Recommended Training Curriculum For Digital Radiography Personnel (Level II) 1 December 2011

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Federal Working Group on Industrial Digital Radiography (FWGIDR) - The FWGIDR is a self-chartered organization consisting of federal and government contract employees and endorsed by the Defense Working Group on Nondestructive Testing (DWGNDT). This working group provides a platform for identifying common concerns and critical issues facing the federal industrial radiographic community as it transitions from film to digital radiography (DR). The FWGIDR, utilizing expertise from within the community, organizes and coordinates technical committees that formulate positions, guidance, and/or solutions for the community’s common concerns and issues.

Background – Recognizing significant difficulties in addressing technical advances in the digital radiographic field, several engineers from the Department of Energy (DOE) and Department of Defense (DoD) organized the FWGIDR in 2007 to address the problems and concerns faced by the industrial radiographic community in transitioning to DR. Digital X-ray systems are revolutionizing medical radiology, as digital cameras revolutionized the photographic community, and similarly have an ever-increasing role in radiographic nondestructive testing. Medical radiology backed by significant development and funding, and digital photography, with rapid public acceptance; have demonstrated the advantages that digital systems offer in image intensive applications. The FWGIDR is focused on a vision for the future radiographic inspection facility, and that vision is digital radiography.

The rapid growth in DR has created transitional issues difficult for the industrial community to assimilate while transitioning from film to digital techniques. These issues include personnel training; data formatting, storage and retrieval; technique development and qualification; equipment qualification and monitoring; process control; and development and acquisition of equipment suitable for industrial applications.

Participants in the FWGIDR are organizations that employ nondestructive testing in support of government contracts. DOE, DoD, prime government contractors, along with other government and contractor personnel are actively contributing to and supporting the efforts of this working group.
Introduction – This paper, “Recommended Training Curriculum for Digital Radiography Personnel (Level II)”, was developed by a task team established by the FWGIDR. It addresses a major concern of the federal industrial radiographic community regarding personnel training. Original equipment manufacturers (OEMs) commonly offer Digital Radiography (DR) equipment familiarization training but provides limited, if any, basic DR training. There has been a need to establish appropriate DR training curriculums for Level I, II and III personnel. In September of 2009, the FWGIDR released a white paper, Paper No. 001-009, which provided a recommended DR training curriculum for Level III personnel. This is a continuation of the FWGIDR efforts to improve DR training. This white paper provides a recommended training curriculum for Level II DR personnel that is specifically designed to ensure compliance with NAS 410 requirements.

Purpose – This paper is intended as a recommended reference/guide for DR training curriculums for Level II radiographic film personnel transitioning to Level II DR functions as well as those that are already employing DR systems and techniques.

Scope – This curriculum covers DR principles, equipment and implementation issues that should be understood by Level II DR personnel. This training curriculum is intended for personnel that will utilize computed radiography systems (CR) and/or digital detector array (DDA) based DR systems.

Prerequisite – This curriculum does not cover basic radiography inspection principles. It was designed for personnel who already have training equivalent to the 80 hours recommended by the ASNT’s recommended practice SNT-TC-1A, Aerospace Industries Association’s NAS 410, or equivalent knowledge.
This training curriculum is intended for certified Level II film radiographers who are transitioning to
digital radiography. The recommended training hours for this curriculum is 40 hours. Suggested hours
for each section are noted in parenthesis. (If the candidate has completed formal training in Level I
digital radiography, subject matter previously covered in the Level I training does not need to be
repeated to the extent it was presented.)

Note: Basic computer competency skills are necessary to transition from film radiography to non-film
radiography.

1. Introduction (1.0 Hours)
   1.1. Definition of Digital Radiography (DR)
   1.2. Overview of DR Systems
      1.2.1. Basic System Components
         1.2.1.1. Computed Radiography (CR) systems
         1.2.1.2. Digital Detector Array (DDA) based systems
         1.2.1.3. Image Intensifier (II) based systems
      1.2.2. DR System Capabilities
      1.2.3. Advantages and Disadvantages of DR
      1.2.4. Application Examples
   1.3. Digital Image Terminology
      1.3.1. Bits
      1.3.2. Bytes
      1.3.3. Pixels
      1.3.4. Bit Depth
   1.4. Cost and Environmental Impact Comparisons (Film vs. DR)

2. DR vs. Film Images (1.0 Hours)
   2.1. Image Quality Parameters
      2.1.1. Linearity
      2.1.2. Latitude
      2.1.3. Pixel Value (Grey Value)
      2.1.4. Signal to Noise Ratio (SNR)
      2.1.5. Contrast Sensitivity (CS)
      2.1.6. Contrast to Noise Ratio (CNR)
      2.1.7. Spatial Resolution (SR)
   2.2. Image File Formats
      2.2.1. Compression
      2.2.2. Lossy and Lossless (jpg, tiff, etc.)
      2.2.3. DICONDE
3. DR System Components (Detailed) (6.0 Hours)

