AN ABSTRACT OF THE THESIS OF

Robert M. Allman for the degree of Master of Science in Radiation Health Physics presented on March 18, 2015

Title: Validation of Radiographic Automatic Exposure Control Device Testing in the Era of Filmless Radiography: And New Variables Associated With Testing

Abstract approved:

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The exposure needed for a clinically useful image requires much less precision when using digital radiography (DR) than when using screen/film (SF) radiography. The Automatic Exposure Control (AEC) device was developed for ensuring accurate and precise exposures with SF technology. This thesis evaluates the importance of the AEC device in DR.

Several tests were performed to evaluate the operation of the AEC devices. A performance test was used to measure variation associated with different tube potentials and phantom thicknesses. The criteria used for the performance test was dependent on the imaging device manufacturer. A balance test measured variation among detectors within the AEC device. The criteria used for the balance test was

dependent on the imaging device manufacturer. A reproducibility test measured variation among exposure values when no changes were made to the testing materials. The reproducibility test was considered acceptable if the coefficient of variation was found to be less than or equal to 5%. A density test was used to measure the amount of user-selectable adjustment to the exposure. Tolerance for this adjustment was a 20 to 50% change in the exposure per step. The appropriateness of the exposure was examined using an Exposure Index (EI) range test. The criteria used for the EI range test was dependent on the imaging device manufacturer. Finally, the overall operation of each AEC device was examined. An AEC was determined to be functioning properly if it passed all above stated tests.

Roughly a quarter of devices failed the performance test. One-third of the AEC devices failed the balance test. No AEC device failed the reproducibility test. Roughly 60% of the AEC devices failed the density test. Approximately 60% of the AEC devices failed the EI range test.

Overall, nearly 80% of all AEC devices tested failed one or more test. There was no significant difference in the table AEC devices versus the upright AEC devices. More than three-fourths of AEC devices used with Cassette Radiography (CR) failed at least one test. All Direct Digital Radiography (DDR) systems failed at least one AEC test.

Although the importance of AEC devices has shifted from ensuring good image quality to maintaining appropriate patient exposures, the research performed in this thesis confirms AEC device calibration is still important for patient care. This

paper also demonstrates the need for updated AEC testing methods developed for use with CR and DDR.

Validation of Radiographic Automatic Exposure Control Device Testing in the Era of Filmless Radiography: And New Variables Associated With Testing

By

Robert M. Allman

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APPROVED:

Major Professor, representing Radiation Health Physics

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Robert M. Allman, Author

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

Chapter 1

INTRODUCTION

Validation of Radiographic Automatic Exposure Control Device Testing In the Era of Filmless Radiography: And New Variables Associated With Testing

This study explores the importance of testing Automatic Exposure Control (AEC) devices in departments with Cassette Radiography (CR) or Direct Digital Radiography (DDR) imaging. In particular the importance of testing AEC devices in filmless radiography is examined, as well as any potential modifications to the methods used with film radiography due to issues arising from the different characteristics of CR and DDR.

CR uses a photo-stimulable storage phosphor (PSP) coated plate as opposed to photographic film, housed in a cassette to capture a latent image. When the PSP plate is processed it releases light, which is then used to create a digital image (Environmental Protection Agency [EPA], 2014). CR is sometimes referred to as PSP imaging.

Digital radiography (DR) can refer to either CR or DDR. DDR is a cassette-less digital imaging method which uses an electronic sensor to convert x-rays to electronic signals (EPA, 2014)

Not long after the development of medical radiography, the need for a device to aid in proper film exposure was realized. The task required technologists with abundant experience, because patients have different body thicknesses and densities and the film used to record the images had a narrow range of acceptable exposure. Thus, the AEC

device was created, which helped films to be exposed properly on a much more consistent basis.

AEC devices, also known as phototimers, account for variances in patient density and positioning. They work by measuring the cumulative amount of radiation at a fixed point in the detection system. The measured signal is then sent back to the x-ray generator to indicate that the imaging device has received enough x-ray quanta for an appropriately exposed image, independent of patient and technique variables. The imaging devices were screen/film (SF) at the time of development, but could be CR or DDR today.

There are a few different AEC configurations. The most common design is to place an x-ray sensitive detector between the patient and the imaging device, as shown in figure 1 (American Association of Physicists in Medicine [AAPM], 1985). The detector is commonly an ion chamber, but could be solid state or fluorescent screen in combination with a photo-multiplier tube (PMT). The current stage of this technology incorporates the AEC directly into the image receptor assembly of DR units.
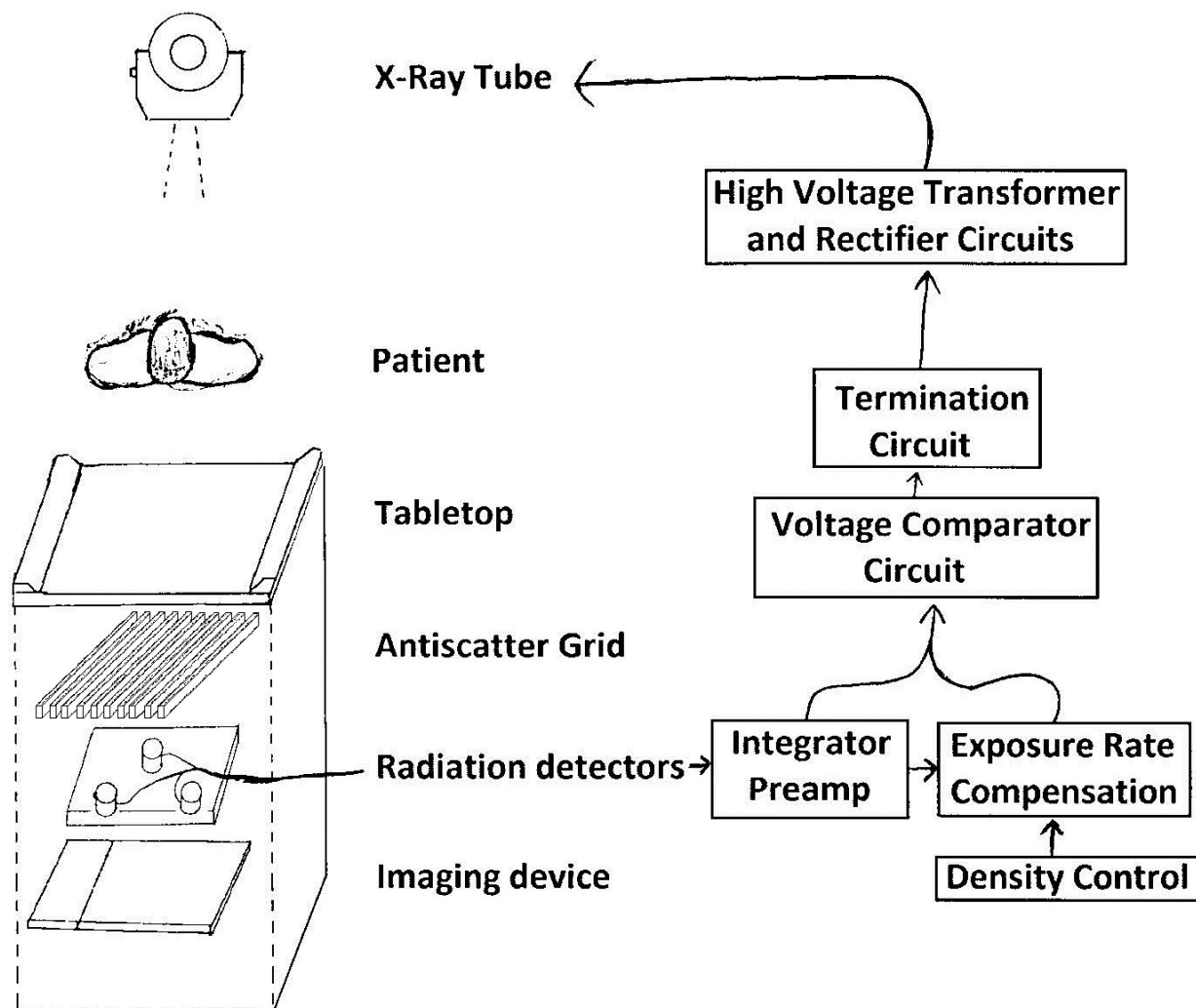
Figure 1. AEC device components and configuration, a derivative of Figure 32 from AAPM report no. 14 (AAPM, 1985).

The primary components of an AEC device are one or more radiation detectors, a signal amplifier, a voltage comparator circuit, a termination switch, and a backup timer (Bushberg, Seibert, Leidholdt, Boone, 2002). On units with a density selector, the operator can adjust the exposure termination reference value. The device which holds the AEC is called a Bucky. The Bucky also houses the grid and imaging device.

The metric to determine appropriateness of exposure with SF is Optical Density (OD). OD is a measure of the image's opacity. The only metric for CR and DDR exposure appropriateness is the exposure index (EI).

The EI was proprietary until a standardized proposal was jointly set by International Electrotechnical Commission [IEC] Standard 62494-1 (2008) and the American Association of Physicists in Medicine [AAPM] Report 116 (2009). Generally the proprietary EI is a measure of the Signal to Noise Ratio (SNR) of a digital image, which in this case is relative to the amount of exposure incident on certain selected region(s) of the detector. Therefore, proper AEC calibration is required for correct EI values.

It has been demonstrated that EI may be used like OD of film as a measure for radiographic quality assurance and AEC calibration (Christodoulou, Goodsitt, Chan, & Hepburn, 2000; Fauber, Legg, & Quinn, 2002).

Chapter 2

LITERATURE REVIEW

2.1 Changes Associated with Transitioning from Screen/Film to Computed Radiography

Often AEC tests are considered less important with DR, due to the wide dynamic range of CR and DDR. This is because the large dynamic range of DR produces images which are almost always readable. If a DR image is not readable, a successful repeat image is often taken with a simple increase in exposure. As will be discussed later, the drawback of this method is that it is not dose conscientious; it only seeks to produce an acceptable image without regard to patient dose optimization.

AEC devices are just as important for DR as they are for SF for keeping image quality and patient exposures in check (AAPM, 2009). In fact according to Samei et al. (2001) "AEC is the primary means for controlling patient exposure in general radiography." However, improper calibration of the AEC device can lead to excessive patient exposures (EPA, 2014). It has been reported that one manufacturer does not perform calibrations of the AEC devices for retrofitted systems (Jones, n.d.). With this in mind, annual testing of AEC devices should be considered to keep in line with the As Low As Reasonably Achievable (ALARA) concept of radiation exposure.

AEC devices have traditionally been set up to result in reproducible OD over a range of kilovolt peak (kVp) and attenuation combinations. However, with DR, the system should be calibrated to produce a constant pixel value over a range of kVp and attenuation combinations (AAPM, 2006). With CR, the x-ray absorption characteristics

and radiographic speed are different than for CR and SF (Samei et al., 2001; AAPM, 2006). Therefore, methods for calibrating AEC devices for use with CR should be investigated (Christodoulou et al., 2000; Samei et al., 2001; Willis, 2002).

Many AEC devices currently in use were designed for use with SF (AAPM, 2009). If the AEC device was calibrated for conventional SF, it should be reevaluated for appropriateness when switching to CR (American Society of Radiologic Technologists [ASRT], 2012; Fujifilm Medical Systems, 2004).

Attention must be paid to the kVp correction curve, which must be recalculated for digital systems to account for the different characteristics of CR image receptors (Jones, 2008). Unfortunately, optimization may be severely limited on systems designed during the SF era. Energy compensation adjustments may be impossible due to the system being hardwired to match SF energy and scatter characteristics, or the adjustments may lack the range needed for optimal performance with CR. (AAPM, 2009; Williams et al., 2007).

