiology and types of interventional procedures where dedicated fluoroscopic equipment should be used. There are also other invasive, radiologically guided procedures performed by non-radiologist physicians,

such as orthopaedic surgeons, gastroenterologists, pneumologists and vascular surgeons, that are frequently carried out without proper radiological equipment and sufficient knowledge of radiology and radiation protection.

The levels of doses to patients and staff in interventional radiology vary enormously as a function of procedure type, fluoroscopy time and, number of images acquired and equipment performance. A poor correlation exists between patient and staff dose, and large variations of dose are reported for the same procedure. The experience of the first operator in conducting a clinical procedure, and the subsequent training of the whole staff on radiation protection, quality assurance and radiology techniques, are other important factors influencing the exposure of both patient and staff.

A relation between patient doses usually evaluated from the dose-area product is difficult to establish, especially in cardiology. However, it could provide a good reference for dosimetric control of staff, as demonstrated recently.

CHAPTER II

REVIEW OF RELATED LITERATURE

Vano E, Gonzalez L, Guibelalde E and Fernandez J M [1], studied the typical occupational dose levels in interventional radiology and cardiology installations, the relation between dose to patient and occupational dosimetry through the dose-area product was established. The study covered a sample of 83 procedures performed by 10 specialists in six laboratories. The radiologists and cardiologists monitored wore nine thermoluminescent chips next to eyes, forehead, neck, hands, left shoulder, left forearm and left arm during each single procedure. In addition, direct reading electronic devices for environmental dosimetry were placed in the C-arm of x-ray system, to estimate roughly the occupational radiation risk level. Typical shoulder doses derived from electronic dosimetry range between 300 and 500 μSv per procedure, assuming no lead protective screens were used. Using these values and patient dose-area data from two laboratories, averaged ratios of 84 and 120 μSv per 10 Gy cm^2 are obtained for cardiology procedures. Finally, occupational dose reductions of approximately 20 % when using highly filtered x-ray beams with automatic tube potential (kVp) reduction (available in some facilities), and by a factor of about three when using ceiling mounted screens, have been found.

William J R [2], studied staff doses related to the dose received by the patient expressed as the dose-are product. A study has been made of patient doses in two x-ray rooms used for interventional procedures associated with vascular and liver diseases. Doses to radiologists in these rooms were normalized to dose-area product. It was found that the average doses to the body, neck and hands were 0.05, 0.89 and 2.45 μSv/(Gy cm^2), respectively for those radiologists with no significant involvement in hepatobiliary procedures. Higher doses were found in one radiologist whose workload included biliary drainage. The whole body dose was 0.17 μSv/(Gy cm^2) or 5800 μSv per year. It was shown that the doses to the neck and hands for biliary drainage work was 6.59 and 29.0 μSv/(Gy cm^2), respectively. This study has demonstrated the value of dose-area product as a measure of radiologist workload in respect of its significance in terms of staff dose.

Cruces R R, Garcia-G J, Diaz R F J and Hernandez A J [3], studied the dose data for some digital angiographic and interventional procedures. Values of measured dose-area product for 143 patients for five types of procedures were presented. Procedures investigated were abdominal angiography, arteriography of lower limbs, biliary drainage, embolisation of spermatic vein and nephrostomy. All the procedures were performed using digital equipment. Values of dose-area product and effective dose were 30 Gy cm^2 and 6200 μSv for arteriography of lower limbs and 150 Gy cm^2 and 38200 μSv for biliary drainage. In each one of these procedures, effective dose values per minute of fluoroscopy and per radiography film have been calculated. It is possible to use this information for the rapid estimation of effective dose.

There have been many reports on the correlation of patient skin dose in interventional radiology with dose-area product. Putte S V D , Verhaegen F and Taeymans Y [4], showed the relationship between dose area product and skin dose. They found the good agreement between the calculated skin dose distributions, using dose area product values averaged over a group of patient who underwent coronary catheterization and left ventricle investigation, and the measured skin dose averaged over the same group of patients.

However, little work has been published quantify the radiation doses received to medical staff. Whitby M and Martin C J [5], studied to ascertain the magnitude and distribution of doses to the legs of radiologists when performing interventional procedures. LiF : Mg, Ti TLD-100 chips were used to measure simultaneously doses to the lower limbs and, for comparison, the hands during 100 interventional procedures. Results show leg dose was dependent upon type and complexity of procedure, equipment used and whether lead protection available. Where no lead protection was used, the dose to the lower limbs were frequently similar to or higher than those received by the hands. The mean dose to the legs ranged from 190 μSv to 2600 μSv per procedure, compared with 40 μSv to 1250 μSv to the hands. During transjugular intrahepatic portosystemic shunt (TIPS) and embolisation procedures the leg dose could be as much as 2 - 3 times greater than that to the hands. When lead protection was used, the dose to the legs was reduced significantly to 20 μSv to 50 μSv per procedure. A clear linear relationship was shown between the dose-area product reading and the dose to the feet of radiologists. As a “rule of thumb” a dose-area product reading 100 Gy cm^2 will give a dose of 1000 μSv to the legs, if no lead protection was used, dropping to approximately 20 μSv if lead protection was present. This study demonstrates that the dose to the legs of radiologists can be higher than that to the hands when no lead protection is used. The inclusion of a lead screen to protect the legs is an effective method of dose reduction when performing interventional procedures.

CHAPTER III

THEORY

3.1 Interventional Radiology [6]

Interventional radiology has developed from diagnostic angiography and now plays a central role in the management patients with vascular disease. These therapeutic angiographic procedures cover a wide range of complexity, and are usually very effective and efficient. The treatment options available to patient often include percutaneous endovascular procedure to be performed instead of a conventional surgical one, but have also increased the range of treatment available by offering procedures to patients, who are either unfit for surgery or whose symptoms do not merit its risks.

Interventional radiology includes transluminal angioplasty and vascular stent insertion, therapeutic embolisation, vascular infusion therapy and the insertion and retrieval of intravascular foreign bodies. The scope and complexity of these procedures, however, continues to grow and patients and undergoing interventional vascular procedures need to have their management explained to them so that they can give informed consent. This includes the diagnosis and prognosis of their condition, the treatment options available for their condition and an explanation of the proposed procedure including its risks and benefits.

3.1.1 Transarterial oily chemoembolisation (TOCE)

The basic technique of therapeutic embolisation involves the injection of embolic material through a catheter selectively positioned in an artery or vein in order to deliberately occlude the artery, vein or vascular bed of an organ by the formation of thrombus in the blood vessels. The picture of transarterial oily chemoembolisation is shown in figure 3.1.

Embolisation is used in the management of patients with neoplastic disease as a properative technique to reduce blood loss during surgery, as a palliative technique to alleviate symptoms and occasionally as a definitive procedure instead of surgery.

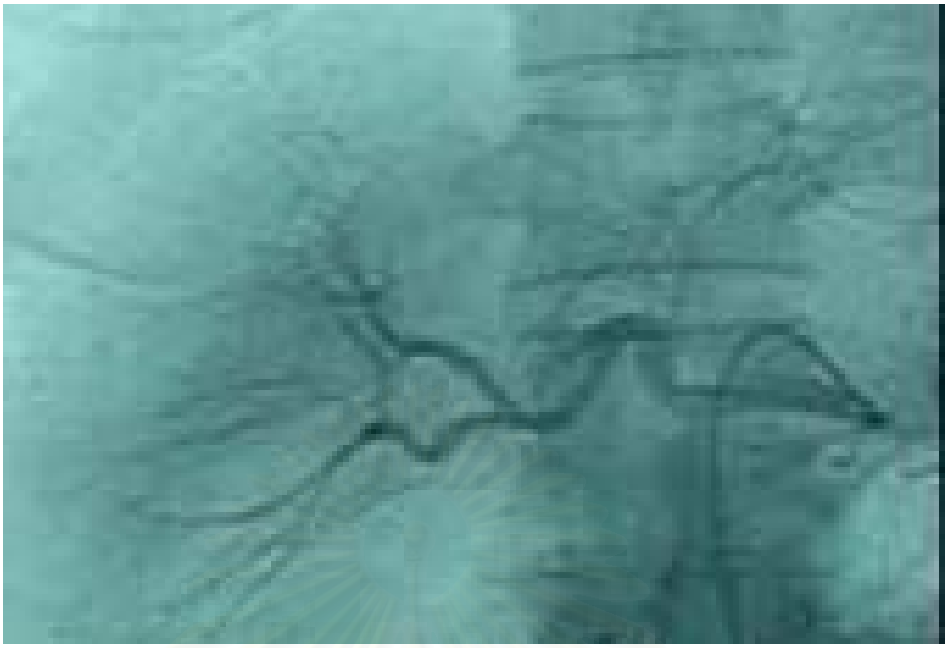


Figure 3.1 Transarterial oily chemoembolisation (TOCE)

Preoperative embolisation of a neoplasm is done to reduce blood loss during the surgery and to decrease tumour size, thus making the surgery much easier. This type of embolisation was frequently performed several days before nephrectomy in patients with renal cell carcinoma, but this can in fact make the surgery more difficult as the inflammatory response that affects the tissue planes around the kidney. Preoperative embolisation is still performed for renal cell carcinoma, but the timing of the procedure should ideally be only a few hours before the surgery. A balloon occlusion catheter can also be effectively used for this purpose. Other tumours that may require preoperative embolisation include intracranial meningioma, nasopharyngeal angiofibromas, chemodactomas, primary bone tumours and primary hepatic tumours.

Palliative embolisation is performed to alleviate symptoms such as bleeding, pain and metabolic effects of endocrine tumours. This type of embolisation is usually performed in patients with hepatic metastases. The liver has dual blood supply and normally receives 75 % of its blood supply from the hepatic portal vein and only 25 % of its blood from the hepatic artery. Tumours however tend to receive 90 % of their blood supply from the hepatic artery, but only 10 % from the portal venous system. Hepatic artery embolisation is therefore contraindicated if the portal vein is occluded.

Embolisation of the hepatic artery with Gelfoam and metal coils is used to control haemobilia in patients with a false aneurysm from hepatic metastases and to reduce pain from stretching of the liver capsule in patients with hepatomegaly from a primary tumour or hepatic metastases by reducing the size of the liver. Embolisation of the liver is effective in controlling the symptoms of flushing and diarrhea produced by 5-hydroxytryptamine in patients with the carcinoid syndrome, by ablating the functioning capacity of the hepatic metastases. Symptomatic relief can

also be produced in patients with hepatic metastases from insulinomas, glucagonomas and vipomas. Chemoembolisation using doxorubicin mixed with Lipiodol has also been used in the treatment of multifocal hepatocellular carcinoma and hepatic metastases.

Therapeutic embolisation has been performed as the definition procedure in the treatment of benign bone tumours, benign hepatic tumours and ectopic parathyroid tumours in the mediastinum. Recently embolisation of the uterine arteries with Ivalon has been used in the treatment of fibroids. Embolisation of adrenal tumours by venous infarction has been performed in patients with Cushing's syndrome and Conn's syndrome.

3.1.2 Percutaneous transhepatic biliary drainage (PTBD) [7]

Percutaneous transhepatic biliary drainage is performed in patients with obstructive jaundice in whom endoscopic drainage is unsuccessful or who have complex hilar lesions shown in figure 3.2. The commonest indication is in malignant disease of bile ducts or pancreas.

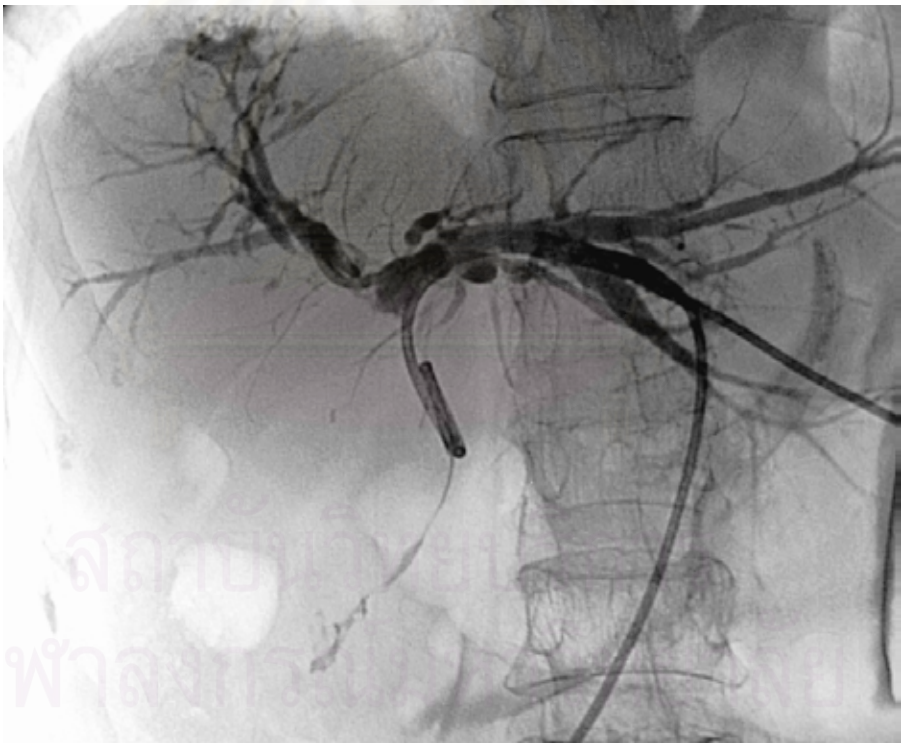


Figure 3.2 Percutaneous transhepatic biliary drainage (PTBD)

3.1.3 Endoscopic retrograde cholangiopancreatography (ERCP) [8]

With the aid of an endoscope in the duodenum, the ampulla of Vater is cannulated and iodinated water-soluble contrast agent injected first for visualization of the pancreatic duct and thereafter into the common bile duct for visualization of the common bile duct, right and left hepatic ducts, and biliary radicles. If the gallbladder is intact, it too will be visualized at this time by passage of the contrast agent through the cystic duct into the gallbladder. The picture of endoscopic retrograde cholangiopancreatography is shown in figure 3.3.

Whenever possible, the complete procedure should be performed for visualization of both of these areas. It is particularly accurate for visualization of pancreatic ductal abnormalities, such as may occur with pancreatitis and carcinoma of the pancreas, for visualization of the gallbladder when it is nonvisualized by oral cholecystography and occupied by neoplasm or stone, or for visualization of common bile duct or hepatic ductal stones.

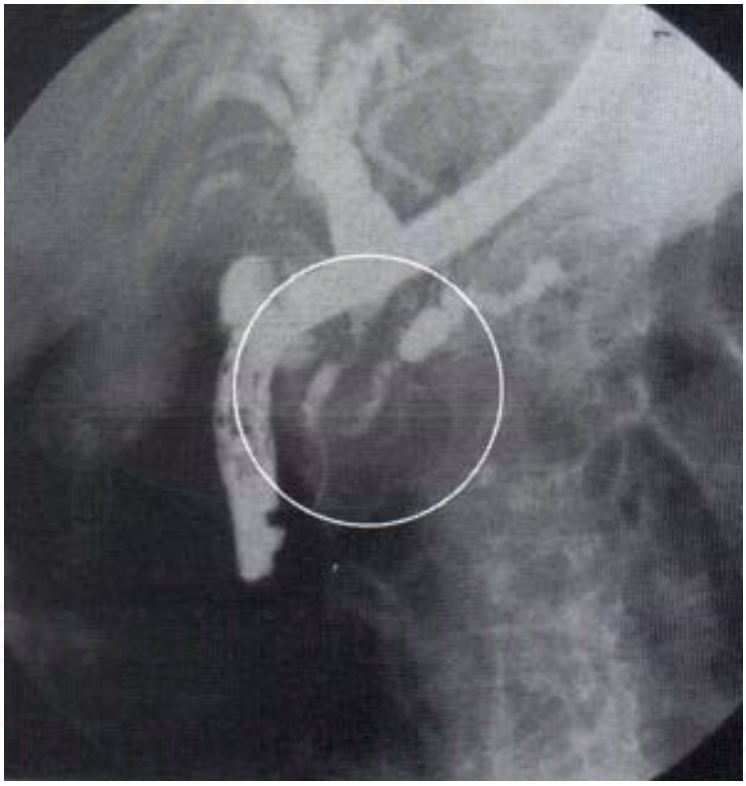


Figure 3.3 Endoscopic retrograde cholangiopancreatography (ERCP)

3.2 Medical Staff Exposures [9]

Interventional radiology procedures performed by radiologists are mainly conducted in dedicated x-ray rooms in radiological departments. Outside radiological departments, however, in area such as :

- Orthopaedic rooms
- Cystoscopy units
- Cardiac catheterization laboratories
- Operating surgery rooms
- Coronary care units
- Gastrointestinal units
- Lithotripsy units

several types of specialist perform an increasing number of procedures that are becoming more and more complex, with potentially high doses given to patients and staff.

Most of the procedures that performed in the areas shown above are carried out with the aid of fixed or mobile fluoroscopic equipment, and in general the personnel involved have limited knowledge of imaging methodology, technology and radiation protection.

The level of radiation exposure varies with the nature of the procedure carried out and with the specific exposure parameters employed (e.g. the type of imaging equipment, source to image distance, fluoroscopy time and distance from the scattering area on the patient). Using standard precautions and according to the level of exposure for the staff, the procedures can be classified as in table 3.1.

Table 3.1 Classification of procedures

	Annual unshielded effective dose to staff (mSv/year)
Low exposure procedure	< 1
Medium exposure procedure	> 1 to < 25
High exposure procedure	> 25

The dosimetry quantities of interest are effective doses for stochastic effects and, for determinestic effects, absorbed doses to eye lens, hands, knees and ankles. Typical air kerma rates for patients and staff for different classes of procedure are shown in table 3.2. These values demonstrate that the highest potential dose in fluoroscopic procedures is usually where staffs work close to the scattering areas on patients during exposures.

Table 3.2 Typical doses from routine imaging procedures

Modality	Air kerma rate at patient surface (mGy/min)	Exposure time / procedure	Air kerma at 1 m (scatter) (mGy/min)	Cumulative air kerma at 1 m (μGy)
Fluoroscopy	10 - 100	Long	10 - 100	250
Cine angiography	100 - 1000	Short	100 - 1000	100
Radiographic spot film	18000	Very short	18000	30

Several reports have shown measured staff doses in different fluoroscopic and interventional radiology procedures. Table 3.3 summarizes staff doses in terms of effective dose for a single procedure and normalized to the patient dose expressed as a dose-area product. The effective dose has been calculated according to the model proposed by Niklason et al. when a body is partially exposed, as in the case of personnel wearing protective aprons. The personal dosimetry systems used were either single or double dosimeter methods, worn under and over protective aprons. There is a high variability of doses between the different studies, demonstrating clear differences in practice and a real need for the optimization of the staff protection. Excluding the values shown in table 3.3, the variability is reduced if the effective dose is normalized to the patient dose area product, but only in a few cases was impossible to evaluate this quantity.

From the reported data the following comments can be derived :

1) Many variables affect staff exposure (e.g. type of equipment used, distance from the patient, beam direction, use of protective screens, type of procedure, operator skill, training and equipment performance).

