FACTORS AFFECTING IMAGE QUALITY AND ENTRANCE SKIN EXPOSURE WHEN USING AUTOMATIC EXPOSURE CONTROL (AEC)

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (MEDICAL TECHNOLOGY) FACULTY OF GRADUATE STUDIES MAHIDOL UNIVERSITY 2004

ISBN 974-04-5269-8

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was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Master of Science (Medical Technology)

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ACKNOWLEDGEMENTS

I would like to express my great gratitude and deep appreciation to my major advisor Assoc. Prof. Chavalit Wongse-ek, M.Sc., and my co-advisors, Assoc. Prof. Manus Mongkolsuk, M.Sc.; Lecturer Napapong Pongnapang, P.hD.; Lecturer Nuttawan Jangsri, M.Sc. for all of your patient guidance as well as your professional help in completing my thesis. I also would like to express my gratitude to Mr. Wattana Intharapan, B.Sc., for any encouragements you gave me especially in organizing the participants along with image evaluations, and allow me using the X-ray facilities at Taksin Hospital. .

I am equally grateful to Lecturer Bancha Ongvilawan, MD., Dipl. Thai Board of General Radiology, for your kind help of giving beneficial suggestions in the line with verifying clinical aspect of radiographs. A great appreciation is also extended to all technologists for your active participation in term of evaluating technical image quality.

I would like to express my sincere gratitude to the HP-V project of the ministry of Health of Indonesia for providing me the scholarship to undertake and complete the study.

My deepest appreciations are owed to my beloved wife, Umi Wafiroh, S.Pd., for her invaluable supports, which has been countless power at every step of my career. I am truly indebted to my charming son, Fadhil Ditya Priandoyo, and I beg him to forgive me for not taking care of him during my two-year study.

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ABSTRACT

The study was carried out to assess factors affecting image quality and entrance skin exposure (ESE) when using automatic exposure control (AEC). A total of 180 radiographs obtained from anthropomorphic phantom were evaluated in terms of clinical quality composite index (CQCI) and technical quality composite index (TQCI). All radiographs passing CQCI, scored by a radiologist, were taken into consideration for TQCI. Twenty experienced technologists blinded to experiment participated in TQCI evaluation. Three factors affecting the image quality and ESE, detector selection, object positioning and collimation, were assessed independently by comparison with the standard routine automatic exposure control procedures. Data were analyzed by means of descriptive statistics, and paired-t test. The p-values of less than 0.05 were deemed significant.

Proper vs. inaccurate detector selection, object positioning and collimation showed a mean TQCI of 1.36 vs. 1.40 ($p<0.02$), 1.37 vs. 1.36 ($p=0.24$) and 1.36 vs. 1.29 ($p<0.03$), and the mean entrance skin exposures (in mR) were 141.71 vs. 116.81 ($p<0.02$), 82.78 vs. 99.48 ($p=0.83$) and 83.65 vs. 98.32 ($p<0.02$) respectively. The data suggests that changing detectors combination may improve image quality if positions of the selected detectors are under the area of interest. The results also showed a variation of the ESE values from different detector combinations. In general, slightly poor positioning of the object from the selected detectors (± 2 cm) did not affect the technical image quality and the skin exposure. However, when the object positions were more than 3 cm away from the selected detectors, ESEs were increased significantly and the image quality was degraded. Improper collimation was also found to reduce the image quality. Reduction in size of collimation generally increased the entrance skin exposures due to the less contribution from scattered radiation to the detectors.

KEY WORDS: FACTORS / AUTOMATIC EXPOSURE CONTROL (AEC) / IMAGE QUALITY CRITERIA / ENTRANCE SKIN EXPOSURE (ESE)

104 pp. ISBN 974-04-5269-8

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LIST OF ABBREVIATIONS

Abbreviation	Term
AAPM	American Association of Physic in Medicine
AEC	Automatic Exposure Control
Avg.	Average
CEC	Community of the European Council
CQCI	Clinical Quality Composite Index
CR	Computerized Radiography
^{o}C	Degree Celsius
ESE	Entrance Skin Exposure
FDA	Food and Drug Administration
FFD	Focus-Film-Distance
HVL	Half Value Layer
ICRUM	International Commission on Radiation Unit and Measurements
ICS	Image Quality Score
IQ	Image Quality
JCAHO	Joint Commission on Accreditation of Health Care Organization (JCAHO)
kVp	kilo Voltage power
mAs	mili ampere second
MEC	Manual Exposure Control
mR	mili Roentgent
NCRP	National Commission on Radiation Protection
NEMA	National Electrical Manufacturer's Association
NEXT	Nationwide Evaluation of x-ray Trends
OD	Optical Density
PA	Posterior-Anterior

LIST OF ABBREVIATIONS (Continued)

Abbreviation	Term
PEP	Patient Equivalent Phantom
QC	Quality Control
QCP	Quality Control Programme
ROI	Region Organs of Interest
SD	Standard Deviation
SFS	Screen-Film-System
TCD	Tube-Chamber-Distance
TED	Tube-Entrance-Distance
TFD	Tube-Film-Distance
TQCI	Technical Quality Composite Index
VGAS	Visual Grading Analysis System

CHAPTER 1
INTRODUCTION

Prior to the development of an automatic exposure control (AEC) system in the late 1940's, all radiographic examination were performed on equipment which required radiological technologists to make educated judgments in relation with the exposure required value of tube potential, tube current, and time needed for a properly exposed radiograph. Though the aid of technique charts was used, these decisions were not standard for a particular projection, due to differences in patient shape and size, variation in positioning, and the presence of anatomical or pathological abnormalities [1].

Using such system in diagnostic radiography is basically to provide an optimum radiograph that makes possible physicians (radiologists) to visualize patient pathology and to allow producing results with optimum density, concerning accurateness of the patient's diagnoses. This system assists the technologists in simplifying or speeding the operation of taking radiographs as well as reproducing consistent radiographic quality from patient to patient, regardless of the size or presence of pathologist [1-3]. Further, numerous benefits can be taken into account in a matter of the diagnostic radiology practices, which in turn giving potential impacts to the practices such as reducing the repeat rate and saving patient dose, or even increasing the department's efficiency [3, 4].

Although this device has been widely used in most of modern X-ray machine for over the years by which probably overcame some problems associated with the human errors, in fact, its uses are still challenging practitioners. The device may be handled by the persons (technologists or technicians) who are not knowledgeable while its operating system requires specific practical skills in term of deciding such proper predetermined technical factors. Since this circumstance frequently occurs in the practices, and therefore, the intention of employing AEC device can beworthless [2]. Regarding this matter, there were three rational considerations from which a study

of factors affecting image quality and ESE when using AEC was interestingly to conduct. They were closely related to the AEC system operation with respect to factors affecting optimum image quality; the important of measuring the entrance skin exposure (ESE); and their interrelationships.

1.1 The AEC system and factors affecting optimum image quality

The basic principle of the automatic timing (AEC) is working with ionization chambers, which are known as detectors that collect the radiation coming from the patient and convert it into an electrical signal to charge the capacitor then controls the exposure according to predetermined density selection. For the film to have the proper density, the detector must sample the radiation coming directly from area of interest [1, 3]. If the detector samples radiation from another area, the film will not have the sufficient density. Regarding this matter, it was considered to examine the three potential factors that possibly affected on image quality and seemed to neglect by the technologists when the AEC system was being employed in radiography. They were the detector selection, patient/object positioning and the collimation [2, 3, 5].

Firstly, improper selection of the detector(s) to be activated and inaccurate adjustment of the density selector degrades the quality of image. Since auto timers may have one to three detectors in their circuits, mostly three in the table and wall-Bucky, deciding of which detector to select becomes challenge and tends to be misundertaken by the radiological technologist [1, 2, 4]. The figure 1 depicts a practical example of improper detector selection. If the patient for example, has undergone a partial pneumonectomy, the detector should not be selected at the effected side when using automatic timing devices for the chest PA projection. An over exposed radiograph would result since the side of the surgical intervention would offer less absorption of the radiation that causes the detector to rapidly accumulate the radiation and resulting in a shorten exposure [3, 4].

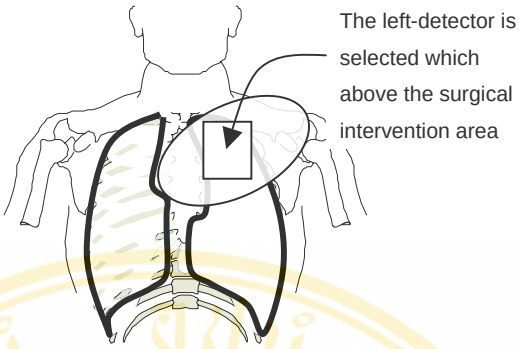


Figure 1 Incorrect selection of the detector

Secondly, inaccurate positioning of the patient or the organ of interest leads to a film with insufficient density. If the desired object is not precise oriented above the cell, radiation from another area will be sampled by the detector, and therefore the film will not have the proper density [3, 5]. As can be seen in the figure 2, it describes that of commonly incorrect positioning relative to the organ of interest under examination. Due to the poor positioning, a portion of the detector is completely outside of the targeted object by which it is directly exposed to the x-ray beam. In this condition, the capacitor is charged very quickly, resulting in a radiograph that is too light to fully demonstrated the joint.

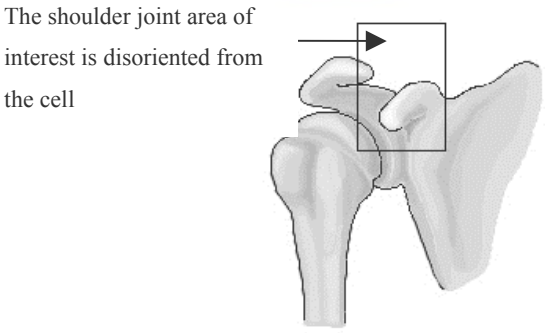


Figure 2 Incorrect object position of the shoulder joint over the detector [2]

Thirdly, a poor collimation can be another factor that causes to improperly exposed radiograph while using the AEC system. Since the detector has a limitation, which is unable to recognize the different between the primary radiation coming from the patient and scattered radiation, and therefore, if large amounts of scattered radiation are being produced due to imprecise X-ray field size used, the scatters will be picked up by the detector, and cause to an early exposure termination which in turn results in a radiograph with insufficient density [3, 5].

Along with the three AEC factors mentioned, accurate diagnostic information for the patients underwent such radiological procedures need a good quality of radiograph. The radiograph with good quality shall be measurable in the view of rendering sufficient indicative information or criteria that is feasible from each radiographic examination [6, 7]. Since objective measures of an image are intrinsically related to the diagnostic utility of a radiograph while the true test of an imaging system and of a radiologist is associated with the detection and accurate depiction of subtle abnormalities, and therefore, a number of image quality indicators namely, the radiographic contrast, sharpness, distortion, artifact and the noise becomes important components when describing or measuring quality criteria of the radiograph [1, 8, 9]. The criteria for diagnostic images, however, are practically more related to clinical and technical aspects by which referring to characteristic features of imagined anatomic structures of each radiograph with a specific degree of visibility, including its optical density [10, 11].

1.2 Entrance skin exposure (ESE)

All medical imaging using ionization radiation involves a compromise between quality of the images and radiation exposure to the patients. Radiologists or Medical Physicists must decide whether the benefits of diagnostic procedure justify the risks to the patients from the radiation exposures [6, 11].

Measurement of the entrance skin exposure (ESE) incurred at particular diagnostic x-ray examinations is crucial whenever prediction about deterministic effects of the radiation delivered to patient during an x-ray examination is needed [9, 11]. In the USA, for example, the Joint Commission on Accreditation of Health Care

Organization (JCHO) requires hospitals to provide risk assessment and performance monitoring data on all medical equipment. For machine that generates ionizing radiation used in hospitals must have some way of measuring output [12]. Additionally, measurement of radiation exposures (in mR/mAs) from typical radiation radiological examinations can aid the preparation of manual technique charts and in the calculation of patient exposures [13]. Data upon radiation output measurements can be calculated or referred to appropriate dose references such as that the periodic survey of X-ray producing devices under the Nationwide Evaluation of X-ray Trends (NEXT) published by CRCPD, USA [6, 9, 13].

The measured ESE shall be importantly set up or be specified to each X-ray system and each exam [6, 14, 15]. The actual reliable conditions of the machine can be evaluated through a comparison between the measured ESE with its reference levels. If the measured ESE is defined to be out of the range reference (guidance) levels, the X-ray machine must be calibrated or corrected [6, 13]. In clinical practice, ESE measures shall be maintained within the recommended levels as possible so that radiation dose incurred during examination is reasonable for the patient safety and achievable for the diagnose purposes. For this reason, it is implied that equipment quality control is important to be carried out continuously along with the use of X-ray facility in radiology department because of its potential to maintain the reliability of X-ray machine as well as to produce consistent values of radiographic exposure. In turn, the measured ESE from projection to projection will comply with suggested dose levels, and possible reduction in retake rate will give significant effect within the services accordingly [6, 7, 13].

1.3 The relation between factors that affect on image quality and the ESE

Since the primary role of AEC in conventional X-ray examinations is to minimize technical factors set by radiological technologist and to keep consistent image quality within the examinations, the accuracy of the patient's diagnoses can be achieved. However, some related AEC factors commonly refused to comply by technologists when employing the AEC system are still existed in practices. They are

often relate to technique/procedure problems that include the object position with respect to detector(s) selection and the use of X-ray field size [2, 3].

For a particular projection, accurately use of detector(s) shall be performed when using AEC system. Incorrect selection of detector or chamber sensor potentially influences film density concerning radiologist's preference, pathology, and surgical intervention. Furthermore, performing accurately such anatomical organ of interest over the selected detector leads to a film with optimum image quality. On the other hand, inaccurate positioning of the organ being examined results in a radiograph with insufficient film density. In addition to that, a proper collimation should be taken into consideration when taking radiograph by means of AEC. Increases the amount of collimation or beam restriction, increases the amount of scattered radiations reaching the detectors, and therefore, this causes to a dark diagnostic radiograph [16].

It is in fact that, as the AEC controls the length of radiation exposure that relates to those predetermined factors, the dose values measured at the object surface which is proportional to the ESE may also be expressed in some variations depending on the degree of errors when makes properly use of the AEC system. By this means, it can induce an increased dose to the patients under examination, although a good image quality is obtained.

This study was an experimental design focusing on the important AEC related factors that affect on image quality (the detector selection, object positioning, and collimation). The influence of each factors concerned were quantitatively measured following serial steps of assessment process and applying two of quality criteria descriptors for overall interpretation upon the image quality fulfilled by an evaluated radiograph. The ESE were also measured and compared with reference levels as a consequence of the AEC operation corresponded to selected techniques/procedures.

CHAPTER 2
OBJECTIVE

The main objective of this study is:

1. To assess factors that affect on image quality and the ESE when using automatic exposure control (AEC) in conventional radiography.

The sub-objectives of this study are:

2. To study image quality criteria in a human mimic phantom.
3. To study the effects of the AEC factors on image quality throughout the three independent steps of assessments:
   a) Assessment of the effect of detector or chamber sensor selections onto image quality.
   b) Assessment of the effects of the object position with respect to the selected detector(s) onto image quality.
   c) Assess of the effect of the X-ray filed size used onto image quality
4. To measure the ESE incurred at the selected procedures, considering the AEC factors and image quality of radiographs.

CHAPTER 3
LITERATURE REVIEW

3.1 Image quality criteria and its measurements

Several investigators have studied about optimum quality criteria necessary to radiographs by inspecting either their compliance to the requirements of clinical and physical aspects or their adherence to the reference quality criteria such as those quality criteria that have been widely suggested and published by the Community of the European council (CEC).

According to Jessen KA (2001), he defined the concept of quality criteria for diagnostic images as a performance level considered necessary to produce images of standard quality for a particular anatomical region and that level could also address any clinical indications. Moreover, the image criteria should include anatomical criteria, which relate to the visualization or critical reproduction of anatomical feature as well as physical criteria measurable by objective means. In addition, another essential element of the quality criteria is diagnostic reference. It should be linked to the clinical and physical criteria in providing a good quality radiograph with reasonable patient dose.

When come to the issue associated with how good of such radiographic quality criteria that involved reasonable radiation dose to the patient can be identified, it is considered to understand that, image quality criteria should be as measurable as the radiation dose in a practice of radiography. Thereby, the use of radiation can be justified for achieving a certain quality results [11]. To measure good criteria of image quality objectively, however, is difficult because the nature of image interpretation seems to be subjective. In a study about measurement of image quality in diagnostic radiology conducted by Marthin CJ et.al (1999), they stated that, the subjective nature of image interpretation made an objective approach to such assessment difficult although some objective methods had been widely applied involve the use of test

objects. The use of the test objects still providing measures that seemed to be difficult to link to clinical formation. Therefore, they recommended an ideal method for evaluating of imaging techniques including radiographic quality through clinical trials by means of applying scoring system toward the resulting image quality criteria that related to features observed in a normal clinical radiograph.

Meanwhile, standard reference of good image criteria for particular organ undergoing diagnostic X-ray examinations is also critical to the production of image quality consistently [10]. A number of researchers have been performed their studies by means of employing the reference image quality criteria such as the European guidelines that extensively published by the Community of the European Council (CEC) [6, 10, 12, 13, 17].

In related to the image quality criteria and the intentions of measuring those criteria objectively with scoring approach, Vano E et.al (1995) studied about image quality criteria from the chest radiography as an evaluation of the CEC guideline. One of their study's aims was to clarify basic principles of scoring films applied to the CEC quality criteria in correlation with other alternatives such the evaluation of physical parameters using phantoms or test objects. They found that the application of scoring films using the reference quality criteria to a large number of studied radiographs helped to correlate this method with the alternative methods. Besides, due to its application, some modifications of image quality criteria, based upon simple essential indicators (minimizing the number of criteria), were needed to verify.

In addition, Sandborg M et.al (2001), examined correlation between clinical and physical image quality measured in chest and lumbar spine screen-film radiography by applying the two scoring methods, which were the image criteria score (ICS) and the visual grading analyzes system (VGAS). These methods were used to assess clinical mage quality whereas a Monte Carlo simulation model of imaging system was used to measure physical image quality (contrast, signal to noise ratio and measures of dynamic range). The voxelized male anatomy model was employed to calculate contrast and signal-to-noise ratio. They came to a conclusion that, in some cases, clinical image quality can be predicted from appropriate measures of physical image quality.

In conclusion from previous studies, image quality criteria should be evaluated in both clinical and physical criteria. The nature of clinical criteria evaluation is subjective, but it can be measured objectively by means of scoring films in relation with features observed in a normal clinical radiograph or applying quantitative method for data collection with accurate manners. Using of this method for image quality evaluation has proven its usefulness to support some methods that make use of standard phantom for physical measurements in predicting the image quality results. However, the use of a human attenuation equivalent phantom as a comparable test objects to predict image quality criteria has been not attempted yet in most of the studies. Although most studies have discussed about image quality criteria from various point of view, the scope of quality criteria evaluation has only respected to a limit number of radiographic examinations. In addition, the term of image quality in most studies were more likely emphasized on either clinical or physical aspects. For these reasons, this study is planned to evaluate image quality criteria for more number of anatomical organs of interest using standard-adult equivalent phantom (anthropomorphic phantom) and applying the scoring method for image criteria evaluation. Moreover, the terms of image quality of radiograph are observed from clinical and technical point of views rather than physical quality aspects.

3.2 ESE and its relation with Image quality when use AEC system

Studies in relation with surface exposure dose or ESE, its effects onto image quality, and the usage of AEC in conventional X-ray diagnostic examination have been done and shown their usefulness when either dose assessment or imaging system comparison is needed to address.

Comparison between the use AEC (automatic exposure control) and MEC (manual exposure control) involved 329 samples of cardiological and cardiosurgery patients had been investigated by Ismailos E et.al (1996). The study evaluated parameters that included various anatomical regions according to their appearance in both PA and Lat radiographs of the chest. The result shown that, the AEC was more potential tool to improve the quality of image in Lat chest radiographs of cardiological and cardiosurgery patients than MEC. In the case of patient dose, the

use of AEC technique for both male and female subjects resulted in lower radiation dose when compared to that of MEC technique.

Blendl C et.al (1997) investigated the AEC system for its suitability in radiological image production using a new method. This method was basically related to the air kerma dose (ESE) and film density measurements with water as an absorbing and scattering medium (water phantom). The characteristic curves of an AEC were developed and compared where showed at what air kerma dose can produce optical density (OD) of different screen-film-system (SFS) that equal to 1.00. The disparity of the characteristics of AEC and SFS and their results on radiological examination can be observed from this study. In addition to that, Wilkinson and Heggie (1997) described a test method to evaluate or to correct AEC function particularly when CR systems were employed. They stated that, since the test method to know AEC function which based on beam quality dependence intimately with optical density (OD) in conventional screen-film is not suitable to the test for CR system with AEC, the relationship between incidence air kerma and a computer generated index supplied with the CR system could be used as a substitute for optical density in monitoring AEC performance with respect to beam quality.

Conway BJ et.al (1984) reported a method to estimate patient exposure from X-ray automatic exposure control for chest examinations by using the beam quality independence attenuation phantom. The phantom has been developed and used to facilitate surveys of the average patient exposure from AEC PA chest radiography. It accurately simulates the primary and scatter transmission through the lung-field areas of a patient-equivalent anthropomorphic phantom for x-ray spectra typically used in chest radiography. Measurement of patient ESE were obtained for a large number of patients on a variety of X-ray system operated in AEC mode using one or both lung-field detectors. Comparison of these data with the exposures derived from the phantom indicated that, the phantom attenuated the X-ray beam such away which can be employed to accurately and consistently estimation of the mean exposure of the average patient under a variety of radiographic conditions.

Brennan PC and Johnston D (2002) performed a test based on the CEC guidelines in randomly selected 16 Irish hospitals. Details on technique and

equipment were recorded for chest, abdomen, pelvis and lumbar spine examinations of standard sized patients: tube potential, focus-to-film distance, automatic exposure control (AEC), film-screen combination, X-ray tube filtration and secondary radiation grid. Varying levels of adherence to the guidelines were evident depending on the parameter being investigated. They concluded that, no hospital demonstrating 100% compliance and no hospital demonstrating 100% non-compliance. For all parameters, with the exception of AEC use, the majority of hospitals exhibited non-adherence for at least one projection. The results suggest that if hospitals in Ireland observe the straightforward examples of good radiographic technique described in the CEC publication, significant reductions in collective dose can be achieved.