AAPM report 14, *Performance Specifications and Acceptance Testing for X-ray Generators and Automatic Exposure Control Devices*, from 1985, was the last AAPM report on AEC. There have been no updates addressing the complexities introduced by DR. AAPM Report 116, *An Exposure Indicator for Digital Radiography*, (2009) provides one- section on DR use with AEC, however the focus of this report is not on AEC device testing.

It is important for AEC devices to be tested when used with DR. AEC devices are commonplace now, with the vast majority of radiography rooms utilizing AEC during exams.

When radiography departments used SF, the AEC was a valuable tool that helped assure films were of useful OD when there was little room for error. By using a properly calibrated AEC, patient dose was reduced by avoiding repeat exam exposure. However, due to the wide dynamic range of CR and DDR, AEC calibration is not as critical for producing useful images. Yet calibration of the AEC is still important for keeping exposures ALARA and maintaining image quality.

2.2 Digital Radiography Differences from Screen/Film

As previously mentioned, one major difference between SF and CR is the large dynamic range over which CR can produce adequate contrast (AAPM, 2009). For SF, the useful dynamic range is contrast limited at approximately 10:1 to 100:1 (Williams et al., 2007).

CR and DDR are quantum noise limited, as opposed to contrast limited, because image processing software will adjust for limited amounts of contrast in the image (Christodoulou et al., 2000). In simpler terms, exposure changes how light or dark a SF image is, but varies the noise level in CR and DDR (AAPM, 2009). Noise in a radiograph can be defined as fluctuations in an image which are not present in the variations of the x-ray attenuation of the object being imaged (Williams et al., 2007). A

CR plate can produce a useful image from a range of 0.01 milliRoentgen (mR) to 100 mR, a factor of four decades (AAPM, 2006).

The contrast is adjusted in DR by algorithms which scale the signal to a predetermined output range, thus providing consistent image grayscale output values regardless of exposure appropriateness (AAPM, 2006). This image processing is able to "compensate by up to 100% for underexposure and up to 500% for over exposure, and still produce a clinically acceptable image" (Butler, Rainford, Last, & Brennan, 2010). This range of compensation is 300 to 400 times greater than what is afforded in SF (Don, 2004).

However, grossly underexposed DR images will contain excessive amounts of noise due to insufficient x-ray photons available to comprise the image. The subsequent amplification reduces SNR and contrast resolution which can lead to missed diagnoses or repeated exams. When images are overexposed they have an unnecessarily low amount of noise and the patient receives more radiation than is necessary. Overexposures are even more concerning, because they are not immediately identified as being overexposed. Exposure to radiation should be optimized so that putative risk is minimized "without sacrificing, or unduly limiting, the obvious benefits in the prevention, diagnosis and also in effective cure of diseases" (International Commission on Radiological Protection [ICRP], n.d.).

2.3 Exposure Creep

 As mentioned before, a well-documented problem with CR and DDR is that excessive exposures result in image quality that is beyond adequate, but at the cost of dose to the patient. Conversely, an underexposed image results in a noisy image that may not be suitable for a clinical interpretation. While a radiographer is likely to receive negative feedback for an underexposed and unusable image, the likelihood of receiving negative feedback for an overexposed, but usable image, is greatly diminished. Consequently, a trend towards overexposure is created through a lack of negative feedback for overexposed images. This problem has been termed exposure creep or dose creep.

 Exposure creep was quickly acknowledged with the adoption of CR and DDR. Technologists often do monitor the EI, but if an image is overexposed and still readable there is rarely any follow up action to prevent reoccurrence.

 Dose creep is a keen observation, but there is little focus on AEC device calibration in regards to unnecessary exposure. AEC devices which are not properly calibrated either contribute to unnecessary patient exposure or images with excess quantum mottle. One study found that ten percent of repeated adult chest CR examinations were a result of "overexposure by at least five times the amount of required radiation" (Don, 2004).

2.4 Patient Exposure to Ionizing Radiation

The best way to minimize radiation risk is appropriate use of an exam and optimization of radiation protection of the patient (ICRP, n.d.). Adherence to the BEIR VII report requires exposure to radiation only when necessary, and to keep necessary exposures ALARA (National Research Council of the National Academies, 2006).

Medical radiation accounted for the largest increase in exposure to the US population from 1987 to 2006 (National Council on Radiation Protection and Measurements [NCRP], 2009). Diagnostic radiographic and fluoroscopic studies, both of which utilize AEC systems, accounted for 74% of the total number of procedures involving the medical use of ionizing radiation, which constitutes 11% of the collective dose from all procedures (Mettler et al., 2009). The dose equivalent for exams which use AEC devices range from about 0.02 mSv for a PA chest exam to 1.8 mSv for a lumbar spine series (Health Physics Society, n.d.). Although the dose contribution from radiographic examinations is relatively small, the ALARA concept still applies.

2.5 Education

With CR or DR the primary benefit of AECs switches from an imaging quality tool to a dose governing aid. Due to the wide dynamic range of CR and DDR, AECs which give excess exposure may not be appropriately managed by technologists or clinicians because they lack assessment training. It is crucial that Radiographic Technologists (RTs) be trained on AEC operation and EIs, and notify managers when values are consecutively or conspicuously off.

Training is especially important when transitioning from SF. One survey found that 64% of RTs received "on the job" training or training from other "super-users" (Don, Goske, John, Whiting, & Willis, 2011). This type of informal education might introduce misunderstandings.

Radiologists should also be educated on EI, and the sources of fluctuations that can occur to the EI value, such as "patient size, artifacts, source to image receptor distance, collimation, centering and [Imaging Plate] IP...size" (Butler et al., 2010).

2.6 Calibration of Computed Radiography Readers

A need for routine CR reader calibration has been reported and will be further demonstrated in this paper (Doyle, Gentle, & Martin, 2005). The errors in calibration are possibly due to a drift in calibration or the EI not being properly calibrated during installation. Currently there are "no industry-wide standards or requirements" for evaluating variability among CR systems (Fauber et al., 2002). CR reader calibration is crucial for proper EI values, which are in turn used to evaluate AEC device operation.

2.7 Exposure Indexes

The EI varies from manufacturer to manufacturer. However, all manufacturers' EIs are dependent on a "calculation based on the histogram, the processing applied, and the amount of exposure reaching the plate" (Cesar, 1997). The EI provides the operator with feedback about image quality.

Most manufacturers incorporate a histogram analysis to determine the image's mean pixel value, which is then used for determining the EI (Exposure Index, 2010). The x-axis of the histogram is the pixel value and the y-axis represents the frequency of occurrence (AAPM, 2006).

Because each manufacturer defines EI differently, there are different relationships to the amount of exposure the IP received. The EI quantifies image quality in terms of the SNR in order to provide an indication of image quality. IEC standard 62494-1 defines EI as "a measure of the detector response to radiation in the relevant image region of an image acquired with a digital x-ray imaging system" (IEC, 2008). It should be noted that EIs used by various CR manufacturers are not easily comparable (Williams et al., 2007).

EI is now defined universally by the IEC as "a dimensionless quantity equal to 100 times the image receptor air kerma [Kinetic Energy Released per unit Mass] (in µGy) under the calibration conditions (Kcal)" (IEC, 2008).

Fuji CR's EI is the sensitivity number, abbreviated as the "S" value, signifying the "photostimulable luminescence (sensitivity) given off by the imaging plate while being scanned in the reader" (Fujifilm Medical Systems, 2004). The "S" value is based on the SF concept of film speed and is therefore a linear value, inversely related to "incident exposure on the IP transmitted through the object" (AAPM, 2006; Krupinski, 2007). However, Fiji's S-number does not correspond exactly with the ISO 9236-1 definition of film speed (AAPM, 2009).

Konica CR's EI is the sensitivity value, abbreviated as the "S" value. The value is similar to Fuji's sensitivity number, including its linear inverse proportionality to exposure and exposure dependence (AAPM, 2009). However, Konica's "S" value is defined by a different incident beam quality than Fuji's "S" value (AAPM, 2009).

Agfa CR's EI is the log of the median (lgM) IP exposure observed from a segmented Region of Interest (ROI) of the raw histogram, which is directly related to incident exposure (Krupinski, 2007). Specifically, the lgM is calculated as:

lgM = 2 x $\log_{10}$(SAL)-3.9478, where SAL = [1800^2 x (speed class/200)x (dose in µGy/20) x IPF]$^{1/2}$, speed class is the user selected nominal speed of the CR plate (e.g., 200, 400, 600, etc.), and IPF is the imaging plate sensitivity correction factor (IPF = 1 for MD10 plate) (Christodoulou et al., 2000).

The DDR systems tested for this research used, EI, DEI, and REX for Carestream, GE, and Canon systems respectively. Carestream's Exposure Index (EI) is "a calibrated measure of the exposure incident on the detector" (AAPM, 2009). Carestream's EI is linear and proportional to the detector's exposure (AAPM, 2009). GE's Detector Exposure Index (DEI) is proportional to the logarithm of incident exposure (AAPM, 2009). Canon's Reached EXposure (REX) value exhibits a log-linear relationship that is proportional to the exposure measured by the detector (AAPM, 2009).

2.8 Types of AEC tests

AEC devices are designed to track changes in tube potential from 50 to 150 kVp, variations in attenuation thickness and density, and different cassette sizes (AAPM, 1985). Tracking means providing the desired EI for a variety of conditions by correctly terminating the x-ray exposure (AAPM, 1985). The end result is consistent SNR for images with varying energies and exposure rates from modifying the amount of exposure incident on the detector (AAPM, 2009).

There are many different operations of an AEC device that can be tested. Specific tests are the Correspondence of Selected Fields to Activated Fields, Minimum Controllable Exposure Duration, Reproducibility, Field Sensitivity Matching (i.e. Detector Balance), Density Control Function, Field Size Compensation, Performance Capability (Sensitivity), and Maximum Allowable Exposure Duration (AAPM, 1985). A description of each test is provided below:

Correspondence of Selected Fields to Activated Fields

This test should be done initially and anytime the AEC is removed from the Bucky. It is not necessary to test this on a regular basis because once it has been shown the correspondence is correct, it will not change on its own. However, it is important to test this initially and after servicing because having the correct anatomical region over the AEC detector is of paramount importance. This way, when a technologist selects a specific chamber, the selected chamber is activated.

Minimum Controllable Exposure Duration

It is important that the AEC operates quickly enough that it works with low exposure exams. If the AEC does not terminate the exposure quickly enough, it will overexpose the patient and imaging device. The minimum controllable exposure duration must be less than or equal to the greater of 1/60 second or 5 milliampere-seconds (mAs) (Code of Federal Regulations [CFR], 2014). However, the duration should be less than or equal to 3 milliseconds or 3 mAs except for single phase, full wave rectified equipment, which should be less than one pulse (AAPM, 1985).

Reproducibility

With all parameters fixed, the output should have minimal levels of variation. Reproducibility is the ultimate goal of an AEC device. The imaging device should get the same exposure regardless of variables with the patient, and therefore with all else being equal the AEC should be reproducible. This test is further examined in the research conducted for this paper.

Field Sensitivity Matching (Detector Balance)

Historically all AEC fields and combination of fields were calibrated to provide equal amounts of exposure. However, some modern systems are designed to produce higher exposures when the left or right chamber is used. All systems tested for this research were assumed to have the historical calibration scheme. This test is further examined in the research conducted for this paper.

Density Control Function

The AEC will compensate for different patient thicknesses. But, some exams are acceptable with less exposure, while some require more exposure for an appropriate diagnosis. A density control function will allow for an intentional increase or decrease in the exposure by a defined amount known as a step. Density control testing measures the performance for appropriate step size and predictability. This test is further examined in the research conducted for this paper.