2) The comparison of personal doses was difficult or, in same cases impracticable when :

- Different dosimetry methods are used or the reported data did not indicate the type and number of procedures performed.
- Dosimeters are worn in different positions on the body.
- The doses reported are very low, suggesting that the dosimeters were not worn all the time by the operators.

3) Staff dose monitoring in interventional radiology requires a proper dosimetry method that takes into account the protective devices adopted in a facility (individual and collective) :

- For the evaluation of effective dose with single or, better, double dosimeters.
- For the evaluation of partial body doses to eye lenses, hands, and the lower extremities.

The normalization of the personal dose to the workload, expressed in terms of the number of procedures or dose area products, allows a straight forward comparison between facilities and helps to identify those clinicians who are not taking effective radiation safety precautions.

Dose constraints are also a useful instrument that can be used in interventional radiology as an indication of optimized staff exposure for standardized and frequent interventional radiology procedures. As a proposal, dose constraints in interventional radiology should be expressed in terms of effective dose per procedure or effective dose per unit of dose are product. It seems necessary to propose a standardized collection of staff doses in order to establish constraint values useful in the optimization process.

Table 3.3 Staff doses per procedure and per unit dose area product in interventional cardiology

Reference	Effective dose (μSv / procedure)	Effective dose / DAP (μSv / Gy cm^2)
Wu et al.	0.2	-
Renaul	2.8	-
Li et al.	8.0	-
Steffenino et al.	15.1	-
Folkert et al.	2.0	-
Watson et al.	1.8	-
Zorzetto et al.	3.7	-
Vano et al.	18.8	0.34
Padovanni et al.	2.2 (CA), 8.8 (PTCA)	0.035 (CA), 0.054 (PTCA)
Williams	-	0.013
DIMOND Spain	2.2 (CA), 4.4 (PTCA)	0.022 (CA) - 0.033 (PTCA)
DIMOND Italy	0.5 (CA), 1.0 (PTCA)	0.006 (CA) - 0.006 (PTCA)
DIMOND Greece	1.0 (CA), 2.0 (PTCA)	0.008 (CA) - 0.011 (PTCA)

Notes
CA = Coronary angiography
DIMOND = The Digital Imaging Measures for Optimizing Radiological Information Content and Dose research programme

Finally, staff protection also requires :

1) A frequent reassessment of the practices being carried out

2) The use of dedicated equipment for interventional radiology

3) The adoption of appropriate procedure (e.g. number of frames, fluoroscopy times, frame rates, magnifications, beam orientations and filed sizes) and radiological techniques (kilovoltages, contrast curves, image quality in fluoroscopy and fluorography, grids, filters)

4) The adoption of proper protection devices

5) Training in radiological imaging and radiation protection

When interventional radiology procedures are performed by non-radiologists the implementation of these actions are particularly difficult and the availability of guidelines or mandatory requirements for collaboration with radiologists, medical physicists and radiographers should be pursued.

3.3 Absorbed Dose Calibration [10]

3.3.1 Medium energy x-rays : 100 kVp to 300 kVp

The primary standard dosimetry laboratory (PSDL) generally has air kerma and exposure standards for several x-ray energy regions. Therefore it is possible at the second standard dosimetry laboratory (SSDL) to transfer calibrations to the user's chamber in terms of exposure N_x (= X_c/M_c) and air kerma N_K (= $k_{air,c}/M_C$). The relationship between these two calibration factors is :

$$N_K = N_x \frac{W}{e} \frac{1}{(1-g)} \qquad \ldots(3.1)$$

The method for the determination of absorbed dose in a water phantom using an exposure or air kerma calibrated ionization chamber will differ somewhat for medium energy x-rays from that at high energy radiation. The main reason is that none of the electrons generated in the water phantom will reach the air cavity. (A 200 keV electron will have a maximum range in graphite less then 0.3 mm, i.e. less than the thickness of most chamber walls.) Electrons producing ionization inside the air-cavity are therefore mainly generated in the chamber walls. (A few electrons are also generated in the air of the cavity.)

$$K_{air} = M_u N_K k_u \qquad \ldots(3.2)$$

The absorbed dose is to be determined by the user in uniform water phantom at the point P (figure3.4). An ionization chamber is placed with its center P′ at that point. A measurement is carried out giving the meter reading (M_u). The air kerma is obtained at a point P″ in the center of air cavity inside the water phantom as the chamber is calibrated to indicate the air kerma free in air, i.e. as if the chamber was not present. This means that we obtain the air kerma at the center (P″) of an air cavity of a size defined by the outer wall surfaces. Correction factors for attenuation in the chamber walls and non-air equivalence of the walls are thus already included in the calibration factor N_K. The radiation quality correction factor (k_u) is required because the ratio K_{air}/M_u may be sensitive to the difference in spectral distribution of the radiation field used for the calibration free in air and that in the phantom at the position of the detector. For most practical situations k_u can be taken as unity, as it is recommended to use reference instruments for which the change in response (i.e. meter reading to air kerma) with energy is small (less than ± 2 % in the range of half-value layers from 2 mm Al to 3 mm Cu, i.e. from approximately 70 kVp to 250 kVp x-ray tube potential).

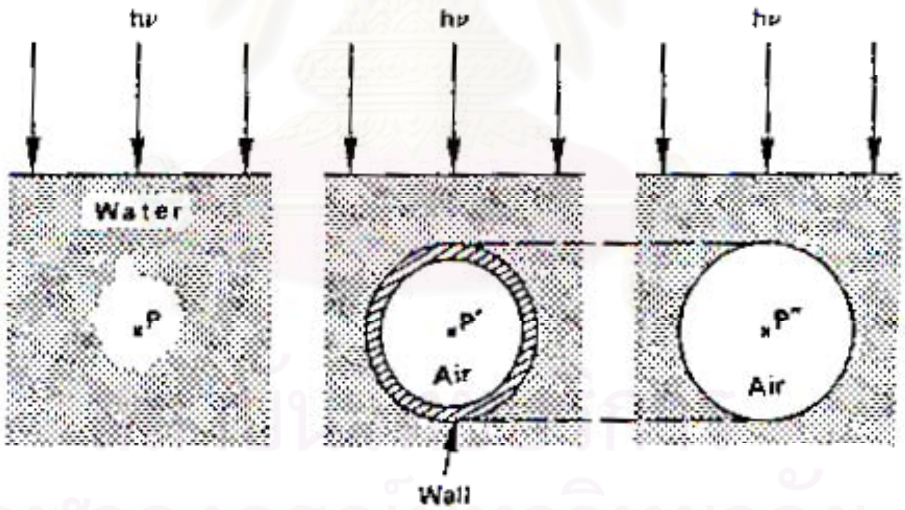


Figure 3.4 Dosimetry in a water phantom

The water kerma is then obtained from

$$\frac{K_w}{K_{air}} = \left(\overline{\frac{\mu_{tr}}{\rho}} \right)_{w,air} \qquad \ldots(3.3)$$

For conventional x-rays the energy transfer to bremsstrahlung from generated electrons is almost negligible, i.e. g = 0 and therefore $(\mu_{tr}/\rho) = (\mu_{en}/\rho)$, and furthermore $K_w \approx D_w$. Equations 3.1 and 3.2 give

$$D_w = M_u N_K k_u \left(\overline{\frac{\mu_{en}}{\rho}} \right)_{w,air} p_u \qquad \ldots(3.4)$$

The perturbation correction factor (p_u) is here introduced explicitly because the equation without this factor would give the absorbed dose to small mass of water at the center P″ of the cavity. In the formalism recommended by ICRU in its Report 23 a 'displacement correction' incorporated in the conversion coefficient (F) but in the medium energy x-ray region no detailed information was available at the time. The perturbation correction factor (p_u) corrects for the replacement of water by air and the chamber wall material. The values of perturbation correction factor (p_u) are evaluated assuming the center of the ionization chamber to be the effective point of measurement. The values of perturbation correction factor (p_u) were derived from measurements of absorbed dose in the phantom by means of an extrapolation chamber and by means of thimble ionization chambers calibrated to indicated air kerma. Monte Carlo calculations by Schneider and Grosswendt support the values. Recent calorimeter work leads to similar results, suggesting that much previous and present dosimetry with medium energy x-rays in phantom is in error. Therefore, use of the formalism described here may produce deviations from the results obtained by produces neglecting perturbation corrections. Absorbed dose values derived by the present formalism will therefore be a few percent higher in the upper energy range with a maximum of up to about 10 % at 100 kVp.

3.3.2 Low energy x-rays : 10 kVp to 100 kVp

The main dosimetric task in this photon energy range is the determination of the absorbed dose at the surface of a phantom. The determination, using a plane-parallel chamber, can either be based on a calibration at the surface of a phantom, method (a), or (when the former method is not available) on a calibration carried out free in air, method (b).

(a) Primary standards based on extrapolation ionization chamber techniques have been established recently. These allow direct calibration of the user's ionization chamber indicating absorbed dose to water at the surface of a water phantom.

As the photon fluence decreases very rapidly within the first few millimeters of depth in the phantom, only plane-parallel ionization chambers with small electrode distances and very thin entrance foils are suitable. These design features do not allow the use of the chamber inside a water phantom and therefore a solid phantom must be used. The calibration factor $N_{D,w}$ is defined as

$$D_w = M_u N_{D,w} \qquad \ldots(3.5)$$

where D_w is the water absorbed dose at the surface of a water phantom as measured with a primary standard, and M_u is the reading of the instrument placed at the surface of a solid phantom, at the same distance from the source. It should be noted that an ionization chamber calibrated free in air should not be used on the surface of a phantom unless a correction factor which takes into account the scattering contribution from the phantom is known and applied.

(b) The chamber may be calibrated in terms of air kerma free in air. A calibration factor (N_K) is then available. No extra phantom is used for the measurement but the ionization chamber may be embedded in some material which then has to be regarded as part of the chamber. The inner surface of the entrance foil is the effective point of measurement. This is brought to the reference point. The absorbed dose to water at that reference point at the surface of a phantom in the absence of the ionization chamber is then given by

$$D_w = M_u N_K B\, k_u \left(\overline{\frac{\mu_{en}}{\rho}} \right)_{w,air} \qquad \ldots(3.6)$$

where B represents for the reference field size. The term $(\mu_{en}/\rho)_{w,air}$ is the ratio of the averaged mass absorption coefficient of water to that of air averaged over the spectral energy fluence distribution at the surface of the phantom. Values of this ratio as a function of the beam quality expressed as half value thickness. The factor k_u corrects for the difference in spectral distribution of the radiation field used for the calibration and that at the surface of the phantom. For most practical situations this factor should be very close to unity.

3.4 Thermoluminescent Dosimetry (TLD) [11]

In recent years many applications of thermoluminescent dosimeter have been reported in the literature, and many more applications have gone unreported. There are hundreds of thermoluminescent dosimeter readers in operation in various laboratories around the word.

Many of dosimetry problems arising in radiation dosimetry can be resolved by using thermoluminescent dosimeter. The small size, good energy dependence, good sensitivity and large useful dose range of thermoluminescent dosimeters are key advantages, as the direct measurement of doses is possible under conditions in which other forms of dosimetry are not practical, measurement of the dose from the primary beam during fluoroscopy is convenient since the dosimeters do not interfere with the study.[12]

There are several solid state systems available for the dosimetry of ionizing radiation. However, none of the systems provider absolute measurement-each needs calibration in a known radiation field before it can be used for the determination of absorbed dose.

There are two types of solid state dosimeters : (a) integrating type dosimeters (thermoluminescent crystals, radiophotoluminescent glasses, optical density type dosimeters such as glass and film), and (b) electrical conductivity dosimeters (semiconductor junction detectors, induced conductivity in insulating materials). Of these, the most widely used systems for the measurement of absorbed dose are the thermoluminescent dosimeter, diode, and film, which are described.

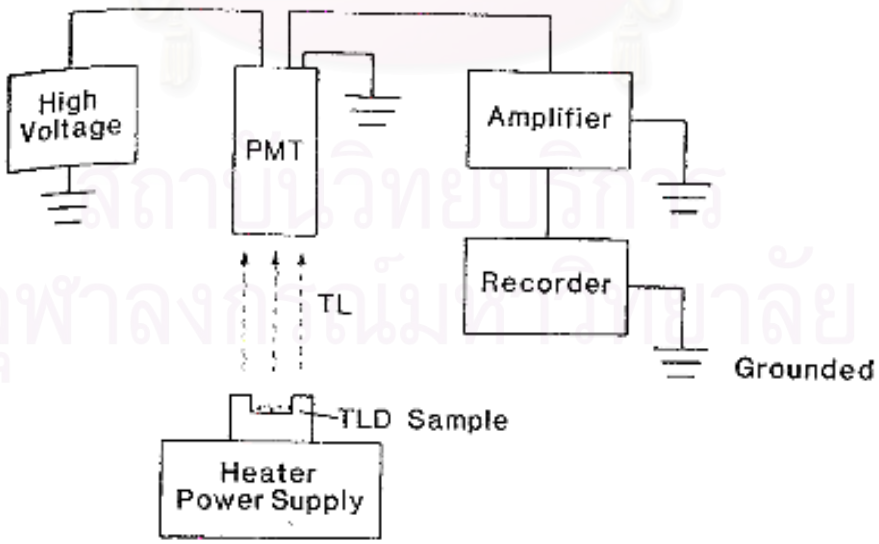


Figure 3.5 Schematic diagram showing apparatus for dose measurement using thermoluminescence

Many crystalline materials exhibit the phenomenon of thermoluminescence used in thermoluminescent dosimeters. When such a crystal is irradiated, a very minute fraction of the absorbed energy is stored in the crystal lattice. Some of this energy can be recovered later as visible light if the material is heated. This phenomenon of release of visible photons by thermal means is known as thermoluminescence.

The arrangement for measuring the thermoluminescence output is shown schematically in figure 3.5. The irradiated material is placed in a heater cup or planchet, where it is heated for a reproducible heating cycle. The emitted light is measured by a photomultiplier tube (PMT) which converts light into an electrical current. The current is then amplified and measured by a recorder or a counter.

There are several thermoluminescence phosphors available but the most noteworthy are lithium fluoride (LiF), lithium borate ($Li_2B_4O_7$), and calcium fluoride (CaF_2). Of these phosphors, LiF is most extensively studied and most frequently used for clinical dosimetry. LiF in its purest form exhibits relatively little thermoluminescence. But the presence of a trace amount of impurities (e.g., magnesium) provides the readiation-induced thermoluminescence. These impurities give rise to imperfections in the lattice structure of LiF and appear to be necessary for the appearance of the thermoluminescence phenomenon.

3.4.1 Simplified theory of thermoluminescent dosimetry

The chemical and physical theory of thermoluminescent dosimeter is not exactly known, but simple models have been proposed to explain the phenomenon qualitatively. Figure 3.6 shows an energy-level diagram of an inorganic crystal exhibiting thermoluminescence by ionizing radiation.

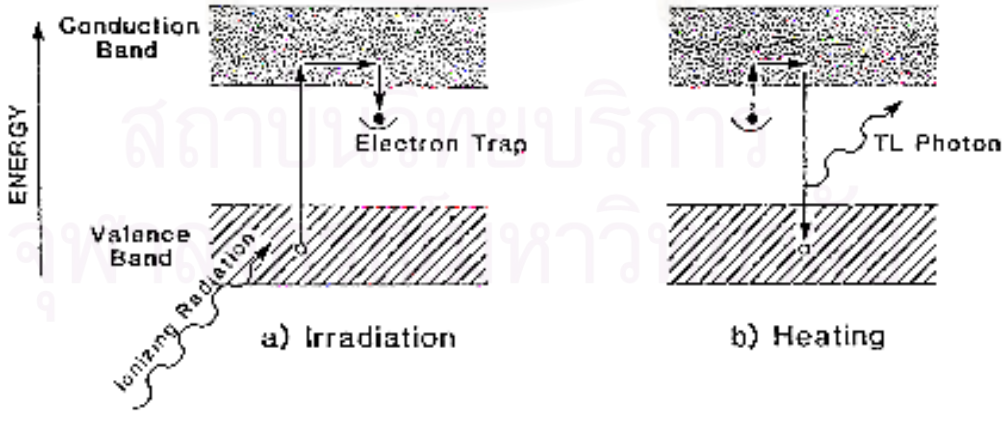


Figure 3.6 A simplified energy-level diagram to illustrate thermoluminescent process

In an individual atom, electron occupies discrete energy levels. In a crystal lattice, on the other hand, electronic energy levels are perturbed by mutual interactions between atoms and give rise to energy bands the "allowed" energy bands and the forbidden energy bands. In addition, the presence of impurities in the crystal creates energy traps in the forbidden region, providing metastable states for the electrons. When the material is irradiated, some of the electrons in the valence band (ground state) receive sufficient energy to be raised to the conduction band. The vacancy thus created in the valence band is called a positive hole. The electron and the hole move independently through their respective bands until they recombine (electron returning to the ground state) or until they fall into a trap (metastable state). If there is instantaneous emission of light owing to these transitions, the phenomenon is called *fluorescence*. If an electron in the trap requires energy to get out of the trap and fall to the valence band, the emission of light in this case is called *phosphorescence* (delayed fluorescence). If phosphorescence at room temperature is very slow, but can be speeded up significantly with a moderate amount of heating (~300°c), the phenomenon is called *thermoluminescence*.

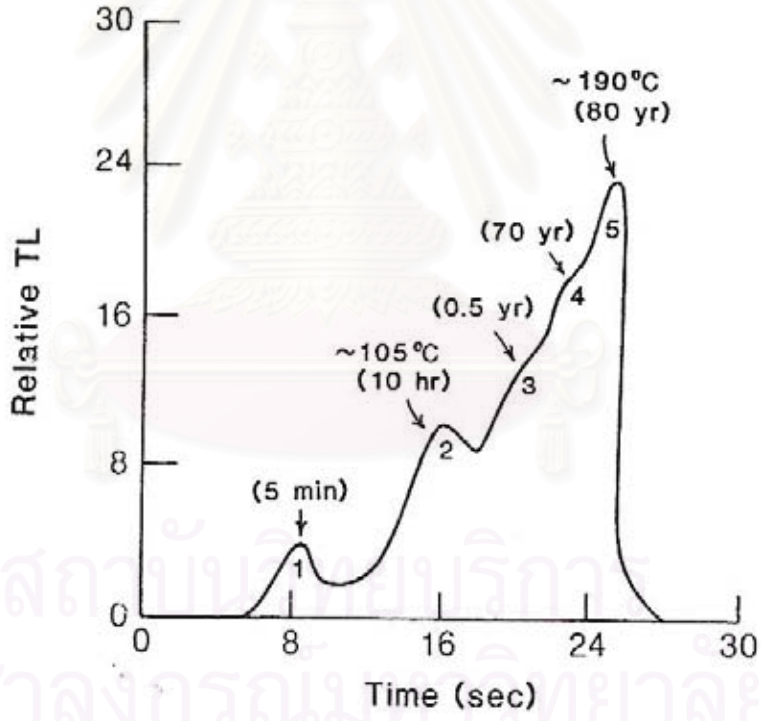


Figure 3.7 An example of glow curve of LiF (TLD-100) after phosphor has been annealed at 400°c for 1 hour and read immediately after irradiation to 100 R

A plot of thermoluminescence against temperature is called a *glow curve* (figure 3.7). As the temperature of the thermoluminescence material exposed to radiation is increased, the probability of releasing trapped electrons increases. The light emitted first increases, reaches a maximum value, and fall again to zero. Because most phosphors contain a number of traps at various energy levels in the forbidden band, the glow curve may consist of a number of glow peaks as shown in figure 3.6. The different peaks correspond to different 'trapped" energy levels.