3.1. Sources (X-Ray and Gamma Ray)
   3.1.1. Energy, Current, Power
   3.1.2. Curies
   3.1.3. Focal Spot / Source Size
   3.1.4. X-Ray Tubes
      3.1.4.1. Open Tubes vs. Closed Tubes
      3.1.4.2. Directional vs. Transmission Tubes
   3.1.5. Gamma Sources
      3.1.5.1. Iridium-192, Cobalt-60, Selenium-75, Ytterbium-169

3.2. Scatter Control Devices
   3.2.1. Filters (Pre and Post Specimen)
   3.2.2. Collimators and Diaphragms
   3.2.3. Masks
   3.2.4. Shielding

3.3. Hardware Manipulators
   3.3.1. Multiple Axis
   3.3.2. Precision and Repeatability
   3.3.3. Weight Capacity
   3.3.4. Motion Control
      3.3.4.1. Manual and Automated
      3.3.4.2. Crash Protection (Limits)

3.4. Detector Types
   3.4.1. Digital Detector Arrays (DDA)
      3.4.1.1. Flat Panel Detectors
         3.4.1.1.1. Amorphous Silicon
         3.4.1.1.2. Amorphous Selenium
         3.4.1.1.3. CMOS
      3.4.1.2. Cameras
         3.4.1.2.1. CCD
         3.4.1.2.2. CMOS
      3.4.1.3. Linear Diode Arrays (LDA)
         3.4.1.3.1. CMOS
         3.4.1.3.2. Photodiode
      3.4.1.4. Scintillators

   3.4.2. Computed Radiography System
      3.4.2.1. Photostimulable Luminescence (PSL)
      3.4.2.2. Imaging Plates (IPs) and Cassettes
      3.4.2.3. CR Scanner and Settings
         3.4.2.3.1. Laser
         3.4.2.3.2. Photomultiplier Tube
3.4.2.3.3. Analog to Digital Converter

3.5. Computer
   3.5.1. Operator Interface
   3.5.2. System Controller
   3.5.3. Image Processor

3.6. Image Displays
   3.6.1. Display Card
   3.6.2. Image Display Monitors
      3.6.2.1. CRT, LCD, LED, Plasma, etc.

3.7. Image Archive and Transmission Media
   3.7.1. Removable Media (CD/DVD/Blue Ray/Tape, Portable Hard Drive, etc.)
   3.7.2. Redundant Array of Inexpensive Disks (RAID)
   3.7.3. Central Server

4. Image Fidelity Attributes (1.0 Hours)
   4.1. Signal
   4.2. Noise
   4.3. Contrast
   4.4. Spatial Resolution
   4.5. Software Tools to Measure Image Attributes
      4.5.1. Histogram
      4.5.2. Line Profile
      4.5.3. Mean and Standard Deviation

5. Image Processing (4.0 Hours)
   5.1. Intensity Transforms
      5.1.1. Windowing (Width and Level)
      5.1.2. Gray Scale Mapping (Look Up Tables)
      5.1.3. Thresholding
      5.1.4. Pseudo Color
   5.2. Image Math
      5.2.1. Addition (Integration)
      5.2.2. Subtraction
      5.2.3. Division
      5.2.4. Multiplication
      5.2.5. Averaging
   5.3. Filtering
      5.3.1. Convolution (Spatial)
         5.3.1.1. Smoothing (Low Pass)
         5.3.1.2. Sharpening (High Pass)
         5.3.1.3. Median
         5.3.1.4. Unsharp Mask
5.4. Advantages and Disadvantages of Image Processing

6. Detector Attributes (4.0 Hours)
   6.1. DDA - Pixel Pitch and Fill Factor
   6.2. CR – Pixel Size vs. Laser Size, Laser Intensity, IP Grain Size and Thickness
   6.3. Sampling Frequency
   6.4. Frame Rates
   6.5. Triggers
   6.6. Bit Depth
   6.7. Linear vs. Log
   6.8. Dynamic Range
   6.9. Low Energy X-Ray Sensitivity (Scatter)
   6.10. Signal To Noise Ratio
   6.11. Fabrication Anomalies (Bad Pixels, Artifacts, panel grading, etc.)
   6.12. Handling and Portability
   6.13. Preset and Manual Settings

7. Image Display Monitor Characteristics (0.5 Hours)
   7.1. Resolution and Pixel Size
   7.2. Bit Depth
   7.3. Brightness
   7.4. Contrast
   7.5. Dynamic Range