Field Size Compensation

The AEC should maintain constant incident exposure to cassettes of all sizes. AAPM Report 14 recommends different sized imaging devices produce results within ± 10% of one another (AAPM, 1985). Additionally AEC systems should function independently of field size collimation.

Performance Capability (Sensitivity)

Performance Capability (Sensitivity) measures the variability over a range of different thicknesses of attenuators and tube potentials. The exposure to the imaging plate should be consistent with varying amounts of attenuation in the beam over the range of kVps used clinically. This test is further examined in the research conducted for this paper.

Maximum Allowable Exposure Duration (Backup Timer)

It is important that the AEC has a backup timer as a secondary method of preventing an overexposure to the patient and imaging device even if the image is improperly exposed. This test measures the set point of the backup timer. This must be set at less than or equal to 600 mAs or 60 kWs for kVps greater than 50 (CFR, 2014).

This paper examines the field sensitivity matching, performance capability, reproducibility, and density tests in real world clinical settings. The correspondence test is not examined in this paper because it should be performed initially and this testing only covers ongoing tests. The maximum exposure duration was not examined because for most equipment it is different for each technique. As a result there are too many combinations to test. The minimum exposure duration was not tested because the detection equipment used has low accuracy at such short exposures. The field size test is thought to be unrelated to AEC performance, however it was not tested to support this thought.

The overall appropriateness of the final resulting EI is compared to a tolerance range for each manufacturer. The tests examined in this research check for proper calibration as opposed to performance among different manufacturers. The main question this study attempts to answer is whether AEC testing is necessary with CR and DDR.

Chapter 3

MATERIALS AND METHODS

In order to reduce certain variables, all tests reported on for this research were performed by one physicist. The radiographic equipment used for this research was located within several different hospital systems and clinics.

3.1 Detection Equipment

A list of equipment manufacturers is provided in Appendix A.

Figure 2. The front and top of an RTI Barracuda cabinet.

An RTI Barracuda was connected to an RTI Multi-Purpose Detector (MPD), a universal detector for a variety of x-ray systems. The Barracuda and MPD were

calibrated by RTI's accredited lab prior to gathering the data used for this research

(Appendix B). Measurement results were displayed on a Palm Tungsten E2 connected

via Bluetooth to the Barracuda. The MPD contains:

> four separate electrometer channels connected to detectors D1,
> D2, D3, and D4 and a movable filter package that can change to
> one of six positions, each a combination of different filters for the
> detectors. (RTI Electronics AB, 2012)

Figure 3. The RTI Multi-Purpose Detector positioned on a stack of PMMA blocks.

Attenuator

Ten Poly-methyl methacrylate (PMMA/Acrylic), density = 1.18 g/cm^3, blocks

measuring roughly 0.95" thick by 9" wide by 11" long were used for various amounts of

attenuation in the x-ray beam (Poly(methyl_methacrylate, n.d.). Entrance exposure was

measured with the MPD placed directly in contact with the acrylic phantoms as seen in

figure 3.

CR

CR cassettes from FujiFilm Medical Systems USA, Inc.; Agfa; and Konica; were used. Each CR cassette housed a PSP IP. A cassette reader was used for extracting the latent image data from the IP. A workstation was used for processing and reviewing the CR images. For this study, 10" x 12" CR cassettes were randomly chosen from the available cassettes routinely used at each imaging site.

DDR

The DDR systems were either Carestream DR, GE Definium 5000, or Canon CXDI 70 DR. A workstation was used for processing the DDR images.

Software

Windows 7, Microsoft Word 2010, Microsoft Excel 2010, MathType 6.9a, and Adobe Acrobat 9 Pro Extended were used to analyze the data and generate this document. RTI's QA Browser Ver. 4.3B (4417) was used in gathering data for this research. Fuji's Flash IIP (Image and Information Processor), Konica's Control Station, Agfa's MUSICA2, Carestream Health, Inc., General Electric Healthcare's Definium, and Canon Medical Systems' processing software was used for this research.

CR Processing

A flat field processing algorithm was used on the images to reduce differences in segmentation. Specifically, flat field processing will correct for non-uniform areas of the

incident exposure, "the offset of the individual pixels; gain correction for the individual pixels; [and] for velocity variation during a scan" (IEC, 2008).

For Fuji systems all cassettes were processed with the Semi-automatic mode using the 'test-sensitivity' image acquisition menu on Fuji's Flash IIP. This program uses a linear input-output transfer curve such that the latitude number (L), "which is the logarithm of the useful range of exposures for analog-to-digital conversion," is set at 2 (Christodoulou et al., 2000). Using this mode, a rectangle in the center of the image is used to create a histogram which is used to determine the S-number.

When using Konica systems, the "test" tag, located under the "QA-QC" palette, was selected on the Control Station software. For Agfa systems, the "UGI" or upper gastrointestinal program was applied for flat field processing using Agfa's MUSICA2 software.

Radiographic System with AEC

A radiographic system comprising of a generator, operator's control panel, x-ray tube, and an AEC device was used for testing. All AEC devices tested contained three sensors.

3.2 Methods

All systems were tested at a Source to Image Distance (SID) equal to the grid focal length. All tests were performed at the clinically programed density for anteroposterior lumbar for the table Bucky and lateral chest techniques for the upright

Bucky. The PMMA plates were placed on a table or touching the upright Bucky, between the tube and the AEC device.

AAPM report 31 was the basis for setting up AEC measurements. The patient-equivalent PMMA phantom was positioned "in the x-ray field between the focal spot and the AEC detectors" (AAPM, 1990). The x-ray field size was collimated to expose all AEC detectors entirely. The RTI MPD was positioned in "the x-ray field between the focal spot and the phantom" (AAPM, 1990). This detector placement is not in line with the AAPM Report 31 recommendation to position the detector 23 cm above the phantom surface, because measured backscatter is minimal with the MPD (AAPM, 1990). Also, the MPD was not placed near the central axis. Instead the detector was set up in the direction perpendicular to the x-ray tube anode-cathode axis, at the edge of the x-ray field. This arrangement was chosen to avoid non uniformity in the exposure from the "heel effect", and to avoid covering the AEC chambers (Christodoulou et al., 2000).

Finally, the control panel was used to program the system to use clinically appropriate technique factors and a CR cassette was inserted into the Bucky tray for non DDR systems. Exposures were then made and the resulting EI value, or MPD exposure value were recorded.

Performance (Sensitivity) Test Method

The AEC performance was tested in accordance with AAPM Report 14. Specifically the EI was recorded "over a broad range of imaging techniques and

attenuator thickness" ranging from approximately 4 to 10 inches of acrylic in 2 inch

increments (AAPM, 1985). The tube potentials were set from the programmed values

for knee, cervical, hip, and lumbar exams. "The exposure duration for the minimum

attenuator thickness…[was] greater than or equal to twice the minimum controllable

exposure duration" (AAPM, 1985). The center chamber of the AEC device was

selected and density was set to the normally programed level. The arrangement of this

test is shown in figures 4 and 5.

The mean EI from the four images was calculated, using (1), and recorded.

Then the largest deviation from the mean is identified, using (2), and recorded. This

value was then checked against the tolerance to determine if each trial passed or failed.

$$\overline{x} = \frac{EI_{4"} + EI_{6"} + EI_{8"} + EI_{10"}}{4} \qquad (1)$$

$$deviation = |x_i - \overline{x}| \qquad (2)$$

Figure 4. Radiographic tube positioned toward the upright AEC device with a PMMA phantom in the radiation field.

Balance Test Method

The AEC balance (sensitivity matching) was tested in accordance with AAPM Report 14. Specifically one exposure was made for each of the three AEC detectors at "a fixed kV, attenuator thickness and tube load such that the duration of exposure [was] greater than twice the minimum controllable exposure duration" (AAPM, 1985). The setup of this test can be seen in figures 4 and 5. The normal programed density was used. Different field combinations were not measured for this report.

The mean EI from the left, center, and right detectors was calculated, using (3), and recorded. Then the largest deviation from the mean was identified, using (4), and recorded. This value was then checked against the tolerance to determine if each trial passed or failed.

$$\overline{EI} = \frac{EI_{Left} + EI_{Center} + EI_{Right}}{3} \qquad (3)$$

$$Difference\ from\ mean = \left| EI - \overline{EI} \right| \qquad (4)$$

Figure 5. Radiographic tube positioned toward to the table AEC device with a PMMA phantom in the radiation field.

Reproducibility Test Method

Reproducibility of the AEC devices was tested in accordance with AAPM Report 14. Specifically four exposure measurements were recorded at "a fixed kV, attenuator thickness, and tube load such that the exposure duration [was] greater than twice the minimum controlled exposure duration" (AAPM, 1985). The center chamber of the AEC device was used at the normal programed density. The MPD was positioned at the edge of the radiation field as shown in figure 6.

The coefficient of variation of the four exposure measurements, measured in mR, was calculated, as in (5), and recorded. This value was then checked against the tolerance to determine if each trial passed or failed.

$$C.V. = \frac{\sigma}{\bar{x}} \leq 0.05 \tag{5}$$

Where

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \mu)^2} \tag{6}$$
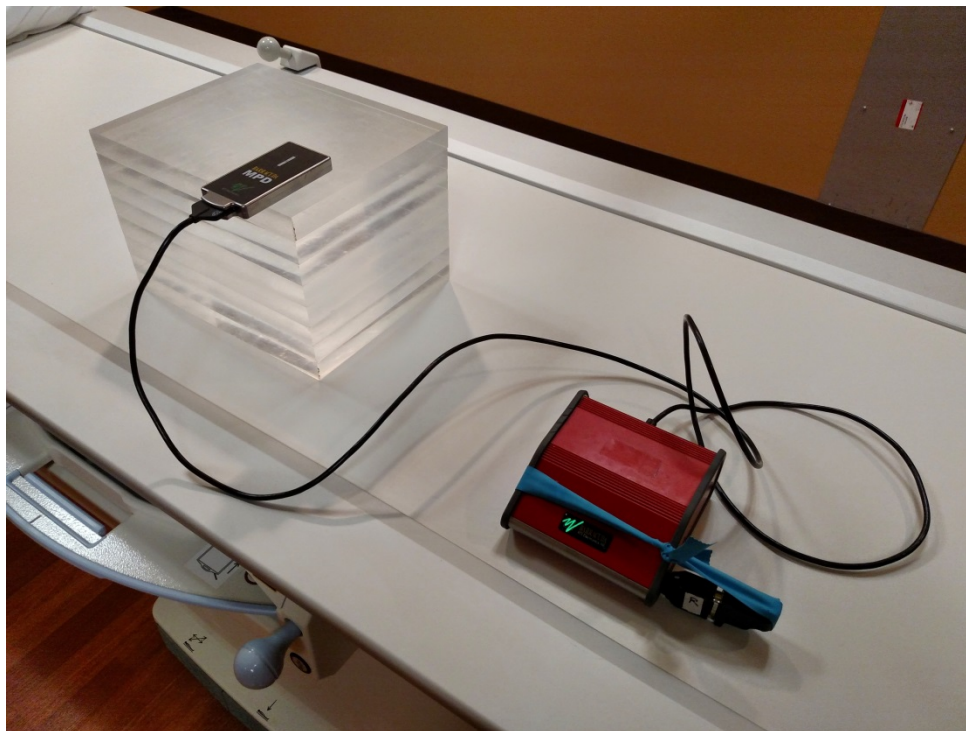
And

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i \tag{7}$$

Figure 6. Exposure measurement using the RTI Barracuda and MPD on a stack of PMMA blocks positioned above the table AEC device.