3.4.2 Lithium fluoride

Lithium fluoride has an effective atomic number of 8.2 compared with 7.4 for soft-tissue. This makes this material very suitable for clinical dosimetry. The dose absorbed in LiF can be converted to dose in muscle by considerations similar to those discussed earlier. For example, under electronic equilibrium conditions, the ratio of absorbed doses in the two media will be the same as the ratio of their mass energy absorption coefficients. If the dimensions of the dosimeter are smaller than the ranges of the electron crossing the dosimeter, then the Bragg-Gray relationship can also be used. The ratio of absorbed doses in the two media will be the same as the ratio of mass stopping powers. The applicability of the Bragg-gray cavity theory to thermoluminescent dosimeter has been discussed by several authors.

3.4.3 Practical consideration

As stated previously, the thermoluminescent dosimeter must be calibrated before it can be used for measuring an unknown dose. Because the response of the thermoluminescent dosimeter materials is affected by their previous radiation history and thermal history, the material must be suitably annealed to remove residual effects. The standard preirradiation annealing procedure for LiF is 1 hour of heating at 400°c and then 24 hour at 80°c. The slow heating, namely 24 hours at 80°c, remove peak 1 and 2 of the glow curve by decreasing the "trapping efficiency". Peak 1 and 2 can also be eliminated by postirradiation annealing for 10 minutes at 100°c. The need for eliminating peak 1 and 2 arise from the fact that the magnitude of these peaks decreases relatively fast with time after irradiation. By removing these peaks by annealing, the glow curve becomes more stable and therefore predictable.

The dose response curve for TLD-100 is shown in figure 3.8. The curve is generally linear up to 10^3 cGy but beyond this it becomes supralinear. The response curve, however, depends on many conditions that have to be standardized to achieve reasonable accuracy with thermoluminescent dosimeter. The calibration should be done with the same themoluminescent dosimeter reader, in approximately the same quality beam and to approximately the same absorbed dose level.

The thermoluminescent dosimeter response is defined as thermoluminescence output per unit absorbed dose in the phosphor. Figure 8.14 gives the energy response curve for LiF (TLD-100) for photon energies below megavoltage range. The studies of energy response for photons above ^{60}Co and high energy electrons have yielded somewhat conflicting results.

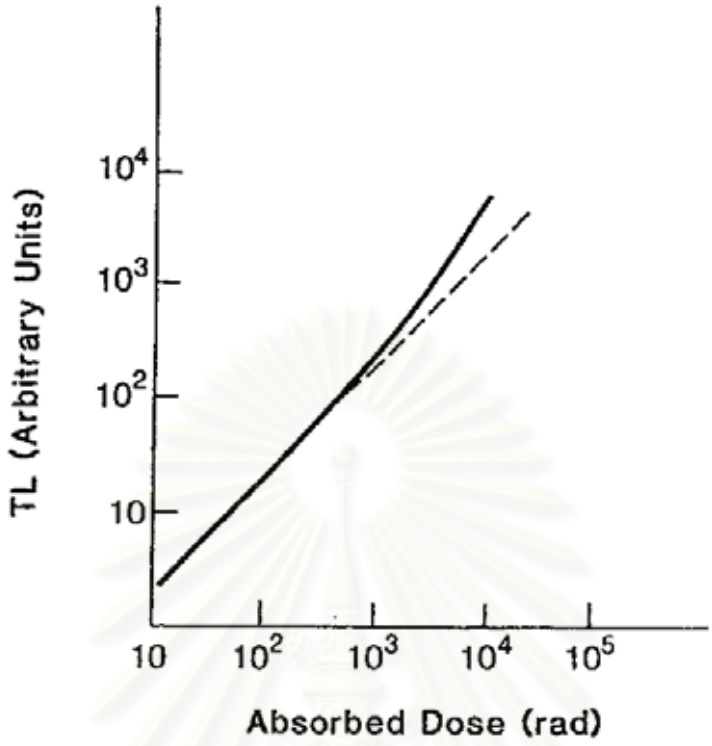


Figure 3.8 An example of thermoluminescence versus absorbed dose curve for TLD-100 powder (schematic)

When considerable care is used, precision of approximately 3 % may be obtained using thermoluminescent dosimeter powder or extruded material. Although not as precise as the ion chamber, thermoluminescent dosimeter's main advantage is in measuring doses in regions where ion chamber cannot be used. For example, thermoluminescent dosimeter is extremely useful for patient dosimetry by direct insertion into tissue or body cavities. Since thermoluminescent dosimeter material is available in many forms and sizes, it can be used for special dosimetry situations such as for measuring dose distribution in the build-up region, around brachytherapy source, and for personal dose monitoring.

3.4.4 Energy response

The photoelectric absorption process is usually the predominant absorption process at low (< 100 keV) photon energies. This interaction, which involves the innermost electrons, is dependent on the nuclear charge of the atom, the atomic number (Z). Consequently, radiation detectors with high atomic number's show a greatly enhanced response at the low photon energies. The energy response of a detector at a particular photon energy may be defined as the response of the detector at that photon energy relative to its response at some reference energy (usually 1-3 MeV) where the photoelectric absorption process is largely inoperative. The dosimeter is said to have a good energy response if its response per roentgen shows little change with photon energy, the energy response is poor if this charge is charge.

Detectors with an effective atomic number approximately that of air (Z = 7.64) show a good energy response while those with an effective atomic number much different from 7.64 show a poor energy response.

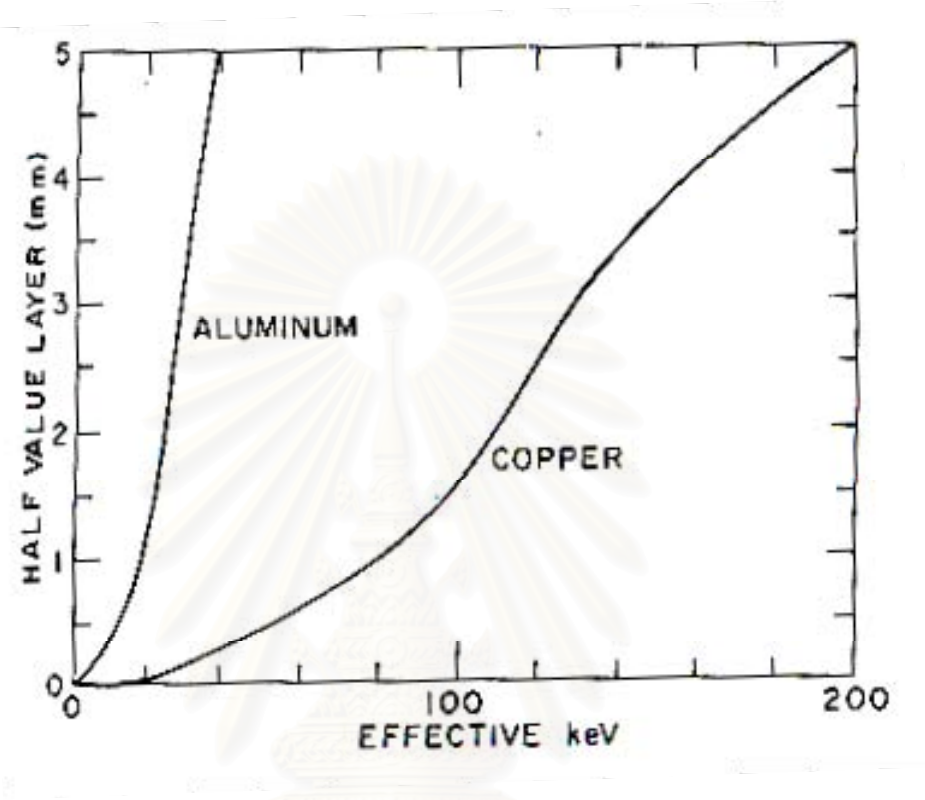


Figure 3.9 Relation of half value layer (HVL) to effective energy

One recurring problem in dealing with energy response is the precise statement of x-ray beam quality. If the radiation source is a monoenergetic gamma-ray emitter (for example, ^{137}Cs) then the beam quality can be expressed simply and accurately as the monoenergetic photon energy (662 keV). On the other hand, if the radiation source used is an x-ray generator that produces a spectrum of photon energies up to the maximum accelerating voltage, then specification of the beam quality is much more difficult. Beam quality may be expressed in terms of 'effective keV' defined as that monoenergetic photon energy which has the same half value layer as does the x-ray beam in question. Conversion from the measured half value layer to effective energy (keV) can be made from figure 3.9. Effective energy (keV) determined in this manner is not a highly precise statement of quality for example, two x-ray beams generated at different accelerating voltages and with different filtrations can have identical half value layer (and consequently the same effective energy). It is often valuable to specify the first and second half value layer as well as the accelerating voltage and the amount of filtration.

There are two ways to determine energy response curves for thermoluminescence phosphors by using experimentally determined values based on effective energy for various x-ray and gamma-ray sources or by using theoretically calculated values from available absorption coefficients for the various photon energies. Experimentally measured values are usually more appropriate when correcting for the energy responses in various experimental irradiations. Figure 3.10 show energy response curve which were calculated by comparing the absorption coefficients of the various thermoluminescence phosphors with the energy deposited in tissue. Energy response is usually related to the exposure in air rather than to the dose in tissue.

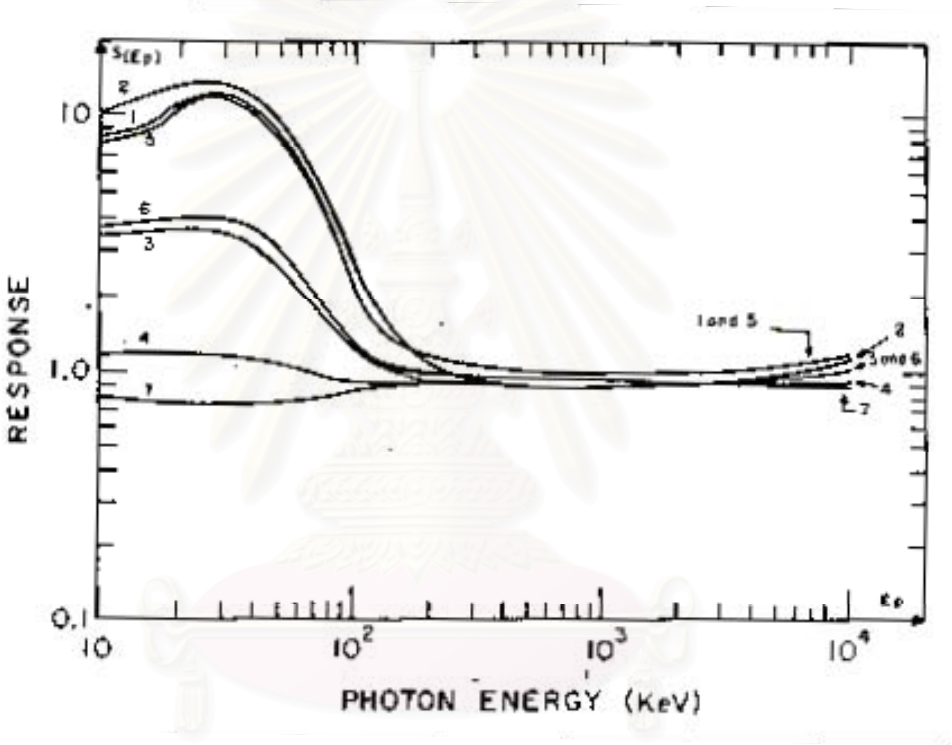


Figure 3.10 Theoretical sensitivity of thermoluminescence phosphors : (1) $CaSO_4$; (2) CaF_2 ; (3) Al_2O_3 ; (4) LiF ; (5) $CaCO_3$; (6) SiO_2 ; and (7) $Li_2B_4O_7$.

3.4.5 Calibration of thermoluminescent dosimeter [13]

The purpose of calibrating a thermoluminescent dosimeter instrument is to produce consistent and accurate reading in dosimetrically meaningful units. The calibration process involves the following 3 steps.

a) Generate calibration dosimeter

In this process, an element correction coefficient (ECC) is generated by using a set of dosimeters, typically 1 - 2 % of the total population to be calibration dosimeters. They are identified and segregated from the field dosimeters.

All dosimeters are annealed to clear them all residual exposure. Duration time between annealing and exposing should be the same for all dosimeters. After being exposed to the known radiation dose, the charge integral value (Q_i) in nanocoulomb (nC) of each dosimeter (i) is read out and recorded. Then the average charge integral ($\overline{Q}$) of all dosimeters is calculated and the element correction coefficient (ECC_i) for individual dosimeter i (i = 1, 2, 3,…, n) is computed by dividing the average charge integral by the individual charge (Q_i) as :

$$ECC_i = \frac{\overline{Q}}{Q_i} \qquad ...(3.7)$$

b) Calibration of thermoluminescent dosimeter reader

A group of dosimeter about 1 - 2 % of dosimeters in (a) which have ECC_i value close to 1 are chosen to be calibration dosimeters. The calibration dosimeters are exposed to known amount of radiation dose (D) in grays and read by thermoluminescent dosimeter reader. As Q_i is the reading for the dosimeter I, the corrected charge integral (Q_{ci}) of the dosimeter is calculated by :

$$Q_{ci} = Q_i \times ECC_i \qquad ...(3.8)$$

Then the reader calibration factor (RCF) is calculated from the equation :

$$RCF = \frac{\overline{Q}_c}{D} \qquad ...(3.9)$$

When $\overline{Q}_c$ is the average corrected charge integral and calculated by :

$$\overline{Q}_c = \frac{1}{n}(\sum_{i=1}^{n} Q_{ci}) \qquad ...(3.10)$$

c) Calibration of dosimeter

The rest of the dosimeter [number of the dosimeters in (a) - number of dosimeters in (b)] are used as field dosimeters. They are exposed by the known radiation dose of L grays and read by thermoluminescent dosimeter reader. The calibration value of element correction coefficient for individual dosimeter (ECC_{ci}) is then calculated by :

$$ECC_{ci} = \frac{(RCF \times L)}{Q_i} \qquad ...(3.11)$$

3.4.6 Determination of unknown radiation dose

The field dosimeters in 3.3.4 (c) are used to measure unknown radiation dose. The unknown dose D in grays is calculated by using ECC_{ci} from the equation :

$$D = \frac{(Q_i \times ECC_{ci})}{RCF} \qquad ...(3.12)$$

When Q_i is the reading of the individual field dosimeter *i* of any user-defined length.

CHAPTER IV

RESEARCH QUESTION AND RESEARCH OBJECTIVE

4.1 Research Questions

4.1.1 Primary research question

How much is the radiation doses to medical staff who perform various interventional radiology procedures measured with thermoluminescent dosimeter ?

4.1.2 Secondary research question

What is the relationship between radiation doses to medical staff in various interventional radiology procedures with the dose received by the patient expressed as the dose-area product ?

4.2 Research Objectives

4.2.1 To find the sensitivity, energy response, linearity and the process of calibration of thermoluminescent dosimeter.

4.2.2 To determine the doses of medical staff at different location of the body when carrying out interventional procedure by thermoluminescent dosimeter.

4.2.3 To record the patient dose by dose-area product measurement.

4.2.4 To establish the relationship between the doses of medical staff when carrying out interventional procedure and the patient doses.

4.3 Hypothesis

4.3.1 The doses of medical staff when carrying out interventional procedure ranged from 100 μSv to 3000 μSv per procedure, the highest radiation dose was expected at the radiologist's hand.

4.3.2 There is a good clear linear relationship between the dose and dose-area product reading per procedure.

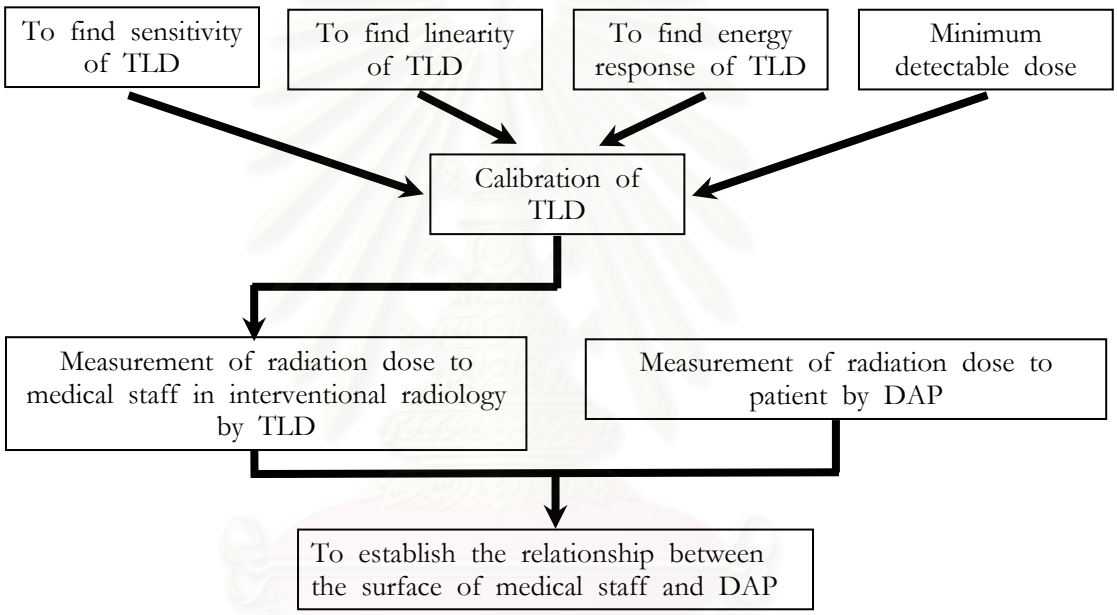
CHAPTER V

RESEARCH METHODOLGY

5.1 Research Design

This study is a descriptive prospective cross sectional study.

5.2 Research Design Model



5.3 Key Word

- Thermoluminescent dosimeter (TLD)
- Dose area product meter (DAP)
- Radiation dose
- Interventional radiology

5.4 The Sample

5.4.1 Target population

Medical staff members who perform interventional procedure at King Chulalongkorn Memorial Hospital.

5.4.2 Sample

Medical staff members who perform transarterial oily chemoembolization (TOCE), percutaneous transhepatic biliary drainage (PTBD) and endoscopic retrograde cholangiopancreatography (ERCP) at King Chulalongkorn Memorial Hospital.

5.5 Material

5.5.1 Thermoluminescent dosimeter (TLD)

The thermoluminescent dosimeter used in this study are lithium fluoride (LiF) crystal doped with magnesium and titanium (LiF:Mg, Ti). It is known as TLD-100. The thermoluminescent dosimeters have a nominal density of 2.64 g/cm^2 and effective atomic number (Z_{eff}) of 8.2, a value close to tissue. Thermoluminescent dosimeter chip with the dimension of 3.2 mm × 3.2 mm × 0.89 mm are used for this study. The picture is shown in figure 5.1.

