

Digital and Film Radiography Comparison and Contrast Reference Handout

A Special Seminar for the ASNT Fall 2015 Conference



Terms and Definitions

- Direct Radiography (DR)* – Radiography that converts radiation directly to stored image data.
- Indirect Radiography – Radiography that uses an intermediate storage medium prior to storage of the image data.
- *Overloaded Acronyms and terms – Acronyms and terms are often used to mean different things, and we need to be careful to try to communicate clearly. For example:

Cameras



Terms & Definitions

- Film Radiography (RT)
- A form of radiographic imaging, where photographic film is exposed to radiation transmitted through an item being inspected, and light or radioactive rays, an invisible image (called a latent image) and a latent image is formed in the emulsion layer of the film. Conversion of the latent image to a visible image is through chemical processing. Traditional Film Radiography must use more radiation to produce an image of similar contrast to digital methods.
- The image is stored on a sheet of radiographic film which is viewed based on the transmission of light through the film.

Terms and Definitions

Digital Radiography (DR)

- A form of radiographic imaging in which digital detectors are exposed to the radiation transmitted through an item being inspected, and convert the transmission data to a digital file to be stored and displayed on a computer.
- A form of radiographic imaging, where digital radiographic sensors are used instead of traditional radiographic film. Advantages include time efficiency through bypassing chemical processing and the ability to digitally transfer and enhance images. Also, in most cases, less radiation can be used to produce an image of similar contrast to film radiography.
- Instead of radiographic film, digital radiography uses a digital image capture device. This gives advantages of immediate image preview and availability; elimination of costly film processing steps; a wider dynamic range, which makes it more forgiving for over- and under-exposure; as well as the ability to apply special image processing techniques that enhance overall display of the image.

Terms and Definitions

Computed Radiography (CR)

- Digital Radiography using storage phosphor plates as an intermediate storage media prior to scanning the plate to create a digital image.
- Implementation is similar to film radiography except that in place of a film to create the image, an imaging plate (IP) made of photostimulable phosphor is used.
- The imaging plate is housed in a cassette and placed under the body part or object to be examined and the radiographic exposure is made. Hence, instead of taking an exposed film into a darkroom for developing in chemical tanks or an automatic film processor, the imaging plate is run through a special laser scanner, or CR reader, that reads and digitizes the image.

Terms and Definitions

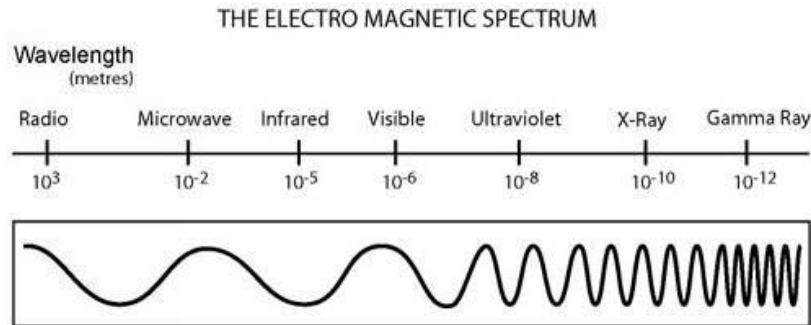
Computed Tomography (CT)

- Digital Radiography that allows data to be displayed in a non standard manner.
- Implementation requires additional image acquisition, additional handling hardware, and complex image processing algorithms
- Makes use of computer-processed combinations of many radiographic images taken from different angles to produce cross-sectional (tomographic) images (virtual 'slices') of specific areas of a scanned object, allowing the user to see inside the object without cutting.
- Image processing is used to generate a three-dimensional image of the inside of the object from a large series of two-dimensional radiographic images taken around a single axis of rotation.

Film vs Digital Comparison

Film	Digital
Development time	Faster (immediate or near immediate results)
Technology and equipment well known and understood	Technology continuously developing and not as well understood
Requires HAZMAT chemical processing	No HAZMAT chemicals
Physical transfer of film	Electronic transfer of data
Simpler and better known process controls	More complex for setup and process controls
	Wider dynamic range
	Ability to process and manipulate data
	Requires less radiation and time for exposures

Radiation Spectrum



- Radiographic inspection utilizes energy levels exceeding ultraviolet light
- Develops penetrating, and ionizing capabilities
- Causes a reaction in the detector used to develop an observable image
- Areas of higher density will allow less radiation to pass through, while areas of lower density will allow more radiation to pass through. This creates an image of defects of higher or lower density than the material around it.