From previous studies above, they showed that the use of AEC was considered to improve image quality and possible to control radiation exposure. The importance of both air kerma dose (ESE) and optical density (OD) measurements can be used to ensure suitability of the AEC device in producing radiographs or to determine the acceptance limits of AEC device operation. The measurement of ESE can be estimated from the phantom study by which adequate optical density can also be evaluated with respect to the ESE measures. A factor of automatic exposure control (AEC) uses, the detector selection, has shown its usefulness when patient ESE is evaluated from the basis of phantom study. Furthermore, applying the CEC standard as good example for radiographic techniques in a large sample has drown evidence that the exception of AEC use may vary the level of adherence to the CEC guideline as well as significant reductions in collective dose that can not be achieved.

Although the ESE, image quality, and particularly the roles of AEC applications have been discussed from the previous studies, factors that have an effect on image quality criteria and ESE when the AEC device is employed, however, have not been considered and evaluated. Therefore, this study will focus on the assessment of major factors involving the AEC uses that is specific to the conventional X-ray diagnostic examinations. A phantom study (anthropomorphic phantom) will be employed to predict image quality and to estimate ESE from each X-ray projection by selected criteria.

3.3 Conceptual framework

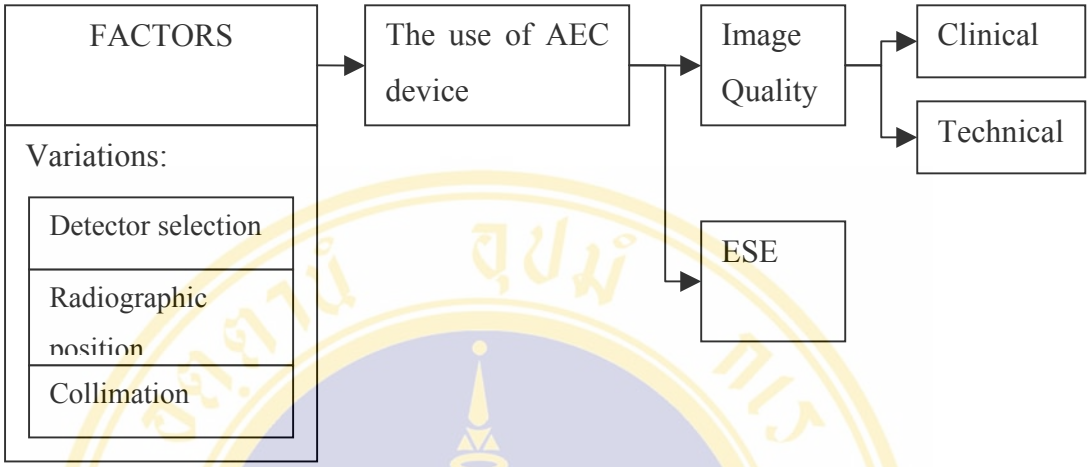


Figure 3 The conceptual framework of the study

The work plan of this study can be drawn as figure 3. In the figure, when a radiograph is produced by means of using the x-ray machine with the AEC device, there would be some factors that may cause to a variation in the image quality and or the ESE. The factors are mainly relate to the projections of the selected-phantom and of some crucial techniques a technologist must decide to perform that consist of the detector selection, radiographic position, and the collimation. If these factors can be specified properly where both a good image quality and lower ESE can be clinically accepted, they could be recommended by meant to optimize the image quality and the patient's exposure.

CHAPTER 4
MATERIALS AND METHODS

4.1 Materials

4.1.1 Object test (a human-mimicking phantom)

A patient equivalent anthropomorphic phantom (Anderson/RSD phantom by Bicron®) for X-ray spectra typically used for educational purposes was the main test object in the study. This RSD phantom consists of the anatomic and radio-fidelity of PIXY that formed human-mimicking phantom of an average male with 175 cm in tall and 74 kg in weight. According to the manufacturer, the RSD skeleton met radiation interaction properties of both cortical bone and spongiest as standardized by the International Commission on Radiation Unit and Measurements (ICRUM). A-10 different parts of the phantom were selected representing kinds of anatomical organs of interest in common radiography examinations [18].

- RS-108T (the head with cervical spine)
- RS-111T (the chest-lung and heart)
- RS-113T (complete pelvis including lumbar spine)
- RS-114T (the right-hand/wrist, natural position)
- RS-115T (the left-hand/wrist, oblique position)
- RS-116T (the right-foot/ankle, natural position)
- RS-117T (the right-foot/ankle, oblique position)
- RS-119T (the left-knee, 90^{O} flexion)
- RS-122T (complete arm/shoulder-natural position), right
- RS-123T (complete leg/hip-natural position), right

4.1.2 Quality control equipments:

- Radcal 9015 Electrometer
- Radcal 10x5-6 Ion chamber (6 cc)
- Gammex/RMI Full fuction meter M242

- Gammex/RMI Collimator and beam test tools M162A
- Gammex/RMI Focal spot test tool M112B
- Gammex/RMI Al HVL attenuator set M115A
- Gammex/RMI Sensitometer M393
- Gammex/RMI Screen/film contact test tool
- Delta OHM pH meter HD8602
- Kodak Al steps 2287

4.1.3 X-ray equipment and supports:

- Radcal 9015 Electrometer
- Siemens general purpose X-ray unit with AEC system (POLIDOROS X30); the sensor chamber arrangement typically depicted as the following figure:

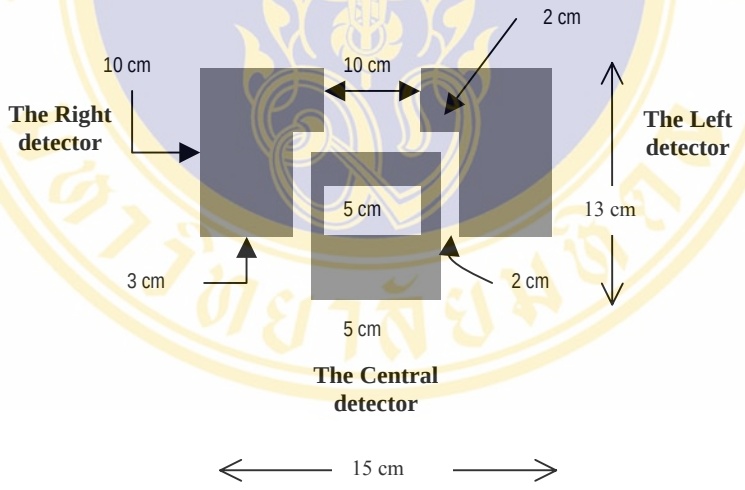


Figure 4 The shape, position and size of the cells

- X-ray cassette with a-400 screen speed system
- Three pieces of X-ray cassette sized 8X10 Inch
- Four pieces of X-ray cassette sized 10X12 Inch
- A pieces of X-ray cassette sized 11X14 Inch
- Two pieces of X-ray cassette sized 35X43 cm
- Three pieces of X-ray cassette sized 18X43 cm

- The rear earth X-ray film (KODAK):
  - Two boxes (@100 sheets) of X-ray film sized 8X10 Inch
  - Two boxes (@100 sheets) of X-ray film sized 10X12 Inch
  - Two boxes (@100 sheets) of X-ray film sized 11X14 Inch
  - Two boxes (@100 sheets) of X-ray film sized 35X43 cm
  - Two boxes (@100 sheets) of X-ray film sized 18X43 cm

4.1.4 X-ray film processor and chemicals:

- An automatic film processor KODAK RP X-Omat, M6B
- Two gallons of X-ray film developer
- Two gallons of X-ray film fixer
- Two gallons of replenished solution

4.1.5 Image quality evaluators and tools

The image quality evaluator was an expert radiologist and a group of 20 technologists with more than 5 years work experiences. The radiologist was contributed to the clinical image quality evaluation whereas the technologists were participated in the technical image quality evaluation. None of the technologists had a specific refreshing course in the matter of using AEC system in radiography during the last 12 months.

The tools used for image quality evaluation were divided in to a checklist and questionnaire. The checklist was employed in evaluating clinical quality criteria while the questionnaire was used for evaluating technical quality criteria

4.2 Methods

An experimental radiography was the major approach of the study entangled with structured assessment processes and observation of data collection. The methods applied for this study consisted of several different parts, but most important methods in the experiment were divided into the three successive stages of study with specific aim that was to assess factors affecting image quality and entrance skin exposure when using AEC system. Prior to the study, the X-ray machine and its supporting

facilities used for the experiments underwent a quality control program (QCP), which was to assure their reliable capability in producing radiographs with optimum quality. This section will describe the QCP and explain the sequence of the entire methods

4.2.1 Quality control program of the X-ray machine and facilities

Basic tests of quality control were carried out during four weeks at the site of research study. Meanwhile, a daily program for checking readiness of the radiography facilities was done in parallel with the tests within the same period of the QCP. The tests were focused on an evaluation of the X-ray generator performances, which comprised of the tests, including the focal spot, mR/mAs linearity, kV accuracy, and HVL and dose reproducibility. Care was specifically made for the radiographic tests with the regard of looking at the AEC performance in agreement with the available imaging systems to produce a certain film density consistently. The field indicator and light/X-ray alignments were tested to ensure whether they still working in a proper condition or not. Besides, the level of fog incurred in the processing room as well as daily sensitometry for the processor was also checked and monitored respectively. Since this study was intended to make use of different X-ray cassette sizes whereas film density homogeneity was essential to be checked with respect to image quality, they were surely underwent the screen/film contact tests.

The QC equipments used for the testing procedures have calibrated routinely following the Thailand government regulatory that usually conducted by the medical science section of ministry of public health. Thus, they were valid instruments for physical measurements to the X-ray system and its supports that were employed in this study.

All of the results came up with the QC test were interpreted and compared with respect to some reference standards that have been widely published by responsible international organizations such as the National commission on radiation protection (NCRP), The American association of physic in medicine (AAPM) or the National electrical manufacturer's association (NEMA) [8, 19, 20]. Additionally, those standards have also been acknowledged to be a workable reference level in this

country as well. Since then, the real performances of the X-ray facilities were identified and verified

4.2.2 Stage I: Study of image quality in a human-mimic phantom

In this stage, the image quality criteria for the phantom object were set up by means of the AEC implementation. Radiographs of different anatomic organ of interests were essentially produced and studied in the order of searching out the quality criteria that were not only appropriate for the phantom radiographs but also suitable for the experiment purposes. Since one of the research's aim was to assess some factors that affect on image quality when use the AEC system, and therefore, the quality criteria settings in the phantom radiograph became useful information in the view of predicting the influence of the factors being concerned. Unfortunately, there were no workable standard AEC procedures in the X-ray system that can be employed, particularly those standards that have been used for producing phantom images with optimum quality. Due to this situation, it was important to find out the routine AEC procedures intended for the system so that suitable image quality criteria of the phantom radiographs (anthropomorphic phantom) could be developed, and the procedures would also be applicable in the line of the experimental radiography along with the study. For these reasons, several steps or procedures, therefore, needed to perform in sequence.

4.2.2.1 Determining of the routine AEC procedures normalized to the phantom imaging

The first step needs to perform was that; an evaluation upon the technique or procedure from the manual book of the Siemens Polydoros X30 [21] was intended to be carried out in order to define suitable techniques/procedures specifically formulated for experimental purposes. Instead, the techniques/procedures were planned to include a more detail AEC parameter, considering the needs of the study.

Eighty variations of the AEC procedures from twenty different views/projections of nine region organs of interest (ROI) in an anthropomorphic phantom were placed into a process of assessment. The underlying principle of the

assessment was to define appropriate routine procedures that can be implemented in the phantom radiography. In the assessment, each set of the procedures represented combined technical factors or parameters typically for the AEC operation. The parameters consisted of the AEC-density setting, detector(s), film-screen speed system, collimation size, Bucky-grid system, focal spot and kVp. In addition, some parameters associated with ESE measurements were collectively considered to be apart of the data collection. This information became one of primary data that was necessary for the investigation of the ESE incurred at the entrance point due to the procedures applied.

The following table presented preliminary technical data sets containing information about all predetermined-AEC parameters or procedures that were plunged into the evaluation processes.

Table 1 The AEC parameter/procedure settings and the ESE parameters

Parameter/ Procedure / ROI/Views		Density	Detector (s)	Screen–film speed system	Collimation sizes	Bucky-grid	Focal spot	kVp	Object thickness	Film focus distance (cm)	Table-entrance point distance (cm)
Skull	Antero-posterior; standard position	(-1.5)	C	400	10x12in	Y	Large	70-73	20	115	23
	Lateral; standard position	(-1.5)	C	400	10x12in	Y	Large	68-71	12	115	15
Chest-lung, and Heart	Antero-posterior; standard position	(-4) to (-1.5)	RL	400	35x43cm	Y	Large	66-125	20	130	23
	Lateral; standard position	(-3) to (-1.5)	C; RL ; L	400	35x43cm	Y	Large	100 - 145	29	130	40
Thoracic spine	Antero-posterior; standard position	(-0.5) to (N)	C	400	18x43cm	Y	Large	77-79	23	115	40
	Lateral; standard position	(-0.5) to (N)	C	400	18x43cm	Y	Large	81	40	115	40

Table 1 (Continued)

Hand	Postero-anterior; standard	(-0.5) to (+3)	C	400	8x10in	Y	Small	46	3	115	4.5
	Oblique; standard position	(-0.5) to (+3)	C	400	8x10in	Y	Small	46	6	115	7
Lumbar spine	Antero-posterior; standard position	(-0.5) to (+1)	C	400	10x12in	Y	Large	81	19	115	22
	Lateral; standard position	(-0.5) to (+1)	C	400	10x12in	Y	Large	90	38	115	29
Pelvis	Antero-posterior; standard position	(-0.5) to (+1)	RL	400	11x14in	Y	Large	77	20	115	23.5
Knee joint	Antero-posterior; standard position	(-0.5) to (+3)	C	400	8x10in	Y	Large	63	12	115	17.5
	Lateral; standard position	(-0.5) to (+3)	C	400	8x10in	Y	Large	63	10	115	11
Tibia and Fibula	Antero-posterior; standard position	(-0.5) to (+3)	C	400	18x43cm	Y	Large	60	11	115	12
	Lateral; standard position	(-0.5) to (+3)	C	400	18x43cm	Y	Large	60	9	115	10
Foot	Dorso-plantar; standard position	(-0.5) to (+3)	C	400	10x12in	Y	Small	52	7	115	7
	Oblique; standard position	(-0.5) to (+3)	C	400	10x12in	Y	Small	52	7	115	7

Radiographic examinations for each region organs of interest (ROI) were performed by means of trial and error methods. All factors/parameters were being treated as the fixed-techniques when taking radiographs. In one side, the parameter related to the density settings from -4 up to +3 were chosen to see their variations from the normal density (N) selection. On the other side, alike those kVp values suggested in the manual book of the X-ray system, tube voltage ranged from 46-145 kVp were deliberately employed in the assessments. The evaluations were only to inspect whether the application of those density and kVp settings were suitable for phantom imaging or not.

An experienced radiologist blended in the image interpretation as well as image assessment using a tool that has developed in the form of the proposed clinical checklists. If the image interpretation/assessment were completed, there would be two expected outcomes that need to be acknowledged. *Firstly*, a number of suitable AEC routine procedures should be obtained in the basis of assessing the clinical quality provided by the evaluated radiographs. *Secondly*, sets of the revised clinical quality required for phantom imaging should be restated and established in the format of the final checklists, considering of the radiologist's recommendations, and additional sources of image quality references such as the good example for quality criteria suggested by the Commission of European Community (CEC) [22], and those criteria adopted from the radiographic positioning textbook [23]. In addition to that, some of unwanted features that would have been probably replaced from the lists were verified and well documented into an additional list, describing information about these matters. The reason for doing so was that, in the experiments, image quality of radiographs was planned to be evaluated from technical aspects point of view too. Meanwhile, a group of technologists would be assigned to evaluate the technical image quality of the radiographs that should have been obtained from the experiments. Since some technical quality aspects would imply information about the clinical quality fulfillments, for instance, "the anatomical features visibility in the evaluated radiograph", therefore, the technologists should be completely informed somewhat on the subject of those unavoidable discrepancies that occurred in the phantom images. These efforts would be a strategy to cope with the image misinterpretation due to the possible limitation of phantom design.

Finally, the results obtained from this stage were analyzed from which several applicable predetermined-AEC procedures for the phantom object test were apparently chosen as the regards of the radiologist's preference. Thus, a number of the routine AEC procedures normalized to the phantom investigation and sets of the clinical quality criteria required for the phantom imaging can be determined while they were also inclusive variables, and would be used for the next image quality studies.

4.2.2.2 Image quality criteria settings

The terms of image quality in this study were appreciably defined into the clinical and technical aspects. The image quality settings should include these aspects and be meaningful in the matters of describing good image quality fulfilled by means of an experimental study.

Referred to the previous stage (sub heading 4.2.2.1), all clinical criteria have completely experienced some clinical justifications through that the process of image assessments as described. Apparently, the revised clinical checklists were clearly set up and ready to be used for the next image quality evaluation.

Meanwhile, the technical image quality criteria required to radiographs were also previously developed in which the scope of quality evaluation were limited to several aspects that commonly faced in the real practice of radiography. The following table described the scope of technical quality criteria.

Table 2 The technical quality criteria settings for phantom radiographs

No	Technical aspects	Scope of interest
1.	Accuracy of the object positioning (Q-1)	• The object shown on the image has to be oriented as a standard radiographic projection (e.g. True AP, True Lateral or oblique positions)
2.	Overall fulfillments of anatomical features (Q-2)	• Critical anatomic features of the organ of interest should be presented in the radiograph • *Note:* Make use of the additional list provided for convenience
3.	The conformity of the x-ray field size used, regarding of the technical quality criteria fulfilled in general (Q-3)	• Proper used of X-ray field sizes needing for a particular examination (e.g. too small, too large or just enough) • Justification of radiation field used in the exam with respect to rendering sufficient diagnostic information (e.g. radiation filed is accurately limited while

Table 2 (Continued)

		radiographic contrast, sharpness and organ detail are well-defined)
4.	Overall optical density (Q-4)	• Degree of film blackening (e.g. too dark, too light or optimum)
5.	Overall image contrast (Q-5)	• Degree of the grayscale tone of the film in reproducing distinction between structures (e.g. high contrast, low contrast or optimum contrast)
6.	Overall image sharpness (Q-6)	• Degree of unsharpness due to physical related aspects (e.g. geometric, photographic factors)
7.	Overall detail of the region of interests (Q-7)	• Degree of clarity of anatomic structures shown on the film (e.g. bone trabeculations, vessel grove in the skull etc.)

A questionnaire with seven close-ended interviewed that covered personal opinion about the technical image quality as presented in the above table was the tool used for radiograph interpretation. In the questionnaire, the additional list (as mentioned in the sub section 4.2.2.1) was put apart as an attachment. By this means, the technical quality (questionnaire) was completely defined, and can be used in parallel with the checklists.

As one of the study's concerns was to assess factors that affects on image quality when employ AEC system, the checklists (used for clinical evaluation), and the questionnaires (used for technical evaluation) were necessary to be grouped according to the factors being concerned. This arrangement was to facilitate evaluation processes to all radiographs undertaken from the experiments. Therefore, the both clinical and technical image quality settings were fully prepared, so the process of images assessments would be convenience.

4.2.2.3 Factor settings

The three foremost factors in the AEC system operation that needed to assess were the detector selections, the object position and the X-ray field size used or the collimation. They were variable, and were arranged altogether with the other fixed-AEC parameters in several ways that different from those routine procedures as have already defined in the early section. Basically, these setting factors were created to study their influences onto image quality whenever the AEC system was employed to produce radiograph with a certain image quality which in turn, a possible impact upon the measured ESE due to the underlying factors could be confirmed. The following parts depicted of how each factor was therefore set up as intended.

(a) Detector setting

Varying modes of detector(s) selection were intended to employ when performing experimental radiography with the phantom object. The figure 5 showed an example where the four different variations of detector (black-shaded box) were chosen for a normal lung antero-posterior (AP) view, instead of the lateral detectors (routine procedure)

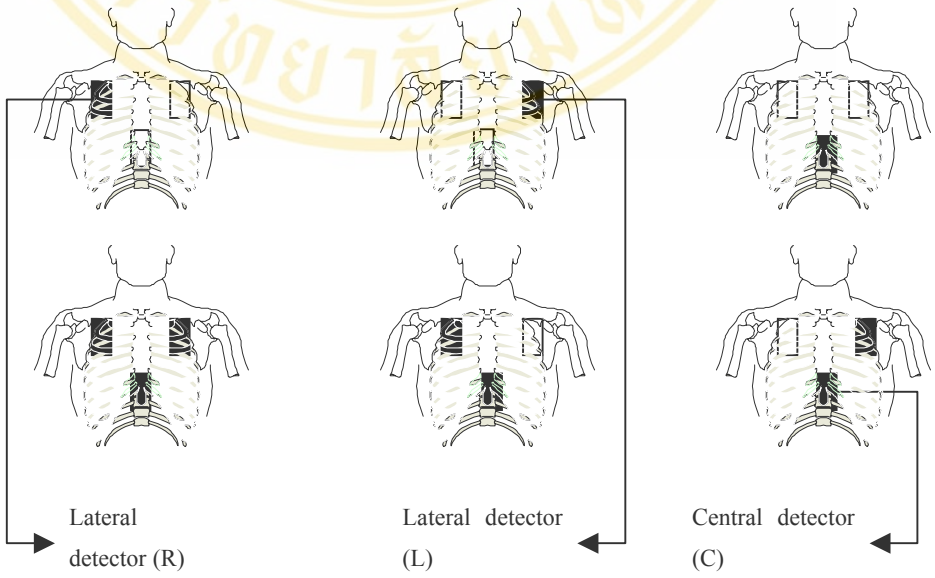
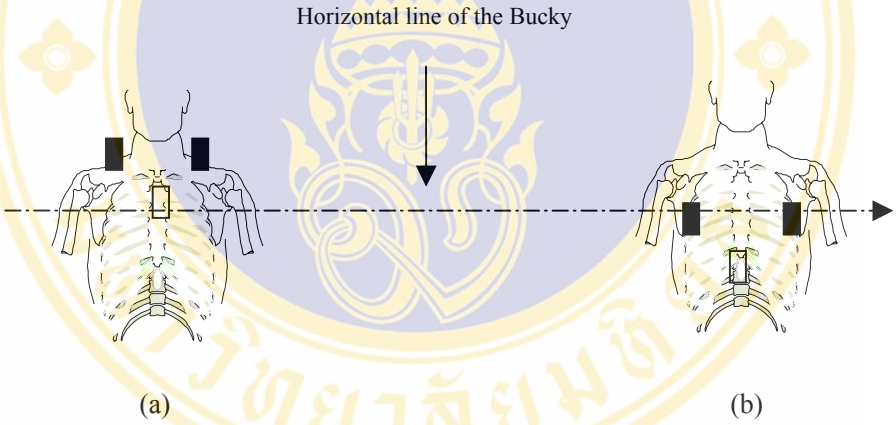


Figure 5 The detector factor settings

(b) Object position settings

The object of interest in the phantom was planned to be positioning over the selected detector(s) with various shifting levels from the standard object positions. The variations can be in certain distances superiorly, inferiorly and even laterally with respect to the selected detector(s). Each varying object-position was not the same from one view/projection to the other that would always be depending on anatomical characteristics of the organ under examination.