Density Test Method

The density control function testing was based off of AAPM Report 14. Five measurements were obtained, the exposure (mR) at normal density, the two steps above normal, and the two steps below normal, at "a fixed kV, attenuator thickness and tube load such that the duration of exposure obtained at the 'Normal' position [was] greater than eight to ten times the minimum controllable exposure duration" (AAPM, 1985). The center chamber was used for this test. The MPD was positioned at the edge of the radiation field as shown in figure 6.

The percent change per step was calculated from exposure measurements, using (8), and recorded. This value was then checked against the tolerance to determine if each trial passed or failed.

$$\text{Percent change per step} = \left\{ \begin{array}{l} \dfrac{Density_i - Density_{i-1}}{Density_{i-1}} x100\% \; for \; i > 0 \\[2ex] \dfrac{Density_i - Density_{i+1}}{Density_{i+1}} x100\% \; for \; i < 0 \end{array} \right\} \quad (8)$$

3.3 Test Tolerances

Performance Tolerance

For this research the maximum allowed deviation from mean for CR systems was Fuji < 38 S; Konica < 38 S; Agfa < 0.15 lgM. The tolerance for DDR systems was Carestream < 50 EI; GE < 0.15 EXI; Canon < 50 REX.

Balance Tolerances

For this research the maximum allowed deviation from the mean for CR was Fuji < 38 S; Konica < 38 S; Agfa < 0.15 lgM. The tolerance for DDR systems was Carestream < 50 EI; GE < 0.15 EXI; Canon < 50 REX.

Reproducibility Tolerance

The allowable tolerance was obtained from AAPM Report 14, which states reproducibility must have a coefficient of variation less than or equal to 5% (AAPM, 1985).

Density Tolerance

The criterion was 20 to 50% change per step for the data obtained for these trials.

Range Tolerances

The acceptable ranges for CR used in this research were 100 to 300 S for Fuji and Konica and 1.9 to 2.35 lgM for Agfa. The tolerance for DDR systems was 200 to 800 EI for Carestream; 0.66 to 1.98 EXI for GE; and 500 to 800 REX Canon.

Overall Failure Rate Tolerance

All AEC tests must meet the stated tolerances to pass the overall test. If one or more tests of the entire unit fail, the overall performance is considered unacceptable.

Chapter 4

RESULTS OF STUDY

In this study 54 AEC devices in total were tested, 28 were table AEC devices and 26 were upright AEC devices. Out of all of the AEC devices, 46 were used with CR and 8 were used with DDR.

Performance Results

As shown in figures 7 and 8, just over 22% (12 of 54 AEC devices) of all AEC devices tested failed the performance test using the criteria mentioned in the methods section. Of the table AEC devices tested, a failure rate of 25% (7 of 28 AEC devices) was observed. Almost 19% (5 of 26 AEC devices) of the upright AEC devices failed.

Of the different CR manufacturers tested, AEC devices paired with Fuji CR had a failure rate of 30% (6 of 20 AEC devices) for the performance test, and both Konica and Agfa had no failures (0 of 22 AEC devices and 0 of 4 AEC devices respectively). Of the DDR systems tested, 75% (6 of 8 AEC devices) of AEC devices failed the performance test.
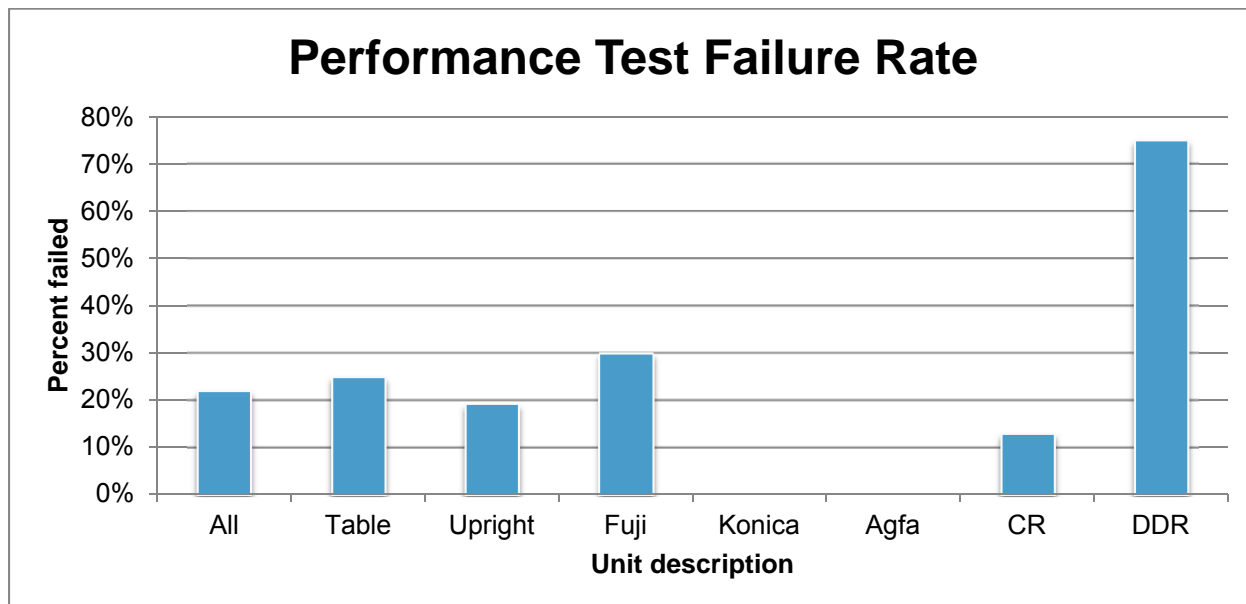
Figure 7. Percentage of systems failing the AEC performance test.
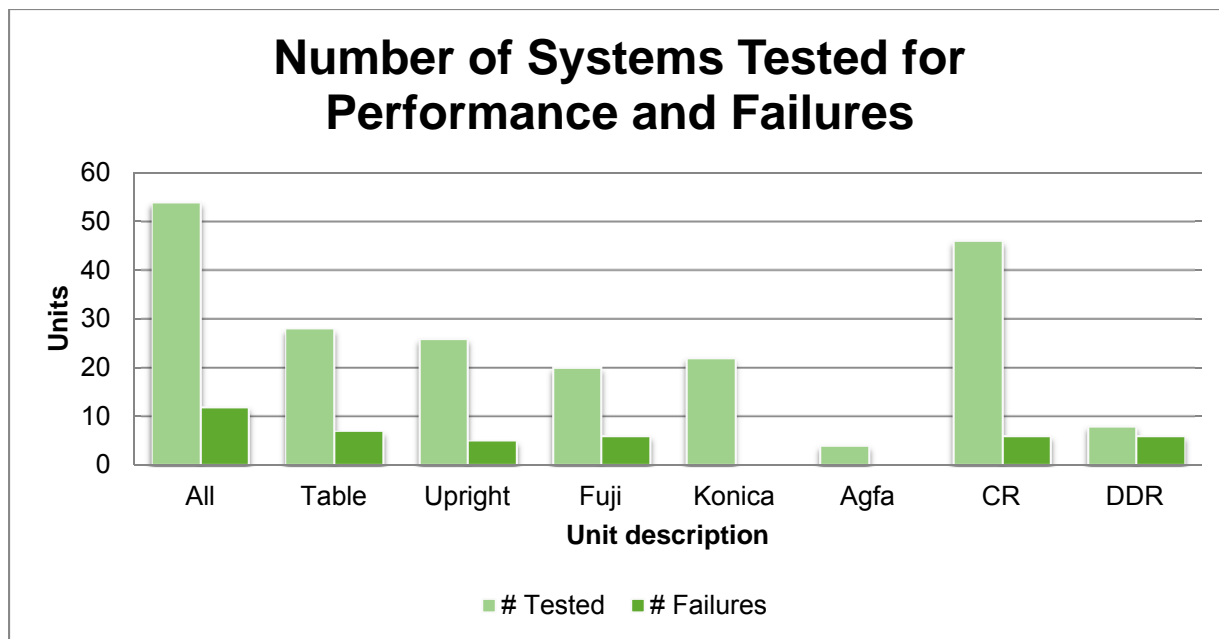

Figure 8. Number of systems tested for AEC performance and corresponding number of failures.

Balance Results

Out of all systems tested, slightly more than 33% (18 of 54 AEC devices) failed the AEC balance test. A graphical representation is provided in figures 9 and 10. The table AEC devices had a failure rate of almost 29% (8 of 28 AEC devices) for the balance test, whereas the upright AEC devices had a failure rate close to 38% (10 of 26 AEC devices).

Among the different CR manufacturers used with the AEC devices, Fuji CR had a balance test failure rate of 35% (7 of 20 AEC devices); Konica CR failed a little more than 27% (6 of 22 AEC devices) of the AEC balance tests; and Agfa had no (0 of 4 AEC devices) associated AEC devices fail the balance test. Of all the DDR systems tested, more than 63% (5 of 8 AEC devices) of the AEC devices did not meet the criteria for the balance test.
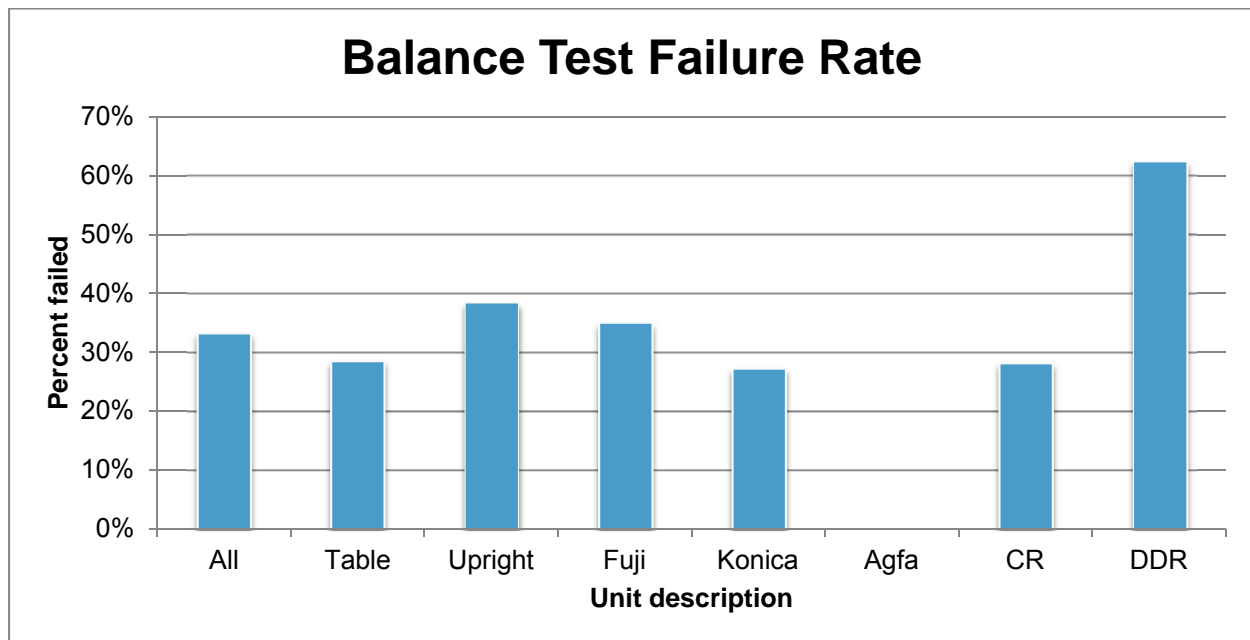