Nyquist-Shannon Sampling Theorem

- This theorem is typically utilized in digital radiography to answer the all important question:

What resolution do I need to see the level of detail required for a given flaw size?

Nyquist-Shannon Sampling Theorem

Definition (abbreviated):

“In the field of digital signal processing, the **sampling theorem** is a fundamental bridge between continuous-time signals (often called "analog signals") and discrete-time signals (often called "digital signals"). It establishes a sufficient condition for a sample rate that permits a discrete sequence of *samples* to capture all the information from a continuous-time signal of finite bandwidth.”¹

“The sampling theorem introduces the concept of a sample rate that is sufficient for perfect fidelity for the class of functions that are bandlimited to a given bandwidth, such that no actual information is lost in the sampling process. It expresses the sufficient sample rate in terms of the bandwidth for the class of functions. The theorem also leads to a formula for perfectly reconstructing the original continuous-time function from the samples.”¹

¹ Excerpts from Wikipedia, the free encyclopedia.

Nyquist-Shannon Sampling Theorem

- **Critical frequency** .¹

To illustrate the necessity of $f_s > 2B$, consider the family of sinusoids (depicted in Fig. 8) generated by different values of θ in this formula:

$$x(t) = \frac{\cos(2\pi Bt + \theta)}{\cos(\theta)} = \cos(2\pi Bt) - \sin(2\pi Bt) \tan(\theta), \quad -\pi/2 < \theta < \pi/2.$$

With $f_s = 2B$ or equivalently $T = 1/(2B)$, the samples are given by:

$$x(nT) = \cos(\pi n) - \underbrace{\sin(\pi n)}_0 \tan(\theta) = (-1)^n$$

Nyquist-Shannon sampling theorem

Pixel pitch = ρ

Nyquist frequency = $\frac{1}{2} \rho$ LP/mm

Examples

- 50 μm pixel pitch: $\text{NF} = 10$ LP/mm
- 100 μm pixel pitch: $\text{NF} = 5$ LP/mm
- 200 μm pixel pitch: $\text{NF} = 2.5$ LP/mm

What is Noise?