The figures 6 a and b were an example simplifying the radiographic experiments of the chest AP projections in that the effects of changing object-position factors with respect to the selected detector(s) were examined.



(a) Symmetric standard positioning with the object superiorly oriented from the detectors.

(b) Symmetric standard position with the object inferiorly oriented from the detectors.

Figure 6 a-b The object position factor settings

(c) Field size settings

Various sizes of the collimation adjustment were applied in the experiments. The field sizes smaller than those sizes from the routine procedures (e.g. the standard sized-cassette) were necessary made in the radiography. For this reason,

possible effects due to the collimation factor when using the AEC system were revealed. As can be seen in the figure 7, the X-ray field size used for the radiographic experiments in the skull lateral-views, for instance, was varied.

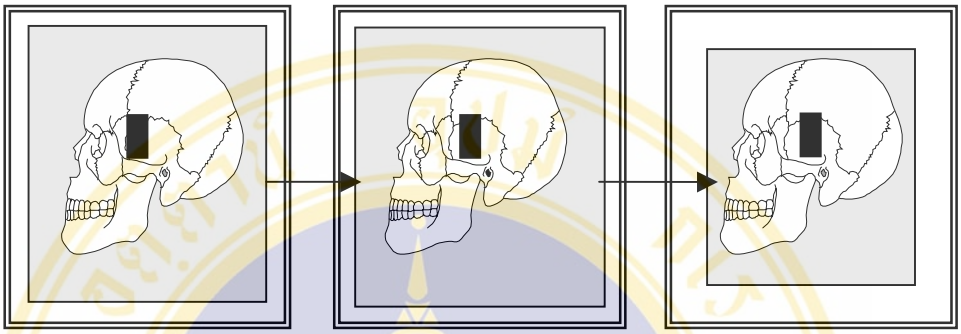


Figure 7 The collimation factor settings

4.2.3 Image quality evaluation

The clinical and technical aspects of image quality were reviewed independently, using rather specific tools that have been documented as the checklists and questionnaires. Scoring systems were applied for quantitative measurement upon the both aspects of image quality [17, 24, 25]. In case of the scoring systems, two image quality descriptors were employed and defined as composite indexes, reflecting overall fulfillments of the clinical and technical quality aspects about the radiographs that have been undergoing such evaluations. The indexes were calculated with discrete equations whereas one index (the clinical quality composite index) needed to be verified first before attempting to calculate another composite index (the technical quality composite index) particularly when figured out the overall image quality fulfilled by the reviewed radiograph. By this means, the clinical composite index became an inclusive variable but it was necessarily to be acknowledged for expediency of overall image quality fulfillments. Based on this method, the nature of image evaluation process that normally performed in the practice was obeyed. Importantly, image quality evaluation in this study was emphasized on the technical aspects rather than the clinical aspects, since the radiologist had already verified the latter.

In the checklists, each list composed of the statements elaborating the clinical quality criteria that critically required for each projection/view of an evaluated radiograph. Therefore, the number of statements for each individual checklist was various. Additionally, choosing one of the optional marks available in the checklist to which evaluated statement such as “yes” or “no” was very convenient for knowing its fulfillment, whereby, a score with the value of one was necessarily given to that the mark “yes” while the score of zero was applied to the mark “no”. An equation [24] was employed in the calculation of the composite index for clinical image quality fulfilled, the so-called the CQCI. The equation was expressed as the following,

$$CQCI = \frac{\text{Number of criteria fulfilled}}{\text{Total number of criteria}} \quad \text{..... (1)}$$

Where,
CQCI = the composite index of clinical quality criteria
$(0 \leq CQCI \leq 1)$

Tough the calculated CQCI values possibly ranged from 0 to1, the indexes that equal to 1 denoted the maximum fulfillment of all critical criteria and became the prerequisite value for passing the evaluated clinical aspects.

Again, an experienced radiologist was assigned to interpret clinical aspect of the entire radiographs being studied, using the checklists provided. As this procedure was important to be done first before stepping to the next procedures, which was the technical image quality evaluation, thus all radiographs must be clarified and passed clinical evaluation.

For the technical quality criteria evaluation, a questionnaire composed of 7 typical closed-ended interviews was the tool used to disclose essential aspects of the radiographic technical quality such as those criteria that related to the object positioning accuracy (Q-1), anatomical organ visibility (Q-2), conformity of the collimation size (Q-3), radiographic optical density (Q-4), contrast (Q-5), sharpness (Q-6) and detail (Q-7) [1, 11, 26]. The answers were categorical having gradual scores

as in the Likert-scale that consisted of the "good" (scored 3), the "adequate" (scored 2) and the "poor" (scored 1), quantitatively describing personal opinion about visual features of those technical criteria fulfilled in the evaluated radiograph [24]. Since there were 20 technologists with at list 5 years experience in practice subsequently participated in the processes of technical image quality evaluation for all the radiographs had previously been assessed by the radiologist, a resemble approach to that scoring system in the CQCI was applied on this evaluation. Yet, a different descriptor for technical image quality, so-called the technical quality composite index (abbreviated the TQCI) was used while it obvious needed to be calculated as well. A simple equation was employed to figure out the mean TQCI value of the 20 evaluators' composite indexes for which of an individual evaluated radiograph. By this circumstance, the technical quality criteria of the radiograph were collectively judged by a group of the evaluators whether it was technically satisfied or not. The TQCI value for a radiograph judged by 20 technologists was computed with the equation as the following,

$$TQCI_{ti} = \sum_{i=1}^{7} (Q_i)/14 \quad \text{..... (2)}$$

$$TQCI_{rn} = \sum_{ti=1}^{20} (TQCI_{ti})/20 \quad \text{..... (3)}$$

Where,

Q_i = Score of technical quality criteria number i in the questionnaire (i = score question 1 to 7)

$TQCI_{ti}$ = Score of technical quality composite index for technologist number i (i = technologist number 1 to 20)

$TQCI_{rn}$ = The averaged technical quality composite index of twenty technologists for the evaluated radiograph number n

$(0.5 \geq TQCI_{rn} \leq 1.5)$

By applying the equation 2, the $TQCI_{ti}$ value of individual image evaluator was calculated, based on the total scores from the seven quality criteria divided by a value of 14. The denominator of 14 basically represented the summation of the seven

technical quality criteria scores in the questionnaire that were categorized as adequate. Importantly, the $TQCI_{rn}$ was also calculated for each radiograph using the equation 3. This method was employed to determine the minimum score that has to be fulfilled by an evaluated radiograph. Thus, the fulfillments of technical quality criteria for particular radiograph can be verified. An example of the both $TQCI_{ti}$ and $TQCI_{rn}$ calculations can be seen in the appendix A of this report.

In brief, the use of the equations 1, 2 and 3 was capable of portraying the both aspects of image quality fulfillments (clinical and technical quality criteria) and therefore, the CQCI and TQCI of the entire evaluated radiographs were needed to obtain. It has been important to remember that all radiographs had to pass clinical evaluation before underwent technical evaluation. From this point, the only technical quality aspects were merely considered in correlation with assessments about factors that influenced to image quality when employed AEC system. Afterwards, the effects of factors were disclosed according to the result analyses toward the TQCI values that obtained from the experiments.

4.2.4 Stage II: Study of the AEC factors that affect on image quality of radiographs

The objective of this study was to examine the influence of the three foremost factors in the AEC application (the detector, object position and collimation) onto image quality. The effects of each factor were possibly observed through experimental studies that included three independent steps of the assessment process with regard to image quality results (clinical and technical aspects).

In the experiments, clinical quality evaluations were needed to perform to all radiographs that were produced by means of applying those AEC procedures with varying factor settings. Thus, the checklists were employed in the clinical evaluation (see appendix B). If a number of radiographs were passed this step of evaluation, clinical quality data (represented by the calculated CQCI) about those radiographs were definitely acknowledged and denoted that the radiographs were being accepted clinically. These CQCI were a prerequisite aspect before taking any of measurements about technical quality data (represented by the TQCI).

The questionnaires (see appendix C) used for the technical image quality observations were more likely to be a useful tool following this step of image evaluations, since the clinical image quality has been defined as one of the inclusive factors. For this reason, technical quality became the main aspect to concern over the subsequent process of image evaluations. Importantly, when assessed the factor effects, the TQCI data of the routine procedures were used altogether with the TQCI data obtained from each step of the assessments.

In related to this stage of study, at list all data about the clinical quality fulfillments (the CQCI values) of the evaluated radiographs in the routine AEC procedure should have been obtained from the early steps. Whereby, there were the three recognized groups of radiograph in the routine procedures (group detector, group position and group collimation) that only needed to experience technical quality verifications, which in turn would be rendering the technical quality data set (the TQCI values). Since then, comparisons were done between the routine and the modified AEC procedures (before and after treatment) within each individual group independently. Hence, the effects of changing factors within the stages can be accordingly observed.

The experimental studies of each of the assessments were designed as the following figure 8 [27]. It was to compare two groups in term of a paired-dependent variable. As shown in the figure, two groups, X_1 (the routine AEC procedures) and X_2 (the varying of factors), were compared by meant of their effect on dependent variable, Z_1 (The resulted image quality)

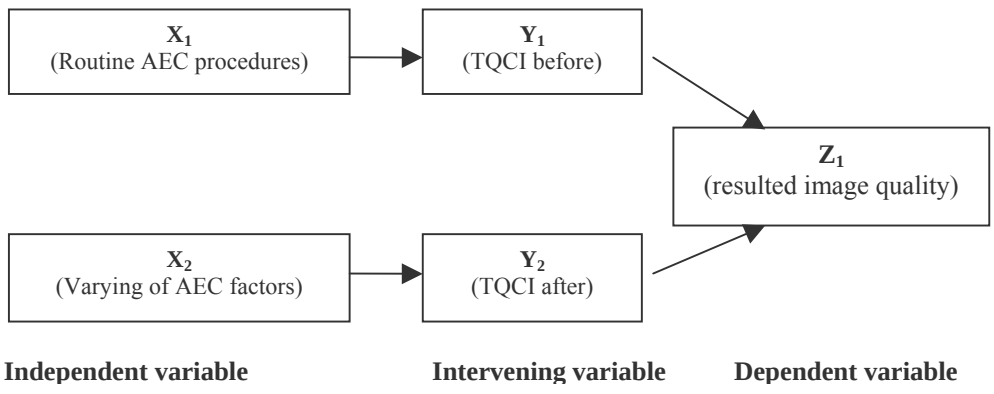


Figure 8 The experimental design

The paired-t statistical test with $\alpha = 0.05$ was the tool used for testing the H_o in each step of the assessments [28, 29]. By this means that, if the H_o were rejected, varying of the AEC factors being concerned when employed AEC system in radiography may have an effect in the technical image quality results. Finally, the impacts of factor changes could be clarified.

4.2.4.1 Assessment of the effect of detector factor with respect to image quality (technical aspects)

23 radiographs produced by means of varying detector factor were studied to identify the effects of detector (s) or the sensor chamber changes that differ from the routine procedure on the resulted quality of image. Evaluating image quality of those radiographs was done with the regards of the TQCI estimations. In this assessment, a null hypothesis was set up as the following:

$$[Ho : \mu_{TQCI\text{-}rd} = \mu_{TQCI\text{-}d}]$$

Where,
$\mu_{TQCI\text{-}rd}$ = mean of technical quality criteria before varying of detector selection
$\mu_{TQCI\text{-}d}$ = mean of technical quality criteria after varying of detector selection

There is no mean difference in technical quality criteria between before and after varying of detector selection when using AEC system in radiography.

4.2.4.2 Assessment of the effect of object position factors with respect to image quality

The influence of object positioning in the AEC radiography was investigated throughout the assessment toward 73 radiographs obtained from the experiment. Similarly, the TQCI values were used when predicting the effects of this factor on to radiographic image quality. The null hypothesis for this assessment was:

$$[Ho : \mu_{TQCI\text{-}rp} = \mu_{TQCI\text{-}p}]$$

Where,
$\mu_{TQCI\text{-}rp}$ = mean of technical quality criteria before varying of object position
$\mu_{TQCI\text{-}p}$ = mean of technical quality criteria after varying of object position

There is no mean difference in technical quality criteria between before and after varying of object position when using AEC system in radiography.

4.2.4.3 Assessment of the effect of collimation factors with respect to image quality

The final stage of the assessments was to examine the effect of X-ray field size factors to image quality. 39 experimental radiographs with several kinds of reduced field sizes different from those sizes in the routine AEC procedures were investigated. Again, data about the TQCI values that collected from the image evaluation were expected to give some evidences associated with the influence of this factor onto image quality results. The null hypothesis for this assessment was set up as the following:

$$[H_o : \mu_{TQCI\text{-}rc} = \mu_{TQCI\text{-}c}]$$

Where,

$\mu_{TQCI\text{-}rc}$ = mean of technical quality criteria before varying of collimation size

$\mu_{TQCI\text{-}c}$ = mean of technical quality criteria after varying of collimation size

There is no mean difference in technical quality criteria between before and after varying of collimation size when using AEC system in radiography.

4.2.5 Stage III: Measurements of the ESE incurred at the selected procedures, considering the AEC factors and image quality of radiographs

Measurements of the ESE value were based on estimation from the free-in-air [30]. Therefore, some of the related ESE parameters such as the Tube-Chamber-Distance (TCD) as well as the distance to entrance point (TED) for all type of examinations were recorded accordingly. Additionally, the measurements were only subjected to those selected AEC procedures that had already been accounted for the radiographs with good/adequate image quality criteria (TQCI ≥ 1).

The figure 9 below portrayed the geometry used for the measurement of the ESE especially when the AEC system was employed [9].

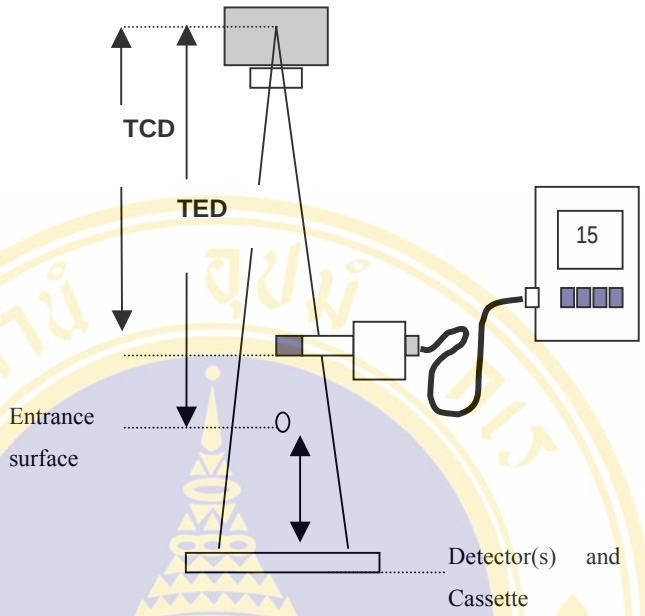


Figure 9 The geometry for the free-in-air measurements

The measured ESE at the surface areas was estimated using the following equation [9, 30]:

$$\text{Exposure @ surface} = \text{mR/mAs} \times (\text{TCD/TED})^2 \times \text{mAs}_2$$

Where,
mR/mAs = the estimated exposure values (free-in-air)
TCD = the Tube-Chamber-Distance
TED = the Tube-Entrance-Distance
mAs_2 = the reading mAs values with respect to each examination

The measured ESE may be expressed in various levels of the exposure dose that specific to the projection/view or factors concerned. Data acquired from the measurements were compared within the selected AEC procedures and inspected their relation about its image quality results.

In addition, this stage of the study was also intended to examine the effects of those AEC factors in the view of the measured ESE with respect to its technical quality visibility (represented by the TQCI values). Therefore, a similar experimental design for which paired-t test statistical analysis was also employed in this stage. However, it was emphasized on the ESE effects due to the implementation of those AEC factors concerned. For this purpose, another three null hypotheses were set up as stated as the following:

1. $[Ho : \mu_{ESE\text{-}rd} = \mu_{ESE\text{-}d}]$

Where,
$\mu_{ESE\text{-}rd}$ = mean of ESE before varying of detector selection
$\mu_{TQCI\text{-}d}$ = mean of ESE after varying of detector selection

There is no mean difference in the ESE between before and after varying of detector selection when using AEC system in radiography.

2. $[Ho : \mu_{ESE\text{-}rp} = \mu_{ESE\text{-}p}]$

Where,
$\mu_{ESE\text{-}rp}$ = mean of ESE before varying of object position
$\mu_{ESE\text{-}p}$ = mean of ESE after varying of object position

There is no mean difference in the ESE between before and after varying of object position when using AEC system in radiography.

3. $[H_o : \mu_{ESE\text{-}rc} = \mu_{ESE\text{-}c}]$

Where,
$\mu_{ESE\text{-}rc}$ = mean of ESE before varying of collimation size
$\mu_{ESE\text{-}c}$ = mean of ESE after varying of collimation size

There is no mean difference in the ESE between before and after varying of collimation size when using AEC system in radiography.

4.2.6 Experimental diagram of the assessments

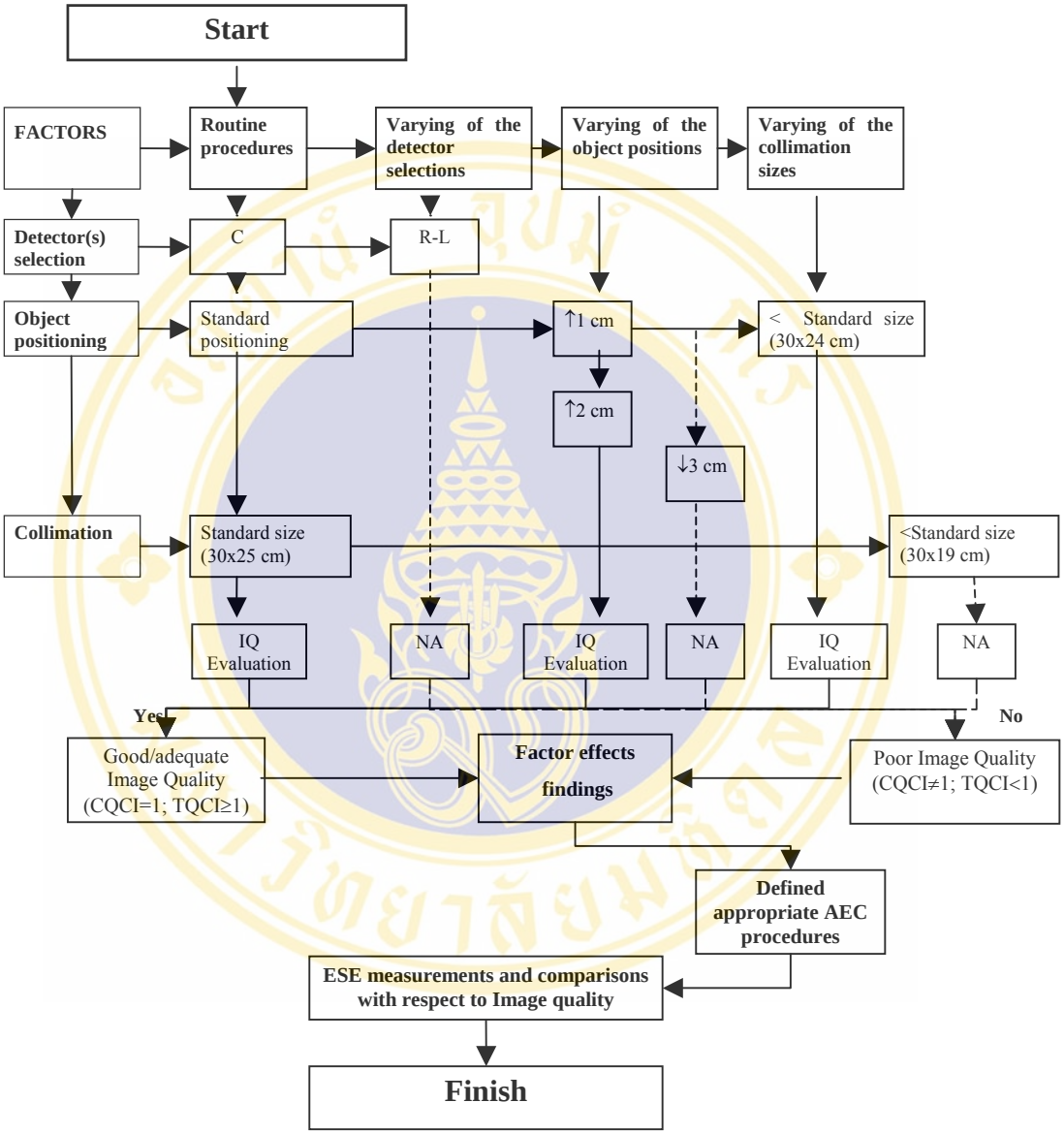


Figure 10 The experimental diagram of the assessments

The figure 10 depicted a chart model of the experiments that applied in the study. Owing to this model, the three factors (the detector selection, object positioning and the collimation) were concerned. Assessments were chronologically started from the routine procedures followed by varying detector factor up to

collimation factor which in that, the influences of these factors were essentially to be examined in the basis of image quality evaluations.

In the model, multi stages of assessment process were performed. *The first stage* was that, the routine AEC procedures were assumed to produce radiographs with good/adequate image quality (CQCI=1; TQCI≥1). Image quality comparisons were made between the radiographs taken from the routine procedures. Hence, the most excellent image quality results were obtained, including their AEC procedures. Further, a set of the AEC procedures in this stage was chosen to be the standardized techniques of the routine AEC procedures while the image quality of the radiographs lead to these AEC procedures was decided as a standard of comparison. *The second stage* was to perform assessment of detector factor by means of applying the same standard techniques as determined. However, varying modes of detector were selected and the resulted radiographs were evaluated. Again, image quality comparison between radiographs was assessed, then, the effects of detector factor were identified. *The third stage* was to perform assessment of object position factor by which the standard techniques were also employed for taking radiograph. Along with this stage, the object positions were varied, and the resulted radiographs were compared in order to verify the effect of this factor. *The fourth stage* was the second end of these serial assessment processes. Alike the previous stages, using the same standard techniques with varying levels of the X-ray field sizes was the experiments to perform over all of this stage. As the image quality comparison has been made for the resulted radiographs, the influence of changing collimation sizes was disclosed. *The final stage* was to measure the ESE values toward those appropriate AEC procedures that have been recognized to produce the finest image quality results. The measured ESEs were then compared within the selected procedures, considering their effects onto image quality.