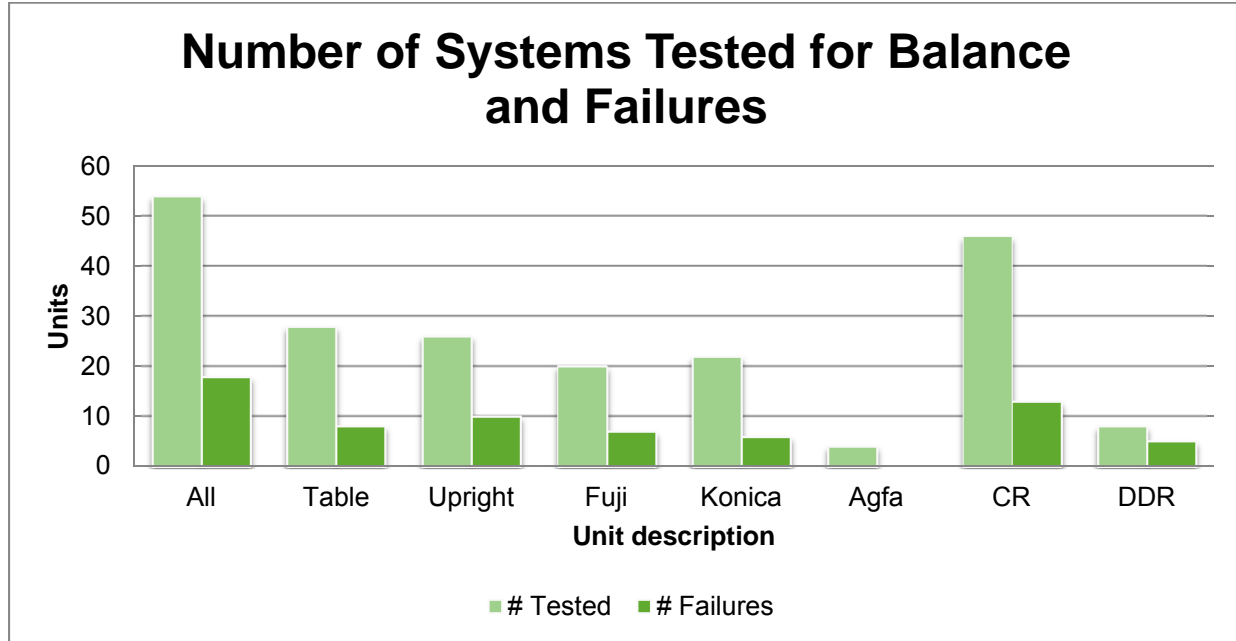Figure 9. Percentage of systems failing the AEC balance test.

Figure 10. Number of systems tested for AEC balance and corresponding number of failures.

Reproducibility Results

   As seen in figures 11 and 12, 100% (54 of 54 AEC devices) of AEC devices were found to be reproducible. None, 0% (0 of 28 AEC devices) of the table AEC devices failed the reproducibility test. In addition, none 0% (0 of 26 AEC devices) of the upright AEC devices failed the reproducibility test.

   This test is based off an exposure (mR) measurement and is therefore not dependent on the CR manufacturer. Out of all the CR systems tested, the reproducibility failure rate was 0% (0 of 46 AEC devices). All (8 of 8 AEC devices) DDR systems passed the AEC reproducibility tests.

Reproducibility Test Failure Rate
(Note: no systems failed)

Percent failed

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

All   Table   Upright   CR   DDR

Unit description
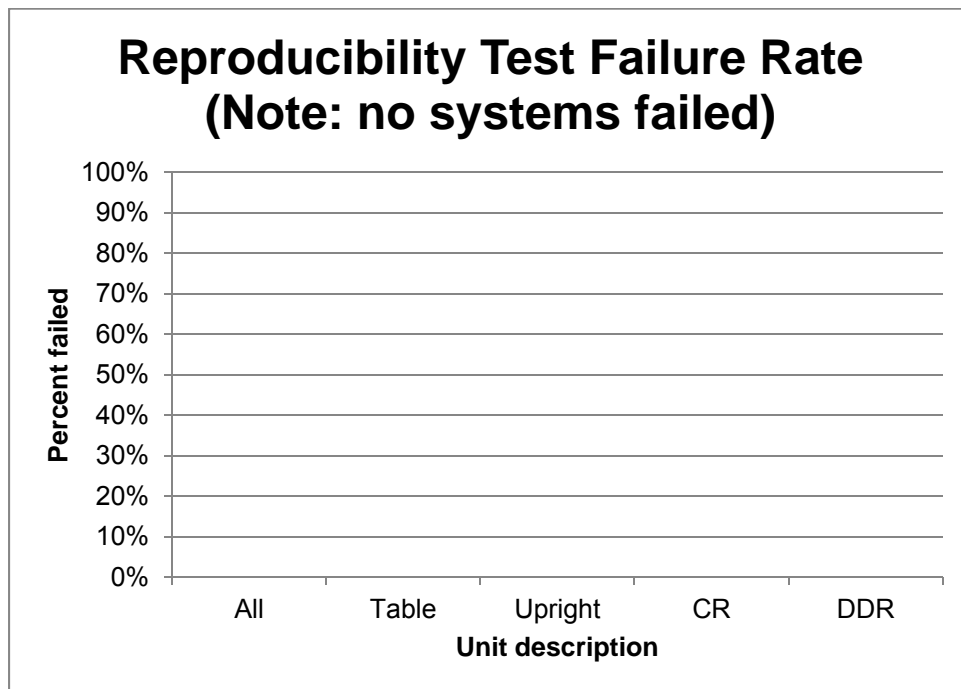
Figure 11. Percentage of systems failing the AEC reproducibility test.

Number of Systems Tested for
Reproducibility and Failures

Units

60

50

40

30

20

10

0

All   Table   Upright   CR   DDR

Unit description

■ # Tested   ■ # Failures

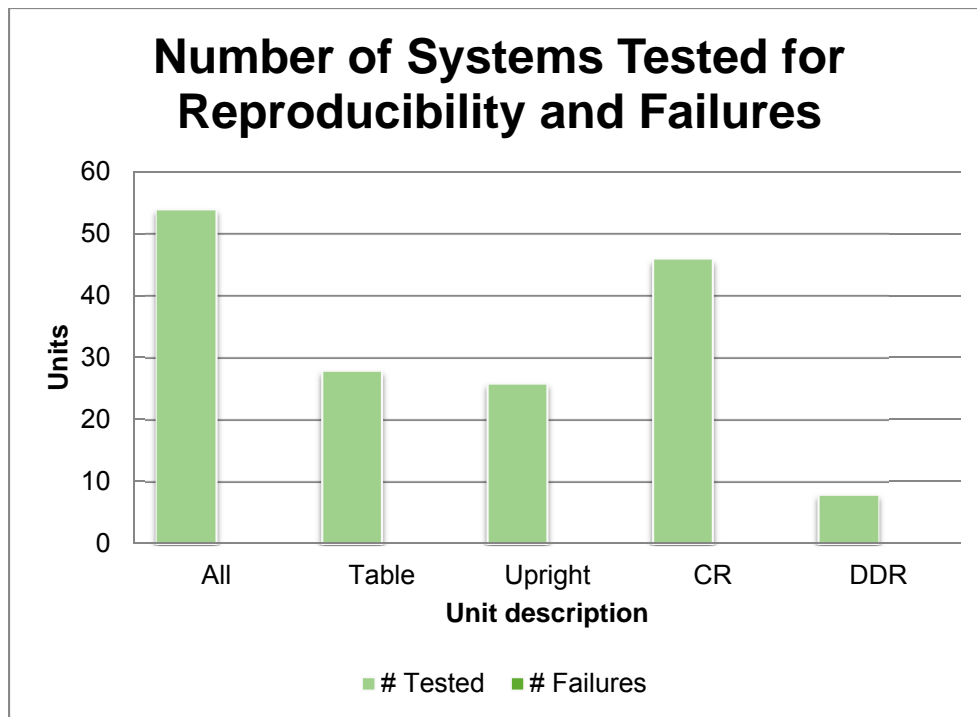Figure 12. Number of systems tested for AEC reproducibility and corresponding number of failures.

Density Results

Figures 13 and 14 demonstrate the finding that among all AEC density tests, a little more than 61% (33 of 54 AEC devices) failed. Approximately 64% (18 of 28 AEC devices) of the table AEC devices failed the density test. The density test failure rate was approximately 58% (15 of 26 AEC devices) for upright AEC devices. Every failure was from too small of a change in output per density step.

The AEC density test is calculated from an exposure (mR) measurement, therefore the manufacturer of the CR is not relevant. Approximately 63% (29 of 46 AEC devices) of AEC devices paired with CR imaging systems failed the density test. 50% (4 of 8 AEC devices) of the DDR systems failed the AEC density test.
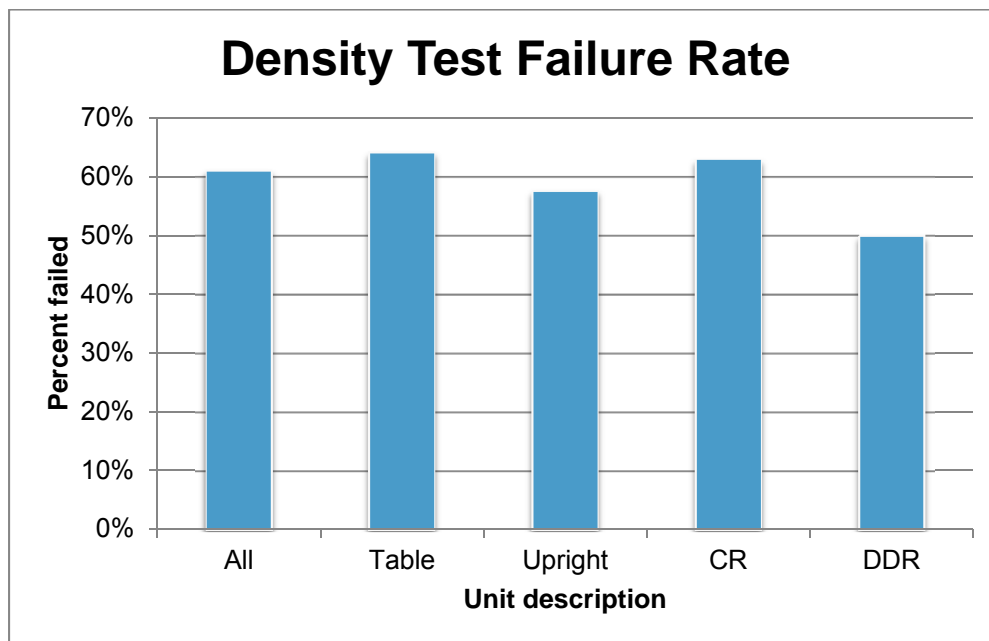

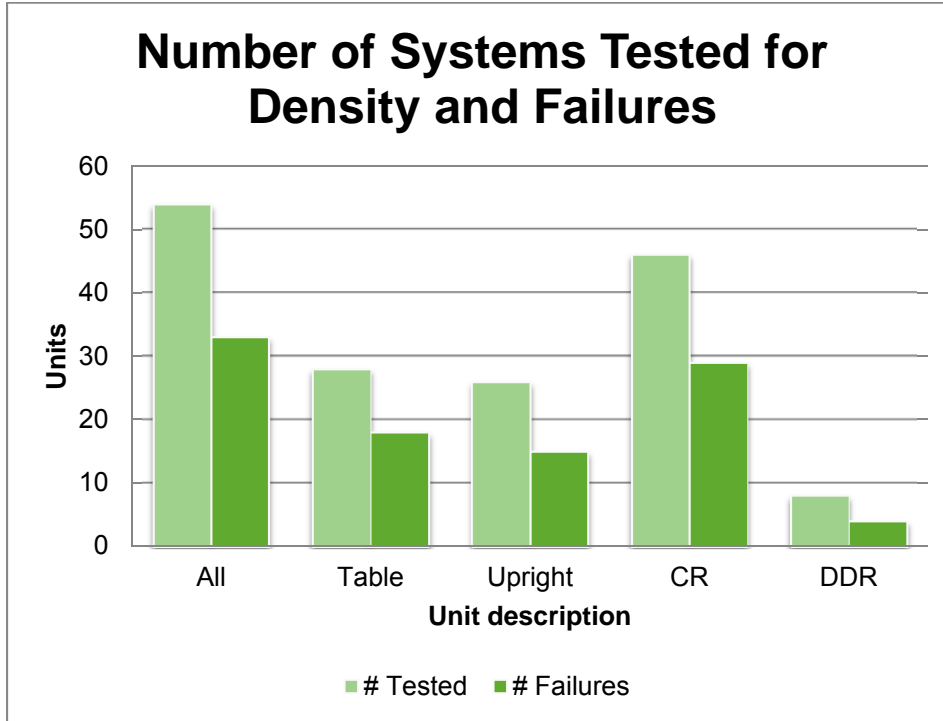Figure 13. Percentage of systems failing the AEC density test.