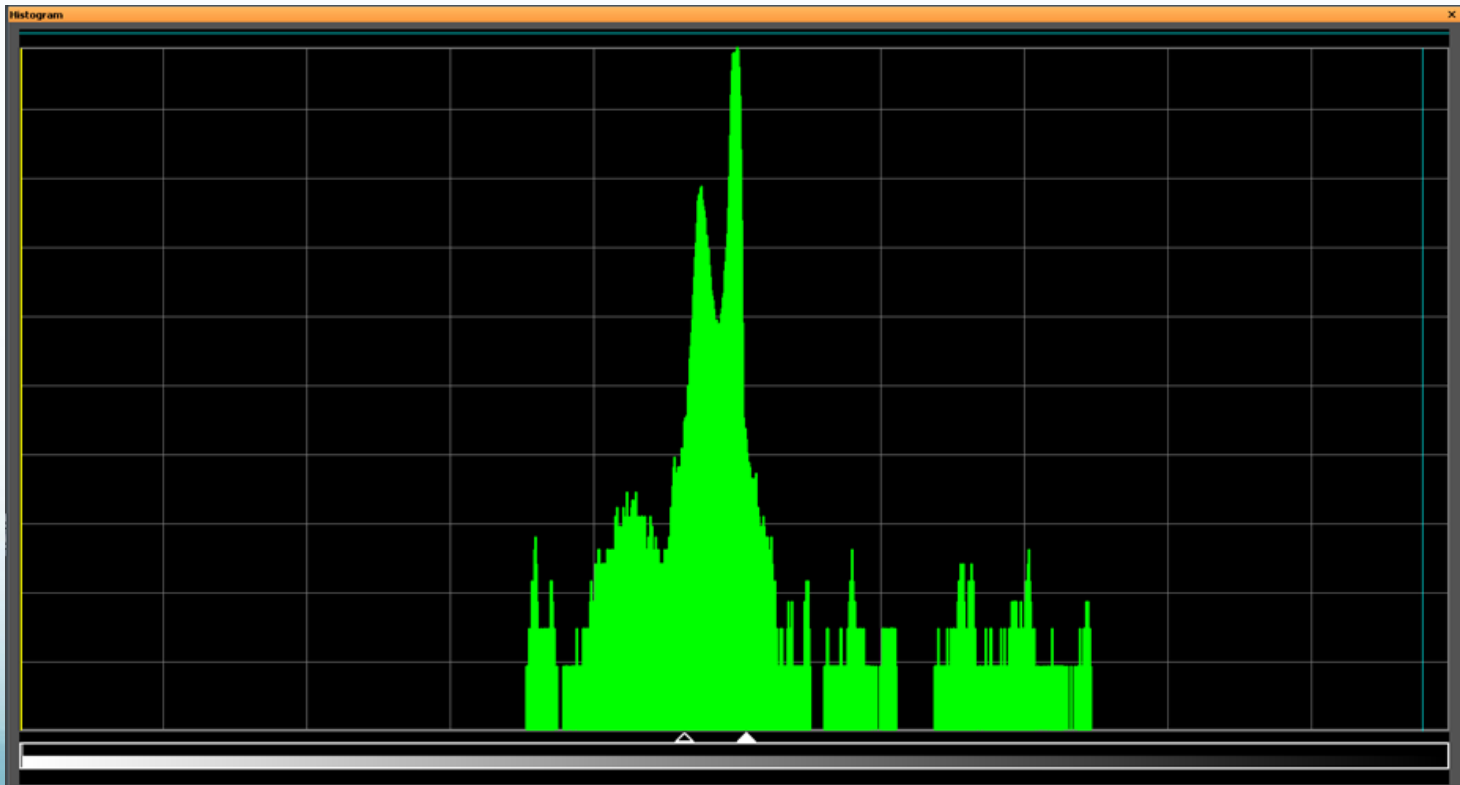
- In Film Radiography noise is caused by scatter, is often referred to as graininess and can be corrected by using a finer film.
- In DR noise is caused by scatter, undesired radiation and other electronic effects that vary by the type of detector.
- In digital techniques, a number on a brightness scale is assigned to a particular value of radiation dose to create an image, when unwanted radiation is present, it takes up those values, reducing the range of values and sensitivity of the test.

Viewing Noise on a Histogram

- A histogram is a representation of all values assigned to every level of dose received on the digital detector.
- If a particular system was capable of assigning 65,536 gray scale values, a test that assigned 45,000 of those values to radiation that passed through the part would be more sensitive than a test that had more scatter and only assigned 25,000 values to the radiation that passed through the part.

Viewing Noise on a Histogram

- This can be seen by looking at the histogram and viewing the assigned gray scale values.



