Flat Panel Detectors: a Possibility for Film Replacement in High Energy NDT Applications

Angela Peterzol-Parmentier, Olivier Burat, and Julien Banchet

Installed Base France
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NDT community has discussed the possibility of film-based radiography replacement by Computed Radiography (CR) and/or Digital Radiography (DR) for more than 15 years.

Standards:
- published in 2005 by CEN, ASTM and ASME to support phosphor IP in lieu of X-ray film
- published in 2010 by ASTM for DR application
- published in 2013 by CEN (ISO 17636_2) for both CR and DR in weld inspection

Codes:
- CR and/or DR not included within the French RCCM, while
- CR and/or DR commonly used in US for nuclear applications according to ASME (Section V, art 2).

AREVA R&D program:
- Since 2006, AREVA has been evaluating the performance of CR in comparison to conventional RT in the framework of EN 14784 for the digital part and the RCCM for the conventional part.
- In 2009 the subject gave rise to collaboration between AREVA NP – NETEC and EDF-CEIDRE, for a joint project aiming to establish performance limits of CR.
Conclusions of this program were so far that:

- For X-Ray tube expositions, CR achieves similar IQI visibility than film radiographs on small steel thickness (< 30 mm).
- For the gammagraphic inspections, conventional RT achieves typically much better IQI visibility than CR; in many cases only class A (basic) of EN 14784 is achieved.

In 2011 a PhD thesis on image simulation-optimisation in CR started at INSA-Lyon (co-supported by EDF R&D)

Entire image chain in CR has been modeled; optimization of cassette composition (type and thickness of metal screens) resulted crucial when dealing with gamma sources

In 2011 we started also to investigate flat panel detectors (FPD) performance for high energy applications
Study Purposes

- Performance evaluation of Digital Radiography (DR) in view of film replacement in NDT nuclear applications
- Comparison to conventional RT and CR
- Evaluation of role played by metal screens (as a function of beam energy and material thickness)
- Consider as means of evaluation/comparison the French RCC-M code and the recently published ISO 17636_2 standard
- Think over the way of introducing DR into RCC-M
**Methods and Materials**

- **Typical set-up for X or γ-ray exposure:**

  ![Diagram showing a typical set-up for X or γ-ray exposure.](image)

- **NB, if DR is being evaluated: a FPD instead of Cassette**
Methods and Materials

- Steel blocks varying in thickness as imaged object.
- Selenium75, Iridium192 and linear accelerator as ionising radiation sources (depending on steel thickness).
- Image quality has been assessed accordingly to ISO 17636-2, and RCCM 2007 by means of the following IQI:
  - Hole IQI in conformity to FE EN 462-2
  - Duplex IQI in conformity to NF EN 462-5
  - Wire IQI in conformity to FE EN 462-1
- Accordingly to ISO 17636-2, also the image signal to noise ratio (SNR) and the basic spatial resolution (SRb) have been measured and used to compute the normalized signal to noise ratio (SNR_N):
  \[ SNR_N = SNR \times (88.6 \mu m/SR_b) \]
- No image processing, only brightness/contrast adjustment allowed
Methods and Materials

- Adopted rules

- $Y$ is used when conformity is respected, $N$, when not

- When scoring the IQI values, it has been noted also if the obtained value is equal to the minimum required by the standard ($Y$), or is larger ($Y(+1)$, $Y(+2)$, ...), or is smaller ($N(-1)$, $N(-2)$, ...).

- ISO 17636-2 “degradation” criterion is used, i.e.:

  “In the case where Ir192 or Se75 sources are used, IQI values worse than listed in tables B.1 to B.12 may be accepted by agreement of contracting parties as follows (single wall single image and double wall single image techniques, class B):
  
  – $10 \text{ mm} < w \leq 40 \text{ mm}$ 1 wire or step-hole value less for Ir192
  – $5 \text{ mm} < w \leq 20 \text{ mm}$ 1 wire or step-hole value less for Se75”

- When conformity to the standard requirements is achieved by invoking this rule, the symbol * is added to the letter $Y$: $Y*$
Results – Different systems comparison with a LA

Tests with a Linear Accelerator (LA) on large thickness samples (80 – 150 mm) with different digital detectors vs conventional RT considered a 9MeV source

Systems under investigation:
1. conventional RT making use of D3 double film.
2. CR system composed by a CR35 scanner (DURR NDT) and IPs KODAK.
3. CR system composed by a CR35 scanner and IPs HD-IP Plus (DURR NDT). Nominal pixel size of 100µm for both 2. and 3.
4. DR - Scintillator coupled to a CCD camera (HAMAMATSU detector). Scintillator is a gadox screen (1.4 mm thickness). Pixel size of the CCD is 660µm.
5. DR - Perkin Elmer and GE flat panel detectors. Pixel of 200 µm for both.

Results: among the CR and DR investigated systems, only the FPDs permitted to achieve conventional RT image quality
Results – FPD performance with $\gamma$

- Calibration artefacts due to afterglow (long exposure time) appeared

Steel thickness = 20mm; source Ir192; after artefacts suppression one more hole IQI seen

- White field images have to be taken with the same integration time employed for part images
Results – FPD performance vs metallic screens

- Role played by metal screens when γ-rays:
  - They act as “additional” filters
  - Se75 gamma source, for the 5-15mm steel thickness range, it is preferred not to use a metal screen between the part and the FPD.
  - Ir192 gamma source, for the 20-83mm steel thickness range, it is preferred to add external filtration (~ 0.5 – 1.0 mm of Ta).