Figure 14. Number of systems tested for AEC density variation and corresponding number of failures.

EI Range Results

As seen in figures 15 and 16, about 61% (33 of 54 AEC devices) of all of the

AEC devices tested resulted in an EI considered to be appropriate by the stated

tolerances. For table AEC devices about 39% (11 of 28 AEC devices) were outside of

the suggested EI range. Approximately 38% (10 of 26 AEC devices) of the upright AEC

devices failed to produce EIs in an acceptable range.

45% (9 of 20 AEC devices) of the AEC devices paired with Fuji CR systems were

not in the acceptable "S" number range. For Konica CR systems, the AEC devices

produced unacceptable "S" numbers for almost 14% (3 of 22 AEC devices) of the tested

units. Agfa CR systems produced acceptable lgM values for 50% (2 of 4 AEC devices)

of the tested units. Overall, close to 70% (32 of 46 AEC devices) of AEC devices

coupled with CR imaging systems produced acceptable EI values. Just fewer than 13% (1 of 8 AEC devices) of the AEC devices associated with DDR systems produced acceptable EI values.

None (0 of 46 AEC devices) of the CR systems were overexposed as a result of the phototimed exposures. 50% (4 of 8 AEC devices) of the DDR systems were overexposed due to the AEC calibration.
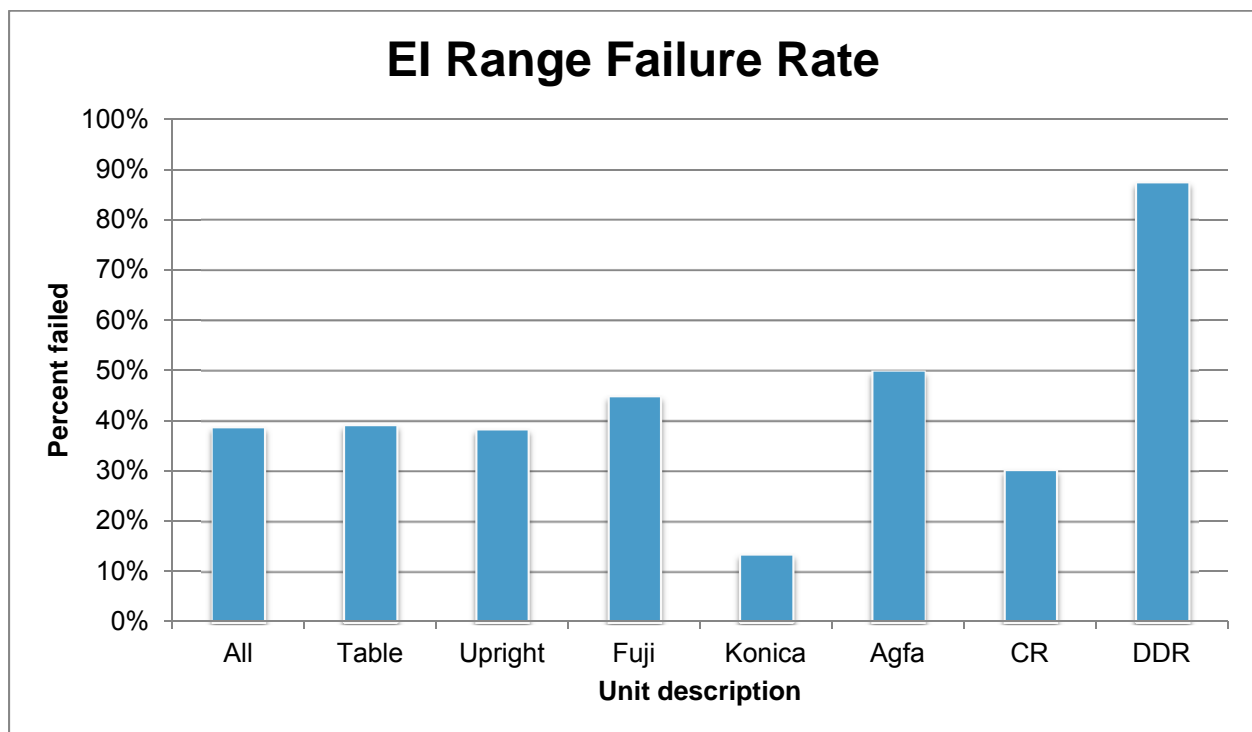

Figure 15. Percentage of systems failing to produce images within an acceptable EI range.
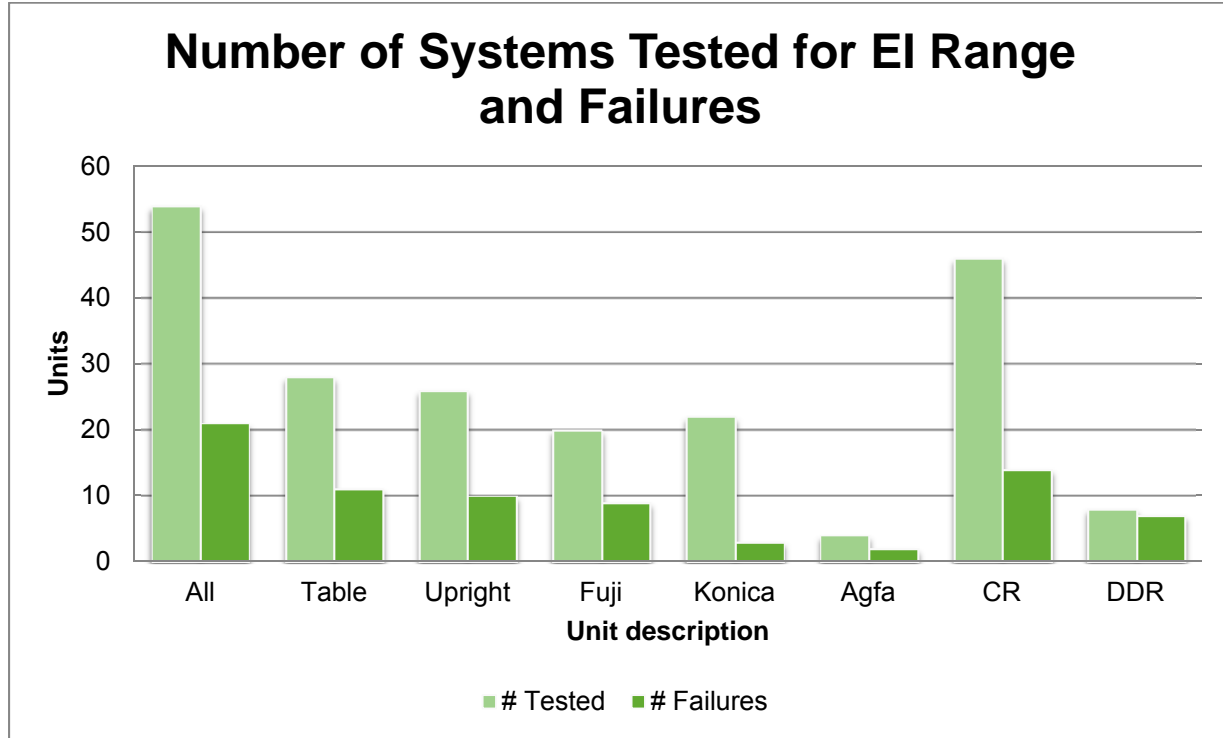
Figure 16. Number of systems tested for images with acceptable EI ranges and corresponding number of failures.

Overall Failure Rate Results

Out of all 54 units tested, 11 passed all performed tests as shown in figure 18. This is just over 20% as shown graphically in figure 17. Slightly over 21% (6 of 28 AEC devices) of the table Bucky AEC devices passed all tests, and just fewer than 20% (5 of 26 AEC devices) of the upright Bucky AEC devices passed all tests. Among the different manufacturers paired with AEC devices, all tests were within tolerance for 30% of the Fuji systems, just over 13% of the Konica systems, and 50% of the Agfa systems. More than 76% of all CR manufacturers failed at least one test. No DDR systems passed all AEC tests.

Figure 17. Percentage of systems failing one or more test related to the AEC.