CHAPTER 5
RESULTS AND DISCUSSIONS

5.1 Quality control program of the X-ray machine and facilities

The sections below described and discussed about the results of quality control program.

5.1.1 Visual check of the facility

Visual checking for the readiness of the X-ray facilities was performed daily during the period of the experiments. For some items linked to the operational system of the X-ray machine and processor were always be inspected at glance to confirm their general conditions before used in the experiments. The following table 3 outlined a brief result of visual inspection about the conditions of the facility.

Table 3 List of visual check

Items	Descriptions	P/F/NA	Action
Overhead tube crane	TFD indicator or marks	P	
	Angulation indicator	P	
	Locks (all)	P	
	Perpendicularity	P	
	Field Light	P	
	Bucky center light	P	
	High tension cable/other cables	P	
	Overhead crane movement	P	

Table 3 (Continued)

Table	Bucky lock	P	
	Cassette lock	P	
	Float and power top switches	P	
	Step stool	P	
	Angulations indicator/stop	P	
Control booth	Window Pb-glasses and the door	P	
	Panel switches/lights/meters	P	
	Programmed AEC technique	NA	RP
	Aprons	P	

Legend: P = Pass; F = Fail; NA = Not applicable; RP = Report

5.1.2 Darkroom safelight and the processor evaluations

A basic test was performed for checking film fog level in the processing room that maybe due to the poor condition of the safe light or the light leakage from surroundings. The table 4 was the result of the darkroom test, based on an optical density (OD) measurement toward two images of Aluminum step.

Table 4 Darkroom Fog test

QC Tool : Aluminum steps (Kodak)
Objective : to evaluate acceptable level of darkroom fog
Limit OD difference : ≤ 0.05 OD
Technique : kV 52; mAs 10; FFD 100 cm; Focal spot = Small

Step	OD of the step (uncovered within 2 minutes)	OD of the step (covered within 2minutes)	OD difference	Miscellaneous	
1	NA	NA		Darkroom visual check	
2	1.21	1.02	0.19	ceiling	Fail
3	1.42	1.17	0.25	door	Fail

Table 4 (Continued)

4	1.65	1.39	0.26	Indicators	Pass
5	1.88	1.62	0.26		
6	2.09	1.84	0.25		
7	2.27	2.04	0.23		
8	2.42	2.24	0.18		
9	2.54	2.4	0.14		
10	2.64	2.52	0.12		
11	2.7	2.61	0.09		
12	2.77	2.69	0.08		
13	2.81	2.75	0.06		
14	2.84	2.79	0.05		
15	2.87	2.82	0.05		
16	2.89	2.86	0.03		
Avg.	2.33	2.18	0.15		

In case of the processor evaluations, five parameters were observed within the six interrupted days of the sensitometic program. Random inspections upon its performance were needed with the aim to identify possible non-technical factors intruding to the operation of processor, and therefore, this method was implemented.

The figures 11-14 described about the charts where consistency of the processing conditions was monitored. In general, the Base+Fog and the developer temperature were mostly in the range of accepted limit (± 0.02 and ± 1 respectively) although the density difference and the medium density appeared to be a bit fluctuating from its acceptance limit at ± 0.10.

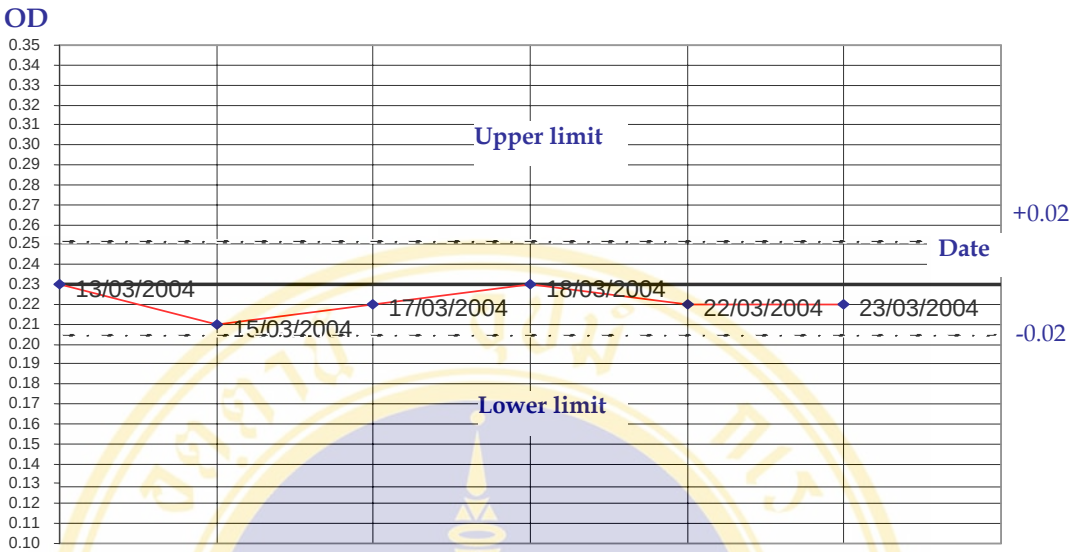


Figure 11 The Base+Fog levels

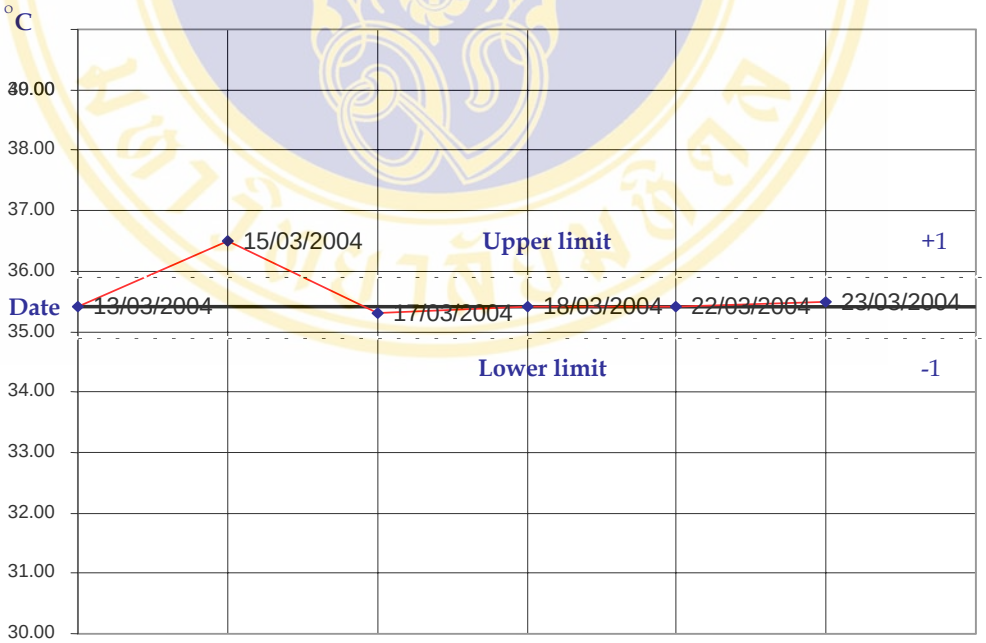


Figure 12 The developer temperature

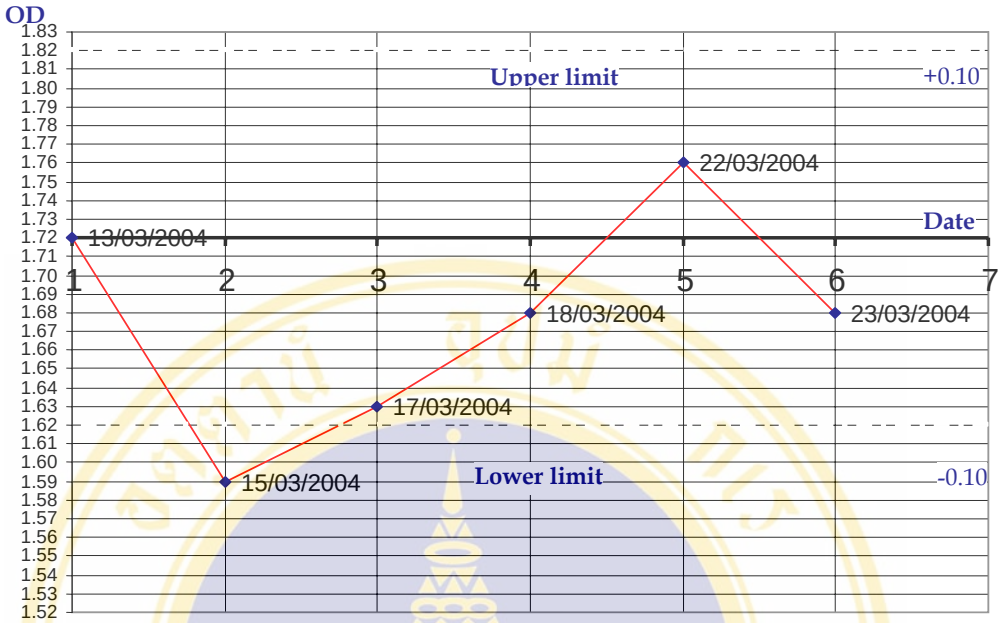


Figure 13 The density difference

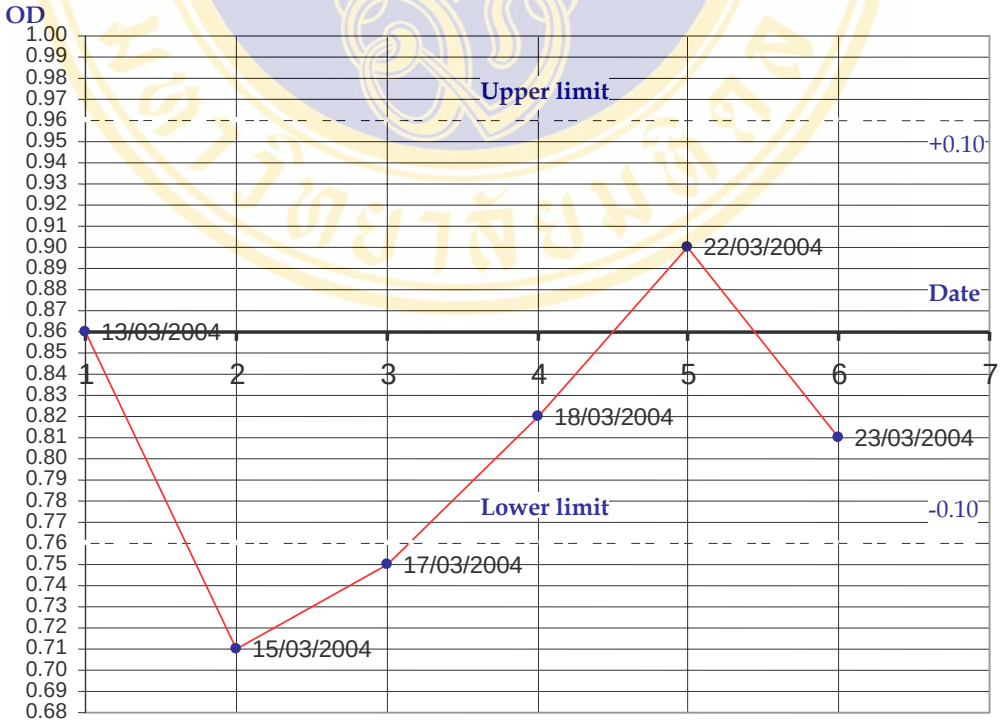


Figure 14 The medium density

Along with the darkroom and processor evaluations, the condition of some selected X-ray cassettes experienced such a test. Possible cassette problems such as poor contact condition of the screen/film system or when a cassette appears to be damage were inspected. The table 5 was results of the tests.

Table 5 Film-Screen contact test

QC Tool : RMI 143C
Objective : to evaluate the appropriateness of screen/film contact

Cassette size	Density uniformity	Blurring/ Unsharpness area	Screen/Film contact condition
8x10in	Yes	No	Good
10x12in	Yes	No	Good
11x14in	Yes	No	Good
30x40cm	Yes	No	Good
35x43cm	Yes	No	Good
18x43cm	Yes	No	Good

5.1.3 Quality control tests of the X-ray generator

A typical general purpose X-ray unit from the Siemens-Polidoros X80 equipped with AEC devices underwent testing procedure to ensure its current performance reliability before used for the experimental radiography in this study. Owing to technical data, the X-ray generator is operated with 3 phases,12 pulses and the frequency is 50/60 Hz. Tube rating for maximum kVp is 120, while dual focal spot dimension (the large size 1 mm and the small size 0.6 mm) is selectable. Typical filters are attached to the X-ray tube which consists of an inherent 1.5 mm and an additional 1 mm of Aluminum filters applied for 80 kV and 70 kV respectively [21]. The priority of tests was mainly emphasized on the evaluation of the six technical parameters of the X-ray generator; the focal spot, the mR/mAs linearity, the kV accuracy, the exposure time accuracy/precision, the exposure reproducibility and the beam quality (HVL). The following informs the results of measurements.

Table 6 Focal spot measurement

QC Tool : RMI 112B
Objective : to estimate effective focal spot size
Technique : kVp 80; mAs 10; FFD 61cm; FPD 46 cm
Film = fine grain-non IS; M 4/3

FS size	lp/mm of group	Estimated dimension of effective FS (mm)	Nominal FS size (mm)	Acceptance
Small	11	0.8	0.6	Yes
Large	7	1.5	1	Yes

Table 7 Consistency of the tube current

QC Tool : Full function meter RMI242
Objective : to evaluate the consistency of the tube current (mAs) from varying mA stations
Acceptance limits : $\alpha < 0.1$
FFD : 100 cm

Number of exposure	Technique-1:	kV mA mAs ms	81 500 20 40	Technique-2:	kV mA mAs ms	81 250 20 80
	Measured in mR			Measured in mR		
1	200			198		
2	199			197		
3	199			197		
4	200			197		
5	200			197		
6	200			197		
7	200			197		

Table 7 (Continued)

8	200		197
9	200		198
10	200		197
$Mean_1$	9.99	$Mean_2$	9.86
		α	0.01
Acceptance	Yes		

Table 8 The tube voltage accuracy and precision

QC Tool : Full fuction meter RMI242
Objectives : 1. kVp accuracy; to determine that the machine is producing the kVp selected on the control panel
2. kVp precision; to determine that the kVp is consistent from exposure to exposure
Acceptance limits : Accuracy ≤ ± 5%; Precision ≤ 5%
Technique : mAs Fixed at 10; kVp = vary; FFD 91 cm; Focal spot = small

Selected kVp	Measured kVp						Accuracy (%)	Precision (%)	Accep-tance
	1	**2**	**3**	**4**	**5**	**Mean**			
50	51.6	51.8	51.2	51.5	51.3	51.48	2.96	0.46	Yes
60	61.9	61.8	61.8	61.8	61.8	61.82	3,0	0.07	Yes
70	73.4	73.5	73.6	73.4	73.5	73.48	4.9	0.11	Yes
90	93.8	93.9	93.6	93.7	93.8	93.76	4.1	0.12	Yes
100	103.9	104.4	104.4	104.2	104.6	104.3	4	0.25	Yes

Table 9 The exposure time accuracy and precision

QC Tool : Full function meter RMI231A
Objective : to evaluate accuracy and precission of the exposure time
Acceptance limits : Accuracy ≤ 5%; Precisions ≤ 3%
Technique : kV 81; FFD 100 cm; mA 500; ms 40

Number of exposure	Setting exposure time (ms)	Reading exposure time (ms)	$(Xi-M_1)^2$
1	40	43	0.01
2	40	45	4.41
3	40	42	0.81
4	40	44	1.21
5	40	43	0.01
6	40	41	3.61
7	40	42	0.81
8	40	42	0.81
9	40	43	0.01
10	40	44	1.21
$Mean_1$	40	42.9	∑12.9
Acceptance	Accuracy	7.25 %	No
	Precisions	2.79 %	Yes

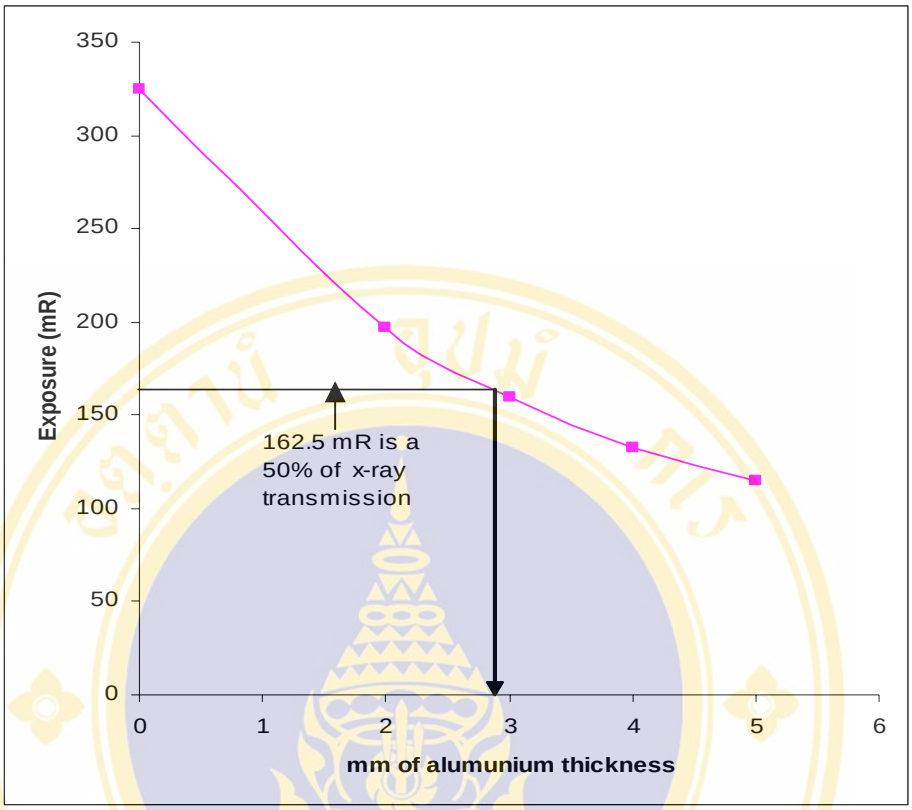


Figure 15 The HVL measurements with 80 kV applied

5.1.4 Radiographic tests

The radiographic tests mentioned here were focused on the tests for the collimator and beam alignment and to be more specific on the evaluation of some essential aspects in the AEC system operation. For the AEC test, performance evaluations included the tests such as the consistency of density control, the consistency of exposure with varying part thickness, also the consistency of sensor chamber. Moreover, the scope of the AEC tests was being limited just to understand ordinary conditions of the system whether it has been well calibrated or not. This practically identified through the test performances, showing capability of the system in contributing consistent OD on radiographs over a wide range of phantom thickness, or sensor and density settings. The following two tables figured out about the results of the collimator and beam alignment tests.

Table 10 Collimator tests

QC Tool : Collimator and beam alignment test tools
Objective : to assure that the light field and the X-ray field are congruent
Selected field size : X = 18.1 cm; Y = 13.8 cm
Technique : kV 50; mAs 10; FFD 90 cm
Acceptance limit : ≤ 2% of FFD (≤ 1.8 cm)

FFD	Long axis		Short axis		% of FFD		Acceptance
	X_1	X_2	Y_1	Y_2	(X_1+X_2)	(Y_1+Y_2)	
90 cm	0.7	0	0.4	0.9	0.8	1.4	Yes

Table 11 Beam alignment test

Objective : to assure that the central point of the x-ray beam is aligned with the focal spot position
Acceptance limit : ≤ 3^o

FFD	Ball image in 1st circle (1.5^o)	Ball image in 2nd circle (3^o)	Outside of the circle ($>3^o$)	Acceptance
90 cm	Yes	-	-	Yes

The figure 15 showed the performance of density control settings with respect to the OD's results that was performed by the table AEC system of the X-ray machine.

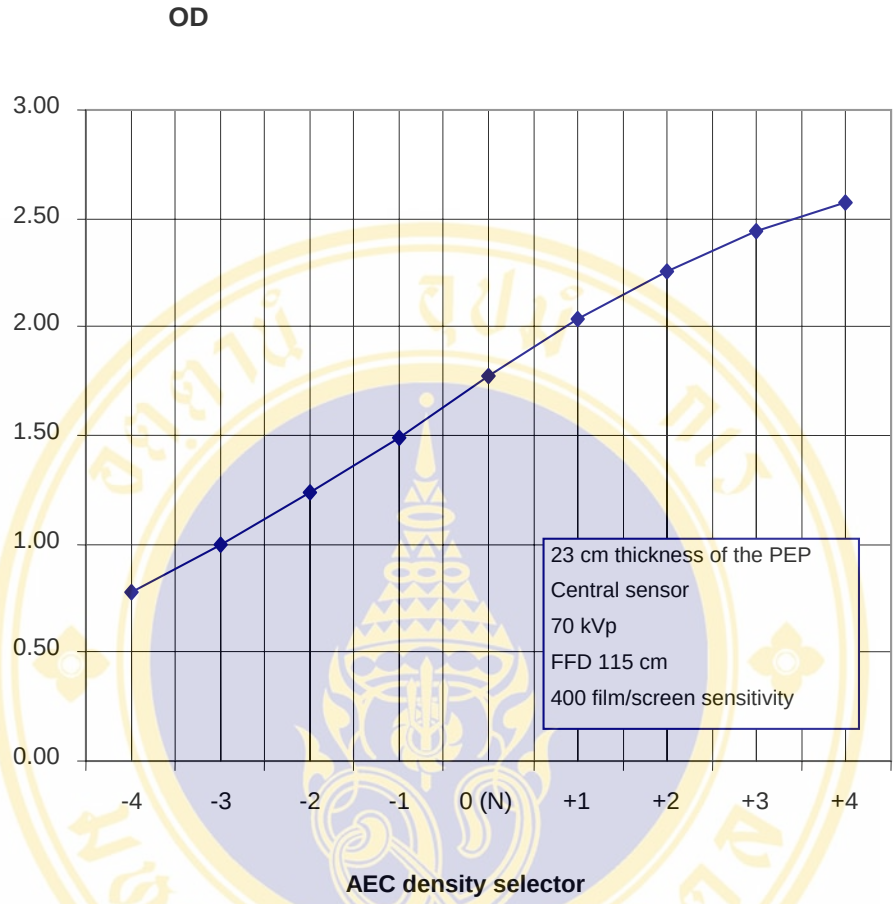


Figure 16 The AEC-density control performances

Table 12 and 13 were the results from measurements about individual and combined modes of detector consistency by means of the mAs readings. Additionally, the mAs readings differences resulted from individual and combined modes of the detectors were illustrated as shown in the figure 17-a; and b.

