Introduction

- **Film Radiography** has been developed for **quality assurance** in industry over decades.
- It is basis for **contractual agreements of Supplier and Purchaser**.
- **Digital Radiography** shall achieve the same **image quality** or better, but with higher efficiency.
- **Selected image quality requirements of different standards** as ASTM, ASME, CEN and ISO are compared.
- The essential parameters for **optimization and prediction** of IQI visibility are discussed.
- **Requirements for equipment selection** are derived for CR and DDAs.
- Newly developed **classification procedures** for RT-D equipment are introduced.
### Basic Requirements in Radiography

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Film Standards</th>
<th>Film Exposure</th>
<th>Digital Standards</th>
<th>Digital Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards</td>
<td>ISO, CEN, ASTM, ASME</td>
<td>Exceed minimum optical density</td>
<td>ISO, CEN</td>
<td>DDAs: Exceed minimum required CNR</td>
</tr>
<tr>
<td>Exceed minimum optical density</td>
<td></td>
<td></td>
<td></td>
<td>CR: expose to EPS plateau (MAI)</td>
</tr>
<tr>
<td>Detector requirements</td>
<td>Use required film system class or better</td>
<td>Use detectors which achieve the required SNR and do not exceed the detector unsharpness limit</td>
<td></td>
<td>Do not exceed image unsharpness limits</td>
</tr>
<tr>
<td>Maximum image unsharpness</td>
<td>Do not exceed the geometrical unsharpness limits</td>
<td>Do not exceed the image unsharpness limits</td>
<td></td>
<td>Do not exceed the image unsharpness limits</td>
</tr>
<tr>
<td>Image quality</td>
<td>Achieve required IQI contrast sensitivity</td>
<td>Achieve IQI contrast sensitivity + duplex wire IQI resolution</td>
<td>Achieve required IQI contrast sensitivity</td>
<td>Achieve IQI contrast sensitivity</td>
</tr>
</tbody>
</table>

### Key Technologies for Film Replacement

- **Computed Radiography** (CR) with storage phosphor imaging plates (IP)
- **Digital Detector Arrays** (DDA)
Image Quality in Radiography
- Influence of SNR and CNR -

![Diagram showing signal, noise, and contrast](image)

**Notch visible!**
- Contrast/Noise is high
- Signal/Noise is high

**Notch not visible!**
- Contrast/Noise is low
- Signal/Noise is low

**Notch is visible in the profile if C > 2.5**

Noise Sources in Radiographic Images

Typical noise sources in digital radiography:

1. **EXPOSURE CONDITIONS**: Photon noise, depending on exposure dose (e.g. mA·s or GBq·min). *This is the main factor!*
   - SNR increases with higher exposure dose.

2. **Limitation for the maximum achievable SNR:**
   1. **DETECTOR**: Structural noise of DDAs and Imaging Plates also called fixed pattern noise (due to variations in pixel to pixel response and inhomogeneities in the phosphor layer).
   2. **OBJECT**:
      - Crystalline structure of material (e.g. nickel based steel, mottling)
      - Surface roughness of test object
Measurement of Contrast to Noise Ratio in DDA Practice

by ASTM E 2698

- CNR shall be measured in the 4T hole for proof of image quality.
- A minimum CNR of 2.5 is required by ASTM E 2698.
- This value needs to be revised!

ASTM E 1025

CNR = 6.7
C = ΔI = 473
Noise = 71
SNR = 155

ASTM E 1025

CNR = 2.5
CNR = 1.25
CNR = 0.625

SRb – basic spatial resolution (effective pixel size)

Human Observer Model: Perception Threshold PT

50 µm pixel size

Noise = 1000
Signal = 30000

CNR = 2.5
CNR = 1.25
CNR = 0.625

PTconst = \frac{d}{SRb} \cdot CNR

PT_{const} - constant human perception threshold = 10
\frac{d}{SRb} - diameter of just visible hole
CNR - contrast to noise ratio
SRb - basic spatial resolution (effective pixel size)

Rose approach, 1946

ASTM E 2698 requires CNR > 2.5
Needs revision!