Three pieces of thermoluminescent dosimeter chips were loaded in the plastic tubes, shown in figure 5.2. These tubes will be irradiated for thermoluminescent dosimeter characteristics study and personnel dose measurement.

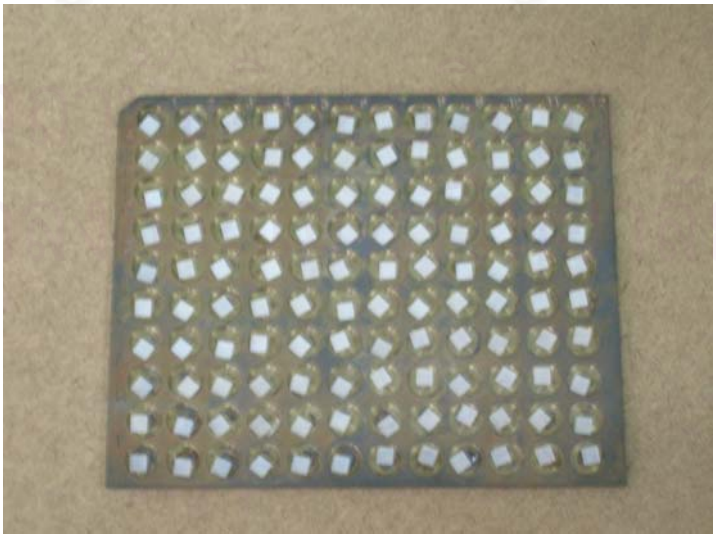


Figure 5.1 Thermoluminescent dosimeter (TLD)

Figure 5.2 Plastic tube with thermoluminescent dosimeter chips inside

5.5.2 The Harshaw model 5500 automatic thermoluminescent dosimeter reader [13]

The Harshaw model 5500 automatic thermoluminescent dosimeter reader, is shown in figure 5.3, it is a personal computer driven, table-top instrument for thermoluminescent dosimeter measurement. It has been designed to economically provide both high performance and high reliability and complies with the latest International Standard Organization (ISO) requirement. This reader is capable of reading 50 dosimeters per loading and accommodates thermoluminescent chips, rods, and cubes in a variety of sizes. The flexible design of the controlling software enables the user to configure the workstation for different applications. The software provides real - time monitoring of the instrument's operating conditions and display of the glow curves and response values. The reader uses hot nitrogen gas heating with a closed loop feedback system that produces linearly ramped temperatures accurate within $\pm$ 1°c to 400°c. The time temperature profile (TTP) is user-defined in three segments : preheat, acquire, and anneal, each with independent times and temperatures. Any number of different time temperature profile may be defined and calibrated. The photomultiplier tube assembly is cooled to a constant temperature maintain consistent performance of the photomultiplier tube. Nitrogen is routed through the photomultiplier tube (PMT) chamber to eliminate condensation.

Figure 5.3 The Harshaw model 5500 automatic thermoluminescent dosimeter reader

5.5.3 Dose-area product meter (DAP)

The diagnostic dosemeter PTW-Diamentor E, is shown in figure 5.4, assists radiologist and radiographers to meet these requirements by recording the patient's exposure during an examination. The total amount of exposure determines the absorbed dose in the irradiated volume of the patient's body. The absorbed dose depends on the radiation exposure and the irradiated area. Therefore, the estimation of the patient's absorbed dose from the dose area product is more easily made than from the x-ray factors.

The Diamentor E measures the dose-area product in the unit cGy cm^2 of the quantity air kerma times area during radiography and fluoroscopy according to international recommendations, e.g. ICRP 16. The technical design of the Diamentor E meet the requirements of the international standard IEC 580.

For recording the dose-area product the flat transparent ionization chamber is fixed to the light beam diaphragm of the x-ray tube. This chamber is light-transparent and thus dose not affect the routine use of the x-ray equipment. The cable connecting the chamber to the main unit can be of any user-defined length.

The Diamentor E is an economic and easy-to-operate high quality dosemeter from the well-known and since many years well-approved PTW-Diamentor series.

The ionization chamber is a light transparent flat chamber. By means of two metal rails the chamber can be slit into the holding device of the light beam

diaphragm of the x-ray tube. Depending on the design of the x-ray equipment, the groove inside the light beam diaphragm holding device is 173 mm or 179 mm wide. The chamber can be supplied to fit both sizes. The size of the chamber is sufficient to cover the cross section of the useful beam at the place where the chamber is located.

The chamber has a standard cable of 1 m length and is designed for a maximum opening of 14.5 cm × 14.5 cm.

The connection between the chamber (that is attached to the light beam diaphragm of the x-ray tube) and the main unit is performed by a special cable. This cable supplied ready with plug and coupling. The standard length is 10 m.

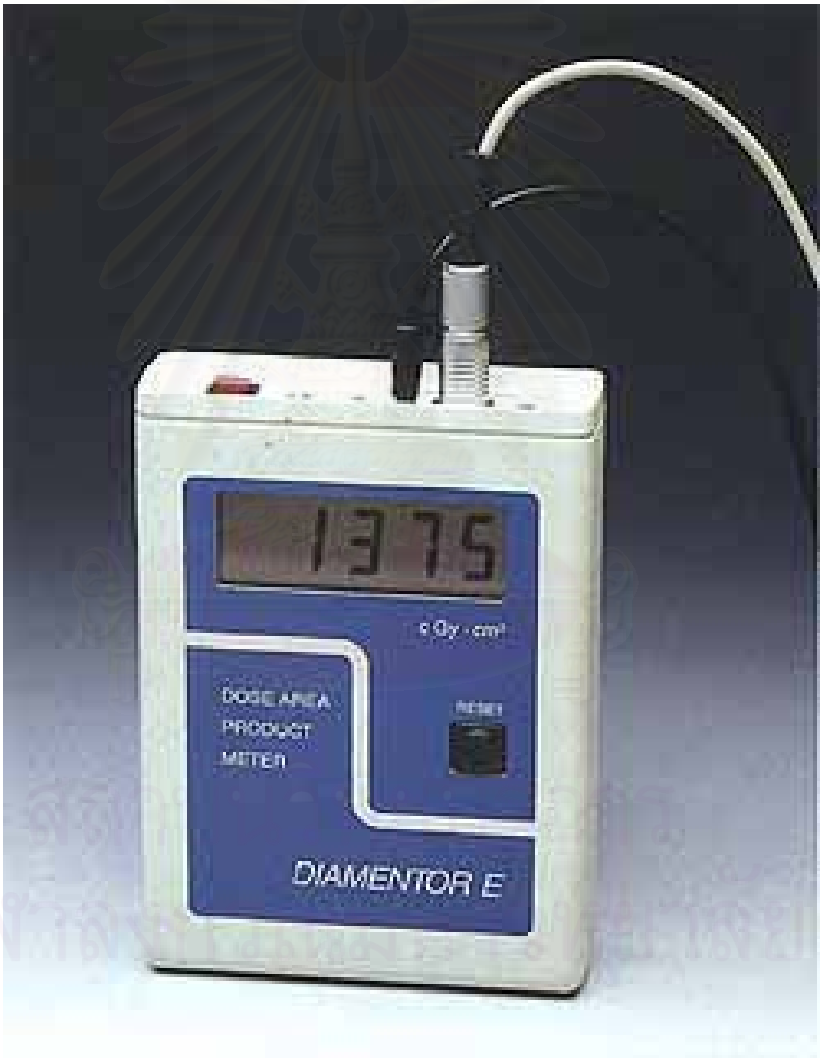


Figure 5.4 Dose-area product meter (DAP)

5.5.4 Secondary standard ionization chamber 0.6 cc graphite guarded stem ion chamber type NE 2571

The system consists of 0.6 cc ionization chamber (guarded stem) type 2571 with thin wall high purity graphite thimble 0.36 mm in thickness and pure aluminum electrode supported by this walled aluminum stem with the build-up thickness 3.87 mm for measuring exposure for 0.3 to 2 MV x-rays or gamma rays from ^{60}Co. The chamber is connected with dosemeter type 2590 for charge reading. The ionization chamber 0.6 cc type NE 2571 is shown in figure 5.5.

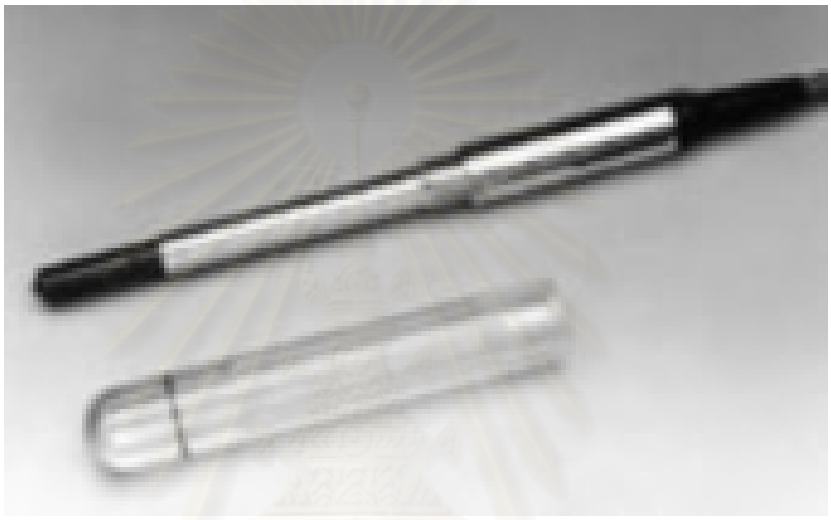


Figure 5.5 Ionization chamber 0.6 cc type NE 2571

5.5.5 Electrometer

The electrometer used with ionization chamber 0.6 cc type NE 2571 is Ionex dosemaster type 2590A which is very wide dynamic range enable accurate measurements of dose. The units are rad, rem, Coulomb per kilogram (C/kg), Gray (Gy), Sievert (Sv) and Coulomb (C) at five digit floating point. Many different types of ionization chambers may be used and many polarizing voltages can be selected to supply the ionization chamber in used. The polarizing voltage range is - 1000 to + 1000 and setting resolution ± 1 volt. The Ionex dosemaster type 2590A is shown in figure 5.6.

Figure 5.6 Ionex dosemaster 2590A

5.5.6 Water phantom

Basic dose distribution data are usually measured in a water phantom, which closely approximates the radiation absorption and scattering properties of muscle and other soft tissue. Another reason for the choice of water as a phantom material, however, poses some practical problems when used in conjunction with ionization chambers and other detectors that are affected by water, unless they are designed to be waterproof. In most cases, however the detector is encased in a thin plastic (water equivalent) sleeve before immersion into the water phantom. The water phantom is shown in figure 5.7.

Figure 5.7 Water phantom

5.5.7 Victoreen 4000M+ [14]

The Victoreen model 4000M+ is a self-contained, noninvasive x-ray test device shown in figure 5.8. In single exposure, it simultaneously measures :

- kVp
- Exposure or Air kerma
- Exposure rate or Air kerma rate
- Time

The model 4000M+ features a dual sensitivity preamplifier for compatibility with radiographic, fluoroscopic and dental x-ray machine. In addition, it is calibrated for both tungsten anode (W/Al) and molybdenum (Mo/Mo) node x-ray tubes, making it suitable for screen film mammography applications. Its automatic waveform phase determination and extensive diagnostics minimize the potential of error.

The external ion chamber port accepts a variety of accessory ionization chambers for various applications, including mammography, photo-timer calibration and input phosphor image intensifier measurements.

The model 4000M+ uses proven technology to compute tube potential with ± 2 % accuracy. Five separate, selectable filter pairs ensure optimum accuracy over the maximum range with minimum filtration dependence. A separate internal ionization measures tube output. Time is measured with crystal quartz accuracy. A microprocessor controls the electronics and performs calculations to obtain the displayed results.

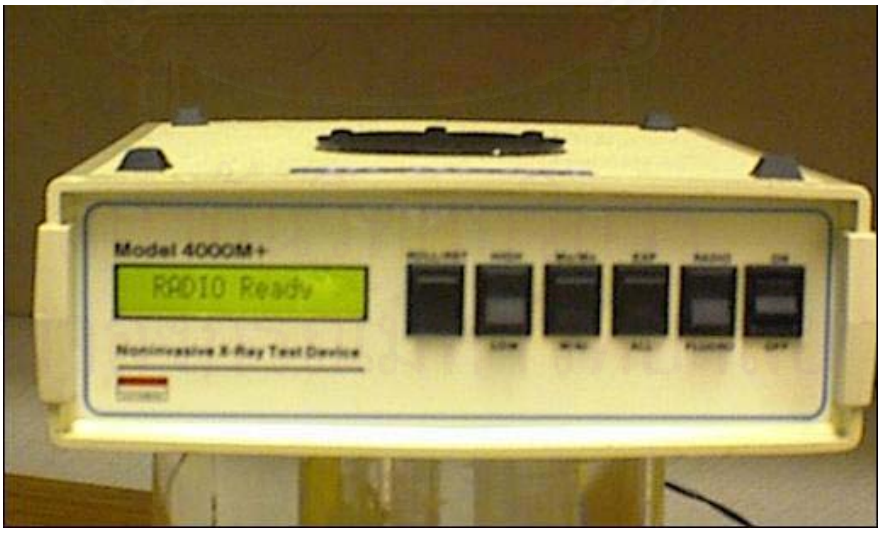


Figure 5.8 Victoreen 4000M +

5.5.8 Varian Ximatron CX

A treatment simulator (figure 5.9) is an apparatus that uses a diagnostic x-ray tube but duplicates a radiation treatment unit in terms of its geometrical, mechanical and optical properties. The main function of a simulator is to display the treatment fields so that the target volume may be accurately encompassed without delivering excessive irradiation to surrounding normal tissues. By radiographic visualization of internal organs, correct marks. Most commercially available simulators have fluoroscopic capability by dynamic visualization before a hard copy is obtained in terms of the simulator radiography.

Figure 5.9 Varian Ximatron CX

5.5.9 ELDORADO 78 cobalt-60 teletherapy machine

The ^{60}Co source is produced by irradiating ordinary stable ^{59}Co with neutrons in a reactor. The nuclear reaction can be represented by $^{59}Co(n,\gamma)^{60}Co$.

The ^{60}Co source, usually in the form of a solid cylinder, discs, or pallets, is contained inside a stainless-steel capsule and sealed by welding. The capsule is placed into another steel capsule which is again sealed by welding. The double-welded seal is necessary to prevent any leakage of the radioactive material. The ELDORADO 78 cobalt-60 teletherapy machine is shown in figure 5.10.

The ^{60}Co source decays to ^{60}Ni with the emission of beta particles (E_{max} = 0.32 MeV) and two photons per disintegration of energies 1.17 and 1.33 MeV. These gamma rays constitute the useful treatment beam. The beta particles are absorbed in the cobalt metal and stainless-steel capsules.

Figure 5.10 ELDORADO 78 cobalt-60 teletherapy machine

Because of the constant emission of the radiation, ^{60}Co is used for thermoluminescent dosimeter absorbed dose calibration.

5.5.10 The x-ray unit, protection available, type of procedure, kilovoltage (kVp) are shown in table 5.1

Table 5.1 The equipment used, lead protection available and kVp

Interventional suite	Protection available	Procedure	Installation	kVp
Siemens Polystar	Lead glass	TOCE, PTBD	1994	60 - 120
Siemens Neurostar	Mobile lead screen, Lead glass	TOCE, PTBD	1999	60 - 120
GE Advantx	None	ERCP	1992	60 - 120

5.6 Method

The study is performed in department of radiology at King Chulalongkorn Memorial Hospital. This study will be carried and into four steps :

- Measurement of half value layer of x-ray beam
- Thermoluminescent dosimeter preparation
- Measurement of surface dose in medical staff in three interventional radiology procedure
- Measurement of dose area product in patient

5.6.1 Measurement of half value layer [15]

The term of half value layer is the thickness of an absorber of specified composition required to attenuate the intensity of the beam to half its original value. Although all beams can be described in terms of their half value layer, the quality of a gamma ray beam is usually stated in terms of the energy of the gamma rays or its nuclide of origin which has known emission spectrum.

In the case of low energy x-ray beams (below megavoltage range), it is customary to describe quality in term of half value layer.

The measurement were performed to find the half value layer of Siemens Polystar, Siemens Neurostar, GE Advantx and Varian Ximatron CX with the kVp change from 60, 70, 80, 90, 100, 110 and 120 is shown in figure 5.11. The Victoreen 4000M+ meter is being used, this may done by holding the detachable cap of the Victoreen 4000M+ firmly in a clamp. A treatment cone of small area should be used and radiation scattered from objects in the room should be avoided but the field size should be cover the sensitive volume of the detector. For constant kV and mAs,

measurements should be made with no added aluminum, then with enough aluminum to reduce the intensity to a little less than one half, and finally with enough to reduce it to a little more than one half. The half value layer can be obtained by interpolation.

Figure 5.11 The measurement of half value layer (HVL)

5.6.2 Thermoluminescent dosimeter preparation [16]

5.6.2.1 Sensitivity and dose calibration

Thermoluminescent dosimeters, TLD-100 chips with the automatic thermoluminescent reader of the Harshaw Model 5500 were used to measure the radiation doses at various points on medical staff. Before using thermoluminescent dosimeters for dose measurement, all thermoluminescent dosimeters of 350 chips were annealing and irradiation 10 cGy of ^{60}Co gamma-ray for ten times.

Then the sensitivity of each dosimeter was determined by exposing 10 cGy of ^{60}Co gamma-ray to 350 dosimeters, the charge integral value of each dosimeter was read and the element correction coefficient (ECC) was calculated according to equation 3.7. The dosimeters that have the element correction coefficient values between 0.8 and 1.2 were selected for using in this study. In addition the dosimeters of element correction coefficient values varied by ± 1 % (0.99 to 1.01) were chosen for absorbed dose calibration. The absorbed dose of 10 cGy of ^{60}Co gamma-ray from ELDORADO 78 ^{60}Co teletherapy were irradiated to these dosimeters, the average value of charge integral reading was used as a factor to convert charge to absorbed dose. This is reader calibration factor (RCF) value, the equation is according to equation 3.9.

5.6.2.2 Linearity

The Varian Ximatron CX was used to determine the linearity of thermoluminescent dosimeter instead of using the interventional x-ray unit which the half value layer change automatically according to the position of the tube toward the patient. The kVp of the Varian Ximatron CX which have the same half value layer range as the conventional x-ray machine were chosen.

First, the Varian Ximatron CX machine was calibrated for absorbed dose values of 60, 70, 80 and 100 kVp at 200 mA. The 0.6 cc NE 2571 connected to ionex dosemaster 2590A was inserted into the water phantom at 2.0 cm depth, the focus to skin distance was 100 cm and the field size was 12 × 12 cm. The setup is shown in figure 5.12. The exposure times were selected to give the dose range between 0.5 and 100 mGy. The absorbed dose was calculated according to equation 3.4. For ^{60}Co machine the calibration was performed at 80 cm source to surface distance, 5 cm depth and 10 × 10 cm field size The absorbed dose was determined by IAEA - TRS 277. After calibration, thermoluminescent dosimeter was irradiated with known dose by varying the time.