Table 12 Consistency of the individual detector with respect to the mAs readings

Number of reading	The mAs readings of the individual detector		
	R	C	L
1	21	34.6	43.6
2	21.1	34.7	43.7
3	20.9	34.4	43.7
4	20.8	34.7	43.4
5	20.6	34.3	43.9
Avg	20.88	34.54	43.66
SD	0.19	0.18	0.18

Table 13 Consistency of the combined detectors with respect to the mAs readings

Number of reading	The mAs reading of the combined detector(s)			
	R-C	R-L	R-C-L	C-L
1	24.2	27.7	29.6	38.5
2	23.8	27.5	29.6	38.8
3	23.5	27.7	29.5	38.2
4	23.2	28.2	29.6	37.5
5	23.1	27.4	29.5	38.7
Avg	23.56	27.7	29.56	38.34
SD	0.45	0.31	0.05	0.52

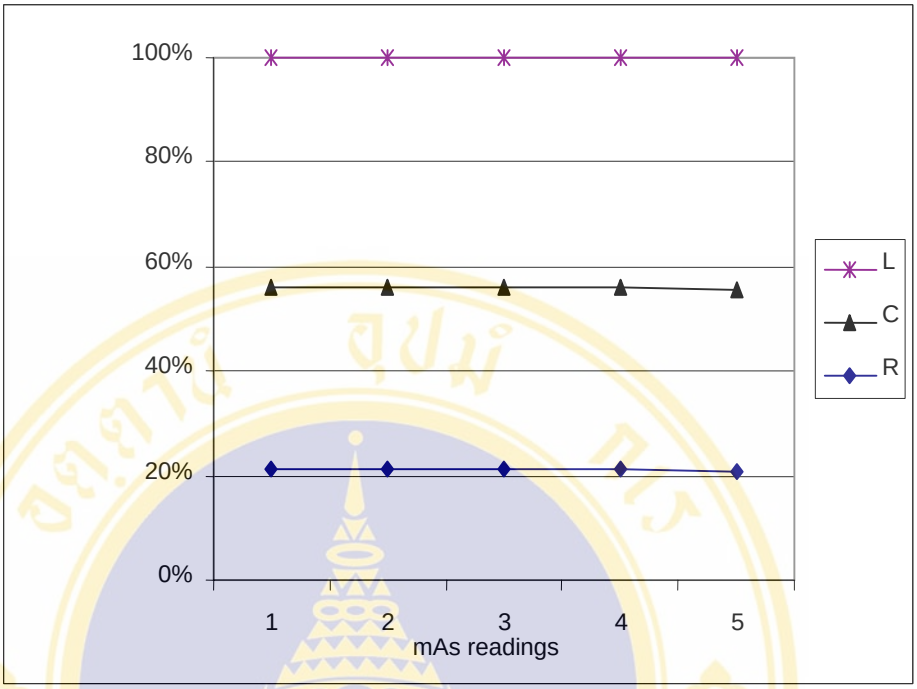


Figure 17-a. The mAs product difference (%) between individual detectors

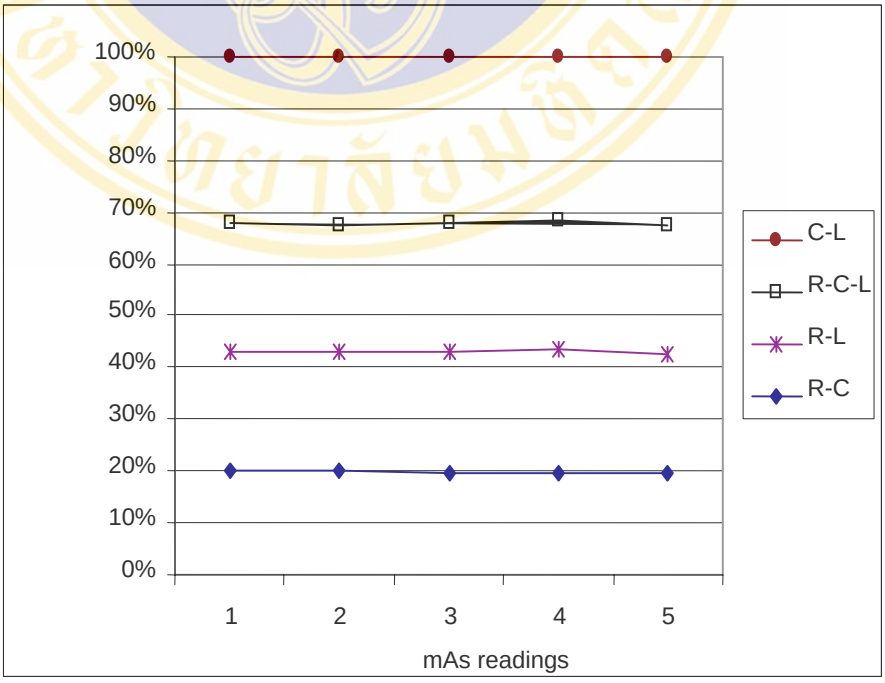


Figure 17-b The mAs product difference (%) between the combined modes of detectors selection

An additional method for checking the detector(s) consistency was also performed in the basis of optical density measurements. The results can be seen in the table 14.

Table 14 Consistency of detector(s) with respect to optical density

Detector(s) modes	Averaged optical density measured at the center of each of the PEP radiographs
R	0.59
C	0.81
R-C	0.7
R-L	0.63
R-C-L	0.67
C-L	0.81

The last AEC evaluation dealt with consistency of the detector(s) with varying thickness parts. The detector(s) constancy in terms of the mAs and OD values was investigated with respect to different slabs of the Patient Equivalent Phantom (PEP) object test (10 cm, 20 cm and 30 cm). The results were described in the figure 18-a, b and c.

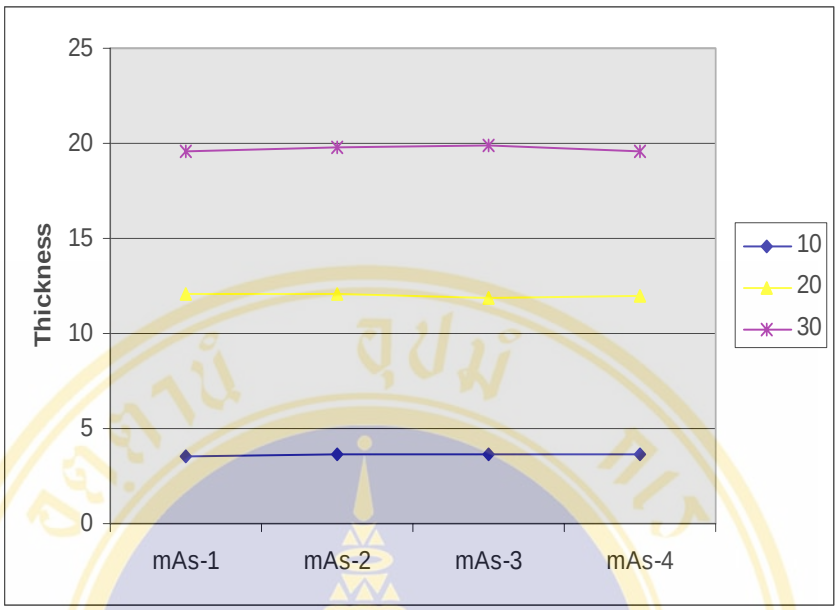


Figure 18-a The mAs consistency with respect to the thickness

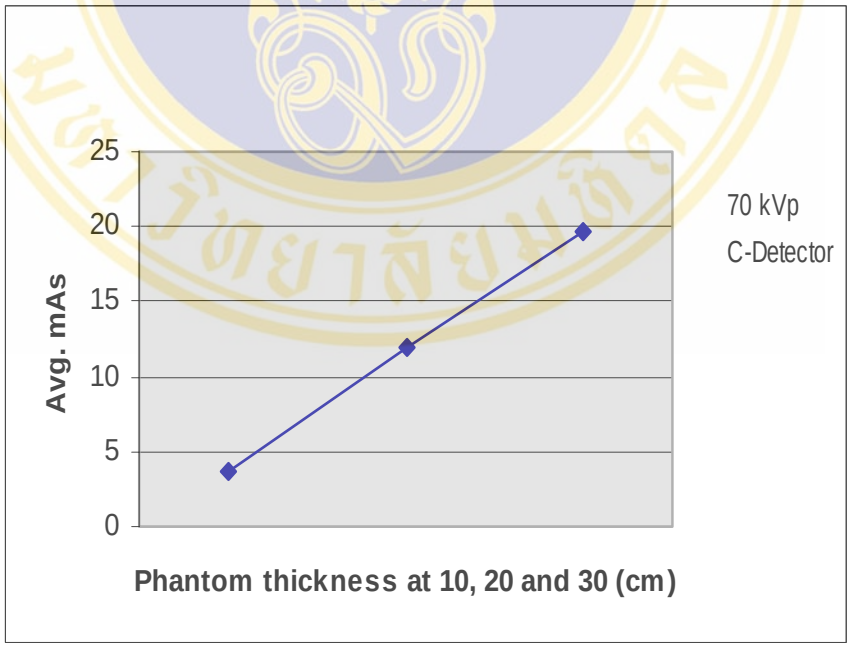


Figure 18-b The thickness Vs Avg. mAs

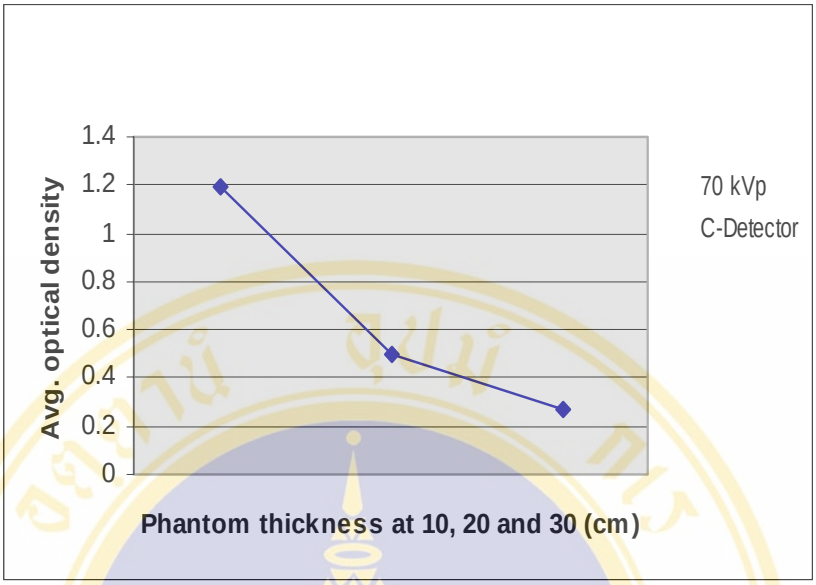


Figure 18-c The thickness Vs Avg. OD

Based on the summarized data in the table 3, daily room condition from visual check, in overall, passed the requirements for the readiness except, one inspected item that was related to the programmed AEC technique.

The overhead tube crane, the table and some supporting facilities such as the window, door, switch etc., were in good condition. On the other hand, data about the exposure techniques in relation with those AEC parameters were not properly set up for all types of radiographic examination. Although some techniques and the parameters have been programmed into the AEC software system to control a view number of radiographic exposures, however, they were not obtained as a result of clinical assessments. Meanwhile, the techniques recommended by the X-ray manufacturer [21] have never been assessed in accordance with the application of the techniques in various types of exam that commonly performed in the services. Due to these matters, using of the Manual Exposure Control (MEC) in daily basis was more frequent than the Automatic Exposure Control (AEC) which in fact there was no a standard techniques or a routine AEC procedure available. This could cause to ineffective use of the AEC system.

Evaluation about the darkroom conditions showed that, the averaged optical density (OD) difference of the tested film was 0.15 (table 4). This level of the fog seemed to be too high when compared to acceptable fog level that recommended OD difference should be equal or less than 0.05 [20]. Basically, darkroom and film processing are final stage of imaging chain in the practice of most conventional radiography. An exposed film taken from such radiographic examination will be processed in the darkroom in order to obtain a radiograph with good quality [31]. Since unprocessed film is sensitive to visible lights and radiation exposures, a "safe" darkroom and processing conditions is needed or otherwise the film will be fogged and the image quality will be degraded [15, 26]. In relation with the test, the wattage bulb of the safelight was appropriated (15-watt) and its physical condition was verified. The problems were attributed to the poor design of the entrance door, the ceiling and the interfaced-lid between the darkroom wall and the two installed processors where the visible light leak from outside of the darkroom still appeared. Since corrective actions have not been performed yet during the period of data collecting, speeding up of the time it takes for film handling was the alternative way that could be safe to the unprocessed film suffering from unnecessary fog density occurred in the darkroom.

In the processor evaluation (see figures 11-14), the monitoring program, theoretically, should be performed daily so that the truth performance of the processor can be assured continuously [15, 32]. However, the intention of this evaluation was also to include observation about non-technical factors that could influence the processor performance along with the processor uses, and therefore, random checks upon its performance were done. It was found that a processor seemed to be prepared for monitoring and experimental purposes in this study. Therefore, the processor has processed a very limited number of the films, for example, those films that were used for QC tests, and may be some incidental films from the service. Thus, it was rarely being employed to process more than 50 films per day. According to Gray JE et.al (1983) stated that, a processor will not operate properly unless at least 25 to 50 14 X 17-inch (35 X 43-cm) films, or equivalent number of square inches of smaller sizes, are processed daily. Consequently, replenishment will be insufficient, the developer will quickly oxidize, and the processed films will become degraded, producing lower

contrast and in turn reducing diagnostic information content. For all of these reasons, the performances of the four-processor parameters were predicted to be potentially inconsistent in the long run of the clinical service over the time. It was essential to perform at least the start up procedure about 2-3 hours to the processor with the intention of keeping its optimal processing condition so that better image quality results would be achieved during the study [31].

Along with the darkroom and processor evaluation, the five different sizes of the X-ray cassette being tested were convict that they were also in a good condition (table 5). It was known that there was no any substantial indication showing an increased light diffusion, which can decrease resolution over all the evaluated films.

For the QC tests of X-ray generator, the results showed that, estimated dimension of the effective focal spot for the large and small sizes were 0.8 mm and 1.5 mm respectively (see table 6). When contrasting these results with the focal spot sizes specified by the X-ray tube manufacturer (0.6 mm for the small and 1 mm for the large sizes), the difference was about 33-50%. It seemed to be recognized that as the NEMA standard allows variation up to 50% of the nominal focal spot sizes which is equal to or lees than 0.8 mm, and therefore, that the measured effective focal spot was still in a proper condition [20, 32].

Meanwhile, consistency of the tube current (mAs) indicated that the computed $\propto$ (0.01) was much lesser than that from the suggested acceptance limit (Acceptance limit $\propto < 0.1$) (see table 7). This showed a very consistent level of the mAs production [20].

For the tube potential (kVp) evaluation, the X-ray machine provided a high accuracy and precision in term of the five different selected levels of kV stations ranged from 50 kV to 100 kV (see table 8). The percentage of accuracy varied about 2.9%-4.3% whilst the precision ranged approximately within 0.07-0.4%. These percentages have complied with the suggested levels that for the accuracy $\leq \pm 5$ %, and the precision ≤ 5 % [20, 33].

However, the exposure time accuracy/precision (see table 9) was partially unsatisfied. The accuracy was 7.25 % that was greater than the suggested level at $\leq$

5%. This showed that the accuracy of the exposure time was not satisfied. For the exposure time precision, meanwhile, still complied with the recommended level that constituted at 2.79 % [20]. It should be noticed, when an exposure time was desired to be a value of 42.9 ms for instance, the selected ms should be set at a value of 40 ms. By this means, the expected exposure could be achieved appropriately.

The last QC test of the X-ray generator was the half value layer (HVL) measurement (see figure 15). This test was to figure out the capability of the X-ray beam in penetrating slabs of Aluminum thickness by which the hardness of the X-ray beam can be verified [15, 20]. As can be seen from the figure 14, a-50 % of the exposure transmission was about 162.5 mR. Thus, the approximate HVL value reached at a value 2.9 mm of aluminum at the tube potential 80 kV. Recommendation that provided by the Food and Drug Administration (FDA) quoted in the NCRP report number 99 stated that the HVL value at 80 kV should be at list 2.3 mm of Aluminum. As the measured HVL value was greater than that of the expected value, the beam quality was appropriate or safe enough in term of dose and image quality effects [15].

For the collimator test, the percentages of the measured X- and Y-axes with respect to the Focus-Film-Distance (FFD) were found at the X = 0.8 % of the FFD and the Y = 1.4 % of the FFD (see table 10). These results met the requirements of the NCRP recommendation. Further, the test about alignment between the tube focus and the center of the X-ray field provided a very convenience result where the image ball appeared in the first inner circle (or $\leq 3^{o}$) which meant, the result definitely complied with the suggested limit [20] (see table 11). In brief the both collimator and beam alignments were satisfied.

In the cases of AEC QC testing performances, the tests verified the ability of the circuits to adjust exposure appropriately for certain standard object test. Basic principle of automatic exposure termination devices includes sensor chamber or phototiming and limiting circuits which terminate the exposure when a preset quantity of radiation has been detected [3, 34]. As functioning well, these controls will assure consistent radiographic results over a wide range of technique and patient variables.

When performed such tests, they essentially required a patient equivalent phantom (PEP) that has made up of slabs of lucyte/acrylic material in which each was

about 25x20x1 cm in size. This typical PEP was removable, quiet light in weight and relatively easy to carry. Thus, its thickness was possible to adjust to 10 cm, 20 cm and 30 cm by which equivalent to 14 cm, 28 cm, 42 cm of the human tissues respectively (1 cm lucyte/acrylic = 1.4 cm human tissue) [20]. Using this kind of PEP was to simulate the human tissue attenuation when performing such measurements particularly in the evaluation of the AEC system [8, 15, 20].

With a 20-cm thickness of the PEP at tube potential 70 kVp, and using of the central sensor, the film density (OD) appeared to increase consistently against the density settings in each step by a value of about 0.2 (see figure 16). These results complied with what was suggested by Papp Jeffrey (1998). He stated that the OD's readings from the center of each of the processed films when checking density control function of the AEC system should consistently increase by a value of 0.2 to 0.25, from the lowest to the highest density settings (-2 to +2). From this point, it was confirmed that, a consistent increment in the film density between each step of the density control settings was satisfied.

With the same PEP, consistency of sensor chamber was examined, using similar techniques as mentioned. Yet, the only normal (N) density setting was employed when checking consistency of each of the three sensor chambers or detectors; the right (R), the Central (C), and the left (L). In addition to this test performance, the use of combined mode of detector selections (R-C; R-L; R-C-L and C-L) was also inspected by which all of the results were analyzed in the basis of the mAs readings that shown on the console panel.

Based upon the data presented in the table 12 and 13, either the individual detector selection or the combined detectors settings have performed their reliability in terms of the mAs values that obtained from five times of the data readings. In the test performance of the individual detector, standard deviation (SD) of the three detectors was not much different that was between 0.18-0.19. The SD ranged from 0.31 to 0.52 was obtained due to the use of a combined mode of two different detectors (R-C; R-L and C-L) where a slight SD difference shown among them. However, when compared these results with the result contributed by means of employing the three sensor chambers simultaneously, it was identified that, they

served an optimum consistency of the sensor chambers with the SD at 0.05. For these reasons, the use of the R-C-L combination implied to produce as much more consistent OD in comparing with the other three modes of detector selection.

It was interesting to look at the chamber consistency from different point of view such as that was depicted in the two figures (17-a and -b). Each individual detector or even more the combined modes of detector selection characteristically worked out with different amount of mAs products. There were about 20-30 % differences in the mAs readings between the individual detector as well as between the combined detectors (see figure 17-a and-b). The C and L detectors contributed to a much higher percentage of the mAs product than that was the R detector (figure 17-a). Therefore, since any of that two detectors combined with the others, the readout mAs values seemed to appear increase significantly (see figure 17-b).

In related to the above tests, again, consistency of the detector(s) was confirmed through a simple test that basically implemented similar method in which has made use of the measured OD's data as presented in the table 14. By contrasting OD data between each of the detector or modes, it has been noticed that the averaged OD difference was about ± 0.2. This also reviled that any mode of the detector uses was still working consistently [32]. In detail, the use of the L and C detectors or any combination with these two detectors, however, contributed to high-density results.

Comparable methods and results have been discussed so far in accordance with the sensor chamber or detector consistency. It was important to keep in mind that although the sensor chambers or detector(s) was in a reliable performance, each mode of detector selections having had their specific characteristics by means of the mAs or OD results. For these reasons, educated judgments should be made to exactly select suitable detector(s) when employ AEC in radiography.

The last QC test of the AEC system was the consistency of exposure with varying part thickness. A three different thickness of the PEP (10 cm, 20 cm and 30) was employed in the QC test to know constancy of the system dealing with various part of object thickness. The only central detector was activated and the normal density setting (N) was chosen when performing the test. Estimation about consistency of the system was indirectly predicted using the two methods of data

interpretation (the mAs readings and the measured OD). The subsequent figures (from figure 18-a to-c) portrayed the results that accounted for the performances of the system.

Consistency of the exposure with varying part thickness can be seen in the figure 18-a. It was obtained based upon a-4 times of the mAs readings with different part thickness which shown its stability.

The averaged mAs readings rose with increased phantom thickness from 10 cm to 30 cm (see figure 18-b). Inversely, the averaged OD decreased gradually with increased phantom thickness. (see figure 18-c). Theoretically, the system should be able to adjust the exposure time and maintain OD with any changes in part thickness [32]. Yet, the results accordingly came out as that was presented. There were three possible reasons that would be an explanation due to these matters. Firstly, scatters in a thickest phantom tended to increase when its up side surface got closer to the X-ray tube while the field sized and focus-film-distance (FFD) remained steady. This means that, the field size was not properly cover all part of a-30 cm volumetric phantom thickness when taking a radiograph. The scatters coming from the edge parts of the phantom gave raise an effect to the remnant radiation that sampled by the chamber, which in turn reduced film density. Secondly, the mA variations; in fact, existed when the phantom thickness changed from 10 cm to 30 cm. These mAs variations were not possible to be controlled, since the AEC system automatically justified the exposure and directly responded to those unexpected scatters incurred in the thickest phantom (30 cm). Therefore, the mAs readings appeared to increase despite the OD's were shown to decrease. Thirdly, the use of the permanent kVp (70 kV) for a slight phantom results in an increased OD, since the scatters was limited with a certain collimation size. However, this fixed kVp technique was not capable of maintaining the film density as the Compton effects dominate in the thickest phantom while the field size and the FFD were still be the same. As a result, OD decreased while mAs readings increased with respect to the phantom thicknesses. Although the patient equivalent phantom that has been used for this typical measurement was not suitable enough by means of the QC tests for AEC system, however, the consistency of the

exposure with varying thickness remained satisfactory considering the results of the previous test (see figure 18-a).