- Large area flaws are better visible than small ones at same Contrast-to-Noise Ratio
- Each row has indications with same CNR = C_{depth}/\sigma
- Each column has holes with same diameter
Verification of $CNR_{\text{min}}$ for ASTM Standard Practice

- ASTM Draft, “Practice for the Use of Digital Detector Arrays and Computed Radiology for Aerospace Casting Inspections” and E 2698 “Standard Practice for Radiological Examination Using Digital Detector Arrays” require for digital images with DDAs in the 2T IQI hole:
  
  $$CNR_{\text{min}} = 2.5$$

- The ASTM E 2698 value ($CNR = 2.5$) is optimized for testing of thin objects with thickness < $\frac{1}{2}$” and typical DDAs in the range of $0.1 \text{ mm} < SR_b < 130 \mu\text{m}$.

- Generally, $CNR_{\text{min}}$ for all digital images can be described more accurate by the equation:

  $$CNR_{\text{min}} = \frac{10 \cdot SR_b^{\text{image}}}{\text{diameter}_{\text{IQI-hole}}}$$

Based on “old” Rose equation as shown before for PT constant.

Contrast Sensitivity as Required by Different Standards

- Almost all standards require image quality indicators on each production radiograph.

- The operator has to evaluate if the required image quality has been achieved.

- He decides about acceptance or rejection of the production radiographs.

- Different international standards require different contrast sensitivities, which yields different inspection quality.

- The thickness sensitivity improves with material thickness.
**8.3 Radiological Methods**  
**DIR 2015**  
**Ghent, June 2015**  
**Ewert and Zscherpel**

**Basic Requirements for IQI Visibility of International Standards in Comparison**

<table>
<thead>
<tr>
<th>Wall Thickness Resolution [%]</th>
<th>Step Holes, ISO 19232-3</th>
<th>Plate Holes, ASME BPVC SC V Ar. 2</th>
<th>ASTM E 1742, E 2104</th>
</tr>
</thead>
</table>

- **Step Holes, ISO 19232-3**: In comparison to ASME S.V Ar.2 and ASTM E 1742
- **Plate Holes, ASME BPVC SC V Ar. 2**: Plate Holes, ASTM E 1742, E 2104

ASME BPVC SC V, Ar. 2, and ISO 17636-class A are about equivalent

ASTM E1742, E 2104, ISO 17636-class B are about equivalent below t=12 mm (1/2”)

**Additional Requirements for Unsharpness and Basic Spatial Resolution**

- In all **film radiography** standards the permitted geometric unsharpness ($U_g$) is limited and the film unsharpness is neglected.

- In digital radiography the **detector unsharpness** ($U_{detector}$) contributes significantly to the image unsharpness ($U_{im}$) or total unsharpness ($U_T$).

- Therefore, the permitted detector unsharpness ($U_{detector}$) is limited in different standard systems, which is relevant for detector selection.

- The **detector unsharpness** shall be always smaller than the permitted geometric unsharpness ($U_{detector} < U_g$).

- The **basic spatial resolution** is defined as $\frac{1}{2}$ unsharpness in digital radiography ($SR_b = \frac{1}{2} U$).
Measurement of Basic Spatial Resolution

Duplex wire IQI
ISO 19232-5
ASTM E 2002

ASTM E 2002
2 new wire pairs D14 D15

- The detector unsharpness \( u_{\text{detector}} \) shall be controlled by reference exposures with the duplex wire IQI.