For the linearity of thermoluminescent dosimeters response, the dosimeters were irradiated in water phantom at absorbed dose of 0.5, 1.25, 4.2, 18.6, 59.3 and 100.6 mGy at the 60 kVp 3.0 mm Al, 70 kVp 3.3 mm Al, 80 kVp 3.8 mm Al, 100 kVp 5.0 mm Al and ^{60}Co (1.25 MeV). Three dosimeters were loaded in the plastic tube which was inserted in the hole of water phantom at 2 cm depth. The setup of the measurement was the same as absorbed dose measurement with ionization chamber for each absorbed dose value, 2 tubes with 6 dosimeters were irradiated.

Figure 5.12 The setup of thermoluminescent dosimeter for linearity dose response

5.6.2.3 Energy response

For evaluation of energy response of thermoluminescent dosimeter, the set up of measurement was the same as linearity procedure. The thermoluminescent dosimeters were irradiated in water phantom at absorbed of 5 mGy at 60 kVp 3.0 mm Al, 70 kVp 3.3 mm Al, 80 kVp 3.8 mm Al, 100 kVp 5.0 mm Al of Varian Ximatron CX, and gamma radiation of ^{60}Co (1.25 MeV). The measurement was repeated 2 times with 2 tubes of 6 dosimeters.

The response of each beam quality was normalized to ^{60}Co beams, then the correction factor for beam energy relative to ^{60}Co beams was calculated

5.6.2.4 Minimum detectable dose

For evaluation of minimum detectable dose, the variation coefficient (VC) and the background were found, then minimum detectable dose (MDD).

$$MDD = 3 \times VC \times BG \quad \ldots(5.1)$$

5.6.3 Measurement of dose for medical staff in three interventional radiology procedure

The study was undertaken on a sample of 23 procedures for transarterial oily chemoembolization, 9 procedures for percetaneous transhepatic biliary drainage and 10 procedures for endoscopic retrograde cholangiopancreatography covering a wide variety of both diagnostic and therapeutic procedures. The radiologists working in three rooms specifically designed for interventional radiology, with different x-ray systems and radiation protection elements, were monitored. The data were collected for first radiologist who worked about 0.6 m close to the patient and second radiologist who worked 1.2 m from the patient. Three TLD-100 chips were loaded in each tube and placed on the surface of eyes, thyroid inner lead apron, thyroid outer lead apron, left shoulder, left forearm, gonad and left leg of radiologists who worked closest to the patient throughout the procedure, the picture is shown in figure 5.13. After exposing, the thermoluminescent dosimeters were read by the reader, the charges reading were applied with the element correction coefficient (ECC) for the sensitivity correction and reader calibration factor (RCF) for changing the charge to dose by equation 3.12. Then the energy correction was applied for each quality of beam used. Results are presented in terms of mean doses (± standard deviation) at each site on the body of first radiologist for all the particular types of procedures.

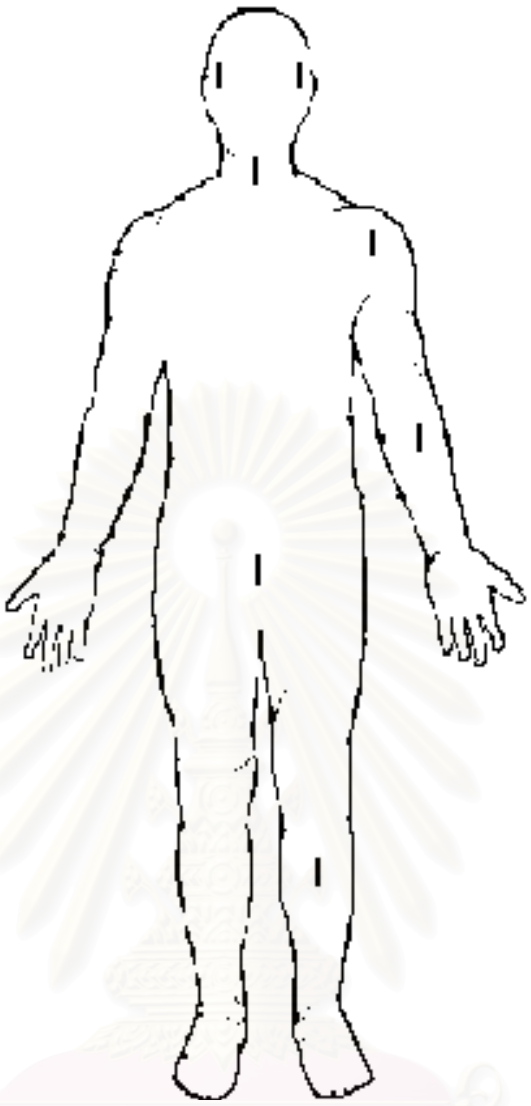


Figure 5.13 Site for dose monitoring for interventional radiologist

5.6.4 Measurement of dose area product in patient

The reading of dose-area product were recorded when the radiologist with thermoluminescent dosimeter placed in various points of the body had performed interventional radiology. The 42 cases were collected.

5.7 Measurement

Independent variables	=	type of procedure, kVp, mA, fluoroscopic time, distance from x-ray beam and size of patient
Dependent variables	=	dose to medical staff

5.8 Data Collection

After thermoluminescent dosimeters have been irradiated, the thermoluminescent dosimeters were then read out on the Harshaw model 5500 automatic TLD reader. Patient dose was collected by dose-area product meter. Kilovoltage, miliampere, fluoroscopy time, size of patient and distance between x-ray tube and the medical staff were recorded in collection forms.

5.9 Data Analysis

5.9.1 Summarization of Data

1. The radiation doses to medical staff are monitored at eyes, thyroid inner lead apron, thyroid outer lead apron, left shoulder, left forearm, gonad, left leg. Results are presented in terms of mean doses (± standard deviation) at each position on the body for all the particular types of procedure.

2. Evaluation and comparison of results among the procedures and sites of dose monitoring will be shown.

3. The relationship between radiation doses to medical staff and dose area product are established.

5.9.2 Data presentation

The table, bar and line graph are presented.

5.9.3 Hypothesis testing

This study is done to find the relationship between the average of measured radiation dose of medical staff and dose-area product measurement.

5.10 Expected Benefit and Application

This study is designed to establish the relationship between the dose received by radiologist and patients. The aim of establishing such a relationship was to be able to identify radiologists whose technique were leading to higher personnel dose and to provide suitable protection devices. The safety use of radiation in interventional radiology will be promoted.

5.11 Ethic Consideration

There are not ethical issues because this study is measured radiation dose of medical staff members who perform interventional radiology everyday.

CHAPTER VI

RESULT AND DISCUSSION

6.1 Measurement of Half Value Layer of Interventional X-ray Units and Simulator Unit

The half value layer in term of millimeter of aluminium for Varian Ximatron CX, Siemens Polystar, Siemens Neurostar, and GE Advantx are shown in table 6.1. The same range of half value layer for Varian Ximatron CX machine were used for thermoluminescent dosimeter calibration in terms of linearity and energy response.

Table 6.1 The measured change in HVL as the kVp is increased from 50 to 150 kVp for representative x-ray imaging system

kVp	Varian Ximatron CX (mm Al)	Siemens Polystar (mm Al)	Siemens Neurostar (mm Al)	GE Advantx (mm Al)
60	3.00	-	-	2.63
70	3.30	2.83	-	3.00
80	3.80	3.25	4.92	3.38
90	-	3.84	5.58	3.63
100	5.00	4.12	7.80	4.08
110	-	4.55	-	5.08
120	-	-	-	5.36

The half value layer for all x-ray machine of 60 kVp to 120 kVp range from 2.63 mm Al to 7.80 mm Al.

6.2 Thermoluminescent Dosimeter Preparation

6.2.1 Sensitivity

The sensitivity or element correction coefficient (ECC) of individual thermoluminescent dosimeter chip was sorted by its readout from the same dosage of 10 cGy. The sensitivity of each thermoluminescent dosimeter was normalized to the average sensitivity to get the sensitivity factors for each thermoluminescent dosimeter according to equation 2.1. The element correction coefficient factors range from 0.828 to 1.155 for thermoluminescent dosimeter chip used in this study. Only the thermoluminescent dosimeters which had the sensitivity factors close to 1.0 (0.99 to

1.01) was selected to be used in the calibration of reader calibration factor (RCF) by equation 3.9.

6.2.2 Linearity

The linearity of thermoluminescent dosimeters response were studied by irradiated in water phantom at absorbed dose of 0.5, 1.25, 4.2, 18.6, 59.3 and 100.6 mGy at 60 kVp 3.0 mm Al, 70 kVp 3.3 mm Al, 80 kVp 3.8 mm Al, 100 kVp 5.0 mm Al and ^{60}Co (1.25 MeV).

The charges corrected by the sensitivity were plotted by the linear regression method, they are shown in figure 6.1, 6.2, 6.3, 6.4 and 6.5 for 60 kVp 3.0 mm Al (r = 0.99), 70 kVp 3.3 mm Al (r = 0.99), 80 kVp 3.8 mm Al (r = 0.99), 100 kVp 5.0 mm Al (r = 0.99) and ^{60}Co (1.25 MeV) (r = 1.00), respectively. Our study dose is in this range (0.5 - 100 mGy), so the dose response of thermoluminescent dosimeter is linear for dose range of 0.5 to 100 mGy.

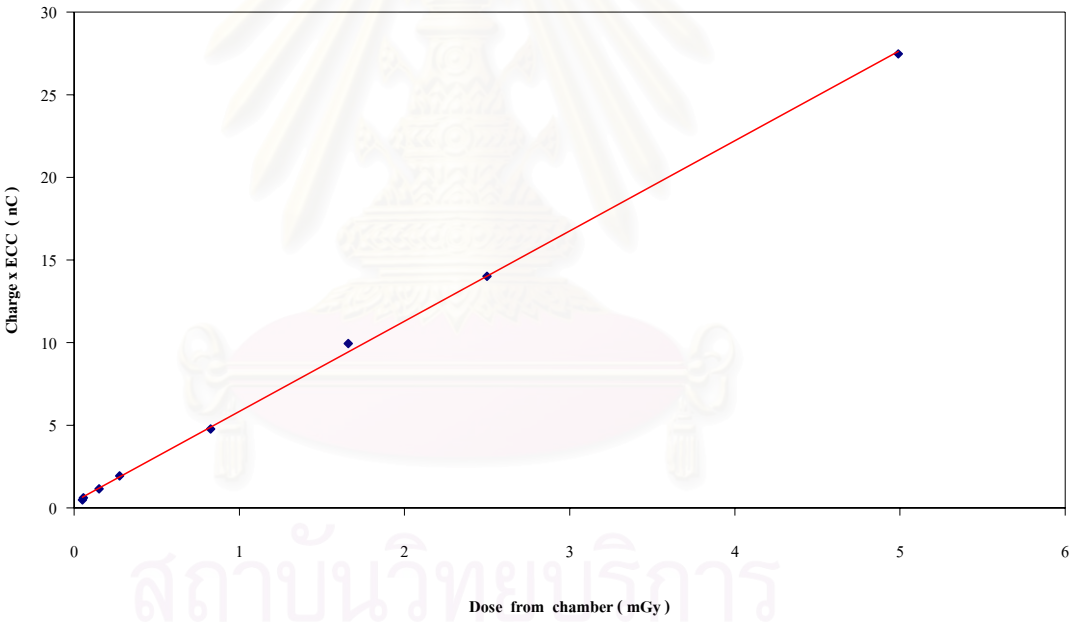


Figure 6.1 Linearity of LiF TLD 100 when irradiated at various doses for 60 kVp 3.0 mm Al

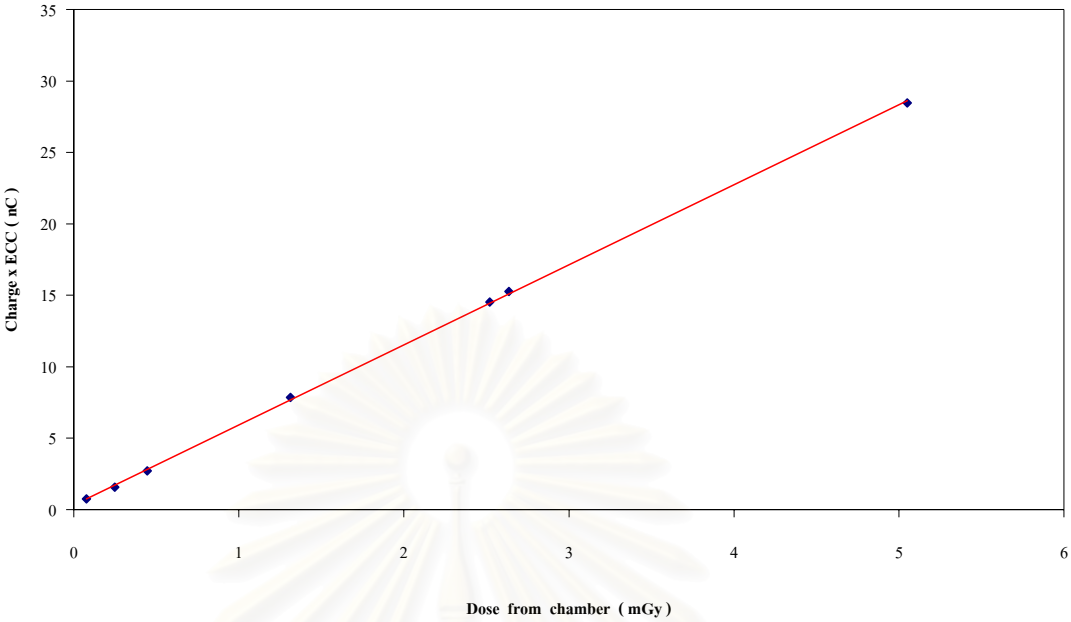


Figure 6.2 Linearity of LiF TLD 100 when irradiated at various doses for 70 kVp 3.3 mm Al

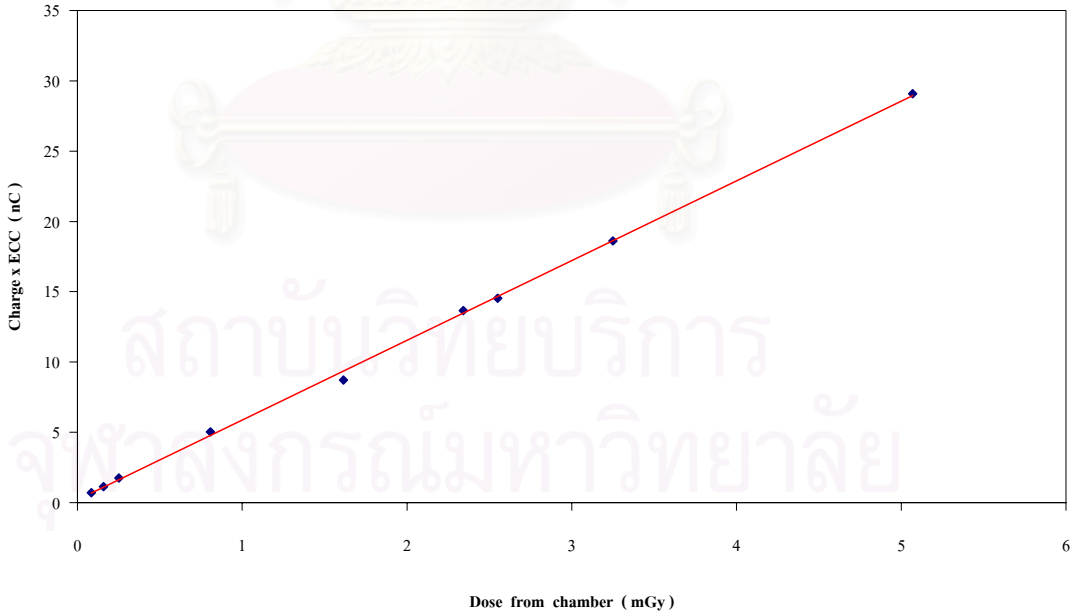


Figure 6.3 Linearity of LiF TLD 100 when irradiated at various doses for 80 kVp 3.8 mm Al

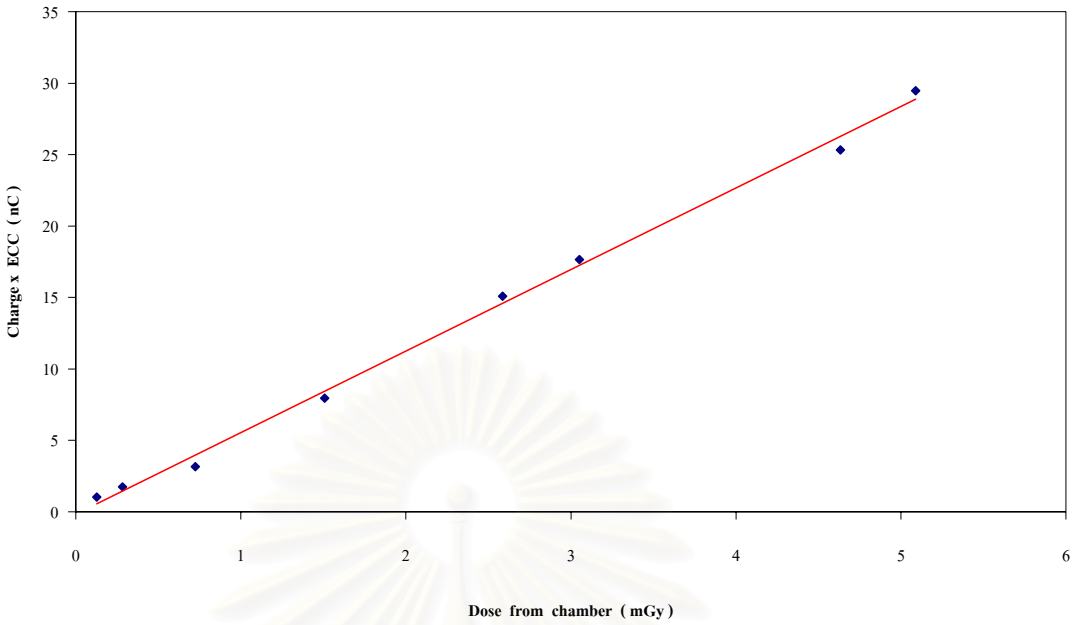


Figure 6.4 Linearity of LiF TLD 100 when irradiated at various doses for 100 kVp 5.0 mm Al

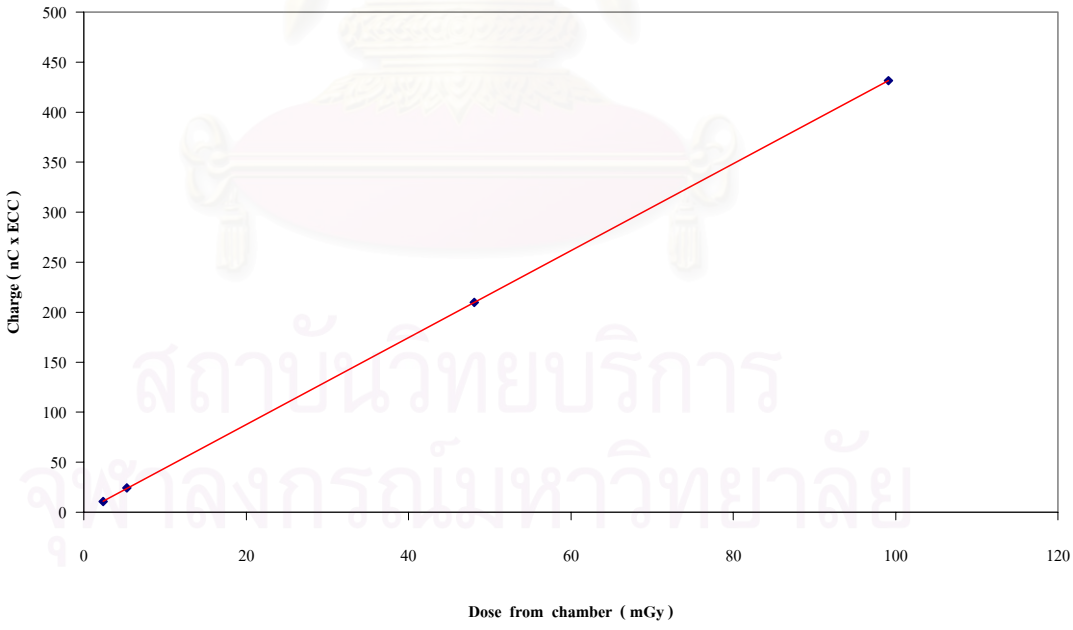


Figure 6.5 Linearity of LiF TLD 100 when irradiated at various doses for ^{60}Co (1.25 MeV)

6.2.3 Energy response

The energy response of thermoluminescent dosimeter in kilovoltage relative to Cobalt-60 gamma rays at absorbed dose of 5 mGy is shown in figure 6.6, the half value layer for kilovoltage range from 2.63 to 5.00 mm Al, the graph shows higher response of thermoluminescent dosimeter at low energy and decreasing when the energy of the beams are higher.