In brief, implication of the QC program, including series of the AEC tests were strongly related to the aims to ensure the actual reliability of the X-ray facilities in the view of producing good quality of radiographs whereas the radiation exposures incurred could be justified. Comprehensive information about the AEC system performances was specifically considered. Care must be made when deciding what detector(s) should be chosen for which specific type of radiographic exams, since they acted uniquely.

5.2 Stage I: Study of image quality in a human-mimic phantom

This study provided two distinguished results. The first result was the routine AEC procedures normalized to the phantom imaging and the second result was the revised clinical image quality criteria as well as technical image quality set up for the phantom radiographs. An additional list about criteria pitfalls shown in phantom radiographs was also defined. These two results intimately related to each other and essentially prepared for the radiographic experiments in the next stage of the study (.the stage II).

As can be seen in the table 15, 68 sets of the routine AEC procedures have decided as the procedures that can be applied for the phantom radiography. The procedures consisted of 17 views/projections from the 9 different region organs of interest (ROI) of the phantom object. A sample of the technical AEC parameters associated with the routine procedures can be inspected in the appendix D of this report.

Table 15 The routine AEC procedures for the phantom radiography by the ROI and the Views/projections

ROI	Views/ Projections	Number of views/projections	Number of the AEC procedures
The skull	AP	3	3
	Lateral	3	3

Table 15 (Continued)

The chest, lung & heart	AP	7	7
	Lateral	4	4
The thoracic spine	AP	4	4
	Lateral	3	3
Lumbar spine	AP	4	4
	Lateral	4	4
The pelvis	AP	4	4
The knee joint	AP	4	4
	Lateral	4	4
The tibia and fibula bones	AP	4	4
	Lateral	4	4
The foot	PA	4	4
	Oblique	4	4
The hand	PA	4	4
	Oblique	4	4
Total		**68**	**68**

Meanwhile, the clinical quality criteria for 17 views/projections were revised and formulated as presented in the table 16. In addition to that, an additional list that contained information about clinical quality discrepancy in the phantom imaging was also defined as was highlighted in the table 17.

Table 16 The clinical quality criteria settings for phantom radiographs, according to the types of radiographs

The skull radiograph

1.	**Antero-posterior view**
a)	Symmetric projection of the skull, particularly cranial vault, orbits and petrous bones
b)	The apex of the petrous temporal bone is projected into the center of orbit
c)	The outer and inner lamina of the cranial vault
d)	The frontal and ethmoidal sinuses

Table 16 (Continued)

2.	**Right lateral view**
a)	The outer and inner lamina of the cranial vault
b)	The apex of the petrous temporal bone
c)	The vascular channels, the vertex of the skull and the trabecular structure of the cranium
d)	Superimposition of the mandibular angles and ascending rami
The chest-lung and heart radiograph	
3.	**Antero-posterior view**
a)	Symmetric projection of the thorax as shown by central position of the spinous process between the medial ends of the clavicles
b)	The whole cage above the diaphragm
c)	The vascular pattern in the whole lungs particularly the peripheral vessels
d)	The trachea and proximal bronchi, the border of the heart and aorta
e)	The diaphragm and lateral costo-phrenic angles
f)	Visualization of the retro cardia lung and the mediastinum
4.	**Left lateral view**
a)	The apex of lungs should be seen clear of the arm/shoulder shadows
b)	Superimposition of the posterior lung borders
c)	The costo-phrenic angles
d)	The posterior border of the heart, the aorta, mediastinum, diaphragm, sternum and thoracic spine
The thoracic spine	
5.	**Antero-posterior view**
a)	Demonstration all of the twelve vertebrae
b)	The X-ray beam is collimated to the thoracic spine
c)	The Vertebral alignment
6.	**Left lateral view**
a)	The vertebrae clearly seen through rib and lung shadows
b)	No patient rotation indicated by the ribs superimposed posteriorly
c)	The vertebral alignment

Table 16 (Continued)

The lumbar spine
7. Antero-posterior view
a) The upper and lower plate surfaces in the centered beam area
b) The spinous and transverse process
c) The cortex and trabecular structures
d) The sacro-iliac joints
e) The vertebral alignment
8. Left lateral view
a) As a single line, of the upper and lower-plate surfaces with resultant visualization of the intervertebral spaces
b) Totally superimposition of the posterior vertebral edges
c) The spinous processes
d) The cortex and trabecular structures
e) The central spinal canals
f) The intervertebral joints particularly the facet joints
g) The vertebral alignment
The pelvic bones
9. Antero-posterior view
a) The pubic and ischial rami
b) The sacrum and its intervertebral foramina
c) The sacro-iliac joints
d) The neck of the femora which should not be distorted by shortening or rotation
e) The spongiosa and corticalis, and of the trochanters
f) Both acetabuli
The knee joint
10. Antero-posterior view
a) The femorotibial joint space is shown , including the medial and lateral compartments of the distal femur

Table 16 (Continued)

b) The knee is seen fully extended
c) The interspaces should be demonstrate equally in width on both sides
d) The patella completely superimposed on the femur
e) No rotation of the femur and tibia
f) Soft tissue around the knee joint
g) Bonny detail surrounding the patella on the distal femur
11. Left lateral view
a) The joint space between femoral condyles and tibia
b) The patella is shown in a lateral profile
a) A slight superimposition of the fibular head and tibia
b) The flexion of the knee is seen approximately 20-30 degrees
c) All soft tissue around the knee joint
d) The patello-femoral space
e) Proper density on the femoral condyles
The tibia and fibula bones
12. Antero-posterior view
a) The ankle an knee joints without rotation
b) The proximal and distal articulations of tibia and fibula with moderately overlapping
c) Trabecular detail and soft tissue for the entire leg
13. Left lateral view
a) The distal fibula lying over the posterior half of the tibia
b) A Slight overlap of the tibia on the proximal fibular head
c) No rotation of the ankle and knee joints
d) No superimposition of femoral condyles due to the divergence of the beam
e) A moderate separation of the tibial and fibular bodies (shafts) except at their articular ends
f) Trabecular detail and soft tissue

Table 16 (Continued)

The foot
14. Antero-posterior view
a) An equal amount of space between the adjacent mid-shaft of the second through fourth metatarsals
b) Overlapped of the second through fifth metatarsal bases
c) The joint spaces
d) The bonny contour and trabecualation
e) The soft tissues
15. Left lateral view
a) The third through fifth tarsal bases free of superimposition
b) The lateral tarsals are shown with less superimposition than in the AP projection
c) The lateral tarsometatarsal and intertarsal joints
d) The tuberosity of the fifth metatarsal
e) The bases of the first and second metatarsals
f) The space between the shaft of the second through fifth metatarsal is seen in equidistance
g) Sufficient density of the phalanges, metatarsals, and tarsals
h) The soft tissues
The hand
16. Postero-anterior view
a) The hand with no rotation, which is in true PA or AP position
b) Slightly separated digits with no soft tissue overlap
c) All anatomy distal to the radius and ulna, including the joints, bonny alignments, trabecular patterns and the soft tissue contour
17. Oblique view
a) Minimal overlap of the third-fourth and fouth-fifth metacarpal shafts
b) Slight overlap of the metacarpal bases and heads
c) Separation of the second and third metacarpals
d) The interphalangeal and metacarpophalangeal joint are seen openly
e) All anatomy distal to the radius and ulna
f) The soft tissue contour and bonny trabeculation

Table 17 An additional list of the clinical criteria discrepancy in the phantom radiographs

ROI	Views	Remarks
Skull	Right-lateral	• The sella floor is poorly shaped and not clearly seen
Chest-lung & heart	Antero-posterior (supine)	• No full inspiration • The lung area is still obscured by the medial border of the scapulae • There is no air filling in the trachea • There is angiogram of the heart • The lungs area is seen to be pneumo thorax
	Left-lateral	• No full inspiration • No air filling in trachea • The apex lung can't be seen free of the shoulder shadows • There is angiogram of the heart
Thoracic spine	Antero-posterior	• A slight rotation deviation appears between the thoracic spine 8 and10
Lumbar spine	Antero-posterior	• Since the lumbar spine is built in apart of the pelvis, which is asymmetric, the sacro iliac joints are seen partially • The psoas shadows can't possibly be seen in this phantom model
Pelvis	Antero-posterior	• The phantom model presented asymmetric design of pelvic bones • There is pubic separation in this phantom model
Knee joint	Right antero-posterior Right lateral flexi	• The patella is too obvious seen than normal anatomy • The patella is too much superimposed to anterior border of the femoral condyle

To perform a radiographic experiment, in fact, needs special techniques or procedures that will involve many technical AEC parameters so that the implementation of the procedures can give considerable results as expected. Based on this reason, the 68 verified routine AEC procedures were decided to be basic

techniques applicable for the radiographic examinations of an anthropomorphic phantom and were used in term of an experimental radiography that performed in the next step of study

It was clarified from the 68 routine procedures that, the use of the both density settings from the step of -3 up to +3 and kVp selections between 52 kVp and 145 kVp sufficiently provided optimum clinical image quality results but they must be specific for each views/projections. Generally, the density should be set at the N position for a wide range of radiographic exposures if the AEC system has been calibrated [35]. However, a slight variation can be accepted in the density settings if the useful film density range of most radiographs tends to be fairly common [3]. In case of the kVp selections, tube voltages for the skull, the chest and the thoracic spine examinations that recommended by the manufacturer were not applicable since the poor film contrast was obtained. Using tube voltages ranged from 68-145 kVp for those examinations was appropriate in producing better radiographic image quality.

Looking back to the results of the clinical quality criteria, the 17 sets of clinical quality criteria were diagnostically defined as critical aspects with respect to the phantom radiographs (see table 16). For some cases, number of clinical checkpoints had to be justified or reduced since they appeared different from the usual anatomical features in the normal radiographs. In the line with the results, the checklists prepared for further clinical quality evaluation experienced some modification following those checkpoints as preferred by the radiologist. By this means that, the tool or the checklist excluded clinical statements associated with unwanted features in phantom images that were not agree with the normal clinical requirements. Thus, the only important clinical aspects were critically restated. In a study about evaluation of the European image quality criteria for chest examination conducted by Vano E et.al (1995) agreed that, modifying or minimizing list of image quality criteria, based upon a simple and essential landmarks should be formulated in daily radiological work. Referred to this view, it was reasonable to reduce unwanted clinical list of the phantom images that was accounted for optimizing clinical aspect of evaluation in this study.

Therefore, as described in the table 17, several justified items about improperly clinical quality criteria were also clarified, based on the radiologist's suggestions. That additional list was documented and attached altogether with the questionnaire, which was used by the technologists when performing technical image quality evaluation in further study. Using such list as one of additional references for technical image quality evaluation was important to the technologists to avoid from miss interpretation about slight poor anatomical features due to the phantom design on the reviewed radiographs.

As a final point, all routine AEC procedures normalized to the phantom imaging and the clinical quality setting were well prepared for the experimental purposes. The necessity of preparing such additional list to assist the technologists in technical quality evaluation was done while it directly justified the clinical quality drawback because of the phantom design-related problems. The image quality evaluators (technologists) would become aware of the phantom problems whenever performing evaluation by means of the questionnaires. Thereby, the evaluators should accept some exceptions about these matters.

5.3 Stage II: Study of the AEC factors that affect on image quality of radiographs

It has been recognized that, there were 68 radiographs in routine AEC procedures that allowed undertaking technical evaluation. Based upon the technical quality analysis, 65 radiographs were judged by the 20 image evaluators (technologists) that they had good/adequate quality with the mean TQCI value at 1.33. Meanwhile, 3 radiographs were identified with poor quality as its mean TQCI value was 0.88. Since then, only the 65 TQCI values were still used as a basic data set representing technical quality achievements from the radiographs that were produced by means of routine AEC procedures (the TQCI values before a variation of the AEC factors). The entire data about TQCI values can be seen in the table 18.

Table 18 TQCI data of 68 radiographs produced by means of the routine AEC Procedures (before a variation of the AEC factors)

Number of radiographs	TQCI	Number of radiographs	TQCI
1	1.36	35	1.36
2	1.4	36	1.44
3	1.37	37	1.44
4	1.44	38	1.36
5	1.44	39	1.44
6	1.34	40	1.33
7	1.40	41	1.36
8	1.46	42	1.44
9	1.31	43	1.36
10	1.15	44	1.36
11	1.21	45	1.40
12	1.37	46	1.40
13	1.26	47	1.32
14	1.33	48	1.32
15	1.31	49	1.40
16	1.32	50	1.40
17	1.36	51	1.38
18	1.28	52	1.38
19	1.37	53	1.36
20	1.37	54	1.44
21	1.36	55	1.40
22	1.37	56	1.32
23	1.22	57	0.89
24	1.30	58	0.89
25	1.21	59	1.21
26	1.33	60	1.34
27	0.94	61	1.35
28	1.42	62	1.36
29	1.25	63	1.22
30	1.26	64	1.22
31	1.36	65	1.40
32	1.44	66	1.40
33	1.26	67	1.32
34	1.44	68	1.31
		Mean	1.33

5.3.1 Assessment of the effect of detector factors with respect to image quality criteria

Based on clinical and technical verification, all the 23 radiographs including their AEC procedures with varying detector factor have been recognized to fulfill both clinical and technical requirements with the CQCI and TQCI greater or equal to 1. The mean value and standard deviation of the TQCI were 1.4 and 0.06 respectively.

The related paired data about that 23 TQCI values were purposively collected from the basic data source presented in the table 18. As a result, the effect of detector factor can be assessed according to TQCI data comparison between before and after varying of detector factor as shown in the table 19.

Table 19 The TQCI comparisons between before and after detector factor variations

AEC Procedures	Before treatments			After treatments		
	Detector	TQCI	Visibility of 7 quality criteria (Q-1 to Q-7)	Detector	TQCI	Visibility of 7 quality criteria (Q-1 to Q-7)
Chest lung & heart-AP	R-L	1.37	G-G-G-A-G-G-G	C	1.28	G-G-G-A-G-G-G
		1.37	G-G-G-A-G-G-G	R-C	1.48	G-G-G-G-G-G-G
		1.37	G-G-G-A-G-G-G	C-L	1.48	G-G-G-G-G-G-G
		1.37	G-G-G-A-G-G-G	R-C-L	1.46	G-G-G-G-G-G-G
Chest lung & heart-Lat	R-L	1.33	G-G-G-A-G-G-G	C	1.37	G-G-G-G-G-G-G
		1.33	G-G-G-A-G-G-G	R-C	1.33	G-G-G-G-G-G-G
		1.33	G-G-G-A-G-G-G	C-L	1.38	G-G-G-G-G-G-G
		1.33	G-G-G-A-G-G-G	R-C-L	1.39	G-G-G-A-G-G-G
Knee joint-Lat	C	1.38	G-G-G-A-G-G-G	R-C	1.50	G-G-G-G-G-G-G
Lumbar spine-AP	C	1.36	G-G-G-A-G-G-G	R-L	1.47	G-G-G-G-G-G-G
		1.36	G-G-G-A-G-G-G	C-L	1.40	G-G-G-A-G-G-G
		1.36	G-G-G-A-G-G-G	R-C-L	1.47	G-G-G-G-G-G-G
Lumbar spine-Lat	C	1.44	G-G-G-A-G-G-G	R-L	1.37	G-G-G-A-G-G-G
		1.44	G-G-G-A-G-G-G	R-C-L	1.45	G-G-G-G-G-G-G
Pelvis-AP	R-L	1.36	G-G-G-G-G-G-G	C	1.39	G-G-G-A-G-G-G
		1.36	G-G-G-G-G-G-G	R-C	1.39	G-G-G-A-G-G-G
		1.36	G-G-G-G-G-G-G	C-L	1.47	G-G-G-G-G-G-G
		1.36	G-G-G-G-G-G-G	R-C-L	1.39	G-G-G-A-G-G-G

Table 19 (Continued)

Thoracic spine-AP	C	1.36	G-G-G-A-G-G-G	R-L	1.25	G-G-G-A-A-A-A
		1.36	G-G-G-A-G-G-G	R-C	1.47	G-G-G-G-G-G-G
		1.36	G-G-G-A-G-G-G	C-L	1.36	G-G-G-A-G-G-G
		1.36	G-G-G-A-G-G-G	R-C-L	1.44	G-G-G-G-G-G-G
Thoracic spine-Lat	C	1.36	G-G-G-A-G-G-G	C-L	1.29	G-G-G-A-A-G-G
Mean		1.36			1.4	

Legends:

A = Adequate; G = Good
C = central detector
R = right detector
L = left detector

In addition, determining the influence of detector factor to image quality was also analyzed according to the percentages of the 20 technologists' TQCI in combination with their final judgments upon the 23 evaluated radiographs (460 repeated observations) whether or not those radiographs can be used for clinical diagnoses. The table 20 showed the results of analysis.

Table 20 The percentages of the observed TQCI values of 23 radiographs produced by means of varying detector factor with respect to technologists' opinions

The TQCI category	Descriptions	Number of observations	Percent
0	TQCI-failed, the radiograph can't be used for diagnosis	1	0.2
1	TQCI-failed, the radiograph can be used for diagnosis	1	0.2
2	TQCI-passed, the radiograph can't be used for diagnosis	6	1.3
3	TQCI-passed, the radiograph can be used for diagnosis	452	98.3
Total		**460**	**100**

As described in the table 19, all the technical quality indexes principally achieved the requirement (TQCI values ≥ 1) in the both before and after a variation of the detector factor with the mean values at 1.36 and 1.40 respectively. For some procedures in the after treatments, the TQCI had the perfect levels as like in the knee joint-lateral view with the R-C detector mode (1.5), and the both chest-lateral views with the R-C or C-L detector mode (1.48). If compared the TQCI data that included the 7 quality criteria fulfillments in before and after detector manipulations, there was a slight difference in the mean value of TQCI. The difference mostly occurred at the quality criteria visibility number 4 (Q-4 = film optical density). Meanwhile, a modest variation about the TQCI values or technical quality visibilities was shown more in the after treatment rather than in before treatments. The effect of inaccurate use of the sensor chamber seemed to be obvious at the thoracic spine-AP view whichever the C detector was replaced with the R-L detectors in that those four quality criteria visibilities (from Q-4 to Q-7) changed tremendously. This specifically pointed out that using the R-L mode was inappropriate to achieve such good technical quality criteria for the thoracic spine image instead of the C mode. Similar event was also recognized in term of the thoracic spine-Lat view. For these reasons, it was believed that the modes of detector selection should be chosen accurately depending on a particular organ being examined. Whereby, the effect of detector factor still has a potency to vary the final formation of image quality.

Furthermore, when looking at particular figures as shown in the table 20, a more detail information associated with effect of the detector factor justified those previous figures. Owing to the information contained in the table, there were 452 comments from 460 repeated observations that agreed the 23 reviewed radiographs having at least good or adequate technical aspects, which contributed to 98.3% of repeated observations in the category 3. In contrast, there were 8 observations (1.7 % of repeated observations) in the categories 0, 1 and 2 that reflected an ambivalent judgment among the observers. This can be an indication reflecting tendentious decisions to reject technical quality fulfilled by some radiographs due to such implementations of detector selection when used AEC. Regarding to the tendency, it

can be said that taking radiographs by means of the AEC operation with various modes of detector selection may have an effect on to the image quality of radiographs.

What interesting from the above analyses was that, the evaluated radiographs after treatment may be good enough in term of their quality. But, for same reasons the image evaluators felt that, several items of technical aspects were not acceptable. For example, the radiographs appear too dark or too light in the chest-AP with the C detector and the thoracic spine-AP with the R-L detectors respectively. These two examples recalled evidences describing about the necessity of selecting accurate detector for specific examination that should be obeyed whenever taking radiograph with the AEC system [3, 5]. For this reason, the effect of detector factor onto image quality results seemed to be obvious although this event was rarely occurred in term of the detector factor assessment.

The result obtained from the paired-t test shown that, the p-value was 0.02 (two-tiles). This caused to reject the H_o with 22 degree of freedom (df) and $\alpha = 0.05$. Therefore, statistical decision denoted that the mean TQCI value between before and after varying modes of the detector selection was not the same. Since rejecting the null hypothesis was true, it was concluded that the change of detector selections, which was different from the routine AEC procedures, has an effect to image quality of the radiographs.

There was a contradictory result where in one hand, the affect of detector factor on image quality seemed to be irrelevant since the entire radiographs being evaluated provided good/adequate image quality while in other hand, that effect of the factor was significant by means of statistical interpretations. Using such modes of detector or sensor chamber variation may be possible to apply in a wide range of different ROI without giving much effect onto image quality particularly when performing radiography with the typical table AEC system. This tends to unparallel with the basic concepts about the importance of selecting appropriate detector(s) when employ AEC in radiography. Theoretically, choosing of the sensor chamber in the AEC system, however, should be specific to the anatomical and pathological condition of the targeted organ under examination [2, 3]. Using both lateral detectors for the normal chest-lung examination, for instance, would give much better lung-soft

tissue patterns than selecting the central detector alone. In addition to that, the central detector should be the best choice for imaging the osseous structures of the lumbar spine rather than the other combined modes of detector selection [3, 31]. A study conducted by Ismailos E et.al (1996), they employed the R-L detectors for the chest-PA and the C detector for the chest-lat in a wide range of cardiological and cardiosurgery patients. This means that, they consider about using typical mode of detector selections, which are specific to both the chest views and the pathological condition of the patients. Due to these matters, there are two possibilities that may clarify why the contradictory results are expressed in this step of assessment.

Firstly, detector arrangements and shapes in the table AEC system may be designed in such away to tolerate problems in accordance with unknowledgeable technologists who decide to choose of which detector(s) should accurately be used for a broaden common radiographic examination. The shapes, sizes and the positions of the three sensor chambers may be convenience to sufficiently serve various views or projections with fewer considerations about the types of anatomical topography in the human-mimic phantom. Distances between the central cell and the two lateral cells are relatively closer to each other (approximately 2 cm) while typically the “L”-like shape of the both lateral cells in combination with the central detector seemed to improve detectors affectivity in sampling radiation whenever such inaccurate detector selection may happen. Whereby, this could be optimizing the functions of the AEC system and reducing the possibility of human errors if untrained technologists operated the system.