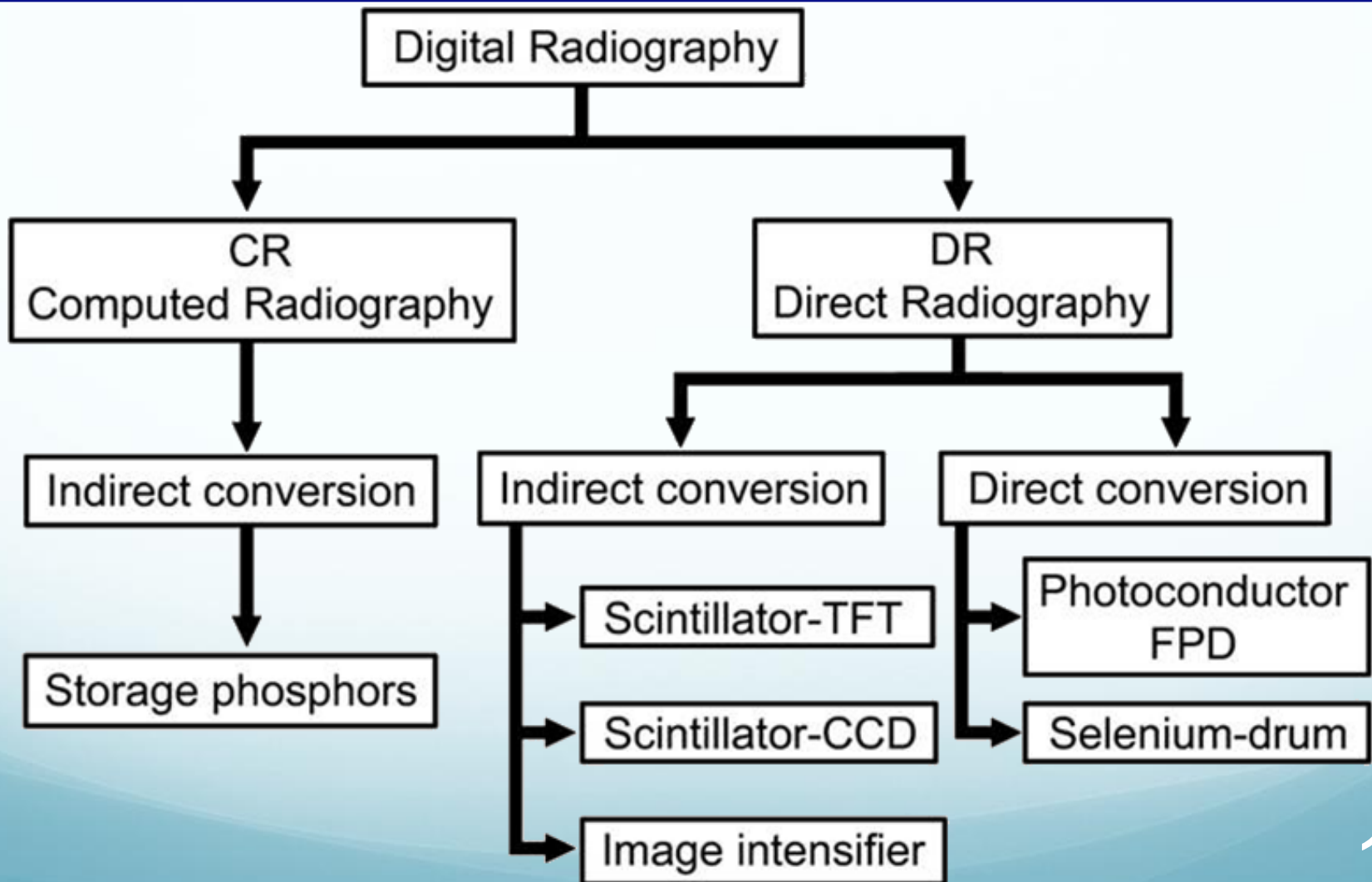
Noise Comparison

Film	DR
Less sensitive to scatter than DR	Far more sensitive to scatter than film
Controlled by scatter reduction	Most easily controlled by scatter reduction; Some detectors (DDA) offer frame averaging capability to increase the Signal to Noise Ratio without overexposing an image
Not easily quantified past IQI sensitivity	Easily and accurately quantifiable using SNR and CNR

Optimization

Film	Digital
Use proper energy to avoid over/under exposure	Use proper energy and flux to avoid detector saturation (blooming effect) or damage
	Use of the “cleanest” source possible and shield detector system to reduce background and scatter problems
	Measurements at different energies can be used to increase/change contrast (ratio of radiographs at different energies for example)
	Depth-of-field can be adjusted with distance scintillator/converter-to-sensor

DR SYSTEM COMPONENTS



Computed Radiography

How is CR Different Than Film

- The CR Image Plate (IP) functions in a completely different fashion than film
- CR has substantially wider latitude than film
- The exposure process requires a different approach partly due to scatter
- The CR scanner functions in a completely different fashion than film processor
- The CR image is displayed on a computer monitor instead of a light box
- Software tools are used to adjust the image in ways film can't be changed
- Image quality measured by Signal to Noise Ratio (SNR) using software tools
- Additional operator training is required

THE ENTIRE PROCESS OF CREATING AN IMAGE
USING Computed Radiography
IS DIFFERENT THAN FILM!