The correction factor of energy response relative to ^{60}Co for thermoluminescent dosimeter used in interventional x-ray beams are calculated, it is shown in figure 6.7, they are the reciprocal of the response. The factors range from 0.786 to 0.827 for half value layer of 2.63 to 5.0 mm Al which are the range of the quality of beams used in interventional radiology machines.

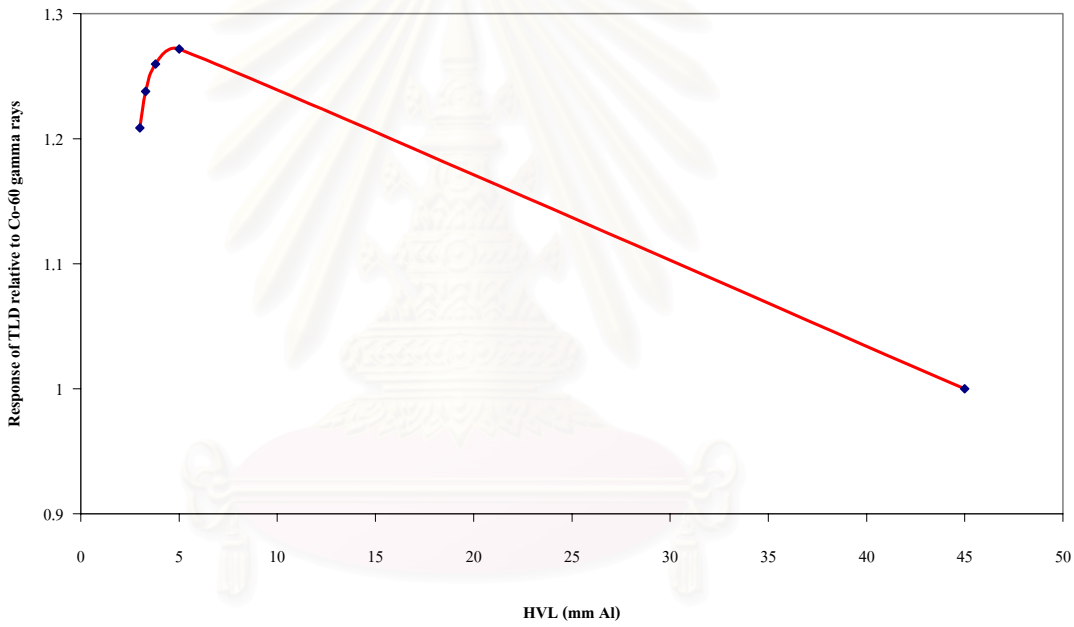


Figure 6.6 Energy dependence of LiF TLD 100 when irradiated in water phantom (absorbed dose of 5 mGy) normalized to ^{60}Co gamma-rays

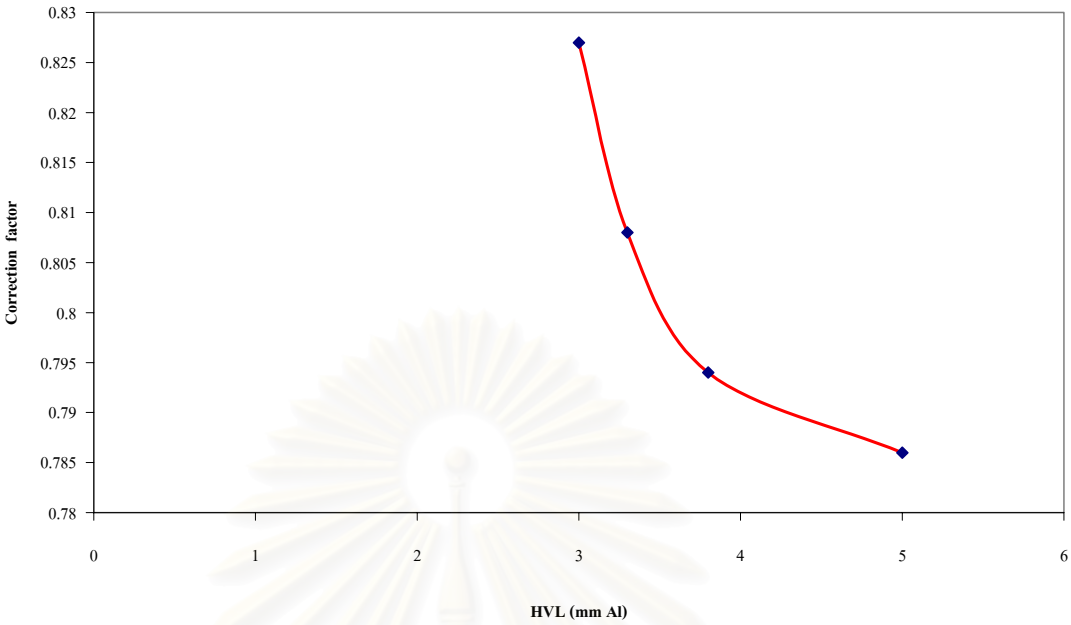


Figure 6.7 The correction factor of energy response for the interventional x-rays

6.2.4 Minimum detectable dose

The characteristic of thermoluminescent dosimeter which are including variation coefficient (VC) of some dose values, background and minimum detectable dose are reported in table 6.2. The results are compared with the results of the country that took part in the International Atomic Energy Agency (IAEA) project of radiation doses in diagnostic radiology and methods for dose reduction. Our results show comparable characteristics. The variation coefficient of 0.5, 1 and 50 mGy show the values of 4%, 13.7% and 7%, respectively. However, the maximum dose used in this study is about 1 mGy so the accuracy of this measurement is within 13.7%.

6.3 Measurement of Dose In Medical Staff

Table 6.3 shows results from thermoluminescent dosimeter in interventional radiology. The radiation doses to the first radiologist range from 1 and 1211 μSv for three interventional radiology procedures. The lowest dose value, close to background, at the thyroid in thyroid shield is 1 μSv and the highest dose value at the left forearm is 1211 μSv. For the case using the lead apron to protect the lower limb, the radiation dose to medical staff is lower than the case without lead apron.

Table 6.2 Characteristics of thermoluminescent doseimetry systems evaluated during the calibration]

Energy response relative to 662 keV	Country					
	Czech Republic	Ethiopia	Ghana	Iran Islam	Romania	This study
Effective energy (keV)						
26.8	1.36	1.36	1.32	1.48	1.44	1.21
54.5	1.18	1.38	1.26	1.26	1.29	1.27
662.0	1.00	1.00	1.00	1.00	1.00	1.00
Variation coefficient (%) of reading at						
50 mGy	3	5	4	5	4	7
1 mGy	6	14	12	15	5	13.7
0.5 mGy	10	9	10	5	17	4
0.1 mGy	21	21	33	30	54	-
Background (mGy) VC (%)	0.068 (18)	0.33 (20.5)	0..37 (16)	0.38 (2)	0.83 (20)	0.094 (14)
Minimum detectable dose (mGy)	0.037	0.020	0.178	0.023	0.5	0.039

Table 6.4 shows the result of radiation dose for interventional radiology in three procedures of 4 radio-fluoroscopy machines. The highest average radiation dose to medical staff on the left forearm of transarterial oily chemoembolisation in Siemens Neurostar room is 407 µSv per procedure and the lowest average radiation dose to medical staff on the gonad in lead apron of endoscopic retrograde cholangiopancreatography in GE Advantx room is 24 µSv per procedure.

In transarterial oily chemoembolisation of Siemens Polystar, the highest radiation dose at the left leg is 245 µSv per procedure. While in transarterial oily chemoembolisation of Siemens Neurostar, percutaneous transhepatic biliary drainage of Siemens Polystar and endoscopic retrograde cholangiopancreatography of GE Advantx, the highest radiation dose at the left forearm are 407, 261 and 352 µSv per procedure, respectively.

In summary the average dose values at the left forearm range between 174 to 407 µSv per procedure, depending on room, equipment and experience of radiologist. These results are agreeable with Vano E, et al [1]who presented the values of 445 µSv per procedure at left forearm.

Table 6.3 Values of dose per procedure in interventional radiology, measured by thermoluminescent dosimeter

TLD location	Sample size	Average (μSv)	Range (μSv)
Whole sample			
Right eye	32	96	16 - 200
Left eye	32	129	5 - 355
Thyroid in thyroid shield	39	82	7 - 318
Thyroid out thyroid shield	30	104	1 - 288
Left shoulder	41	246	19 - 658
Left forearm	42	313	4 - 1211
Gonad	38	29	2 - 76
Left leg	41	147	3 - 888
With lead screen			
Right eye	14	101	24 - 180
Left eye	14	158	5 - 355
Thyroid in thyroid shield	13	51	20 - 97
Thyroid out thyroid shield	13	150	7 - 288
Left shoulder	14	339	19 - 658
Left forearm	14	407	4 - 1211
Gonad	14	31	10 - 74
Left leg	13	32	10 - 67
Without lead screen			
Right eye	17	145	15 - 270
Left eye	17	154	23 - 282
Thyroid in thyroid shield	27	120	7 - 318
Thyroid out thyroid shield	17	111	1 - 207
Left shoulder	27	221	55 - 534
Left forearm	27	306	73 - 755
Gonad	26	51	4 - 179
Left leg	27	251	9 - 887

These data were plotted to show the radiation dose at various locations of radiologists during different type of procedures and radio-fluoroscopy machine, the histogram is shown in figure 6.8. The dose to the left forearm from transarterial oily chemoembolisation of Siemens Neurostar is higher than Siemens Neurostar in the same procedure because the level of half value layer of Siemens Neurostar is higher than Siemens Polystar so the dose of Siemens Neurostar to medical staff is high. On the other hand, the dose to left leg of medical staff work in Siemens Polystar is higher than Siemens Neurostar because Siemens Polystar has no mobile lead screen to protect the lower extremities of medical staff but Siemens Neurostar has mobile lead screen to protect the lower extremities. For percutaneous transhepatic biliary drainage and endoscopic retrograde cholangiopancreatography, the doses are quiet low because

the procedures are taken at the shorter time than the transarterial oily chemoembolisation.

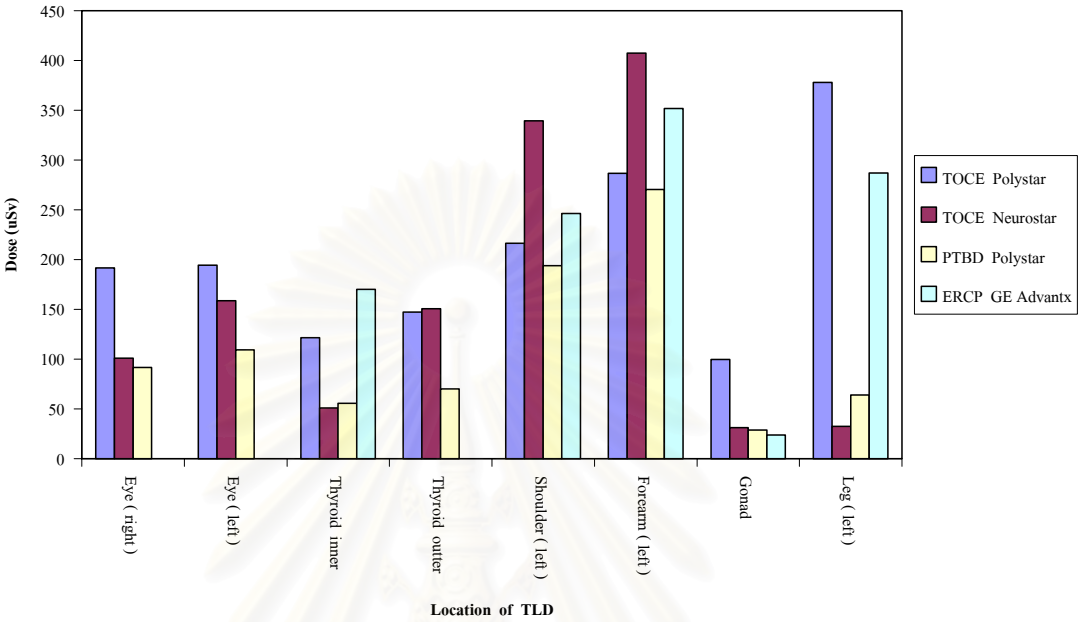


Figure 6.8 Average doses to the radiologist in different locations

The histogram of average radiation dose to primary radiologist and secondary radiologist is shown in figure 6.9. The histogram shows the difference dose between primary radiologist and secondary radiologist. This is due to the fact that the primary radiologist's distance to the primary beam was approximate 0.6 m, whereas for the secondary radiologist was about 1 - 1.2 m. The average dose differences between the primary and secondary radiologist is 52 %, the result is statistically significant ($p < 0.05$).

Table 6.4 Values of dose per procedure for transarterial oily chemoembolization (TOCE) in Siemens Polystar, transarterial oily chemoembolization (TOCE) in Siemens Neurostar, percutaneous transhepatic biliary drainage (PTBD) in Siemens Polystar and endoscopic retrograde cholangiopancreatography (ERCP) in GE Advantx

TLD location	Sample size	Average (μSv)	Range (μSv)
TOCE (Siemens Polystar)			
Right eye	9	101	46 - 144
Left eye	9	102	23 - 150
Thyroid in thyroid shield	9	52	27 - 86
Thyroid out thyroid shield	9	74	27 - 128
Left shoulder	9	135	31 - 209
Left forearm	9	174	24 - 342
Gonad	9	35	9 - 76
Left leg	9	245	53 - 468
TOCE (Siemens Neurostar)			
Right eye	14	101	24 - 180
Left eye	14	159	5 - 355
Thyroid in thyroid shield	14	51	20 -97
Thyroid out thyroid shield	14	151	7 - 288
Left shoulder	14	339	19 - 658
Left forearm	14	407	4 - 1211
Gonad	14	31	10 - 74
Left leg	14	32	10 - 67
PTBD (Siemens Polystar)			
Right eye	9	85	16 - 200
Left eye	9	110	23 - 282
Thyroid in thyroid shield	9	51	7 - 111
Thyroid out thyroid shield	9	63	1 - 200
Left shoulder	9	198	55 - 534
Left forearm	9	261	73 - 631
Gonad	9	25	2 - 48
Left leg	9	57	3 - 169
ERCP (GE Advantx)			
Right eye	-	-	-
Left eye	-	-	-
Thyroid in thyroid shield	10	170	98 - 318
Thyroid out thyroid shield	-	-	-
Left shoulder	10	246	123 - 476
Left forearm	10	352	111 - 755
Gonad	10	24	5 - 64
Left leg	10	287	64 - 888

The relationship between the fluoroscopy time and average dose to left forearm of the most exposed limb was also investigated. There is little correlation between the dose to the left forearm and fluoroscopy time per procedure from transarterial oily chemoembolization in Siemens Neurostar (r = 0.71) but there is good correlation between the dose to the most exposed left forearm and fluoroscopy time per procedure from transarterial oily chemoembolization in Siemens Polystar (r = 0.86), percutaneous transhepatic biliary drainage in Siemens Polystar (r = 0.93) and endoscopic retrograde cholangiopancreatography (r = 0.91) in GE Advantx, these relationship are shown in figure 6.10, 6.11, 6.12 and 6.13.