**8.3 Radiological Methods**

** REQUIREMENTS FOR RT-D**

**DIR 2015**
**Ghent, June 2015**

**Ewert and Zscherpel**

---


**Maximum detector or image unsharpness** (2•SR\(_b\))

<table>
<thead>
<tr>
<th>Penetrated thickness ( w )-mm</th>
<th>Image Quality Class A: Duplex wire ISO 19232-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w \leq 1.5 )</td>
<td>( D \leq 0.08 )</td>
</tr>
<tr>
<td>( 1.5 &lt; w \leq 4 )</td>
<td>( D \leq 0.13 )</td>
</tr>
<tr>
<td>( 4 &lt; w \leq 8 )</td>
<td>( D \leq 0.125 )</td>
</tr>
<tr>
<td>( 8 &lt; w \leq 12 )</td>
<td>( D \leq 0.16 )</td>
</tr>
<tr>
<td>( 12 &lt; w \leq 20 )</td>
<td>( D \leq 0.20 )</td>
</tr>
<tr>
<td>( 20 &lt; w \leq 200 )</td>
<td>( D \leq 0.32 )</td>
</tr>
<tr>
<td>( w &gt; 200 )</td>
<td>( D \leq 0.40 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Penetrated thickness ( w )-mm</th>
<th>Image Quality Class B: Duplex wire ISO 19232-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w \leq 1.5 )</td>
<td>( D \leq 0.13 )</td>
</tr>
<tr>
<td>( 1.5 &lt; w \leq 4 )</td>
<td>( D \leq 0.16 )</td>
</tr>
<tr>
<td>( 4 &lt; w \leq 8 )</td>
<td>( D \leq 0.20 )</td>
</tr>
<tr>
<td>( 8 &lt; w \leq 10 )</td>
<td>( D \leq 0.32 )</td>
</tr>
<tr>
<td>( 10 &lt; w \leq 150 )</td>
<td>( D \leq 0.40 )</td>
</tr>
<tr>
<td>( w &gt; 150 )</td>
<td>( D \leq 0.40 )</td>
</tr>
</tbody>
</table>

For double wall technique, single image. The DDA reading for system evaluation is to be used. The IQ testing shall be performed.

For double wall technique, single image. The DDA reading for system evaluation is to be used. The IQ testing shall be performed.
Unsharpness Requirements of Different International Standards – No International Harmonization

Unsharpness requirements

<table>
<thead>
<tr>
<th>Thickness in inch</th>
<th>E 1742</th>
<th>ISO 17636 class A</th>
<th>ISO 17636 class B</th>
<th>MAI</th>
<th>Co-60, High Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.00</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>1.0</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>2.0</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>3.0</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>4.0</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>5.0</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
</tr>
<tr>
<td>6.0</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.10</td>
</tr>
</tbody>
</table>

8.3 Radiological Methods
DIR 2015
Requirements for RT-D
Ghent, June 2015
Ewert and Zscherpel

Qualification of CR-Systems
- The EPS Concept -

EPS – Procedure is proposed accepted for CR qualification in
ASTM E 20445/6 draft and the draft on “Practice for the Use of … Computed Radiology for Aerospace Casting Inspections” (USA: MAI – group)

- The EPS (equivalent penetrameter sensitivity) measurement is based on
ASTM E 746

A smooth ¾ inch (19 mm) steel plate with a set of plate holes is radiographed at 200 kV in ≥ 1 m distance
- The exposure is performed with different mAs settings
- A graph is generated, see next pages
- The calculation of just visible hole diameter is given by:

\[ d_{\text{visible}} = PT \cdot \frac{SR_{\text{image}}}{\mu_{\text{eff}} \cdot \text{SNR}} \]

New formula

ASTM E 746

PT depends slightly on operator and viewing conditions
\( \mu_{\text{eff}} \) for 200 kV and 19 mm Fe is about 0.05 mm⁻¹
Example: EPS Test with HD CR Scanner at 20 µm Pixel Size

Do you see the holes?

¾" (19 mm) steel plate, 200 kV

1 mm steel step for measurement of \(\mu_{\text{eff}}\)

Visibility of EPS holes (E 746) with HD-CR

Do you see the holes?

CNR \(\approx 0.8\)
New Formula for Conversion of SNR\textsubscript{N} Measurements to EPS Values and Working Range for CR (ASTM Draft E 2033)

- PT' is about 2\times 100 for visibility of the 2 T hole of IQIs corr. to ASTM E 1025
- EPS by ASTM E 746 with 200 kV, t = 19 mm Fe plate and \( \mu_{\text{eff}} = 0.05 \text{ mm}^{-1} \)

\[
\text{EPS} = \frac{\text{PT'}}{\text{SR}_b^{\text{detector}}} \sqrt{\mu_{\text{eff}} \cdot \text{SNR}}
\]

### Old CR Classification Scheme

<table>
<thead>
<tr>
<th>System class</th>
<th>Minimum normalised SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP 1/Y</td>
<td>130</td>
</tr>
<tr>
<td>IP 2/Y</td>
<td>117</td>
</tr>
<tr>
<td>IP 3/Y</td>
<td>78</td>
</tr>
<tr>
<td>IP 4/Y</td>
<td>65</td>
</tr>
<tr>
<td>IP 5/Y</td>
<td>52</td>
</tr>
<tr>
<td>IP 6/Y</td>
<td>43</td>
</tr>
</tbody>
</table>

Note 1: The normalized SNR values of Table 1 are similar to those of EN 584-1. They are calculated by \( \text{SNR} = \log(e) \) (Gradient/Granularity) of Table 1 in EN 584-1. The measured SNR values are calculated from linearised signal data.
New CR Performance Scheme

New classification by performance levels as given in ASTM E 2446 (2015).