CCD

- CCD: Charge Coupled Device
- Advantages:
 - Large field of view (FOV)
 - High Quantum Efficiency (QE)
 - Different speed read-out (up to a few MHz)
- Disadvantages:
 - Relatively slow system (seconds acquisition time)
 - Lengthy transfer of the data causing dead time between acquisition of radiograph (seconds)
 - Dark current not negligible (reduced when CCD is cooled)

Detector Comparison

Film	Digital
Film Speed	CR and DR generally faster requiring lower dose.
Limited Latitude. Logarithmic film curves.	CR and DDA's have extremely high latitude (bit depth) and linear response. 12, 16, or 32-bit gray scale
Automatic or manual film processing	CR Scanning of IPs. Direct link on DDA's Computer Image Processing to produce images.
Reliance on Chemicals and	Clean processing
Manual Film Cassette Handling	Automation allows CT scans in seconds to minutes, Radiography in fractions of seconds CR can be setup to handle same as film.
Storage of Film in large vaults with possible degradation of image.	Storage of data on file servers requires little space, and indefinite shelf life.
	Capability to perform lens-based magnification
	Lifetime is years (with appropriate shielding)
	Flexibility in field-of-view and spatial and/or time resolution

Computed Tomography

- Radiographs are limited to the collapsing of a 3D object on a 2D image
- Computed/Computerized Tomography (CT) allows reconstruction of the information inside an object
- Reconstruction of a 3D object from 2D radiographs/projections at different angles around the object:
 - Usually stepping angle is fixed
 - Reconstruction provides cross-sections of the object showing density/linear attenuation coefficient mapping
- Some reading material: G. T. Herman, “Fundamentals of Computerized Tomography”, Springer, ISBN: 978-1-85233-617-2

Reconstruction

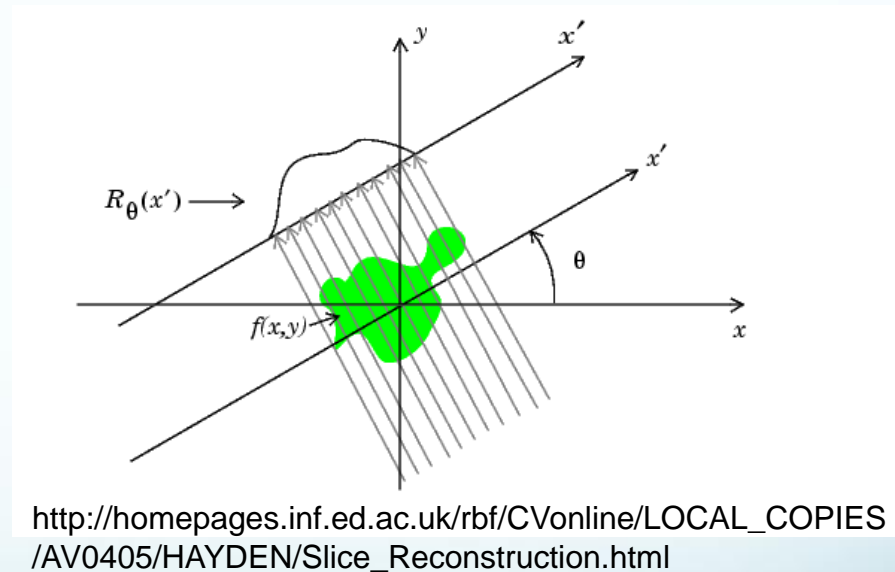
- Several algorithms can be used to reconstruct an object in 3D:
 - Filtered-back projection:
 - Works in Fourier Space
 - Fast but requires data acquisition of projections at a defined stepping angle
 - Little to no missing projection
 - Object with good contrast/attenuation
 - Iterative reconstruction
 - Works in Real Space
 - Computer-intensive
 - Is able to reconstruct an object even with missing projections
 - Can reconstruct objects with very low contrast/attenuation

Reconstruction

- Algebraic – Algorithm that iteratively solves a system of linear equations
- Bayesian – Algorithm that works based calculating a result using probabilistic mathematics
- Compressive Sampling – Reconstruction based on minimizing the sparseness of data

Filtered Back Projection

- Projection is smeared back across the reconstructed image
- Based on Radon Transform
 - Filtering performed before normalization
 - Similar to Fourier Transform: line integrals through $f(x,y)$
 - Data is moved to reciprocal space (1/real space)
- Data is filtered before reconstruction
 - Sharp filter improves achievable spatial resolution