8. Viewing Environment (0.5 Hours)
   8.1. Ambient Lighting
   8.2. Humidity and Temperature
   8.3. Glare, Reflections, Fingerprints, etc.
   8.4. Eye Adaptation
   8.5. Ergonomics

9. DR Techniques (Part Specific) (4.0 Hours)
   9.1. Basic Parameters and Settings
      9.1.1. Radiation Energy (kV) / Gamma Source
      9.1.2. X-Ray Tube Current (mA) / Gamma Source Strength
      9.1.3. Exposure Time (Frame Rate or Integration Time for DDAs)
      9.1.4. Filtering (pre or post)
      9.1.5. Masking
      9.1.6. IQI Selection and Placement
         9.1.6.1. IQI pixel value vs. Area of Interest (plus/minus 15%)
   9.2. DR Distinctive Parameters and Settings
      9.2.1. Signal To Noise Ratio (SNR)
9.2.2. Contrast to Noise Ratio (CNR)
9.2.3. Basic Spatial Resolution ($S_{Rb}$)
9.2.4. Geometric Magnification (FDD, FOD, Optimizing for focal spot and $S_{Rb}$)
9.2.5. Normalized Image Unsharpness ($U_{Im}$)
9.2.6. Field of View
9.2.7. Pixel Dimension (Apparent pixel size at field of view based on known dimension)
9.2.8. DDA Specific
  9.2.8.1. Gain and Offset Corrections (Detector Calibration)
  9.2.8.2. Frame Rate
  9.2.8.3. Frame Integration
  9.2.8.4. Frame Averaging
  9.2.8.5. Binning
  9.2.8.6. Triggering (Internal and External)
9.2.9. CR Specific
  9.2.9.1. IP Selection
  9.2.9.2. IP Erasure
  9.2.9.3. Scanner Settings
9.2.10. Image Processing
  9.2.10.1. Window Width and Level
  9.2.10.2. Intensity Transforms Parameters
  9.2.10.3. Filtering Parameters
  9.2.10.4. Processing Algorithms and Parameters
9.3. Technique Documentation
9.3.1. Exposure Parameters
  9.3.1.1. Radiation Source Parameters
    9.3.1.1.1. kV, current, Focal Spot, Beam Filters, etc.
  9.3.1.2. DDA Settings
    9.3.1.2.1. Frame Rate
    9.3.1.2.2. Frame Averaging
    9.3.1.2.3. Binning
    9.3.1.2.4. Gain/Offset
    9.3.1.2.5. Post Filters
  9.3.1.3. CR Scanner Settings and IPs
    9.3.1.3.1. IP Type, Cassette Type, Cassette Screens/Filters
    9.3.1.3.2. Laser Spot Size
    9.3.1.3.3. Scanner Presets
    9.3.1.3.4. Sampling Rate
    9.3.1.3.5. Gain Settings (Photomultiplier Tube)
9.3.2. Set-up Geometry
  9.3.2.1. Focal Spot to Detector Distance (FDD)
  9.3.2.2. Focal Spot to Object Distance (FOD)
9.3.2.3. Geometric Magnification
9.3.2.4. Geometric Unsharpness ($U_g$)
9.3.2.5. Normalized Image Unsharpness ($U_{nm}$)

9.3.3. Image Review Requirements
9.3.3.1. Window Width and Level
9.3.3.2. Digital Zoom

9.3.4. Image Processing Requirements

9.3.5. Measurement Calibration Requirements

9.3.6. Digital Reference Images

10. Image Interpretation (3.0 Hours)

10.1. Image Qualification
10.1.1. Area of Interest (AOI) vs. Region of Interest (ROI)
10.1.2. IQI and/or RQI Feature Verification (type, material, size, position, visibility, etc.)
10.1.3. Measure SNR
10.1.4. Measure CNR
10.1.5. Pixel Value Range
10.1.6. Image Identification, Traceability
10.1.7. Part Coverage

10.2. Image Evaluation
10.2.1. Identify Artifacts (acceptable or re-image required)
10.2.2. Relevant vs. Non-Relevant Indications
10.2.3. Measurement Calibration and Accuracy
10.2.4. Accept/Reject Criteria
10.2.4.1. Discrete vs. Digital Reference Images

10.3. Examination Reports and Records

11. Process Controls (System Baseline and Degradation Monitoring) (6.0 Hours)

11.1. CR System Performance Tests (System Characterization – E2445)
11.1.1. Normalized SNR ($SNR_{nm}$)
11.1.2. Geometric Distortion
11.1.3. Laser Beam Function
11.1.4. Blooming/Flare
11.1.5. Jitter
11.1.6. Scanner Slippage
11.1.7. Shading
11.1.8. IP Erasure
11.1.9. IP Artifacts
11.1.10. Characterization Tools and Use
11.1.10.1. CR Phantoms
11.1.10.1.1. ASTM E2445 Phantom
11.1.10.2. Gages and Use
   11.1.10.2.1. E2002 Duplex Wire Gage
   11.1.10.2.2. Converging and Parallel Line Pair Gages
   11.1.10.2.3. EPS Gages (E746 and E1735)