Additionally, a specified EPS performance is required.

<table>
<thead>
<tr>
<th>CR System Classification</th>
<th>Minimum $\text{SNR}<em>N$ (normalized to $\text{SR}</em>{b}=88.6 , \mu\text{m}$)</th>
<th>Maximum $\text{iSR}_{b,detector}$ value [µm]</th>
<th>Maximum achieved EPS by E 746 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR Special</td>
<td>200</td>
<td>50</td>
<td>1.00</td>
</tr>
<tr>
<td>CR Level I</td>
<td>100</td>
<td>100</td>
<td>1.41</td>
</tr>
<tr>
<td>CR Level II</td>
<td>70</td>
<td>160</td>
<td>1.66</td>
</tr>
<tr>
<td>CR Level III</td>
<td>50</td>
<td>200</td>
<td>1.92</td>
</tr>
</tbody>
</table>

Qualification Spider Graph and Classification Statement

Qualification of CR-System XY

Interpolated $\text{SR}_{b,detector}$ for E 2795, ISO 17636-2 users

SR$_{b,detector} = 145\mu$m

Achievable SNR$_b$ for ISO 17636-2 user

$\text{aSNR}_b = 88$

Achievable CS for E 2597 user

Csa = 0.8

Achievable EPS Specific for CR

$\text{aEPS@mag} = 1.65$

Speed as defined for film

ISO Speed@SNR$_{N130} = 400$

Efficiency@1mGy = 115

Efficiency as defined for DDAs in E 2597

Performance level I
DDA Technology provides better image quality than film with a special calibration procedure!

Images high pass filtered for better presentation

BAM 5, 8mm steel

Fujifilm IX25

SNR \(_N\) \approx 265

PerkinElmer 1620

SNR \(_N\) \approx 1500

Magn. = 3.5
Qualification of Digital Detector Arrays
- Management of Underperforming Pixels -

A bad pixel can be corrected if it has at least 5 good neighbors

Definition and Test of Bad Pixels:

- 6.2.1.1 Dead Pixel
- 6.2.1.2 Over Responding Pixel
- 6.2.1.3 Under Responding Pixel
- 6.2.1.4 Noisy Pixel
- 6.2.1.5 Non-Uniform Pixel
- 6.2.1.6 Persistence/Lag Pixel
- 6.2.1.7 Bad Neighborhood Pixel

6.2.2 Types or Groups of Bad Pixels:

- 6.2.2.1 Single Bad Pixel
- 6.2.2.2 Cluster of Bad Pixels
- 6.2.2.3 A cluster without any CKP is well correctable.
- 6.2.2.4 A cluster with CKP is labeled a relevant cluster.
- 6.2.2.5 A single bad line segment is a special irrelevant cluster.

ASTM E 2597M

<table>
<thead>
<tr>
<th>single bad pixel</th>
<th>2x2 cluster</th>
<th>2x3 cluster</th>
<th>3x3 cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>C C C C C C C C</td>
<td>C C C C C C C</td>
<td>C C C C C C C</td>
<td>C C C C C C C</td>
</tr>
<tr>
<td>C C C C C C C C</td>
<td>C C C C C C C C</td>
<td>C C C C C C C C</td>
<td>C C C C C C C C</td>
</tr>
</tbody>
</table>