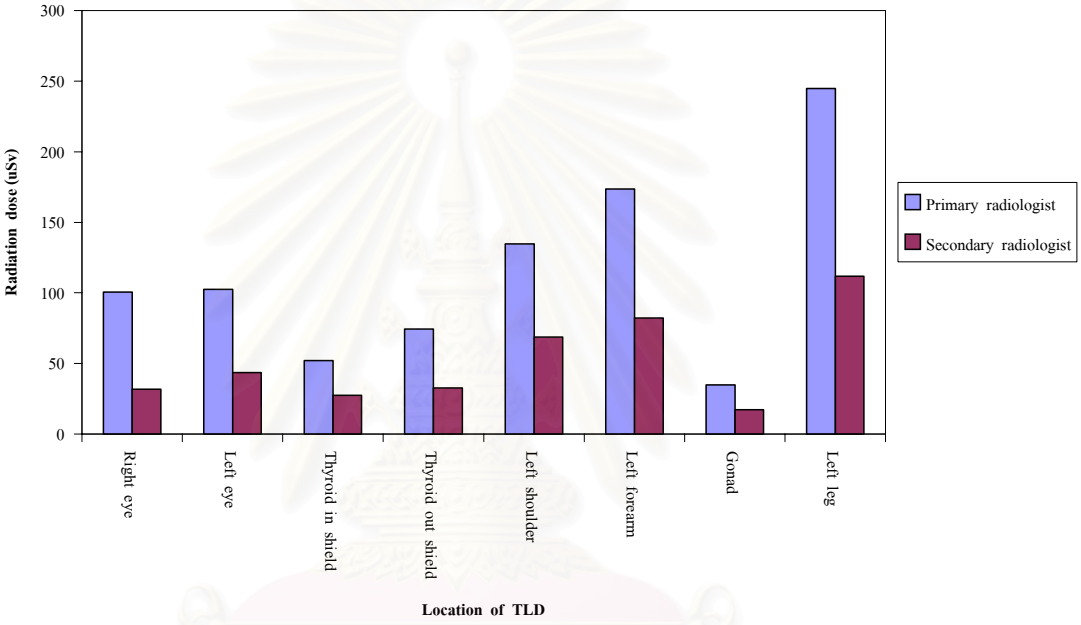


Figure 6.9 The average dose (μSv) of primary radiologist and secondary radiologist at various locations

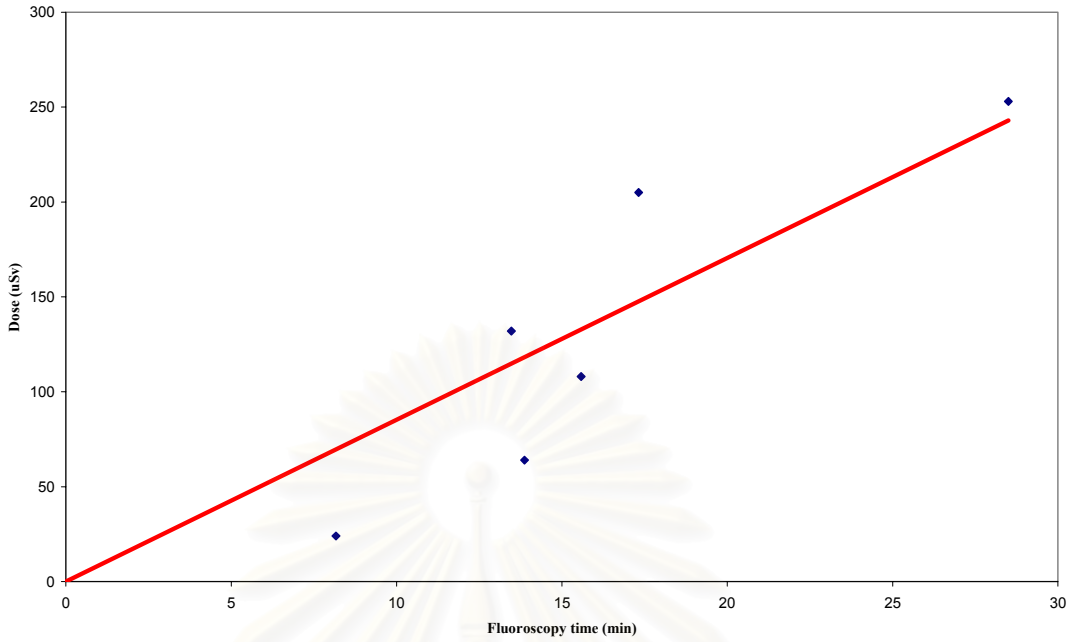


Figure 6.10 Relationship between fluoroscopy time and average dose at the left forearm of radiologist in TOCE procedure (Siemens Polystar)

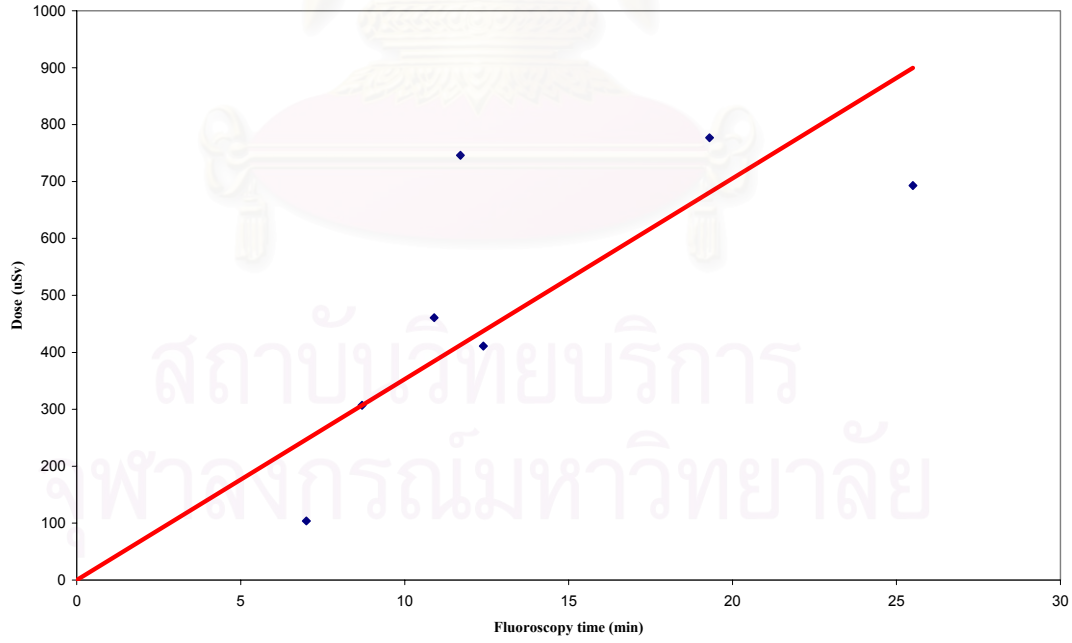


Figure 6.11 Relationship between fluoroscopy time and average dose at the left forearm of radiologist in TOCE procedure (Siemens Neurostar)

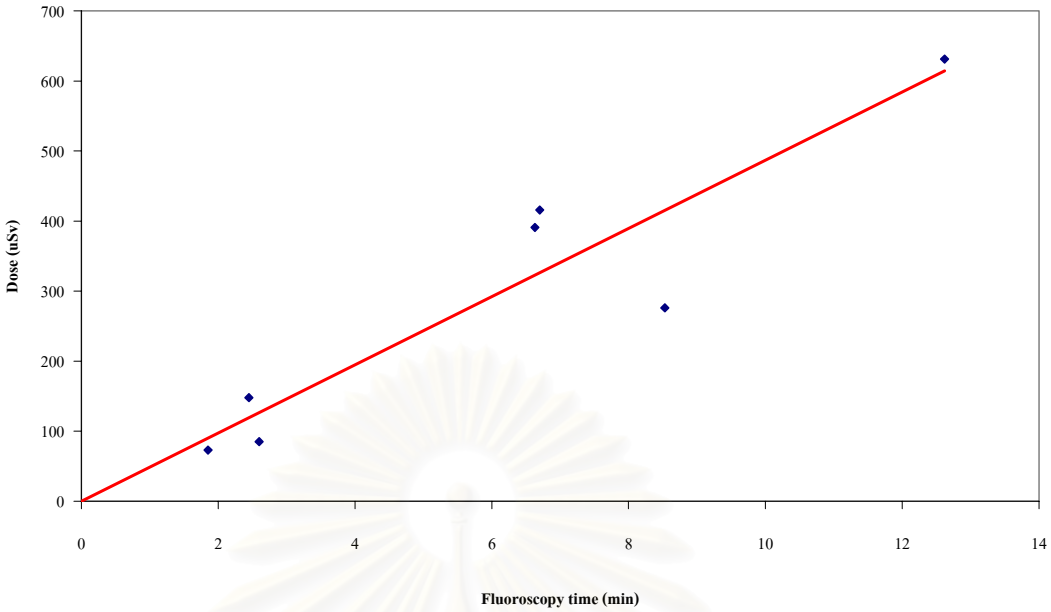


Figure 6.12 Relationship between fluoroscopy time and average dose at the left forearm of radiologist in PTBD procedure (Siemens Polystar)

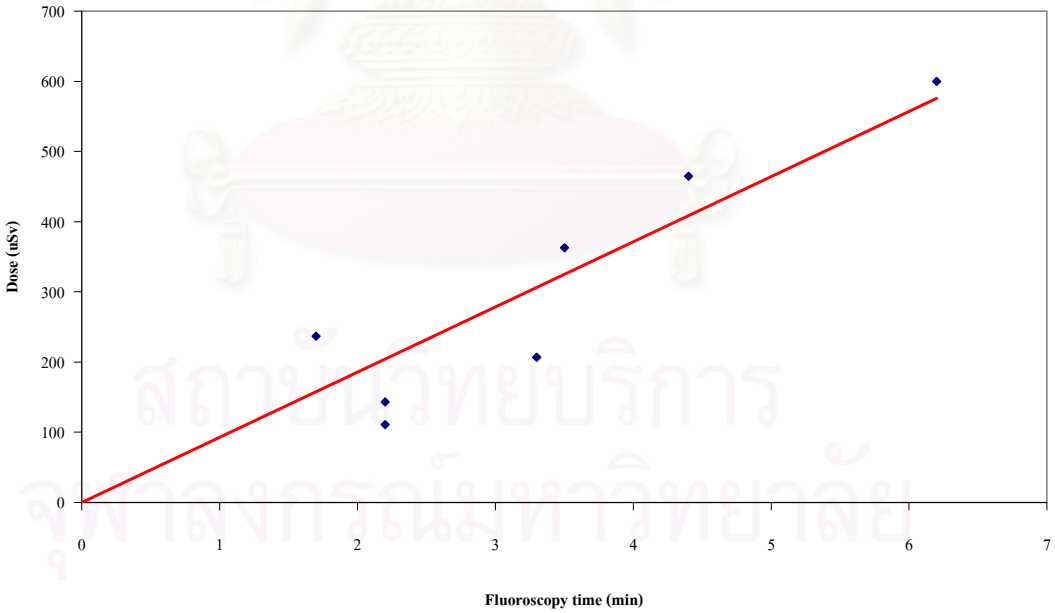


Figure 6.13 Relationship between fluoroscopy time and average dose at the left forearm of radiologist in ERCP (GE Advantx)

6.4 Measurement of Dose Area Product In Patient

The results of measurement of dose-area product in patient are shown in table 6.5. Dose-area product average values are 19028, 18025, 1760 and 3504 cGy cm^2 per procedure, for transarterial oily chemoembolization of Siemens Polystar, transarterial oily chemoembolization of Siemens Neurostar, percutaneous transhepatic biliary drainage of Siemens Polystar and endoscopic retrograde cholangiopancreatography of GE Advantx, respectively. The highest dose-area product reading is in transarterial oily chemoembolization. The dose-area product from transarterial oily chemoembolization from 2 x-ray machines are in the range 7020 - 37937 cGy cm^2 for 6.07 - 29.20 minute fluoroscopy time. It is comparable to Padovani R [9] who reported the dose-area product in the range of 700 - 91800 cGy cm^2 for 1 - 90 minute fluoroscopy time.

Table 6.5 Value of dose per procedure in interventional radiology, measured by dose-area product meter

Procedure	Sample size	Fluoroscopy time (min)	Dose-area product reading (cGy cm^2)	
			Range	Average
TOCE (Polystar)	9	6.07 - 28.50	13951 - 37937	19028
TOCE (Neurostar)	14	7.00 - 29.20	7020 - 33216	18025
PTBD	9	1.85 - 13.77	282 - 3270	1760
ERCP	10	1.70 - 23.00	958 - 10539	3504

6.5 The Relationship Between the Dose of Medical Staff and Dose-Area Product

The relationship between the dose-area product and dose to forearm of the most exposed limb was also investigated. The correlation between the doses to the most exposed forearm and dose-area product reading per procedure from transarterial oily chemoembolization in Siemens Polystar (r = 0.39) and transarterial oily chemoembolization in Siemens Neurostar (r = 0.64) are not quiet linear, but there are good correlation between the doses to the forearm and dose-area product reading per procedure from percutaneous transhepatic biliary drainage in Siemens Polystar (r = 0.83) and endoscopic retrograde cholangiopancreatography in GE Advantx (r = 0.96) these relationship are shown in figure 6.14, 6.15, 6.16 and 6.17.

The relationship between the dose-area product and average dose to left forearm of transarterial oily chemoembolization is poor correlation because the radiologists did not stay all the time with the patient during procedure, the radiologists moved to the control room during taking the radiograph but for percutaneous transhepatic biliary drainage and endoscopic retrograde cholangiopancreatography, the radiologists stayed all the time with the patients for complete procedure.

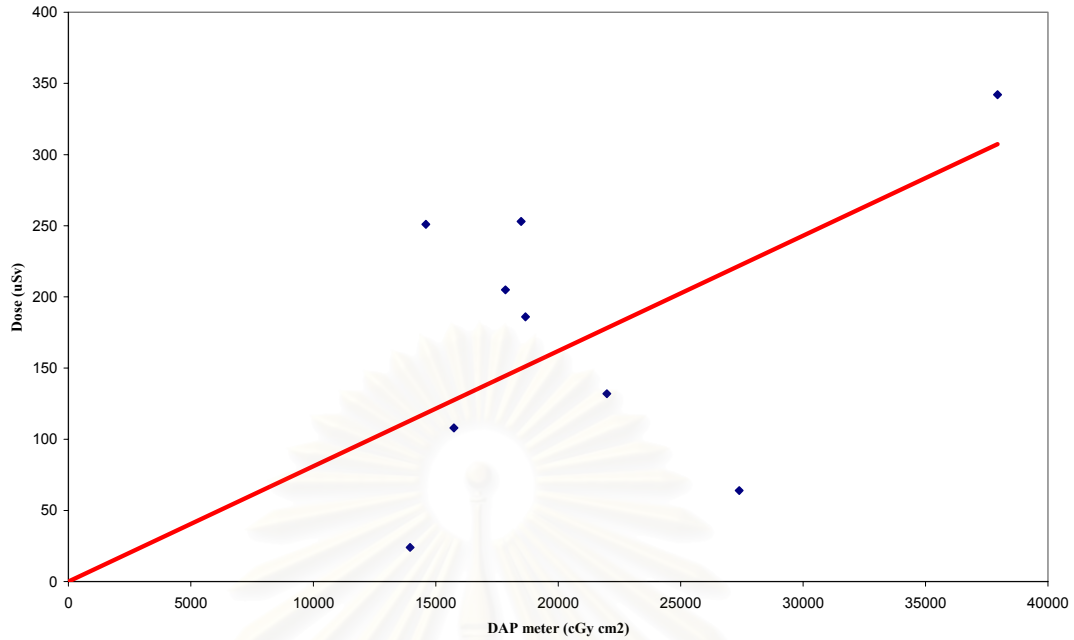


Figure 6.14 Relationship between dose-area product and average dose at the left forearm of radiologist in TOCE procedure (Siemens Polystar)

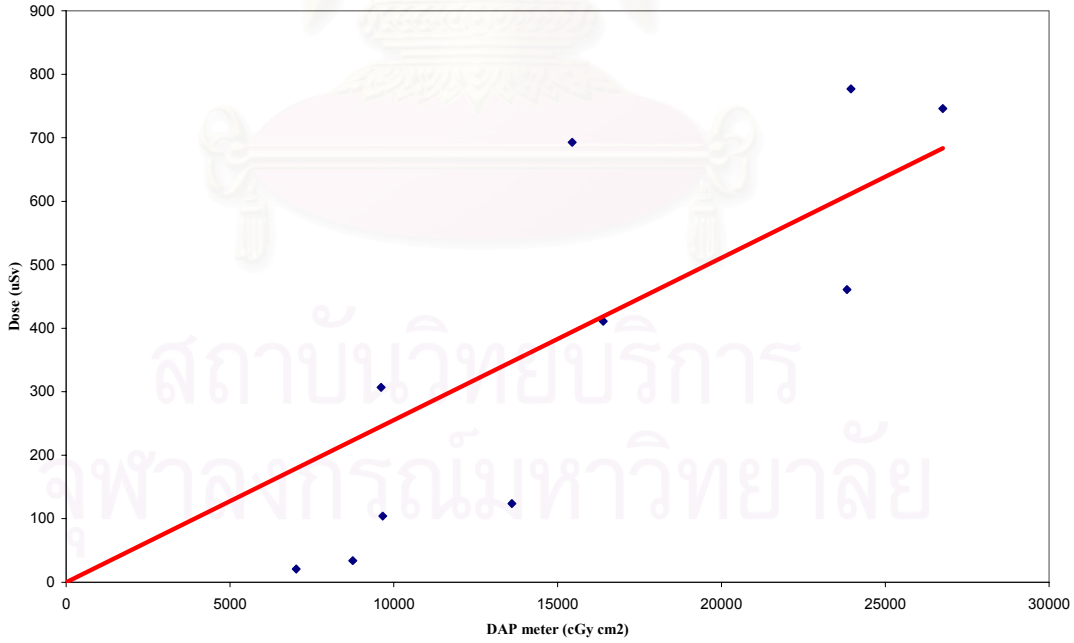


Figure 6.15 Relationship between dose-area product and average dose at the left forearm of radiologist in TOCE procedure (Siemens Neurostar)

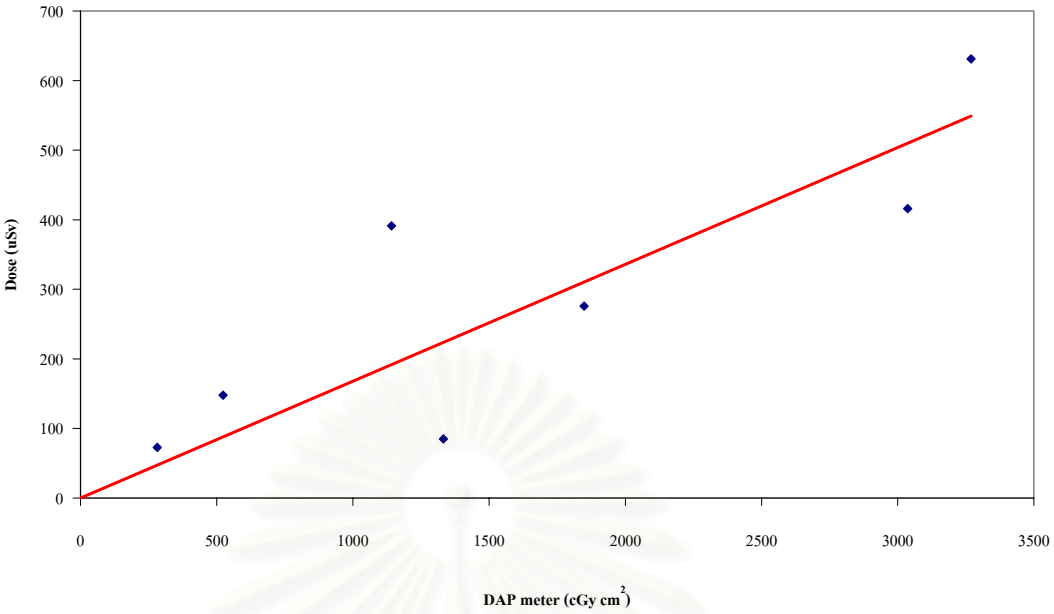


Figure 6.16 Relationship between dose-area product and average dose at the left forearm of PTBD procedure (Siemens Polystar)

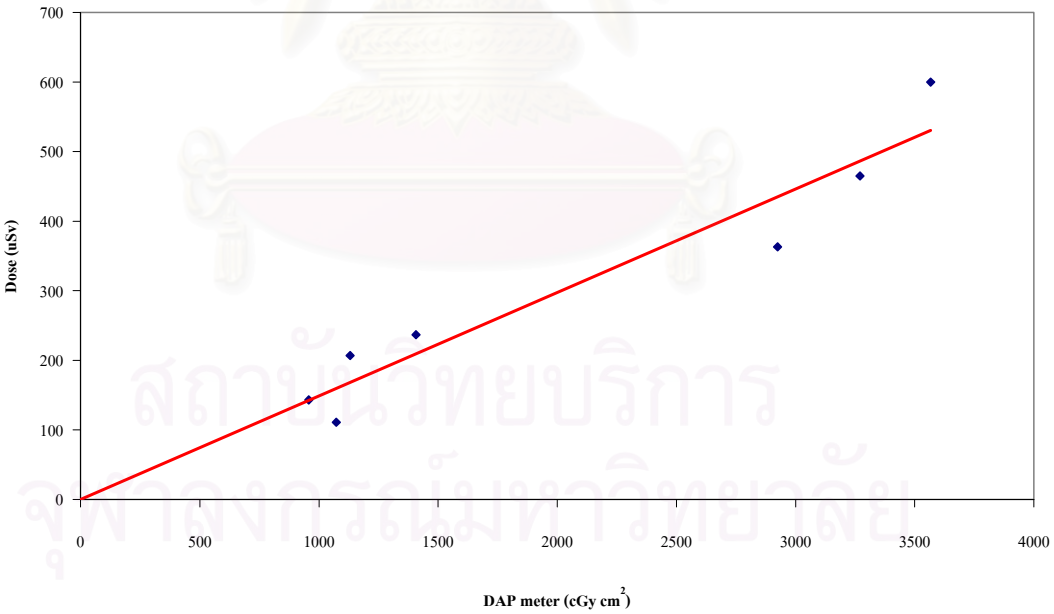


Figure 6.17 Relationship between dose-area product and average dose at the left forearm of radiologist in ERCP procedure (GE Advantx)

Table 6.6 The ratio of averaged values between occupational doses and dose-area product in μSv / 10 Gy cm^2 from thermoluminescent dosimeter reading at eight locations on staff and from dose-area product

Location	TOCE (Polystar)	TOCE (Neurostar)	PTBD (Polystar)	ERCP (GE Advantx)
Right eye	5.31	5.60	48.29	-
Left eye	5.36	8.82	62.50	-
Thyroid in thyroid shield	2.73	2.83	29.98	48.02
Thyroid out thyroid shield	3.89	8.38	35.79	-
Left shoulder	7.09	18.81	112.50	70.21
Left forearm	9.15	22.58	148.29	100.46
Gonad	1.84	1.72	14.20	1.26
Left leg	12.88	1.78	32.39	81.91

A relation between occupational doses from thermoluminescent dosimeter and patient doses evaluated from the dose-area product was established and shown in table 6.6. For 9 locations of the body, the highest ratio between average occupational doses and dose-area product is the left forearm of percutaneous transhepatic biliary drainage and the lowest ratio is the gonad of endoscopic retrograde cholangiopancreatography. The highest ratio is 148.29 μSv/10 Gy cm^2 and the lowest ratio is 1.26 μSv/10 Gy cm^2. Considering the 4 studied techniques, the ratio between average occupational doses and dose-area product of transarterial oily chemoembolisation show lower value than percutaneous transhepatic biliary drainage and endoscopic retrograde cholangiopancreatography. The dose received by radiologists when performing transarterial oily chemoembolisation was low, because the radiologist was exposed only scatter radiation from fluoroscopy but not to the scatter from taking radiographic images, they went out of the room during radiography. This makes the ratio between occupational doses and dose-area product to be low, although the average dose from the dose-area product from transarterial oily chemoembolisation is high.