11.2. DDA System Performance Tests (System Characterization – E2737)
   11.2.1. Basic Spatial Resolution (SRb)
   11.2.2. Contrast Sensitivity
   11.2.3. Material Thickness Range
   11.2.4. SNR
   11.2.5. Signal Level
   11.2.6. Image Lag
   11.2.7. Burn-In
   11.2.8. Offset Level
   11.2.9. Bad Pixel Distribution
   11.2.10. DDA Phantoms
      11.2.10.1. Duplex Plate
         11.2.10.1.1. E2002 Duplex Wire Gage
         11.2.10.1.2. IQIs (E1025 or E1742)
   11.2.10.2. Five Groove Wedge

11.3. Image Display Monitor Performance Tests
   11.3.1. SEMPTE - RP 133 Test Pattern
   11.3.2. Minimum Brightness
   11.3.3. Minimum Contrast Ratio
   11.3.4. Aliasing
   11.3.5. Resolution
   11.3.6. Screen Flicker
   11.3.7. Distortion
   11.3.8. 5% DDL Blocks
   11.3.9. Background Ambient Light
   11.3.10. Performance check periodicity

12. Equipment Maintenance (1.0 Hours)
   12.1. Open X-Ray Tubes
      12.1.1. Focal Spot Degradation
   12.2. CR Scanners
   12.3. IP Cleaning and Artifact Management
   12.4. Manipulators
   12.5. Image Display Monitor Cleaning

13. Specific Equipment Training (8.0 Hours)
   13.1. Software
   13.2. Hardware
13.3. Total System
Note: The listed 8 hours may be conducted separately from a classroom environment, and shall be conducted on specific equipment and procedures used by the employer.

14. Reference Documents

Government Documents:
United States Air Force Research Lab

Industry Documents:
Aerospace Industries Association of America (AIA/NAS)
NAS 410 NAS Certification and Qualification of Nondestructive Test Personnel

ASME Boiler and Pressure Vessel Code (BPVC)
Section V – Nondestructive Examination, Article 2 – Radiographic Examination
Section V – Nondestructive Examination, Article 2, Appendix VIII & IX

America Society for Nondestructive Testing (ASNT)
SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing

ASTM International
E746 Standard Practice for Determining Relative Image Quality Response Industrial Radiographic Imaging Systems
E747 Standard Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology
E1000 Standard Guide for Radioscopy
E1025 Standard Practice for Design, Manufacture and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology
E1161 Standard Practice for Radiologic Examination of Semiconductors and Electronic Components
E1165 Standard Test Method for Measurement of Focal Spots of Industrial X-Ray Tubes by Pinhole Imaging
E1255 Standard Practice for Radioscopy
E1316 Standard Terminology for Nondestructive Examinations
E1411 Standard Practice for Qualification of Radioscopic Systems
E1416 Radiologic Examination of Semiconductors and Electronic Components
E1647 Standard Practice for Determining Contrast Sensitivity in Radiology
E1734 Standard Practice for Radioscopic Examination of Castings
E1742 Standard Practice for Radiographic Examination
E1817 Standard Practice for Controlling Quality of Radiological Examinations by using Representative Quality Indicators (RQIs)
E1936  Standard Reference Radiograph for Evaluating the Performance of Radiographic Digitization Systems
E2002  Standard Practice for Determining Total Image Unsharpness in Radiology
E2033  Standard Practice for Computed Radiology (Photostimulable Luminescence Method)
E2104  Standard Practice for Radiological Examination of Advanced Aero and Turbine Materials and Components
E2339  Standard Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICOM)
E2422  Standard Digital Reference Images for Inspection of Aluminum Castings
E2445  Standard Practice for Qualification and Long Term Stability of Computed Radiology Systems
E2446  Standard Practice for Classification of Computed Radiology Systems
E2597  Standard Practice for Manufacturing Characterization of Digital Detector Arrays
E2660  Standard Digital Reference Images for Investment Steel Castings for Aerospace Applications
E2662  Standard Practice for Radiological Examination of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications
E2669  Standard Digital Reference Images for Titanium Castings
E2698  Standard Practice for Radiological Examination Using Digital Detector Arrays
E2736  Standard Guide for Digital Detector Array Radiology
E2737  Standard Practice for Digital Detector Array Performance Evaluation and Long Term Stability

European Standards

Society of Motion Picture and Television Engineers (SMPTE)
SMPTE RP 133  Specification for Medical Diagnostic Imaging Test Pattern for Television Monitors and Hard Copy Recording Cameras