K: CKP = defect pixel < 5 good neighbors
D: defect pixel => 5 good neighbors

Requirements for RT-D

8.3 Radiological Methods
DIR 2015
Ghent, June 2015
Ewert and Zscherpel

Qualification of Digital Detector Arrays
- Pixel Coverage Recommendations -

Best Number of pixels to cover a defect

ASTM E 2736

<table>
<thead>
<tr>
<th>Defect dimensions</th>
<th>1 pixel</th>
<th>2-3 pixels</th>
<th>4-6 pixels</th>
<th>&gt;6 pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Risk, Not recommended</td>
<td>High Risk, ok with High SNR, large contrast</td>
<td>Moderate Risk</td>
<td>Low Risk</td>
<td>Best Practice, if available</td>
</tr>
</tbody>
</table>

- Pixel coverage can be obtained by DDA pixel pitch or geometric magnification
- If possible want a minimum of 3 effective pixels to cover the longest dimension of a defect from both a detectivity and bad pixel management perspective.
- Contrast, size, and aspect ratio of defect, and SNR of DDA also impact this.

Requirements for RT-D

8.3 Radiological Methods
DIR 2015
Ghent, June 2015
Ewert and Zscherpel
Compensation Principle (II) of ISO 17636-2

Compensation of high detector unsharpness by increased SNR

- Unsharp digital systems may be applied for NDT if they enable to compensate the missing sharpness by increased SNR.
- That means, achieves a digital system not the required visibility of the separated duplex wires, it can be used for NDT, if one or two single wires more than required (see tables B.1 –B.12 of ISO 17636-2) can be seen clearly in the digital image for one or two missing duplex wire pairs. Compensation of 3 wires vs. wire pairs requires agreement of contracting parties.

\[ d_{\text{visible}} = PT \cdot \frac{SR_{\text{map}}}{\sqrt{\mu_{\text{eff}} \cdot \text{SNR}}} \]

Example: Compensation Principle (II) of ISO 17636-2

Interesting for detectors with higher unsharpness

Compensate missing spatial resolution by increased single wire sensitivity:

- A lower spatial resolution i.e. a lower double wire score (D) may be compensated by a higher single wire sensitivity i.e. higher single wire score (W).
- Max. two (or three) single/double wire scores may be exchanged.

<table>
<thead>
<tr>
<th>Duplex wire score</th>
<th>Single wire score</th>
<th>Required:</th>
<th>OK:</th>
<th>OK</th>
<th>OK by agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>D13</td>
<td>W13</td>
<td>D12</td>
<td>D11</td>
<td>D10</td>
<td>D9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W14</td>
<td>W15</td>
<td>W10</td>
<td>W17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Qualification of Digital Detector Arrays
- Efficiency Measurement -

![Graph showing efficiency measurement with different energy levels and materials.

Qualification by ASTM E 2597M

---

Qualification of Digital Detector Arrays
- Contrast Sensitivity by CNR-Step Wedge Measurement -

Measure contrast and noise per step

Contrast sensitivity (CA) at 5% notch in a step wedge by 1/CNR

![Step wedge with notch.

Qualification by ASTM E 2597M

---
Qualification of Digital Detector Arrays
- Contrast Sensitivity by CNR-Step Wedge Measurement -

Qualification by ASTM E 2597M

![Contrast Sensitivity Graph]

- Working range (4s)

Qualification of Digital Detector Arrays
- SMTR by SNR-Step Wedge Measurement -

Qualification by ASTM E 2597M

![SNR Limits Graph]

- SNR = 250
- SNR = 130
Qualification of Digital Detector Arrays

DDAs are qualified by different tests of ASTM E 2597. Five relevant parameters shall be provided:

- Basic spatial resolution ($SR_b$)
- Specific Material Thickness Range
- Efficiency
- Image lag
- Contrast sensitivity

Qualification by ASTM E 2597M

Inspection of castings: prEN 12681:2014
Revision of film standard by CEN TC 190 WG10 „Inner Defects“, secretary at DIN „GINA“

Since 2012 new work item for standard revision, splitted into

Part 1: Film  content of old EN12681 nearly unchanged, but
- tables from ISO 5579 (old EN 444) and ISO 19232 (old EN 462) in Annex A, therefor prEN 12681-1 without any other standard applicable!
- new Appendices: Annex B to F - Severity Levels for Steel-, Fe- and Gray Cast iron, Al-, Mg- und Cu-Alloys, Titanium and Alloys,
- Assignat of Severity Levels 1 - 4 to ASTM Film- and digital Catalogues

Part 2: Digital Detectors  content similar to ISO 17636-2
- Testing class A und (B) identical with ISO 17636-2, in film standards no differences between testing requirements between castings and weldings
- Additionally, testing classes $A_A$ und $B_A$ similar to Radioscopy (EN 13068-3), often applies in castings inspection as compromise (current state of art)
Part 1: Film radiography

- Founding — Radiographic testing — Part 1: Film techniques
  - Class A: basic techniques;
  - Class B: improved techniques.