DDA vs. CR vs. Film

<u>Process/criteria</u>	<u>DDA Radiography</u>	<u>Computed Radiography</u>	<u>Film</u>
Procedure:	Direct Image	IP Scanner	Film Development
Resolution:	≥ High Quality Film	Equivalent to MX125	Universal Image Std.
Image Format:	Digital – Discrete Pixels	Digital – Sampled Pixels	Analog
Time to image:	Seconds or Less	Up to 90 sec	10-30 min
Environmental:	None	None	Chemical Disposal
Image Enhancement:	Software Adjust	Software Adjust	Cannot Adjust
Equipment Cost:	\$160K	\$100K	\$80K
Consumable Cost:	Occasional Detector	Small – Replace IP	Relatively Larger
Cassette:	N/A	Flex or rigid	Flex or rigid
Image Storage:	Electronic	Electronic	Physical
Equipment Space:	Computer and Monitor	Computer & Monitor	Dark Room
Portability:	Semi portable	Yes	Yes

Techniques

- Film – Film Speed, Processor Type, Source to Film Distance, Energy Level, exposure time
- DR – Detector Type, Image Processing, Energy Level, Source to Object Distance, Source to Detector Distance, CNR/SNR Usage, Monitor (selection, verification), automation, measurement tool calibration
- CR Plates – sampling rate, pixel resolution of scanner, exposure time
- DDA – pixel resolution of detector, exposure time, frame averaging, detector calibrations
- CCD Camera – pixel resolution, exposure time, image averaging, detector calibrations, detector cooling, florescent screen properties (thickness, brightness, decay, grain size), lens properties (focal spot, F-Stop)

ASTM Standards

General Radiography	Neutron Radiography
94 – Radiographic Examination	STP-624 Neutron Radiography
747- Wire IQIs	E-803-91 Determination of L/D ratio
801 – RT of Electronic Devices	E-748 Thermal Neutron Radiography
1025 – Hole Type IQIs	E-748-2 Thermal Neutron Radiography
1030 – RT of Metal Castings	E-2023-11 Fabrication of Neutron Radiographic Sensitivity Indicators
1032 – RT of Welds	E-2003-10 NRT Beam Purity Indicators
1165 - Focal Spots for X-ray tubes	E-2861-11 Measurements of Beam Divergence and Alignment in Neutron Radiographic Beams
1411 – Qualification of RT Systems	E-721-11 Neutron Energy Spectra from Neutron Sensors for Radiation-Hardness Testing for Electronics
1647 – Contrast Sensitivity	
1817 – Use of Radiographic Quality Indicators	

ASTM Standards

Film	Digital
999 - Film Processing	1255 – Radioscopy
1079 - Densitometer Calibration	1416 – Radioscopy of Welds
1254 – Storage of Radiographs and Film	1441 – Guide for CT Imaging
1390 – Illuminators for RT	1475 – Computer Fields for Transferring Digital Data
1815 – Classification of Film Systems	1570 – Standard Practice for CT
	1695 – Test Method for CT System Performance
	2002 – Image Unsharpness
	2007– Standard Guide for CR

ASTM Standards

Film (continued)	DR (continued)
	2033 – Standard Practice for CR
	2339 - DICONDE
	2445 – Long Term Stability for CR
	2446 – Classification of CR Systems
	2597 – Characterization DDAs
	2698 – Standard Practice for Using DDA
	2736 – Guide for DDA

Standards with reference images were ignored for purposes of this comparison

ASTM Standards

Film (continued)	DR (continued)
	2737 – Long Term Stability DDA
	RP 133 – SMPTE Monitor Test Pattern

Standards with reference images were ignored for purposes of this comparison

ASTM Standards

There are specific standards applicable to each of the radiographic modalities, covering:

- General Radiography – 10 standards
- Neutron Radiography – 8 standards
- Film Radiography – 5 standards
- Digital Radiography – 17 standards