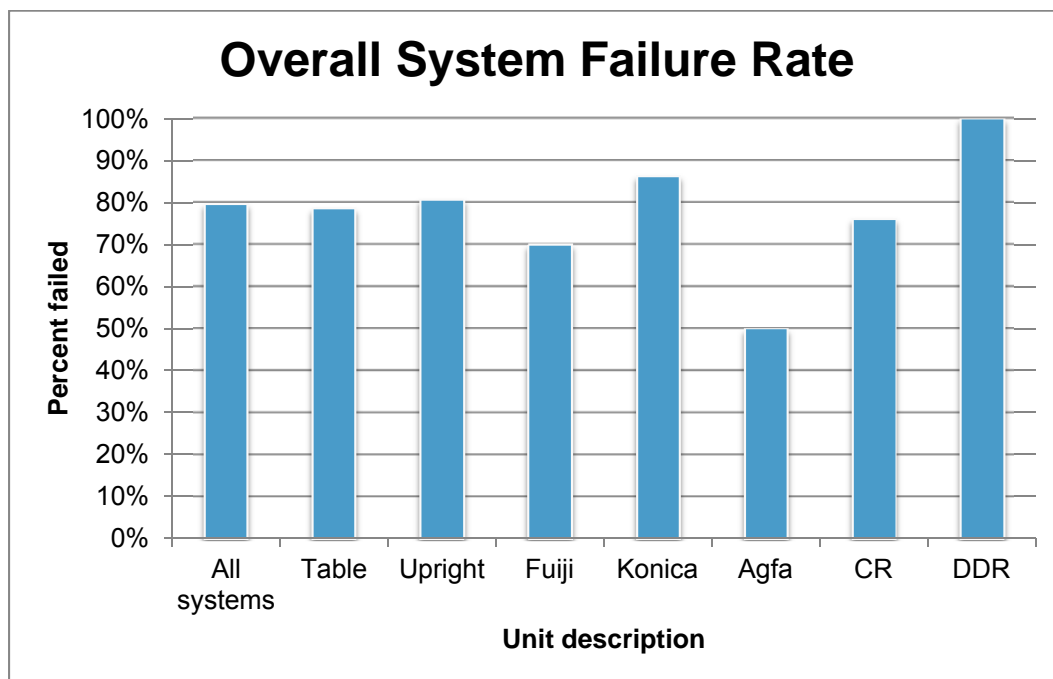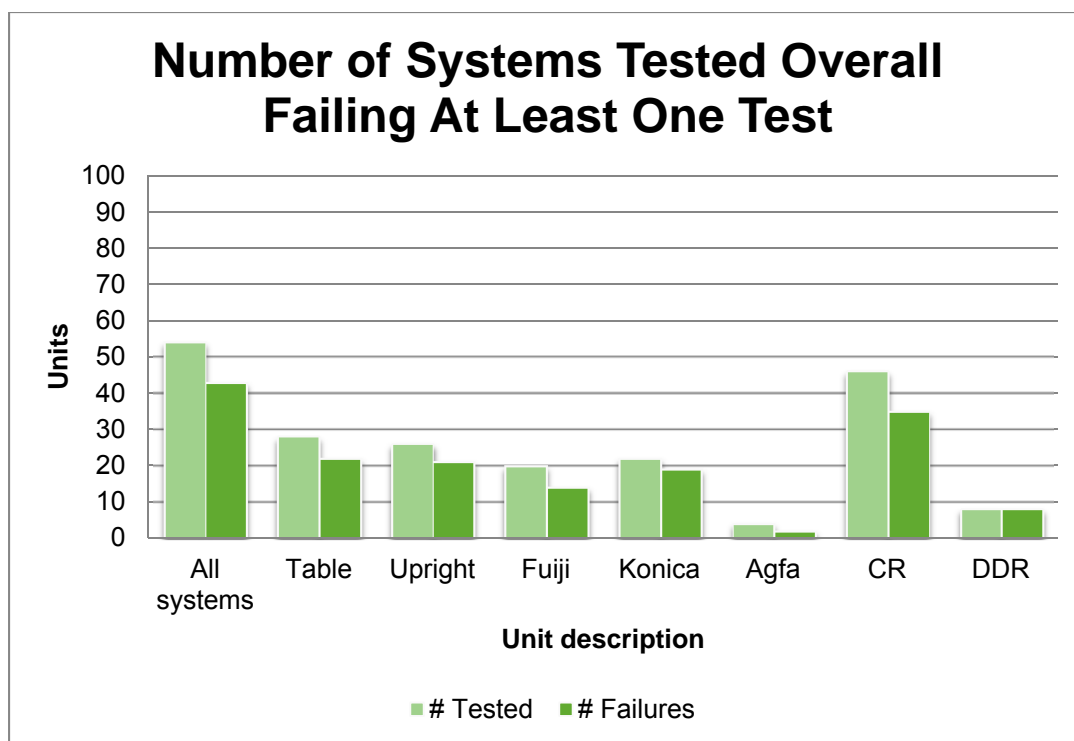Figure 18. Number of systems tested overall and corresponding number of systems failing one or more test.

Chapter 5

DISCUSSION

5.1 Evaluation of Tests Results

DDR systems were not analyzed by manufacturer due to the low number of units

tested. There was no noticeable difference among the results for different DDR

manufactures.

Evaluation of Performance Results

The most interesting finding was that only one CR manufacturer experienced

failures in the performance tests, and that manufacturer had a failure rate of 30% for

meeting the performance testing criteria. It was discovered that 5 of the 6 Fuji CR

failures from this research were at one department using an IP with a significantly

different sensitivity than the others used for testing. This cassette was subsequently

removed from service. The AECs were not immediately retested using a single IP or

IPs tested for minimal variation. This IP contributed to failures for the Performance,

Balance, and Range tests results.

While AEC devices paired with Agfa CR systems had no failures for the

performance test, this is likely due to a larger tolerance given to Agfa systems by err. It

wasn't discovered until after the data was analyzed that Agfa CR systems were allowed

a larger tolerance than the other CR systems. Specifically, the acceptable performance

and balance tests variation was set at approximately one fifth of the acceptable range

for Fuji and Konica systems, while the range of Agfa systems was set to approximately one third of the acceptable range.

Also notable is the high failure rate of performance tests for AEC devices used with DDR systems. Of the 8 AEC devices tested which used DDR, 6 were systems designed for use with either CR or film. It is possible calibrations were not performed to account for the DDR updates, although this information is unknown. Only one of the 6 DDR retrofitted systems passed the performance test. Of the 2 systems designed for use with DDR, 1 failed and 1 passed the performance test. More data is needed to draw any conclusions about the high performance test failure rate of AEC devices used with DDR.

There was no significant difference between the failure rate of the table and upright AEC devices for the performance test.

It should be noted, AAPM Report 14 recommends independently evaluating attenuator thickness and tube potential (AAPM, 1985). However, the testing reported in this paper varied both attenuator thickness and tube potential simultaneously. Also note, AAPM Report 14 recommends varying attenuator thickness from 5 to 35 cm, the tests reported on in this paper used approximately 9.6 to 24 cm (AAPM, 1985).

Evaluation of Balance Results

Approximately one third of the AEC devices failed the balance test. Slightly more of these failures were from the upright Bucky AEC devices. Notably AEC devices

paired with Agfa CR systems had no failures for the balance test. This is likely due to the larger tolerance given to Agfa systems mentioned above.

The DDR systems performed much worse than CR in the balance test. This might be because some newer systems employ a different balance scheme and the DDR systems are newer than the CR systems.

Evaluation of Reproducibility Results

The reproducibility test had the lowest number of failures out of all the performed tests. This is an important observation because the goal of an AEC device is to produce consistent results over a range of different tube potentials and patient thicknesses. In order to get consistent exposures with these variances, the equipment must be reproducible without any variances.

There was no significant difference between the failure rate of the table and upright AEC devices for the reproducibility test.

Evaluation of Density Results

Although more than half of the systems tested failed the density test, every system that failed did so due to insufficient adjustment per step. This is preferred to a failure from too large of a change per step, because the operator might still be able to achieve the intended exposure by increasing the amount of steps required. However, the amount of steps available is finite.

There was no significant difference between density tests failure rates of AEC devices paired with CR systems versus DDR systems. Nor was there a significant difference between the failure rate of the table and upright AEC devices for the density test.

AAPM Report 14 recommends a density tolerance of 20 to 25% change in exposure per step for units with ±4 steps (AAPM, 1985). The upper range was expanded for this research due to the limitation of some systems to only ±2 steps.

It is also important to note the AAPM Report 14 recommendation was suggested for adjustment of contrast when using SF (AAPM, 1985). There are no current AAPM guidelines for AEC density control when using CR or DDR. AAPM Report 74 recommends "0.15 to 0.30 OD per step," which is not applicable to DR (Jones, 2008). NCRP 99 recommends the AEC density is "tested for proper operation and similar step size," which is too vague to be useful (Jones, 2008).

Most units have between ± 2 to 5 steps. When there is a 20 to 50% change per step ± 3 steps should provide ample exposure compensation when used with DR. Because the exposure is directly related to the amount of noise in DR a smaller step, possibly a 10% change, is more appropriate.

It should be noted, AAPM Report 14 recommends using the SF OD or mAs measurements for analysis as opposed to the exposure (AAPM, 1985). However, exposure is directly proportional to mAs and therefore an acceptable metric to use for this test.

Evaluation of Range Results

Half or close to half of the AEC devices paired with Agfa and Fuji CR systems, failed to meet the criteria for the range test. However, for AEC devices paired with Konica CR systems, only 14% of the devices failed. This might suggest Konica systems drift less, or are more often calibrated relative to Agfa and Fuji CR.

There was a significant difference between the failure rates of AEC devices paired with CR systems (30%) versus DDR systems (88%). This suggests the DDR systems are not being calibrated or the ranges used for evaluation are not appropriate.

There was no significant difference between the failure rate of the table and upright AEC devices for the range test.

5.2 Sources of Error

EI ranges are non-normative. It is practically impossible to apply one acceptable range to multiple radiographic systems due to the combination of different manufacturers, models, exams, radiologists' preferences, and beam filtration. In addition, EIs are influenced by scatter, source distance, field collimation, and the delay in processing from time of exposure.

Performance errors

Williams et al., (2007), uses acceptable ranges for EI values as follows: Fuji S number between 150 and 300 and Agfa lgM between 2.05 and 2.35. However, the paper warns against using these values due to variations in x-ray generator output characteristics and CR IP energy sensitivities. In addition the acceptable EI varies by

model for some manufacturers, exam type, patient size, and radiologist's preference, thus no absolute standard range is available. This has resulted in a variety of published ranges.

Use of multiple kVps relies on calibration of EI with tube potential correction curves. The state of this calibration was unknown for all units. The IP and cassette reader (write/read) reproducibility was only assumed for the tests. Variation as a result of the IPs and readers is further discussed later in this section.

The exposure to the IP should be the same across the range of thicknesses and kVps. For DR, AAPM Report 116, suggests the incident air KERMA not to very more than ± 7% over a range of various attenuation thicknesses and kVps (AAPM, 2009). Perhaps it would be more appropriate to calculate variance on the percent difference from the mean as opposed to an absolute maximum deviation from the mean as recommended in AAPM Report 14 (AAPM, 1985).

Balance errors

Some manufacturers have changed balance schemes so the left and right chambers are set to 1.15 times the exposure of the center chamber. Others keep with the traditional balance scheme where all chambers are set to provide equal exposure. The method used for this research assumed all chambers were programed with the traditional balance scheme where all chambers are equal. Prior work was discovered which warns against a "one-size-fits-all" method when testing balance on a variety of systems (Jones, n.d.).

The IP and cassette reader (write/read) reproducibility was only assumed for the tests. Variation as a result of the IPs and readers is further discussed later in this section.

Reproducibility errors

There are no known errors. The test assumes reproducibility of other equipment. The generator reproducibility was confirmed for these results using the same detector, which would confirm reproducibility of both the generator and detector.

Density errors

There are no known errors. The test assumes reproducibility of other equipment. The generator reproducibility was confirmed for these results using the same detector, which would confirm reproducibility of both the generator and detector.

Calibration and Accuracy of Exposure Index

The calibration of CR readers was not verified for the devices used in this research. IP read-write reproducibility was only assumed. Initial EI calibration and quarterly EI accuracy tests are recommended by AAPM Report 93 (AAPM, 2006).

The accuracy of the EI is dependent upon verification of the CR reader (AAPM, 2009; Jones, n.d.; Thakur et al., 2012). Improper calibration is one of the most significant sources of variability among manufacturers (AAPM, 2009). AAPM Report 93

strongly recommends the vendor to include a quality control phantom and EI assessment program when a CR system is installed (AAPM, 2006).

Fuji recommends testing S number calibration monthly, with a FCR quality assurance program and the Fuji 1 Shot Phantom (MacCutcheon, 2004). Agfa also recommends periodic quality control to check for CR system sensitivity (Schaetzing, 2004). Canon requires weekly calibration of DR systems to adjust for drifts from environmental and power changes to keep REX values representative of the exposure to the detector (Arreola, & Rill, 2004).

Some manufacturers state the EI values have an accuracy within ± 20%, others quote ±10% (Butler et al., 2010). AAPM report 93 recommends linearity of reader response to the IP exposure should correlate within 10% (AAPM 2006). This is unknown for all of the data, linearity of the reader was not tested.

Internal AEC Variation

Some upright AEC devices are set up to provide a higher exposure relative to the table Bucky AEC device due to historical differences in SF speed classes between table Bucky work and upright Bucky work (Christodoulou et al., 2000). The data obtained for this research does not indicate any of the tested systems were configured this way.

Variation Among Cassette Imaging Plates

It is important when testing CR and multiple cassettes are used, that the sensitivities of the CR plates used have minimum variation from each other. AAPM Report 14 states for SF the variation must be less than 3% (AAPM, 1985). Fuji quotes

the S-numbers should be within ± 20% from IP to IP (Fauber et al., 2002). As

mentioned previously, one IP was found to have significant variation in sensitivity from

other IPs used for testing. This contributed to several failures on the tested units.