The ratio between average occupational doses and dose-area product in the percutaneous transhepatic biliary drainage at the right eye, left eye and left forearm are 48.29, 62.50 and 148.29 μSv/10 Gy cm^2, respectively. The results can be compared with Vano E [1], et al who derived the average value of the ratio between occupational doses and dose-area product at the right eye, left eye and left forearm, they are 45, 60 and 120 μSv/10 Gy cm^2, respectively. It could be stated as a rule of thumb "a dose-area product reading of 10 Gy cm^2 will give a dose of 20, 150 and 100 μSv to the left forearm for transarterial oily chemoembolization of Siemens Neurostar, percutaneous transhepatic biliary drainage of Siemens Polystar and endoscopic retrograde cholangiopancreatography of GE Advantx, respectively. In addition a dose of 10 Gy cm^2 from dose-area product gives 10 μSv to the left leg for transarterial oily chemoembolization of Siemens Polystar".

The data obtained from dose-area product are agreed with thermoluminescent dosimeters which are affected by distances at different locations on staff, protective elements and protocols. Therefore, ratios between occupational dose and dose-area product supply information which is more comprehensive, assuming normal values of both quantities. This provides, in addition, an assessment of the working procedure of a specialist in respect of radiation protection and of some equipment operation conditions (level of scatter radiation).

6.6 Summary of Staff Doses In Interventional Radiology

Annual staff doses are summarized in table 6.7. The dose report for each procedure is less than dose limit but if one radiologist performed all the procedures, the total dose at the left forearm is 221.17 mSv per year. Although this is lower than the dose limit, but one radiologist performed more than these 3 procedures. The occupational dose may be over dose limit. The availability and regular use of protective tools such as aprons, glasses, gloves and screens should be reduced the dose to the saving limit. Image quality control must be carried out on a regularly scheduled basis. Practices based on performing the procedures at the most suitable location with reference to the patient, with well collimated beams, using magnification only when strictly needed and low cine frame rates should be recognized as critical to radiation protection optimization strategies.

Table 6.7 Calculation of primary radiologist dose per year

Type of procedures	Number of cases per year	Average dose per procedure (mSv)	Dose limit (mSv)	Dose per procedure per year (mSv)
TOCE (Siemens Polystar)				
- left eye	150	0.102	150	15.30
- left forearm	150	0.174	500	26.10
- left leg	150	0.245	500	36.75
TOCE (Siemens Neurostar)				
- left eye	157	0.159	150	24.96
- left forearm	157	0.407	500	63.89
- left leg	157	0.032	500	5.02
PTBD (Siemens Polystar)				
- left eye	98	0.110	150	10.78
- left forearm	98	0.261	500	25.58
- left leg	98	0.057	500	5.59
ERCP (GE Advantx)				
- left eye	300	-	150	-
- left forearm	300	0.352	500	105.6
- left leg	300	0.287	500	86.1

CHAPTER VII

CONCLUSION

Our results show an ample range of variation in occupational dose at all the locations monitored on the staff, which confirms the influence of the equipment features, its adjustments use on the risk level. Mobile lead screens are very efficient protective tools, although they yield poorer protection in daily practice than expected, considering their theoretical attenuation factor, as they are sometimes used improperly or not even used at all. Instead of a radiation absorption effect through 1 or 2 mm lead equivalent shielding, an average value of 245 μSv per procedure to the leg of the specialist is reduced to 32 μSv per procedure as the screen is used. This is a rather low decrease, although higher reduction factors could be found in other body zones of the medical specialist performing the interventional radiology.

In some interventional radiology rooms where no articulated screen is available and in the case of radiologists not wearing protective elements, doses up to 1211 μSv to forearm and eye lens have been measured in a single procedure. Thus the threshold for the deterministic effects could probably be exceeded by working for several years in these conditions.

The use of thermoluminescent dosimeter chips for the radiologist provides an effective method to estimate the occupational risk. Average values range between 174 to 407 μSv per procedure at the left forearm, depending on room and equipment, although doses may increase at distances shorter than the one considered usual. The protection improvement due to highly filtered beams produced by some commercial equipment has been verified in daily practice, with reductions in average doses of between 20 and 25 %

It is possible to relate dose values measured by thermoluminescent dosimeter with dose-area product data. This suggests a good possibility to estimate both occupational and patient doses. The ratio is different depend on the techniques and machines used. For transarterial oily chemoembolisation of Siemens Polystar, the maximum average value at the left leg is 12.88 μSv/10 Gy cm^2. The maximum average values at left forearm for transarterial oily chemoembolisation of Siemens Neurostar, percutaneous transhepatic biliary drainage of Siemens Polystar and endoscopic retrograde cholangiopancreatography of GE Advantx are 22.58, 148.29 and 100.46 μSv/10 Gy cm^2, respectively.

It could be stated as a rule of thumb “a dose-area product reading of 10 Gy cm^2 will give a dose of 20, 150 and 100 μSv to the left forearm for transarterial oily chemoembolization of Siemens Neurostar, percutaneous transhepatic biliary drainage of Siemens Polystar and endoscopic retrograde cholangiopancreatography of GE Advantx, respectively. In addition a dose of 10 Gy cm^2 from dose-area product give 10 μSv to the left leg for transarterial oily chemoembolization of Siemens Polystar”

REFERENCES

1. Vano E, Gonzalez L, Guibelalde E, Fernandez J M, Ten J I. Radiation exposure to medical staff in interventional and cardiac radiology. Br J Radiol 1998 ; 71 : 954 - 60.

2. Williams J R. The interdependence of staff and patient doses in interventional radiology. Br J Radiol 1997 ; 70 : 498 - 503.

3. Ruiz C R, Garcia-G J, Diaz R F J and Hernandez A. Estimation of effective dose in some digital angiographic and interventional procedures. Br J Radiol 1998 ; 71 : 42 - 47.

4. Putte S V, Verhaegen F, Taeymans Y, Thierens H. Correlation of patient skin doses in cardiac interventional radiology with dose-area product. Br J Radiol 2000 ; 73 : 504 - 13

5. Whitby M, Martin C J. Radiation dose to the legs of radiologists performing interventional procedures : are they a cause for concern ?. Br J Radiol 2003 ; 76 : 321 - 27.

6. David S. Textbook of Radiology and Imaging. Vol. 1. 7th ed. China : Churchill Livingstone, 2003.

7. David K and Iain R. Interventional Radiology. China : Churchill Livingstone, 2000.

8. Isadore M and David J O. Introduction to Diagnostic Imaging. USA: WB Saunders Company, 1984.

9. International Atomic Energy Agency. Radiological Protection of Patients in Diagnostic and Interventional Radiology, Nuclear Medicine and Radiotherapy. Austria. IAEA, 2001 : 203 - 220.

10. International Atomic Energy Agency. Absorbed dose determination in phantom and electron beams. IAEA TRS 277, 1987.

11. Khan F M. The Physic of Radiation Therapy. 3rd ed. USA: Lippincott Williams & Wilkins, 2003.

12. Cameron J R, Suntharalingam N and Kenney G N. Thermoluminescent dosimetry. Milwaukee. The University of Wisconsin Press, 1968.

13. Harshaw Bicron radiation measurement produced. Model 5500 automatic TLD reader user's manual Ohio : Saint - Gobian / Norton industrial ceramics, 1993.

14. Instruction Manual of Victoreen 4000M+ X-ray Test Device. Ohio : Cardinal Health, 2003.

15. Harold E J, John R C. The physic of Radiology. 3rd ed. Illinois. Charles Thomas, 1977.

16. International Atomic Energy Agency, Report of a co-ordinated research programme jointly organized by the International Atomic Energy Agency and the Commission of the European Communities ,Radiation doses in Diagnostic Radiology and Methods for Dose Reduction, April 1995 : 11 - 18.

APPENDICES

APPENDIX I

ข้อมูลสำหรับอาสาสมัคร

การศึกษา : การวัดปริมาณรังสีที่แพทย์และเจ้าหน้าที่ได้รับในรังสีร่วมรักษาด้วยเครื่องวัดรังสีเทอร์โมลูมิเนสเซนท์โดสมิเตอร์

เรียน อาสาสมัครทุกท่าน

ท่านเป็นผู้ได้รับเชิญจากผู้วิจัยให้เข้าร่วมการศึกษาเพื่อวัดปริมาณรังสีที่แพทย์และเจ้าหน้าที่ได้รับในรังสีร่วมรักษา โดยใช้เครื่องวัดรังสีเทอร์โมลูมิเนสเซนท์โดสมิเตอร์ ก่อนที่ท่านตกลงเข้าร่วมการศึกษาดังกล่าว ขอเรียนให้ท่านทราบถึงเหตุผลและรายละเอียดของการศึกษาวิจัย ในครั้งนี้

แพทย์และเจ้าหน้าที่ในหน่วยงานรังสีร่วมรักษา มีความเสี่ยงที่จะได้รับปริมาณรังสีสูงกว่าแพทย์และเจ้าหน้าที่ในหน่วยงานอื่นๆ ภายในโรงพยาบาล เพราะเจ้าหน้าที่โดยเฉพาะรังสีแพทย์ในขณะที่ทำการตรวจหรือการรักษาจะยืนอยู่ใกล้กับหลอดเอกซเรย์ ทำให้มีความเสี่ยงที่จะได้รับปริมาณรังสีสูงกว่าปริมาณรังสีสูงสุดที่เจ้าหน้าที่สามารถรับได้

ดังนั้นการศึกษาวิจัยในครั้งนี้ มีวัตถุประสงค์เพื่อ วัดปริมาณรังสีที่แพทย์และเจ้าหน้าที่ได้รับในส่วนต่างๆ ของร่างกาย ต่อการตรวจหรือการรักษาแต่ละครั้งว่าเป็นปริมาณเท่าไร และมีวิธีการลดปริมาณรังสีที่แพทย์และเจ้าหน้าที่ได้รับอย่างไร เพื่อไม่ให้เกินปริมาณรังสีสูงสุดที่เจ้าหน้าที่สามารถรับได้

เครื่องวัดรังสีเทอร์โมลูมิเนสเซนท์โดสมิเตอร์ ทำมาจากลิเทียมฟลูออไรด์ซึ่งมีแมกนีเซียมและไททาเนียมเป็นส่วนผสมอยู่ มีขนาดกว้าง 3.2 มิลลิเมตร ยาว 3.2 มิลลิเมตร หนา 0.89 มิลลิเมตร ซึ่งมีขนาดเล็กมากจึงไม่เป็นอุปสรรค ในการทำงานของแพทย์และเจ้าหน้าที่ขณะปฏิบัติงาน

ในการเก็บข้อมูลจะเก็บทั้งหมด 60 การตรวจซึ่งแบ่งเป็น Transarterial oily chemoembolization (TOCE) จำนวน 20 การตรวจ, Percutaneous transhepatic biliary drainage (PTBD) จำนวน 20 การตรวจ, Endoscopic retrograde cholangiopancreatography (ERCP) จำนวน 20 การตรวจ

หากท่านตกลงที่จะเข้าร่วมการศึกษาวิจัยนี้ จะมีข้อปฏิบัติร่วมดังต่อไปนี้

- ท่านไม่ต้องเสียค่าใช้จ่ายใดๆ ทั้งสิ้น
- ก่อนเริ่มการตรวจในแต่ละครั้ง ผู้วิจัยจะติดตัววัดรังสีเทอร์โมลูมิเนสเซนท์ ในส่วนต่างๆ ของร่างกาย คือ ตาซ้าย, ตาขวา, ต่อมไทรอยด์ข้างในเสื้อตะกั่ว, หัวไหล่ซ้าย, แขนซ้าย, บริเวณเข็มขัดข้างในเสื้อตะกั่ว, ขาซ้าย
- หลังจากที่แพทย์และเจ้าหน้าที่ทำการตรวจหรือการรักษาเสร็จในแต่ละการตรวจ ผู้วิจัยจะทำการเก็บตัววัดรังสีเทอร์โมลูมิเนสเซนท์ออก เพื่อนำไปอ่านปริมาณรังสีที่แพทย์และเจ้าหน้าที่ได้รับในการตรวจครั้งนั้นๆ

การเข้าร่วมการศึกษาวิจัยนี้ เป็นไปโดยสมัครใจท่านอาจจะปฏิเสธที่จะเข้าร่วม หรือถอนตัวจากการศึกษาวิจัยนี้ได้ทุกเมื่อ

ประการสำคัญที่ทานควรทราบ คือ ผลของการศึกษาวิจัยนี้ จะใช้สำหรับวัตถุประสงค์ทางวิชาการเท่านั้น โดยข้อมูลต่างๆ จะไม่มีการแพร่งพรายสู่สาธารณชน ขอรับรองว่าจะไม่มีการเปิดเผยชื่อของท่านตามกฎหมาย

หากท่านมีปัญหา หรือข้อสงสัยประการใด กรุณาติดต่อ นายสรจรส อุณห์ศิริ โทร 01 – 8305996 ซึ่งยินดีให้คำตอบแก่ท่านทุกเมื่อ

ขอขอบคุณในความร่วมมือของท่านมา ณ ที่นี้

APPENDIX II

ใบยินยอมเข้าร่วมการวิจัย (Consent form)

การวิจัย เรื่อง การวัดปริมาณรังสีที่แพทย์และเจ้าหน้าที่ได้รับในรังสีร่วมรักษาด้วยเครื่องวัดรังสีเทอร์โมลูมิเนสเซนท์โดสมิเตอร์

วันให้คำยินยอม วันที่.....เดือน.....พ.ศ.....

ก่อนที่จะลงนามในใบยินยอมให้ทำการวิจัยนี้ ข้าพเจ้าได้รับการอธิบายจากผู้วิจัยถึงวัตถุประสงค์ของการทำวิจัย วิธีการวิจัย อันตรายหรืออาการที่อาจเกิดขึ้นจากการทำวิจัย รวมทั้งประโยชน์ที่จะเกิดขึ้นจากการทำวิจัยอย่างละเอียดและมีความเข้าใจดีแล้ว

ผู้วิจัยรับรองว่าจะตอบคำถามต่างๆ ที่ข้าพเจ้าสงสัยด้วยความเต็มใจไม่ปิดบังซ่อนเร้นจนข้าพเจ้าพอใจ

ข้าพเจ้ามีสิทธิที่จะบอกเลิกการเข้าร่วมในโครงการวิจัยนี้เมื่อใดก็ได้ และเข้าร่วมโครงการวิจัยนี้โดยสมัครใจ และการบอกเลิกการเข้าร่วมการวิจัยนี้ จะไม่มีผลใดๆ ต่อข้าพเจ้า

ผู้วิจัยรับรองว่าจะเก็บข้อมูลเฉพาะเกี่ยวกับตัวข้าพเจ้าเป็นความลับ และจะเปิดเผยได้เฉพาะในรูปที่เป็นสรุปผลการวิจัย การเปิดเผยข้อมูลเกี่ยวกับตัวข้าพเจ้าต่อหน่วยงานต่างๆ ที่เกี่ยวข้องกระทำได้เฉพาะกรณีที่จำเป็น ด้วยเหตุผลทางวิชาการเท่านั้น

ผู้วิจัยรับรองว่าหากเกิดอันตรายใดๆ จากการทำวิจัยดังกล่าว ข้าพเจ้าจะได้รับการรักษาพยาบาล โดยไม่คิดมูลค่า และจะได้รับการชดเชยรายได้ที่สูญเสียไประหว่างการรักษาพยาบาลดังกล่าว ตลอดจนเงินทดแทนความพิการที่อาจเกิดขึ้นตามความเหมาะสม

ข้าพเจ้าได้อ่านข้อความข้างต้นแล้ว และมีความเข้าใจดีทุกประการ และได้ลงนามในใบยินยอมนี้ด้วยความเต็มใจ

ลงนาม.....ผู้ยินยอม

(.....)

ลงนาม.....พยาน

(.....)

ลงนาม.....ผู้ทำวิจัย

(.....)

VITAE

NAME	Mr. Sornjarod Oonsiri
SEX	Male
NATIONALITY	Thai
DATE OF BIRTH	2 March 1981
PLACE OF BIRTH	Bangkok, Thailand
INSTITUTIONS ATTENDED	Mahidol University, 2003 : Bachelor of Science (Radiological Technology) Chulalongkorn University, 2005 : Master of Science (Medical Imaging)
HOME ADDRESS	49 Soi. Thewet 3 Krungkasem Road Bangkhunprom Pranakorn Bangkok Thailand 10200 Tel. 02-282-1032