	Source	Detector	Image Review	Process controls for image quality
Neutron Radiography	Isotope Electrical (accelerator) Nuclear Reactor	Film	Reader must understand neutron attenuation; Film viewer with optical magnification (loupe, magnifying glass, etc.)	Film density, different IQI based on difference in radiation attenuation
Film radiography	Isotope Electrical (tube or accelerator)	Film	Film viewer with optical magnification (loupe, magnifying glass, etc)	Film density
Digital Radiography (DR)	Isotope Electrical (tube or accelerator)	Linear Array CMOS DR Panel Cameras	Computer Review with image manipulation and analysis tools	Monitor checks, CNR, SNR, image processing filters, detector calibrations
Digital Radiography (CR)	Isotope Electrical (tube or accelerator)	Phosphor Imaging Plates	Computer Review with image manipulation and analysis tools	Monitor checks, CNR, SNR, image processing filters
Computed Tomography (CT)	Isotope Electrical (tube or accelerator)	Linear Array CMOS DR Panel Cameras	Computer Review with image manipulation and analysis tools	Monitor checks, CNR, SNR, image processing filters, detector calibrations

Summary

- Overview of Digital and Film Radiography was presented:
 - Further in-depth understanding is critical for digital radiography as the field is broad and is constantly evolving
 - Method selection depends on the source and the application (for example, fast kinetics with ms time resolution may be best suited with digital imaging, whereas hard-to-reach field applications may be better suited with film)

Summary

- Digital capabilities are versatile and flexible, provide the capability to collect data with higher dynamic range, and require image processing and analysis expertise, along with equipment set-up knowledge and fast computers/servers for data storage, processing and analysis.

ASTM Standards

- E 94 Standard Guide for Radiographic Examination
- E192 Reference Radiographs of Investment Steel Castings for Aerospace Applications
- E 543 Standard Specifications for Agencies Performing Nondestructive Testing
- E 592 Standard Guide to Obtainable ASTM Equivalent Penetrameter Sensitivity for Radiography of Steel Plates 1/4 to 2 in. (6 to 51 mm) Thick with X-Rays and 1 to 6 in. (25 to 152 mm) Thick with Cobalt-60
- E 746 Standard Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems
- E 747 Standard Practice for Design, Manufacture, and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology
- E 748 Standard Practices for Thermal Neutron Radiography of Materials
- E 801 Standard Practice for Controlling Quality of Radiological Examination of Electronic Devices
- E 999 Guide for Controlling the Quality of Industrial Radiographic Film Processing
- E 1000 Standard Guide for Radioscopy
- E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
- E 1030 Standard Test Method for Radiographic Examination of Metallic Castings
- E 1032 Standard Test Method for Radiographic Examination of Weldments
- E 1079 Practice for Calibration of Transmission Densitometers
- E 1165 Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging
- E 1254 Standard Guide for Storage of Radiographs and Unexposed Industrial Radiographic Films
- E 1255 Standard Practice for Radioscopy
- E 1316 Standard Terminology for Nondestructive Examinations
- E 1390 Standard Specification for Illuminators Used for Viewing Industrial Radiographs
- E 1411 Standard Practice for Qualification of Radioscopic Systems
- E 1441 Standard Guide for Computed Tomography (CT) Imaging
- E 1453 Standard Guide for Storage of Media that Contains Analog or Digital Radioscopic Data
- E 1475 Standard Guide for Data Fields for Computerized Transfer of Digital Radiological Examination Data
- E 1570 Standard Practice for Computed Tomographic (CT) Examination
- E 1647 Standard Practice for Determining Contrast Sensitivity in Radiology
- E 1672 Standard Guide for Computed Tomography (CT) System Selection
- E 1695 Standard Test Method for Measurement of Computed Tomography (CT) System Performance
- E 1735 Standard Test Method for Determining Relative Image Quality of Industrial Radiographic Film Exposed to X-Radiation from 4 to 25 MeV
- E 1742 Standard Practice for Radiography Examination
- E 1815 Standard Test Method for Classification of Film Systems for Industrial Radiography
- E 1817 Standard Practice for Controlling Quality of Radiological Examination by Using Representative Quality Indicators (RQIs)
- E 2002 Standard Practice for Determining Total Image Unsharpness in Radiology
- E 2003 Standard Practice for Fabrication of the Neutron Radiographic Beam Purity Indicators
- E 2007 Standard Guide for Computed Radiology (Photostimulable Luminescence (PSL) Method)
- E 2033 Practice for Computed Radiology (PSL Method)
- E 2339 Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)
- E 2422 Standard Digital Reference Images for Inspection of Aluminum Castings
- E 2445 Standard Practice for Qualification and Long-Term Stability of Computed Radiology Systems
- E 2446 Standard Practice for Classification of Computed Radiology Systems
- E 2597 Standard Practice for Manufacturing Characterization of Digital Detector Arrays
- E 2660 Standard Digital Reference Images for Investment Steel Castings for Aerospace Applications
- E 2663 Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for Ultrasonic Test Methods
- E 2669 Standard Digital Reference Images for Titanium Castings
- E 2698 Standard Practice for Radiological Examination Using Digital Detector Arrays
- E 2699 Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for Digital Radiographic (DR) Test Methods

