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Qualification and Process Control of Computed Radiography Systems

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Canada

Outline of Presentation

- Film vs Digital Radiography
- Introduction of Computed Radiography (CR)
- Qualification & Process Control of CR (ASTM E2445)
- CR for High Resolution Applications
- Summary

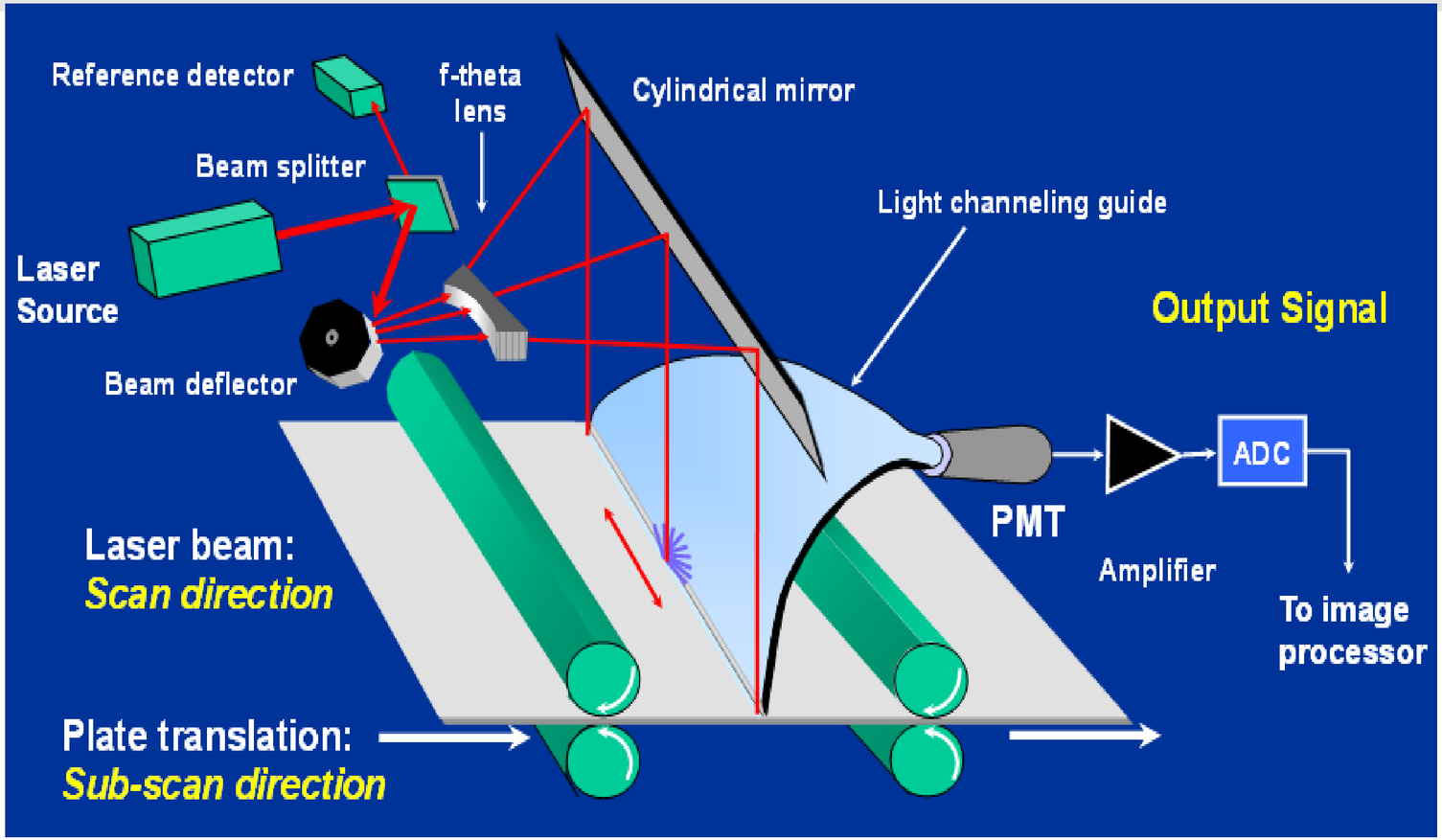
Objectives of the Study

- **Qualification of CR systems in accordance with ASTM E2445 standards**
- **Investigation of EPS concepts for aluminum alloy**
  - Baseline EPS performance of CR system/Imaging Plates
  - Estimation of minimum, range, linearity of exposure
- **Developing process control of CR imaging applications**
  - To ensuring a high degree of repeatability of inspection results
- **Investigation of CR for high resolution applications**