Secondly, the evaluators maybe not capable of differentiating such changes in image quality results due to the application of varying modes of detector selection. This is reasonable since the TQCI values before and after treatment has been acknowledged with a slight difference at the value of 0.04. Thus, it is implied that, to recognize a very small difference in technical quality visibility during performing image evaluation seems to be quite hard and tends to be bias when inconsistent condition among the evaluators who must interpret about hundreds of radiograph within a relative limit time frame (± 2 weeks) may be occurred. Therefore, the

majority of evaluators' observations appear to be no technical quality differentiations from one to the other evaluated radiographs.

As the statistical analysis included sufficient data about the TQCI values that also distributed normally, nevertheless, a variation of the detector selections was believed had a significant effect onto the image quality of radiographs in particular when the quality criteria were predicted from typical object test of a human-mimic phantom.

5.3.2 Assessment of the effect of object position factors with respect to image quality criteria

In the case of AEC procedures with a variation of the object positioning there were 56 radiographs fulfilled CQCI requirements and underwent technical quality evaluation. Results from technical quality clarification showed that, 53 radiographs were successful to achieve TQCI requirement with the mean and standard deviation at 1.25 and 0.08 respectively. Meanwhile, 3 radiographs were found with poor technical quality result because their TQCI values were less than 1.

Also, analyses about the TQCI values were performed between before and after a variation of object position factor. Yet, the paired data sets for this analysis were selectively limited to the 15 radiographs/procedures that had been identified with good or adequate technical quality only (TQCI values ≥ 1). The following table showed a comparison about all paired data sets.

Table 21 The TQCI comparison between before and after object position factor variations

AEC Procedures	Before treatments			After treatments		
	Object position	TQCI	Visibility of 7 quality criteria (Q-1 to Q-7)	Object position	TQCI	Visibility of 7 quality criteria (Q-1 to Q-7)
Chest lung & heart-AP	Std-3	1.37	G-G-G-A-G-G-G	1 cm-rl	1.48	G-G-G-G-G-G-G
Foot-PA	Std-16	1.36	G-G-G-A-G-G-G	2 cm-sp	1.39	G-G-G-G-G-G-G
Foot-Oblique	Std-17	1.40	G-G-G-G-G-G-G	1.5-cm ll	1.44	G-G-G-G-G-G-G
Hand-PA	Std-7	1.42	G-G-G-G-G-G-G	1.5 cm-ll	1.29	G-G-G-A-G-G-G

Table 21 (Continued)

Hand-Oblique	Std-8	1.44	G-G-G-G-G-G-G	1.5 cm-if	1.38	G-G-G-G-G-G-G
Knee joint-AP	Std-12	1.32	G-G-G-A-G-G-G	4 cm-sp	1.33	G-G-G-G-G-G-G
Knee joint-Lat	Std-13	1.38	G-G-G-A-G-G-G	4 cm-if	1.33	G-G-G-G-G-G-G
Lumbar spine-Lat	Std-10	1.44	G-G-G-A-G-G-G	2 cm-ll	1.36	G-G-G-G-G-G-G
Pelvis-AP	Std-11	1.36	G-G-G-G-G-G-G	2 cm-sp	1.33	G-G-G-A-G-G-G
Skull-AP	Std-1	1.37	G-G-G-A-G-G-G	1 cm-rl	1.32	G-G-G-G-G-G-G
Skull-Lat	Std-2	1.44	G-G-G-G-G-G-G	1 cm-ll	1.35	G-G-G-G-G-G-G
Thoracic spine-AP	Std-3	1.36	G-G-G-A-G-G-G	3 cm-rl	1.30	G-G-G-G-G-G-G
Thoracic spine-Lat	Std-4	1.36	G-G-G-A-G-G-G	3 cm-rl	1.27	G-G-G-G-G-G-G
Tibia & fibula-AP	Std-14	1.40	G-G-G-G-G-G-G	1.5 cm-rl	1.44	G-G-G-G-G-G-G
Tibia & fibula-Lat	Std-15	1.21	G-G-G-A-A-A-A	2 cm-rl	1.42	G-G-G-G-G-G-G
Mean		1.37			1.36	

Legend:

Std = standard object positioning A = Adequate G = Good
rl = Object shifts to the right lateral of the selected detector(s)
ll = Object shifts to the left lateral of the selected detector(s)
sp = Object shifts superiorly from the selected detector(s)
if = Object shifts inferiorly from the selected detector(s)

A comparable approach in data analyses was performed to dig a more detail information about the effect of object position factor toward image quality of radiographs. However, the analysis included all 56 TQCI data from the radiographs, which was technically accepted. It basically interpreted through the 20 technologists' TQCI values including their concluding statements upon the entire 56 evaluated radiographs (1120 repeated observations). The results as can be seen in the table 22.

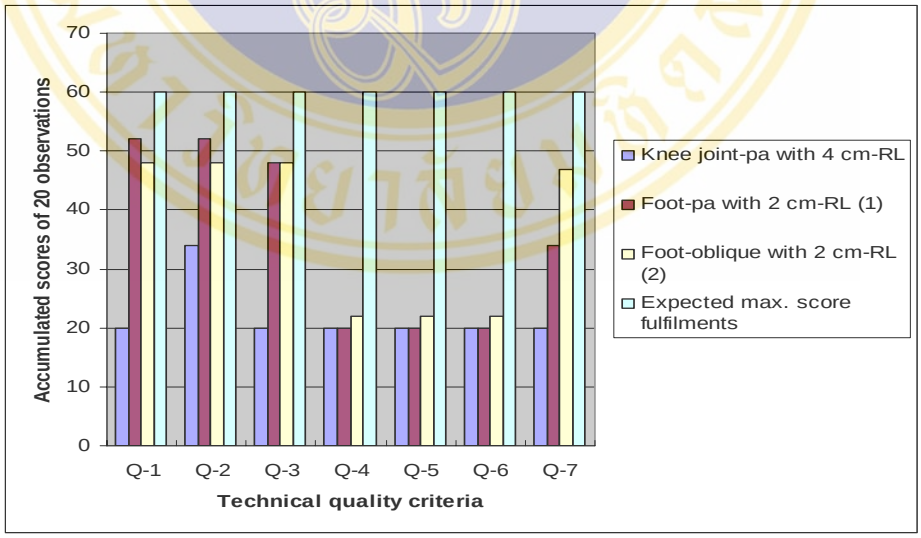
Table 22 The percentages of the observed TQCI values of 56 radiographs produced by means of varying object position factor with respect to technologists' opinions

The TQCI category	Descriptions	Number of observations	Percent
0	TQCI-failed, the radiograph can't be used for diagnosis	124	11.1

Table 22 (Continued)

1	TQCI-failed, the radiograph can be used for diagnosis	19	1.7
2	TQCI-passed, the radiograph can't be used for diagnosis	102	9.1
3	TQCI-passed, the radiograph can be used for diagnosis	875	78.1
Total		**1120**	**100**

Furthermore, the radiographs with inadequate technical quality were clarified as depicted in the figure 19. They accounted for the three radiographs; the knee joint-AP, foot-pa and oblique views that were produced by means of shifting object position to the right lateral of the selected detector with various certain distances from 2 cm up to 4 cm.



Legends:

- 4 cm-RL = the object position shifted 4 cm to the right-lateral from the routine selected detector
- 2 cm-RL = the object position shifted 4 cm to the right-lateral from the routine selected detector

Figure 19 The overall scores of the three rejected radiographs in object position factor by means of technical judgments

As shown in the table 21, the mean TQCI between before and after a variation of object position factor was not much different (1.37 and 1.36 respectively). It also showed that, a miss object positioning within 1-2 cm away from the selected detector(s) may not affect radiographic quality. Specifically, when roughly examined the pattern of the technical quality criteria visibility in before and after, a trivial difference was mostly expressed in the visibility of the quality criteria 4 (Q-4 = film optical density). The film densities in the after treatment improved to be good. A significant increase in the technical quality score (TQCI) and its visibility was seen at the tibia and fibula-Lat view when the object positioning was shifted about two centimeters to the right lateral of the selected detector, which was different from the standard positioning-15. This indicated the tibia and fibula bones were properly oriented just above the selected detector (the C detector) that in fact increased the TQCI as well as technical quality visibility. Nevertheless, since the mean difference from the two paired data sets was very small, this constituted at 0.01, and therefore, such variations in the object positioning that different from those standard procedures could be irrelevant in term of giving a noticeable affect on image quality.

Looking at the results presented in table 22, approximately 78 % of the observations were fully satisfied that the reviewed radiographs had a good or an adequate technical quality result, and the radiographs can absolutely be used for clinical diagnoses. Meanwhile, about 11% of the observations expressed that some of the evaluated radiographs were poor and those radiographs cannot be used for diagnoses. This clearly implied that, the image evaluators (the 20 technologists) unanimously accepted most technical image quality of the reviewed radiographs even though they were taken with some variations in term of the object positioning.

The null hypothesis of this assessment was also tested whether to know the mean differences in the TQCI values between before and after experiments as a consequence of the object position variations [H_o: $\mu_{TQCI\text{-}rp} = \mu_{TQCI\text{-}p}$]. In the analysis, the 15 paired data sets about the TQCI values as presented in the table 12 were used. With α 0.05 and the degree of freedom at 14, it was found that the effect was not significance as the p-value was 0.14 (two-tails). This showed the mean TQCI values between before and after the experiment were not different. Therefore, it can be said

that, the statistical interpretation affirmed the preliminary predictions about the effect of positioning on radiographic quality as discussed in the early analyses.

For the radiographs that were technically rejected by the image evaluator (see figure 19), it was already known that, the three radiographs had been produced by means of employing routine detector modes (the C detector). Due to inaccurate object positioning or missed position about 2 cm – 4 cm to the right lateral side of the C detector, this absolutely contributed to individual accumulated scores that less than their maximum technical quality criteria fulfillments at a prevalent value of 60. In other words, those three radiographs had insufficient technical quality in all 7 quality criteria aspects that included the object position accuracy (Q-1); anatomical feature fulfillments (Q-2); conformity of collimation adjustment (Q-3); radiographic film density (Q-4); contrast (Q-5); sharpness (Q-6) and detail (Q-7). For these reasons, it can be said that the object positioning should be aligned with the detector or otherwise this would affect on image quality of radiograph.

A review was performed to scrutinize each individual score in the radiographs that have been technically accepted. Many of them still composed of the scores that were not precisely achieved their maximum levels or even more there was a relative large discrepancy in the resulted scores within the seven technical quality criteria visibility. For instance, 3/4 of the scores reached the maximum at 60 yet 1/4 of the score extremely contributed to the minimum score that close to 20. It was clear that, despite the computed TQCI values from the evaluated radiographs met the requirement (TQCI $\geq$1) but some substantial scores were partially fulfilled. Moreover, numerous final statements in the questionnaire expressing about whether the evaluated radiographs can be use for diagnosis or not, were disagree with its computed TQCI values. In one side, the values were achieved its requirements whilst the final statements were being contradictory to that computed values (see table 22). These have shown uncertainty in the evaluators' decision about the existence of technical image quality on the evaluated radiographs that produced with object position variations.

The underlying reasons regarding to this matter possibly relate to either the bias reporting films due to individual performance of the evaluators or the absence of image quality standardizations that shall be used as the references.

Some evaluators (technologists) were inconsistent in performing their individual capability to assess many different levels of image quality criteria due to various applications of the AEC system. None of them has been well-trained in AEC areas recently while they were also unfamiliar to review the radiographs resulted from its applications in a wide range of conventional radiographic examinations. Careless may be seen amongst the evaluators' performances particularly in making a distinction between image quality results when inaccurate object positions were presented on radiographs with certain distances away from the respected detector(s). The one that was taken in to account by means of the technologists' ability was more likely linked to those general manner visually shown on radiograph such as symmetric or not symmetric object positioning (the Q-1 related criteria), and the radiographs too dark or too light (the Q-4 related criteria). On the contrary, a slight different in radiographic contrast (the Q-5 related criteria), sharpness (the Q-6 related criteria) and detail (the Q-7 related criteria) did not make sense in term of technical image quality judgments. For these reasons, a slight biased-image interpretation, therefore, occurred in the evaluators' performances.

The participated evaluators come from different general hospital in which of the hospital may have its own acceptance technical image quality references that are dissimilar from one facility to another. Whereby, they tend to follow their individual perspectives in accordance with the hospital circumstances or the local radiologists' preferences rather than to use their educated judgments about rejecting or accepting technical quality aspects. This condition is normally happened in term of image quality evaluation since there is no workable standardization of image quality nationally [36].

The two arguments explained in above are reasonable, that is why many technical accumulated scores are unsuccessful to achieve the expected maximum value while they still existing in most of the evaluated radiographs.

To sum up, variations toward a factor with respect to the object position had no significant impact on radiographic image quality when used the AEC system. A relative low image quality was noticed when the position incorrectly oriented above the detector(s) or sensor chambers being selected such as those radiographs in the knee joint-AP and the foot-Lat views. At list, this evidences was parallel with theoretical concept that recalled a correct alignment of the body part (ROI) and detector fields is needed to obtain an optimum image quality when producing radiographs with AEC [3, 5]. However, this conclusion can not be generalized because of the majority of technical quality composite index (TQCI) from the studied radiographs had been expressed within acceptable levels (TQCI ≥1) whereas also the evaluators' performances still be influenced by miscellaneous factors associated with needing of skill or knowledge about the AEC operation as well as interpreting of image quality due to its application. Additionally, such workable technical image quality standard that should have been recognized by the evaluators nationally was not available which in turn caused to some variations of the technologist's judgments, regarding of the local habits.

5.3.3 Assessment of the effect of collimation factors with respect to image quality

According to clinical evaluation, 33 radiographs/procedures provided quality criteria with acceptable CQCI values. After this group of radiographs underwent a technical quality clarification, 29 radiographs were decided to pass the evaluation with averaged TQCI values and standard deviation at 1.21 ± 0.18 respectively. Four radiographs from three different groups of ROI failed to fulfill technical quality aspects, as their TQCI values were less than 1.

A further step of contrasting the paired data about the TQCI values expressed in before and after a variation of the X-ray field sizes was attempted to disclose the effect of collimation factor to image quality. Again, the paired data sets used in the analysis were only restricted to 16 radiographs/procedures that rendered good/adequate TQCI values. It can be assessed through the table of comparison as shown as the following.

Table 23 The TQCI comparison between before and after collimation factor variations

AEC Procedures	Before treatments			After treatments		
	Standard field sizes	TQCI	Visibility of 7 quality criteria (Q-1 to Q-7)	Reduced Field sizes	TQCI	Visibility of 7 quality criteria (Q-1 to Q-7)
Chest lung & heart-AP	43x35cm	1.37	G-G-G-A-G-G-G	40x35cm	1.46	G-G-G-G-G-G-G
Chest lung & heart-Lat	43x35cm	1.33	G-G-G-A-G-G-G	43x29cm	1.23	G-G-G-A-A-A-A
Foot-Oblique	25x20 cm	1.40	G-G-G-G-G-G-G	23x13cm	1.21	A-A-A-G-G-G-A
Foot-PA	25x20 cm	1.36	G-G-G-A-G-G-G	23x13cm	1.35	G-G-G-G-G-G-G
Hand-Oblique	25x20 cm	1.44	G-G-G-G-G-G-G	16x19cm	1.30	G-G-G-G-G-G-G
Hand-PA	25x20 cm	1.42	G-G-G-G-G-G-G	16x19cm	1.37	G-G-G-G-G-G-G
Knee joint-AP	20x25 cm	1.32	G-G-G-A-G-G-G	16x16cm	1.10	G-G-G-A-A-A-A
Knee joint-Lat	20x25 cm	1.38	G-G-G-A-G-G-G	20x16cm	1.19	G-G-G-A-G-G-G
Lumbar spine-AP	25x30 cm	1.36	G-G-G-A-G-G-G	25x12cm	1.41	G-G-G-G-G-G-G
Lumbar spine-Lat	25x30 cm	1.44	G-G-G-A-G-G-G	25x19cm	1.24	G-G-G-A-A-A-A
Pelvis-AP	27x35 cm	1.36	G-G-G-G-G-G-G	24x29cm	1.22	G-A-A-G-G-G-G
Skull-AP	30x25 cm	1.37	G-G-G-A-G-G-G	30x22cm	1.47	G-G-G-G-G-G-G
Skull-Lat	30x25 cm	1.44	G-G-G-G-G-G-G	30x22cm	1.39	G-G-G-G-G-G-G
Thoracic spine-AP	43x18 cm	1.36	G-G-G-A-G-G-G	43x10cm	1.39	G-G-G-G-G-G-G
Tibia & fibula-AP	43x18 cm	1.21	G-G-G-G-G-G-G	43x12cm	1.08	A-G-G-A-A-A-A
Tibia & fibula-Lat	43x18 cm	1.22	G-G-G-A-A-A-A	43x12cm	1.29	G-G-G-G-G-G-G
Mean		1.36			1.29	

Legends: A = Adequate; G = Good

By using all TQCI data from the reviewed radiographs, a comparable analysis was done with respect to the 20 technologists' TQCI values including their final statements upon the entire 33 evaluated radiographs (660 repeated observations). The results were presented in the table 14.

Table 24 The percentages of the observed TQCI values of 33 radiographs produced by means of varying collimation factor with respect to technologists' opinions

The TQCI category	Descriptions	Number of observations	Percent
0	TQCI-failed, the radiograph can't be used for diagnosis	59	8.9
1	TQCI-failed, the radiograph can be used for diagnosis	9	1.4
2	TQCI-passed, the radiograph can't be used for diagnosis	16	2.4
3	TQCI-passed, the radiograph can be used for diagnosis	576	87.3
Total		**660**	**100**

Specific reasons for rejecting technical image quality criteria in the four radiographs can be seen in the figure 20.

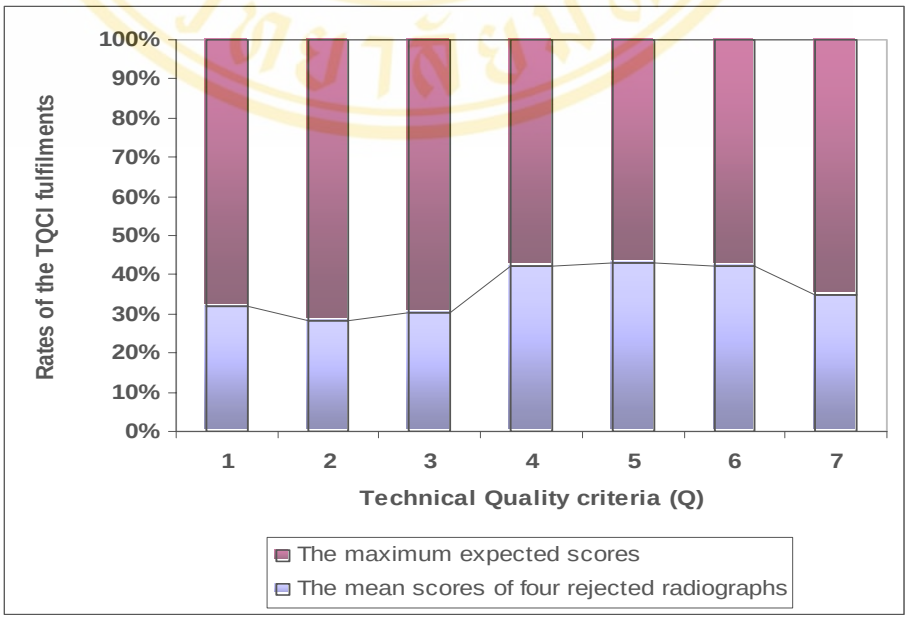


Figure 20 Percentages of technical quality criteria fulfilled by the rejected radiographs

The variability of TQCI values including its visible quality criteria between before and after varying of collimation factor was clearly seen in table 23. The mean TQCI values in both procedures were 1.36 and 1.29. Using the reduced field sizes that were smaller than standard collimation sizes generally affected on the technical quality visibility on the evaluated radiographs. However, the effects were apparent particularly when various types of the reduced field sizes were employed in the chest-lat, foot-oblique, knee joint-AP, lumbar spine-Lat and the tibia and fibula-AP/Lat views. A fairly good technical quality visibility was mostly expressed in terms of the Q-4 (films too dark); Q-5 (films loss of contrast); Q-6 (unsharpness images) and Q-7 (miss detail images). By this means that, narrowing collimation sizes as small as possible was not always improving technical quality visibility since the resulted films appeared too dark.

In addition, the effect of narrowing X-ray field sizes was also inspected in the basis of technologist's opinions (table 24). As can be seen from the table 24, 3.8 % of the opinions remained exits in the category 1 and 2, as the observers were unsure about diagnostic usefulness of radiographs that had been taken by means of using the reduced field sizes. Moreover, 8.9 % of the opinions were convict that numbers of the evaluated radiograph have had insufficient technical quality and believed that the radiographs cannot be used for diagnoses. This figured out that the image reviewers (technologists) were aware of missing several critical items in technical quality, which in turn could reduce diagnostic information containing in the radiographs.

The paired student-t test, using the same TQCI data source as displayed in the table 14 with 15 df and α 0.05, showed that, the p-value was 0.02 (two-tails), which was significant. By this result meaning that, the mean TQCI values between before and after varying of the collimation factor was not equal. It can be said that there was a significant effect on image quality when the collimation sizes were varied that different from the standard field sizes.

As shown in the figure 20, specific reasons for rejecting the radiographs basically related to poor achievements about their 7 technical quality aspects (Q-1 to Q-7). When reviewing the averaged scores of those rejected radiographs individually, the proportion of the Q-3 (field size conformity) among the radiographs had only

about 30 % of its maximum, which was just above that the lowest percentage in the Q-3 (overall fulfillment of anatomical features) at approximately 28%. The evaluators maybe agree that the field sizes used in those radiographs were not appropriate since they could not clearly observed several quality items such as whether or not the object position was accurate (Q-1) and the detail structure of the ROI was visible (Q-7). These implied that the effect of collimation could be existed, and may influence image quality of radiographs when used AEC in radiography.

Referred to the above analyses, the effect of the collimation factor onto image quality was obvious. Although image quality appeared to be optimum on most of the evaluated radiographs, in some cases, when the field sizes (collimation sizes) were limited too small that nearly exceeded the minimal object coverage, they caused to various technical quality criteria fulfillment. The use of the standard X-ray field sizes (standard cassette sizes) generally provided a more consistent image quality from one procedure to another.