- E 2736 Standard Guide for Digital Detector Array Radiology
- E 2737 Standard Practice for Digital Detector Array Performance Evaluation and Long-Term Stability
- E 2738 Digital Imaging and Communication Nondestructive Evaluation (DICONDE) for Computed Radiography (CR) Test Methods
- E 2767 Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for X-ray Computed Tomography (CT) Test Methods
- E 2903 Standard Test Method for Measurement of the Effective Focal Spot Size of Mini and Micro Focus X-ray Tubes
- E 2934 Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE) for Eddy Current (EC) Test Methods

ASTM E2699

[ASTM E2699 - 11 Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation \(DICONDE\) for Digital Radiographic \(DR\) Test Methods](#)

Significance and Use

Personnel that are responsible for the creation, transfer, and storage of digital X-ray test results will use this standard. This practice defines a set of information modules that along with Practice [E2339](#) and the DICOM standard provide a standard means to organize digital X-ray test parameters and results. The digital X-ray test results may be displayed and analyzed on any device that conforms to this standard. Personnel wishing to view any digital X-ray inspection data stored according to Practice [E2339](#) may use this document to help them decode and display the data contained in the DICONDE-compliant inspection record.

1. Scope

1.1 This practice facilitates the interoperability of digital X-ray imaging equipment by specifying image data transfer and archival methods in commonly accepted terms. This document is intended to be used in conjunction with Practice [E2339](#) on Digital Imaging and Communication in Nondestructive Evaluation (DICONDE). Practice [E2339](#) defines an industrial adaptation of the NEMA Standards Publication titled Digital Imaging and Communications in Medicine (DICOM, see <http://medical.nema.org>), an international standard for image data acquisition, review, storage and archival storage. The goal of Practice [E2339](#), commonly referred to as DICONDE, is to provide a standard that facilitates the display and analysis of NDE results on any system conforming to the DICONDE standard. Toward that end, Practice [E2339](#) provides a data dictionary and a set of information modules that are applicable to all NDE modalities. This practice supplements Practice [E2339](#) by providing information object definitions, information modules and a data dictionary that are specific to digital X-ray test methods.

1.2 This practice has been developed to overcome the issues that arise when analyzing or archiving data from digital X-ray test equipment using proprietary data transfer and storage methods. As digital technologies evolve, data must remain decipherable through the use of open, industry-wide methods

for data transfer and archival storage. This practice defines a method where all the digital X-ray technique parameters and test results are communicated and stored in a standard manner regardless of changes in digital technology.

1.3 This practice does not specify:

1.3.1 A testing or validation procedure to assess an implementation's conformance to the standard.

1.3.2 The implementation details of any features of the standard on a device claiming conformance.

1.3.3 The overall set of features and functions to be expected from a system implemented by integrating a group of devices each claiming DICONDE conformance.

1.4 Although this practice contains no values that require units, it does describe methods to store and communicate data that do require units to be properly interpreted. The SI units required by this practice are to be regarded as standard. No other units of measurement are included in this standard.

1.5 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents *(purchase separately)*



The documents listed below are referenced within the subject standard but are not provided as

part of the standard.

ASTM Standards

[E1316](#) Terminology for Nondestructive Examinations

[E1475](#) Guide for Data Fields for Computerized Transfer of Digital Radiological Examination Data

[E2339](#) Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)

[E2597](#) Practice for Manufacturing Characterization of Digital Detector Arrays

Other Standard

DICOM National Electrical Manufacturers Association Standard for Digital Imaging and Communications in Medicine (DICOM), 2008

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