It is recommended to perform the testing according to class A, if not otherwise specified in the order. Class B techniques will be used when class A might be insufficiently sensitive.

- IQI requirements according to ISO 19232-3, tables 1 – 4,
- Reduction of requirements of testing class B
- no arrangements with double wall penetration
- Specifications for IQI near to film
- IQI near to film only with agreement of contractor

Part 2: Radiography with digital detectors (CR and DDA)

- Founding — Radiographic testing — Part 2: Techniques with digital detectors
  - The radiographic techniques for film replacement are divided into two classes:
    - Class A: basic techniques;
    - Class B: improved techniques.
  - The techniques for automated DDA based testing are divided into two classes:
    - Class A: basic automated techniques;
    - Class B: improved automated techniques.

NOTE Automated DDA based techniques are used in industry for fast inspection of castings mainly in serial testing. IQI requirements are either agreed by contracting parties, based on fitness for purpose requirements or on general requirements as provided in Tables A.1-3. These automated techniques are not considered as film replacement technique.

It is recommended to perform the testing according to class A or A, if not otherwise specified in the order, class B or B techniques will be used when class A or A might be insufficiently sensitive.
**New Concept of prEN 12681:2014**

### Different requirements on basic spatial resolution

Table A.3:

<table>
<thead>
<tr>
<th>lower thickness limit in mm</th>
<th>upper thickness limit in mm</th>
<th>Class A&lt;sub&gt;0&lt;/sub&gt; minimum DW value</th>
<th>Maximum SR&lt;sub&gt;b&lt;/sub&gt; in mm</th>
<th>Class A&lt;sub&gt;0&lt;/sub&gt; minimum DW value</th>
<th>Maximum SR&lt;sub&gt;b&lt;/sub&gt; in mm</th>
<th>Class B&lt;sub&gt;0&lt;/sub&gt; minimum DW value</th>
<th>Maximum SR&lt;sub&gt;b&lt;/sub&gt; in mm</th>
<th>Class B&lt;sub&gt;0&lt;/sub&gt; minimum DW value</th>
<th>Maximum SR&lt;sub&gt;b&lt;/sub&gt; in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>5</td>
<td>0.08</td>
<td>12</td>
<td>0.063</td>
<td>13</td>
<td>0.05</td>
<td>13</td>
<td>0.05</td>
<td>13</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>10</td>
<td>0.125</td>
<td>10</td>
<td>0.1</td>
<td>12</td>
<td>0.063</td>
<td>13</td>
<td>0.063</td>
<td>13</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>24</td>
<td>0.2</td>
<td>8</td>
<td>0.16</td>
<td>10</td>
<td>0.1</td>
<td>11</td>
<td>0.08</td>
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### Conclusions

- Replacement of film radiography by digital techniques in NDT requires careful selection of suitable digital detectors.
- Standards on digital radiography were published and revised since 2005 in ISO, CEN, ASTM and ASME, defining requirements for image quality and detector selection.
- International standards define different requirements for image quality and detector selection.
- The image quality depends on the essential parameters: specific contrast $\mu_{eff}$, SNR and basic spatial resolution $SR_b$.
- CR is accepted as film replacement technology:
  - The prove of image quality requires $SNR_N$ measurements and IQI visibility (ISO 17636-2).
  - CR classification and qualification is under major revision.
  - Classification will consider $SNR_N$, $SR_b$<sub>detector</sub> and EPS
- DDAs can achieve a significantly better contrast sensitivity with suitable detector calibration than film radiography.
  - The prove of image quality requires CNR measurements and IQI visibility (ASTM practice E 2798).
- DDAs are qualified by different but similar procedures than CR systems, because the DDA detector calibration and image integration influences seriously the qualification, and DDAs provide currently better image quality than CR.