5.4 Stage III: ESE measurements of the selected procedures, considering the AEC factors and image quality of radiographs

Skin exposure measurements were carried out to which of the selected techniques or procedures that had been defined along with the study in the stage II. Accordingly, the measurements worked out with those essential ESE parameters as had already documented in term of the routine AEC procedures and the procedures with a variation of the AEC factors (detector, object position and collimation). The effects of the factors onto the measured ESE were best described as the results that can be seen in the following tables.

Table 25 ESE comparisons between before and after varying of detector factor in selected procedures with respect to TQCI value and specific to ROI

AEC Procedures	Before treatments			After treatments		
	Detector	ESE (mR)	TQCI	Detector	ESE (mR)	TQCI
Chest lung & heart-AP	R-L	16.07	1.37	C	8.71	1.28
		16.07	1.37	R-C	5.98	1.48
		16.07	1.37	C-L	5.75	1.48
		16.07	1.37	R-C-L	5.52	1.46
Chest lung & heart-Lat	R-L	53.31	1.33	C	54.40	1.37
		53.31	1.33	R-C	66.13	1.33
		53.31	1.33	C-L	46.16	1.38
		53.31	1.33	R-C-L	53.31	1.39
Knee joint-Lat	C	47.36	1.38	R-C	31.12	1.50
Lumbar spine-AP	C	249.60	1.36	R-L	163.17	1.47
		249.60	1.36	C-L	202.66	1.40
		249.60	1.36	R-C-L	184.03	1.47
Lumbar spine-Lat	C	378.00	1.44	R-L	213.92	1.37
		378.00	1.44	R-C-L	258.57	1.45
Pelvis-AP	R-L	222.13	1.36	C	258.57	1.39
		222.13	1.36	R-C	236.15	1.39
		222.13	1.36	C-L	210.22	1.47
		222.13	1.36	R-C-L	214.42	1.39
Thoracic spine-AP	C	83.75	1.36	R-L	45.06	1.25
		83.75	1.36	R-C	59.66	1.47
		83.75	1.36	C-L	58.41	1.36
		83.75	1.36	R-C-L	53.71	1.44
Thoracic spine-Lat	C	206.21	1.36	C-L	250.89	1.29

Legend:
C = central detector
R = right detector
L = left detector

Table 26 ESE comparison between before and after varying of object position factor in selected procedures with respect to TQCI value and specific to ROI

AEC Procedures	Before treatments			After treatments		
	Object position	ESE (mR)	TQCI	Object position	ESE (mR)	TQCI
Chest lung & heart-AP	Std-3	16.07	1.37	1 cm-rl	5.03	1.48
Foot-PA	Std-16	7.98	1.36	2 cm-sp	7.80	1.39
Foot-Oblique	Std-17	7.98	1.40	1.5-cm ll	6.87	1.44
Hand-PA	Std-7	11.99	1.42	1.5 cm-ll	11.60	1.29
Hand-Oblique	Std-8	12.96	1.44	1.5 cm-if	8.99	1.38
Knee joint-AP	Std-12	71.15	1.32	4 cm-sp	52.62	1.33
Knee joint-Lat	Std-13	47.36	1.38	4 cm-if	19.54	1.33
Lumbar spine-Lat	Std-10	378.00	1.44	2 cm-ll	484.96	1.36
Pelvis-AP	Std-11	222.13	1.36	2 cm-sp	220.73	1.33
Skull-AP	Std-1	84.39	1.37	1 cm-rl	96.66	1.32
Skull-Lat	Std-2	52.69	1.44	1 cm-ll	58.23	1.35
Thoracic spine-AP	Std-3	83.75	1.36	3 cm-rl	92.41	1.30
Thoracic spine-Lat	Std-4	206.21	1.22	3 cm-rl	380.34	1.27
Tibia & fibula-AP	Std-14	30.31	1.40	1.5 cm-rl	27.92	1.44
Tibia & fibula-Lat	Std-15	8.72	1.21	2 cm-rl	18.44	1.42

Legend:
Std = standard object positioning
rl = Object shifts to the right lateral of the selected detector(s)
ll = Object shifts to the left lateral of the selected detector(s)
sp = Object shifts superiorly from the selected detector(s)
if = Object shifts inferiorly from the selected detector(s)

Table 27 ESE comparison between before and after varying of collimation factor in selected procedures with respect to TQCI value and specific to ROI

AEC Procedures	Before treatments			After treatments		
	Routine collimation sizes (cm)	ESE (mR)	TQCI	Reduced X-ray field sizes (cm)	ESE (mR)	TQCI
Chest lung & heart-AP	43x35cm	16.07	1.37	40x35cm	4.76	1.46
Chest lung & heart-Lat	43x35cm	53.31	1.33	43x29cm	71.99	1.23
Hand-Oblique	25x20 cm	12.96	1.44	16x19cm	11.05	1.30
Hand-PA	25x20 cm	11.99	1.42	16x19cm	9.51	1.37
Knee joint-AP	20x25 cm	71.15	1.32	16x16cm	96.40	1.10
Knee joint-Lat	20x25 cm	47.36	1.38	20x16cm	44.77	1.19
Lumbar spine-AP	25x30 cm	249.6	1.36	25x12cm	295.04	1.41
Lumbar spine-Lat	25x30 cm	378.	1.44	25x19cm	462.11	1.24
Pelvis-AP	27x35 cm	222.2	1.36	24x29cm	238.95	1.22
Skull-AP	30x25 cm	84.39	1.37	30x22cm	115.41	1.47
Skull-Lat	30x25 cm	52.69	1.44	30x22cm	62.67	1.39
Thoracic spine-AP	43x18 cm	83.75	1.36	43x10cm	102.42	1.39
Tibia & fibula-Lat	43x18 cm	8.72	1.21	43x12cm	7.24	1.08
Tibia & fibula-AP	43x18 cm	30.31	1.22	43x12cm	31.41	1.29
Foot –PA	25x20 cm	7.98	1.36	23x13 cm	9.09	1.39
Foot-Oblique	25x20 cm	7.98	1.40	23x13 cm	10.33	1.21

Based on the results in the table 25, in general, the entrance skin exposure values appeared in the AEC procedures with a variation of detector factor were a slight lower than that from the ESE in the procedure with routine detector selection. Specifically, changing the combination of detector selection or sensor chamber in different types of examination had a tremendous impact on the ESE or image quality. For example, the use of four different modes of detector selection (C, R-C, C-L, and R-C-L) in the pelvis-AP views characteristically demonstrated various levels of the ESE as well as the TQCI value when contrasted them with that the values where the only R-L mode of detector selection was activated. The effect of detector factor to ESE was also clearly depicted through the use of the three different detector modes in the chest-AP views with the C; R-C; C-L and R-C-L detector application. It showed a

much low level of the skin exposures with a relative high value of the technical quality criteria (TQCI) in comparing with those obtained from the application of the R-L detectors. These clearly explained that, an appropriate detector selection was therefore needed in order to achieve a possible low ESE with an optimum image quality result by which specific to the type of organ under examination.

Another ESE comparison was also performed in term of the routine AEC procedures and the AEC procedures where the object position was varied, as described in the table 26. All radiographs taken from the experiment were solely attempted to disobey the rule that the object position should be precisely over the selected detector(s) while the ESE was indirectly calculated in each procedure applied. Generally, the results showed the ESE values after a variation of object positions were higher than that of the values before the variations. Furthermore, the technical image quality criteria in the both procedures expressed approximately same mean TQCI values (± 1.4) that also dictated to an optimum quality fulfilled by most of the evaluated radiographs. When carefully inspected toward individual paired data about ESE and TQCI values from the table above, alterations in term of the object position caused to various levels either the measured skin exposures or the calculated technical image quality indexes. For a particular example here, the ESE value in the chest-AP view with a pretended miss-object position about 1 cm to the left lateral side of the R-L detectors was almost ten times lower than the value that expressed in the same view/projection with routine procedures. This figured out that an accurate object positioning was very important whenever the need of maintaining a reasonable patient exposure with optimum image quality was became the main concern to address. The area of interest should be allocated just above the sensor being used when taking radiograph by means of AEC so that the patient dose could be maintained.

The final ESE comparison was performed with respect to the two distinguished procedures as can be seen in the table 27. The ESE and TQCI values in each of individual AEC procedures before and after a variation of collimation were varied. For some of the procedures, the ESE and TQCI values appeared to increase when the field sizes were reduced such as in the lumbar spine-AP, pelvis-AP and Skull-AP. Again, a significant decreased ESE has shown in the chest-AP when the

field size was reduced to 40 x 35 cm from its standard filed size. In other words, changing of the X-ray field sizes could increase or decrease the skin exposures incurred at the entrance point in each procedure and the observed technical quality criteria on the radiograph especially when employed AEC in radiography. The chamber in the AEC system will compensate the length of exposure to achieve sufficient film density whenever the scatters increased which in turn potentially increased the measured ESE too. For this reason, most of the ESE values for particular examinations with typical reduced collimation sizes were increased. Therefore, it was important to adjust collimation as appropriate as possible according to the area of interest that needed to investigate, and keep in mind that the field sizes should include all area of the selected detector(s).

With the paired-t test, testing the three null hypotheses in term of the effect of the AEC factors to the measured ESE was done, based on the paired data collections in each procedure being investigated. It was defined that the detector and collimation factors had considerable effects to the amount of skin exposures as its null hypotheses were rejected with α 0.05 (p-values 0.02 and 0.03 respectively). However, the effect of object position factor was not significant, as its null hypothesis cannot be rejected with the same significant level at α 0.05 (p-value 0.24). A more data collection maybe needed to disclose about the effect of the latter factor appropriately.

CHAPTER 6
CONCLUSIONS

The objective of this study was to assess factors affecting image quality and entrance skin exposure (ESE) when using automatic exposure control (AEC). There were three factors, detector selection, object positioning and collimation, were considred to analyzed. A total of 180 radiographs obtained from anthropomorphic phantom were assessed for image quality. The image quality evaluation in terms of clinical quality composite index (CQCI) and technical quality composite index (TQCI) were performed by a radiologist and twenty experienced technologists blinded to the experiment respectively. Only radiographs passing the CQCI were taken for the TQCI evaluation. The measurements of ESE were also independently performed to assess the exposure values from each radiographic examination. Comparison of TQCI and ESE obtained from proper and inaccurate detector selection, object positioning and collimation were performed. Descriptive analysis of pair t-test with p-values of less then 0.05 was deemed significant. The results from this study showed that;

6.1 The effect of detector selection:

Selection of detector combinations has an impact on the technical image quality. The results showed that changing detector combinations may improve image quality as long as the selected detectors are under the area of interest. The exceptions were found when performed radiographic examinations of chest, lateral view of the lumbar spine and AP and lateral views of the thoracic spine. The degraded image quality was resulted from locations of the selected detectors were away from the anatomical area of interest. Regarding the entrance skin exposure, the results from the study showed variations of the radiation exposure depending on locations of the selected AEC detectors. Even though the overall trends of ESE were reduced when compared with the routine technique, no relationship between image quality and ESE was found.

6.2 The effect of object positioning:

Regarding object positioning, it was found that slightly poor positioning of the object from the selected detectors (± 2 cm.) did not affect the technical image quality as well as the ESE. However, if the object was away from the selected detectors for more than 3 centimeters, the ESEs were increased significantly. The image quality was also degraded if the objects were poorly positioned.

6.3 The effect of collimation:

In This study, improper collimation was found to have effects on both image quality and the ESE. Inappropriate X-ray field size opening had an impact on the image quality. Significant reduction of the TQCI was found. The results showed an increased in ESE when the collimation size was reduced. This may be because the detector cells received less amount of exposure due to the limited contribution from scattered radiation and made the phototimer compensate by extending the exposure time. Yet, in some radiographic examinations such as AP view of the chest, reduction of collimation size reduced the ESE significantly while maintaining good image quality.

The goal of radiology imaging is to provide optimal image quality while maintaining the acceptable radiation dose to the patients. Automatic exposure control help minimizing retake rate in terms of radiographic exposure settings. However, there is still a need that radiological technologists maintain their professional standard in terms of technical settings of the patient's anatomy, selection of proper AEC cells and collimation to practically optimize the utilization of the AEC systems.

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APPENDIX

APPENDIX A
AN EXAMPLE IN CALCULATING THE SCORE OF TECHNICAL IMAGE QUALITY CRITERIA

Organ of interest/View : The Skull Antero-posterior

Technologists	Technical image quality scores							Total score	$TQCI_{ti}$
	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7		
T_1	3	3	3	2	2	3	3	19	1.357
T_2	3	3	3	2	2	2	2	17	1.214
T_3	3	3	3	2	3	3	3	20	1.429
T_4	3	3	3	2	2	2	2	17	1.214
T_5	3	3	3	2	3	3	3	20	1.429
T_6	3	3	3	2	3	3	3	20	1.429
T_7	3	3	3	2	3	3	3	20	1.429
T_8	3	3	3	2	3	3	3	20	1.429
T_9	3	3	3	2	3	3	3	20	1.429
T_{10}	3	3	3	2	2	2	2	17	1.214
T_{11}	3	3	3	2	3	3	3	20	1.429
T_{12}	3	3	3	2	2	2	2	17	1.214
T_{13}	3	3	3	3	3	3	3	21	1.500
T_{14}	3	3	3	3	3	3	3	21	1.500
T_{15}	3	3	3	3	3	3	3	21	1.500
T_{16}	3	3	3	2	2	2	2	17	1.214
T_{17}	3	3	3	2	2	2	2	17	1.214
T_{18}	3	3	3	2	2	2	2	17	1.214
T_{19}	3	3	3	2	3	3	3	20	1.429
T_{20}	3	3	3	2	3	3	3	20	1.429
$TQCI_{ri}$									**1.361**

The TQCI for individual technologist is calculated by the equation 2 as the following:

$$TQCI_{ti} = \sum_{i=1}^{7} (Q_i)/14 \quad \text{..... (2)}$$

Appendix a (Continued)

$$= \quad 19/14 \quad = 1.357$$

After all the TQCI values have been obtained, thus, the next step is to calculate the average value of the twenty technologists by using the equation 2:

$$TQCI_{rn} = \sum_{ti=1}^{20} (TQCI_{ti})/20 \quad \text{.....} \quad (3)$$

$$= \quad 27.214/20 \quad = 1.361$$

APPENDIX B

AN EXAMPLE OF CLINICAL CHECKLIST

The Chest antero-posterior view

Diagnostic requirements	Visibility	
1. Performed at deep inspiration (as assessed by the position of the ribs above diaphragm either 6 anteriorly or 10 posteriorly)	O good	O poor
2. Symmetrically reproduction of the thorax as shown by central position of the spinous process between the medial ends of the clavicles	O good	O poor
3. Medial border of the scapulae to be out side the lung field	O good	O poor
4. Reproduction of the whole cage above the diaphragm	O good	O poor
5. Reproduction of the vascular pattern in the whole lungs particularly the peripheral vessels	O good	O poor
6. Visually sharp reproduction of :	O good	O poor
a. the trachea and proximal bronchi, the border of the heart and aorta	O good	O poor
b. the diaphragm and lateral costo-phrenic angles	O good	O poor
7. Visualization of the retro cardia lung and the mediastinum	O good	O poor
	O good	O poor
Total Score		

*) thick (√) to which evaluated item

APPENDIX C

THE TECHNICAL QUALITY CRITERIA QUESTIONNAIRE

Instruction:

1. Evaluate the technical image quality criteria of the radiograph you are observing
2. Choose the appropriate type of radiography examination and answer the questions by giving a check (✓) in the box/circle available

The types of Radiography examination:

☐ Skull-AP	☐ Skull-Right lateral	☐ Chest, lung and heart-AP
☐ Chest, lung and heart-Left lateral	☐ Thoracic spine-AP	☐ Thoracic spine-Left lateral
☐ Lumbar spine-AP	☐ Lumbar spine-Left lateral	☐ Lumbar sacral-Left lateral
☐ Pelvis-AP	☐ Gleno humeral joint-Right AP	☐ Forearm-Right AP
☐ Forearm-Right lateral	☐ Hand-Right AP	☐ Hand-Left oblique PA
☐ Femur-Right AP	☐ Femur-Right lateral	☐ Knee joint-Right AP
☐ Knee joint-Right lateral	☐ Tibia and Fibula, Right AP	☐ Tibia and Fibula, Right lateral
☐ Ankle joint-Right AP	☐ Ankle joint-Right lateral	☐ Foot, Right DP
☐ Foot, Right oblique DP		

Questions:

		Good	Adequate	Poor
1.	What do you think about *accuracy of the object positioning* as shown on this radiograph?	○3	○2	○1
2.	What do you think about overall *fulfillments of anatomical features* that visually shown on this radiograph in overall?	○3	○2	○1
3.	What do you think about *conformity of the x-ray field size used for this radiograph, regarding of the technical quality criteria fulfilled in general?*	○3	○2	○1
4.	What do you say about *overall optical density* as visually shown on this radiograph?	○3	○2	○1

Appendix c (Continued)

5.	What do you say about *overall image contrast* as visually shown on this radiograph?	O$_3$	O$_2$	O$_1$
6.	What do you say about *overall image sharpness* as visually shown on this radiograph?	O$_3$	O$_2$	O$_1$
7.	What do you say about *overall detail of the region of interests* as visually shown on this radiograph?	O$_3$	O$_2$	O$_1$

According to your experience, this radiograph O can or O cannot be used for clinical diagnoses.

APPENDIX D

A sample of the AEC routine procedures in the nine region organs of interest

1 ***Standard routine AEC procedures***

ROI/views	Bucky	Det.	Densit.	Obj.Post	Collimat.	kV	mAs	F.S	S/F system	SID	quality visibility	TQCI	ESE (mR)	Rd.ID
Chest-lungs & Heart-AP	yes	**R-L**	**(-2.5)**	Standard	35x43 cm	**66**	4.19	**Large**	400	130	G-G-G-A-G-G-G	1.37	16.07	R-12
Chest-lungs & Heart-LAT	yes	**R-L**	**(-3)**	Standard	35x43 cm	**125**	2.91	**Large**	400	130	G-G-G-A-G-G-G	1.33	53.31	R-14

2 ***Standard routine AEC procedures***

ROI/views	Bucky	Det.	Densit.	Obj.Post	Collimat.	kV	mAs	F.S	S/F system	SID	quality visibility	TQCI	ESE (mR)	Rd.ID
Thoracic spine-AP	yes	**C**	**N (0)**	Standard	18x43 cm	**77**	8.03	**Large**	400	115	G-G-G-A-G-G-G	1.36	83.75	R-21
Thoracic spine-LAT	yes	**C**	**N (0)**	Standard	18x43 cm	**81**	18	**Large**	400	115	G-G-G-A-G-G-G	1.36	206.21	R-23

3 ***Standard routine AEC procedures***

ROI/views	Bucky	Det.	Densit.	Obj.Post	Collimat.	kV	mAs	F.S	S/F system	SID	quality visibility	TQCI	ESE (mR)	Rd.ID
Lumbar spine-AP	yes	**C**	**N (0)**	Standard	10x12 in	**81**	33.5	**Large**	400	115	G-G-G-A-G-G-G	1.36	249.60	R-47
Lumbar spine-LAT	yes	**C**	**N (0)**	Standard	10x12 in	**90**	36.4	**Large**	400	115	G-G-G-A-G-G-G	1.44	378.00	R-51

4 ***Standard routine AEC procedures***

ROI/views	Bucky	Det.	Densit.	Obj.Post	Collimat.	kV	mAs	F.S	S/F system	SID	quality visibility	TQCI	ESE (mR)	Rd.ID
Pelvis-AP	yes	**R-L**	**N (0)**	Standard	27X35cm	**77**	31.7	**Large**	400	115	G-G-G-G-G-G-G	1.36	222.13	R-59

5 ***Standard routine AEC procedures***

ROI/views	Bucky	Det.	Densit.	Obj.Post	Collimat.	kV	mAs	F.S	S/F system	SID	quality visibility	TQCI	ESE (mR)	Rd.ID
Skull-AP	yes	C	(-1.5)	Standard	25x30cm	73	11.7	Large	400	115	G-G-G-A-G-G-G	1.37	84.39	R-3
Skull-LAT	yes	C	(-1.5)	Standard	25x30cm	70	9.5	Large	400	115	G-G-G-G-G-G-G	1.44	52.69	R-5

6 ***Standard routine AEC procedures***

ROI/views	Bucky	Det.	Densit.	Obj.Post	Collimat.	kV	mAs	F.S	S/F system	SID	quality visibility	TQCI	ESE (mR)	Rd.ID
Knee joint-AP	yes	C	(+2)	Standard	20x25cm	63	16.9	Large	400	115	G-G-G-A-G-G-G	1.32	71.15	R-71
Knee joint-LAT	yes	C	(+2)	Standard	20x25cm	63	12.8	Large	400	115	G-G-G-A-G-G-G	1.38	47.36	R-75

7 ***Standard routine AEC procedures***

ROI/views	Bucky	Det.	Densit.	Obj.Post	Collimat.	kV	mAs	F.S	S/F system	SID	quality visibility	TQCI	ESE (mR)	Rd.ID
Tibia & Fibula-AP	yes	C	(+2)	Standard	18x43cm	60	8.86	Large	400	115	G-G-G-G-G-G-G	1.40	30.31	R-79
Tibia & Fibula-LAT	yes	C	(+2)	Standard	18x43cm	60	2.65	Large	400	115	G-G-G-A-A-A-A	1.21	8.72	R-83

8 ***Standard routine AEC procedures***

ROI/views	Bucky	Det.	Densit.	Obj.Post	Collimat.	kV	mAs	F.S	S/F system	SID	quality visibility	TQCI	ESE (mR)	Rd.ID
Foot-PA	yes	C	N (0)	Standard	25x20cm	52	3.42	Small	400	115	G-G-G-A-G-G-G	1.36	7.98	R-94
Foot-OBL	yes	C	N (0)	Standard	25x20cm	52	3.23	Small	400	115	G-G-G-G-G-G-G	1.40	7.98	R-98

9 ***Standard routine AEC procedures***

ROI/views	Bucky	Det.	Densit.	Obj.Post	Collimat.	kV	mAs	F.S	S/F system	SID	quality visibility	TQCI	ESE (mR)	Rd.ID
Hand-PA	yes	C	(+3)	Standard	25x20cm	46	5.85	Small	400	115	G-G-G-G-G-G-G	1.42	11.99	R-40
Hand-OBL PA	yes	C	(+3)	Standard	25x20cm	46	6.04	Small	400	115	G-G-G-G-G-G-G	1.44	12.96	R-44

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