- Role played by metal screens when LA:
  - In the 80-150 mm thickness range at least 1.0mm of Pb is necessary

- Comparison to CR:
  - No intensification (screen is not in contact with radiation sensitive layer)
  - Less crucial parameter
  - However, a FPD in some cases already contains a metallic screen close to scintillator, but few literature on the subject
Results – FPD performance with γ

Comparison to CR and film, for Se75 exposure of 5mm of steel

<table>
<thead>
<tr>
<th>Test Object</th>
<th>Detector</th>
<th>Wire IQI seen</th>
<th>Hole IQI seen</th>
<th>Conformity to ISO 17636 W/H</th>
<th>Conformity to RCCM W/H</th>
<th>Duplex IQI saw</th>
<th>Nominal pixel size</th>
<th>SNR₀ measured</th>
<th>Conformity to ISO 17636 D IQI/SNR₀</th>
<th>Exposure Time (min) (30 Ci)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mm steel</td>
<td>DR</td>
<td>0,125mm/W15</td>
<td>0,32 mm/H5</td>
<td>Y*/Y*</td>
<td>Y/Y</td>
<td>D8 (160µm)</td>
<td>144µm</td>
<td>230</td>
<td>N(-4)/Y</td>
<td>1</td>
</tr>
<tr>
<td>5 mm steel</td>
<td>CR</td>
<td>0,125mm/W15</td>
<td>0,32 mm/H5</td>
<td>Y*/Y*</td>
<td>Y/Y</td>
<td>D13 (50µm)</td>
<td>25µm</td>
<td>256</td>
<td>Y(+1)/Y</td>
<td>10</td>
</tr>
<tr>
<td>5 mm steel</td>
<td>film</td>
<td>0,125mm/W15</td>
<td>0,32 mm/H5</td>
<td>Y*/Y*</td>
<td>Y/Y</td>
<td>D11 (80µm)</td>
<td>NAN</td>
<td>NAN</td>
<td>N(-1)/NAN</td>
<td>6,5</td>
</tr>
</tbody>
</table>

SNR₀ threshold (5mm) = 100

- DR : Vidisco (FlashX Pro) FPD
- CR : HR imaging plate (IP) and DURR NDT Scan
- film : D3 double

DR allows to detect requested wire and hole IQI (thanks to an excellent SNR), though a spatial resolution being “4 Duplex IQI far away” from the standard!

With HR IP and a 25µm pixel, CR does satisfy the standard (Duplex IQI), but exposure time becomes larger than that of film!
Results – FPD performance with γ

Performance with Ir192 source for different steel thicknesses

<table>
<thead>
<tr>
<th>Test Object</th>
<th>Wire IQI seen</th>
<th>Hole IQI seen</th>
<th>Conformity to ISO 17636 W/H</th>
<th>Conformity to RCCM W/H</th>
<th>Duplex IQI saw</th>
<th>SNRₜ measurerd</th>
<th>Conformity to ISO 17636 D IQI/SNRₜ</th>
<th>Exposure Time (min) (100 Ci)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 mm steel</td>
<td>0,25 mm/W12</td>
<td>0,80 mm/H9</td>
<td>Y(+1)/Y*</td>
<td>Y(+2)/Y(+1)</td>
<td>D7 (200μm)</td>
<td>152</td>
<td>N(-3)/Y</td>
<td>1,7</td>
</tr>
<tr>
<td>43 mm steel</td>
<td>0,40 mm/W10</td>
<td>0,90 mm/H9</td>
<td>Y/Y</td>
<td>Y(+1)/Y(+2)</td>
<td>D7 (200μm)</td>
<td>101</td>
<td>N(-2)/Y</td>
<td>2,8</td>
</tr>
<tr>
<td>63 mm steel</td>
<td>0,50 mm/W9</td>
<td>1,00 mm/H10</td>
<td>Y/Y</td>
<td>Y/Y(+1)</td>
<td>D7 (200μm)</td>
<td>95</td>
<td>N(-2)/Y</td>
<td>15</td>
</tr>
<tr>
<td>83 mm steel</td>
<td>0,63 mm/W8</td>
<td>1,25 mm/H11</td>
<td>Y/Y</td>
<td>Y/Y(+1)</td>
<td>D7 (200μm)</td>
<td>171</td>
<td>N(-2)/Y</td>
<td>85</td>
</tr>
</tbody>
</table>

SNRₜ threshold (33mm and 43mm) = 100; SNRₜ threshold (63mm and 83mm) = 70

- DR allows to detect requested wire and hole IQI (thanks to an excellent SNR), though a spatial resolution being “3-2 Duplex IQI far away” from the standard!
- The key parameter is the SNRₜ and not the spatial resolution alone!
Conclusions

- FPD represents a valid alternative to film radiography
- Performance with gamma-sources and LA allows detecting IQI (wire and hole) requested by ISO 17636_2 standard and French RCC-M code
- Though the fact Duplex IQI never reached the requested ISO value, the normalized SNR was always larger than the minimum threshold
- Depending on FPD type and application, gain in exposure time (in respect to film) is larger than a factor 5
- Metal screens are less important parameter in respect to CR
- However, for Ir192 and LA thickness applications, filters have to be used
In order to allow using FPD for steel part weld inspection in conformity to the ISO 17636_2 standard, the latter has to be modified:

- Detector basic spatial resolution (SRb) alone should not be a key criterion
- Essential criterion shall remain wire/hole IQI detectability
- The latter depends on both SRb and SNR, and it is well correlated to the SNR<sub>N</sub>

If introduction of DR into RCC-M is envisaged, the same considerations hold.

The choice of metal screen in close contact to FPD scintillator has to be further explored for high energy applications; preferably in collaboration with FPD manufactures.
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