Variation within a Single Imaging Plate

One source found "S" number variance within individual IPs to be < 20% of the

mean for consistent exposures, which was considered insignificant (Fauber et al.,

2002).

Variation Among Readers

On occasion multiple readers within a department were used when testing an

AEC device. Variation among multiple CR readers was found to be statistically

significant by at least one report (Fauber et al., 2002).

Daily variation among a single CR reader was found to be less than ± 20% of the

calculated mean from day to day (Fauber et al., 2002). All measurements in this report

were made the same day for an individual AEC test.

Scatter and Background

PSP IPs are highly sensitive to radiation, including scatter and natural

background radiation (Cesar, 1997). Thus infrequently used IPs can increase mottle

within the image and affect the displayed EI. Cassettes used for this testing were not

erased prior to testing. Fuji recommends erasing any IP that has not been used within

48 hours (Fujifilm Medical Systems, 2004).

Processing Delay

The delay from the time of exposure to when images were read was not recorded for this research, but thought to be minimal, due to relative similarity. However, it should be noted uncertainties are introduced from the decay of prompt phosphorescence in the recorded signal (AAPM, 2006). A ten minute delay is commonly recommended to reduce these uncertainties (AAPM, 2006). Thus, image processing delay most likely did contribute to fluctuations in the EI.

Beam Filtration

AEC calibration "involves beam quality dependencies of detector absorption efficiencies" (Jones, 2008). The sensitivity of the EI to kVp and beam energy variations can be reduced with a hardened x-ray beam (AAPM, 2009).

The collective effect of kVp and thickness variation is likely to be less for DR and CR than for SF (Jones, 2008). In fact it has been shown that CR has a small variation in response with kVp (Christodoulou et al., 2000). For the same dose, there was "a 10% increase in the S number…as the kVp was increased from 60 to 100 kV" (Doyle et al., 2005). This supports the method of simultaneously varying the kVp and phantom thickness.

Sensitivity Drift versus Calibration

It should be noted that testing reported on for this project only included devices that had been tested on an annual basis prior to these results (no initial acceptance testing was performed for this research). Furthermore, this paper does not separate

units that had been tested in the prior 12 months from those that had not been tested in more than 12 months. Service dates and frequency was not obtained, thus drift is unknown. Drift is assumed to be less for units which were calibrated a relatively short time before testing. Additionally, the initial calibrations are not accounted for, thus the unit might have been properly or improperly calibrated during installation.

Processing Errors

The EI depends on the image region analyzed, meaning different reported EI values will be displayed when a different image region is selected. Each body part and anatomical view can use a different processing algorithm. Thus, the correct selection must be used when processing the image. The segmentation used to calculate the EI is based off of the chosen selection. However, the segmentation algorithm selected is considered image-independent when "the same correction is applied to all images independent of the image contents" (IEC, 2008). In other words EI fluctuations are independent of the selected region, but the EI range is dependent on the selected region when using a flat field algorithm for each image.

Cassette Radiography Reader Errors

In the absence of an "extreme overexposure" incomplete erasure of the IP should not have been a problem because, "essentially all of the residual trapped electrons are removed during the erase cycle" (AAPM, 2006).

Overall Sources of Noise in a Cassette Radiography Image

There are several possible sources of noise in a CR image. These sources are:

> x-ray quantum mottle, variation in the photostimulable
> luminescence of the imaging plate, electronic noise from the
> digitization process, and structured noise (from nonrandom
> sources such as nonuniformities in the phantom, grid
> defects, non-uniform response of the CR plate due to
> physical or chemical nonuniformities (e.g., variations in
> thickness, density, or number of electron traps at different
> locations on the plate, etc.) (Christodoulou et al., 2000).

Other Errors

AEC performance may change depending on the type of cassette and radiation

detector used as a result of backscatter from the cassette. Grid selection is another

source of possible errors. Grids were not examined in this testing unless there was a

noticeable problem.

Chapter 6

CONCLUSION

6.1 Case for Continuing to Test Automatic Exposure Control Devices in the Era of Filmless Radiography

Regulations are required for kVp accuracy, beam filtration, timer accuracy, mAs linearity, field size calibration, etc. But national regulations for AEC devices only address the minimum and maximum exposure duration. It is important to check other aspects of AEC devices, because the process of using the AEC is largely automated. AEC calibration is directly related to patient exposure and overexposures are capable of being masked by processing software. Considering this, the overall failure rate of AEC devices, as tested in this research, was unacceptably high. Proper functioning and calibration of AEC devices is important to keep exposures ALARA. As a result regulations should require regular evaluation of AEC devices, which include the performance, balance, reproducibility, and density tests, when used with all imaging device types. However, regulations are unlikely to exist without standards for testing AEC devices which are used with DR equipment.

The data presented for this research demonstrates a serious lag between the current standards and current technology. This gap needs to be addressed. There were far too many failures discovered during this investigation. However, it is not clear if these failures are due to equipment malfunctions or testing the equipment against improper tolerances. Standards revised for DR should consider the wider dynamic

range while using the lowest exposure possible to produce an image which is of diagnostic quality.

Standards are needed for AEC operation with DR imaging devices as well as DR EI ranges and EI variances. The AEC standard should take into consideration the EI range and variance standards. The EI range and variance standards should account for the related standard of care entrance exposure.

Maybe the standard for the AEC performance test should measure entrance exposure simultaneously with EI values. Using the entrance exposure for a variance measurement would remove uncertainties associated with the imaging device. However the image quality is ultimately what must remain constant. Accordingly, the EI should be the primary test metric for systems used with DR imaging devices.

The standard for the AEC Balance test should recognize additional balance schemes. As a result, the standard will require multiple acceptable tolerances which would be dependent upon the specifics of each balance scheme.

The standard for the AEC reproducibility test can remain unaffected by the changes associated with DR technology. The imaging device is irrelevant to the reproducibility test, thus no updates are needed.

Although the AEC density adjustment is dependent upon manufactures' specifications, all devices should adjust density steps within a standard range. A national standard currently exists only for SF technology, and should be reevaluated for operation with DR imaging devices. The standard must be revised for the density test in order to address the change in SNR relative to incident exposure for digital images.

Acceptable ranges for uniform, flat field, test images need to be established for each DR imaging device. These numbers would likely be different for each manufacturer based on the quantum detection efficiency of the detectors, but they could be based on a standard, agreed upon, SNR. Additionally these ranges should cover a spectrum of SNR which is considered acceptable for diagnostic image quality. The variance within each range, for the same type of image, should also be established. Current standards for both range and variance exposure appropriateness exists only for SF.

The research conducted in this paper also highlights the importance of CR reader calibration and variation among cassette IP sensitivity when performing AEC tests. This research supports the recommendation to test CR readers and cassette IPs to ensure proper operation.

6.2 Future Work

Additional research is required to help develop the standards and regulations previously mentioned. Each individual AEC test must be examined with the use of DR technology in order to determine specific tolerances. More research is also needed to determine appropriate EI ranges and variances. The manufacturers of CR and DDR equipment need to assist in the development of acceptable EI values.

Research is also needed examine the source of AEC errors to determine the extent of drift versus initial calibration errors. This information will be required to establish a reasonable frequency of AEC testing.

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Appendix A

List of equipment used for this research.

Agfa Medical Systems (Ridgefield Park, NJ)

Bluetooth www.Bluetooth.com. (Kirkland, WA)

Canon CXDI 70 DR (Melville, NY)

Carestream DR (Rochester, NY)

Fuji Medical Systems (Stamford, CT)

GE Definium 5000 (Pittsburgh, PA)

Konica Imaging Systems (Wayne, NJ)

Palm Tungsten E2 Palm, Inc. (Sunnyvale, CA)

RTI Barracuda www.rti.se/products/barracuda

Appendix B

CALIBRATION CERTIFICATE ✓ RTI | From Radiation to Information

LABORATORY ACCREDITATION BUREAU
ACCREDITED ISO/IEC 17025
Certificate # L2338 Calibration

Calibration certificate issued by an accredited calibration laboratory.
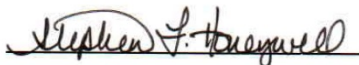
AIR KERMA

Page 1 of 2

Certificate Number	141F22903U
Serial number	MPD-08120102
Date of calibration	2014-01-13
Object	kVp-, dose-, doserate- and time-meter
Manufacturer	RTI Electronics
Type	Barracuda MPD
Man. part number	9622002

Environment
All climatic conditions are within RTI's limits for a reliable calibration environment, i.e. 18-26 deg C, 90 -110 kPa, and <70 % air humidity. For the solid-state detectors manufactured by RTI Electronics no temperature or pressure corrections of readings are required.
Room temperature 24,2 °C
Air pressure   101,3 kPa

Geometric arrangement
The detector was irradiated perpendicular to the entrance window.
The reference point is 8,13 mm behind the cross on the surface of the detector. The depth is marked with a rim on the detector side.

Method
The method is described in the document MTD-020 Calibration method-Dose, by RTI Electronics Inc.

Traceability
The calibration is performed by comparison against a reference ion chamber. The reference ion chamber is traceable through PTB (Germany) to national or international measurement standards.

Uncertainty
The expanded uncertainty for the calibration factor, NK, at reference conditions when calibrating is ±1.4 %. The reported expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, which for a normal distribution corresponds to a coverage probability of approximately 95 %. The standard uncertainty of measurement has been determined in accordance with EAL Publication EA-4/02.

Pass/Fail criteria
Pass/Fail criteria is set so that the objects specifications are fulfilled with a margin including the expanded uncertainty of the calibration. The criteria are specified in the method description referred to above.

Evaluation
A new calibration factor is derived every time the detector is recalibrated.

Next calibration
2016-01-07 according to manufacturers recommendation.

Authorized by:

[signature]

The calibration results refer exclusively to the object.
This calibration certificate may not be circulated other than in full.
Template version: 2012.11B

APPENDIX B (Continued)

CALIBRATION CERTIFICATE

AIR KERMA

Certificate Number	141F22903U				
Serial number	MPD-08120102				
Date of calibration	2014-01-13				
Radiation quality	Designation	R1			
	Reference (kVp)	70 kV			
	X-ray target	Tungsten			
	Total filtration	2,17 mm Al + 0,83			
	HVL	3,09 mm Al			

Calibration factor	N_K	$0,1245 \cdot 10^6$ Gy/C		Before adjustment	$0,124183 \cdot 10^6$ Gy/C
	N_K	$14,21 \cdot 10^6$ R/C		Before adjustment	$14,169 \cdot 10^6$ R/C

Calibration factor N_K in terms of air kerma

Reading with a meter: When the object is used with an RTI electrometer with a valid calibration certificate, the expanded uncertainty of the dose and dose rate readings at reference conditions is 2,7%, see measured results below.

	Reference	Object	Deviation	Tolerance	Status
After adjustment	1,2025 mGy	1,2027 mGy	0,0%	±5,0%	Pass
	137,21 mR	137,23 mR	0,0%	±5,0%	Pass
Before adjustment	1,2025 mGy	1,1992 mGy	-0,3%	±5,0%	Pass
	137,21 mR	136,83 mR	-0,3%	±5,0%	Pass

Reference equipment	013-R1-130502	Dose Detector	RTI R100 Dose Detector
	30-RF4-120328	Voltage divider	Sedecal Internal Divider
	31-R4-120328	RTI US X-ray lab 4, R/F	Sedecal, Mod. SHF 535
	110-4-120328	Electrometer	RTI Solidose 400 Electrometer
	301-120328	Thermometer	Testo 925
	303-120328	Barometer	GTD 1100