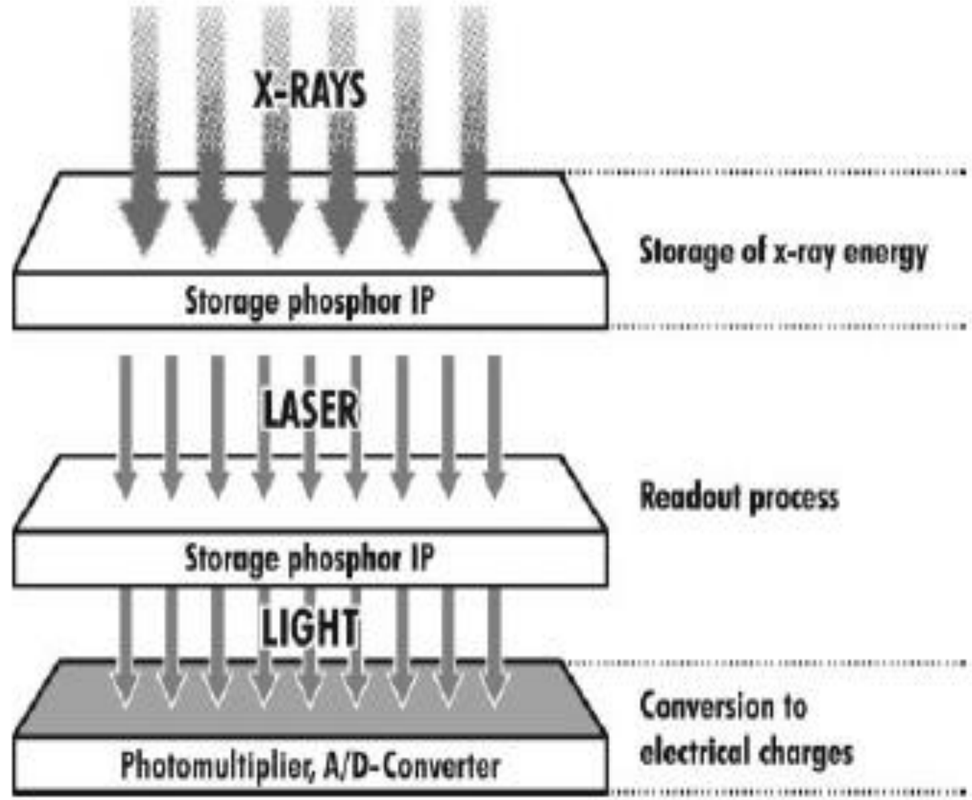
Background: Film vs Digital Radiography

- **Film for NDT applications is gradually diminishing (time, cost, hazardous chemical, lack of digital advantage)**
- **Digital Radiography (DR/CR) allow faster/easier image acquisition**
- **DR/CR Widespread application still poses significant challenges**
  - Initial cost of system, Steep learning curve
  - Lack of procedure to choose parameters
  - Lack of demonstrated system performance
- **Performance assessment required (If CR/DR can effectively provide equal or better performance than the existing film-based technology)**

Computed Radiography (CR)



Ref: www.ndt-ed.org

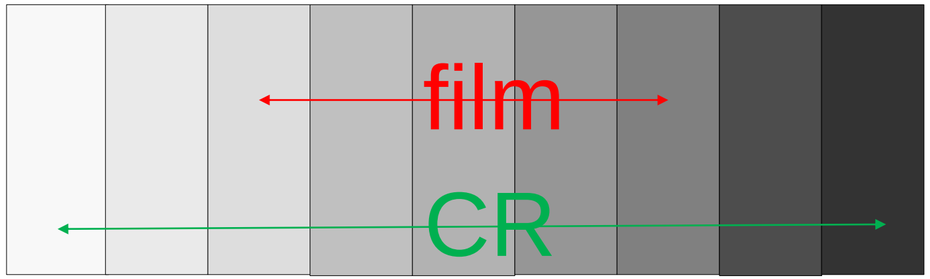


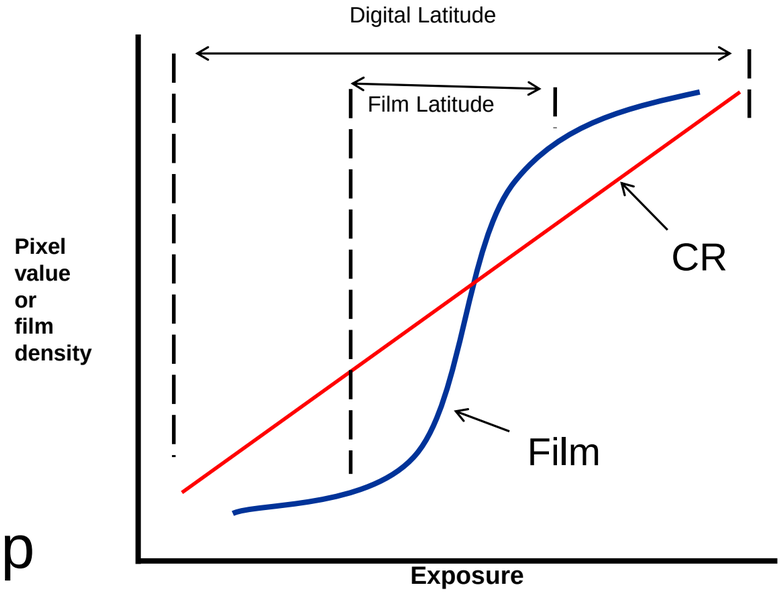
Ref: Korner, M., "Advances in Digital Radiography"

- CR uses a reusable phosphor imaging plate and allows faster image acquisition digitally, improved capabilities for analysis and digital storage

Contrast in CR

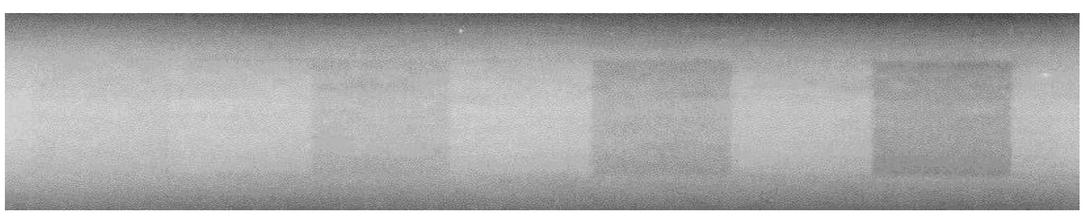
- **In general CR has better "<u>latitude</u>" than film**
- **CR can cover a wide range of thicknesses/densities in a single exposure**





- **CR has better <u>contrast sensitivity</u> (CS)**

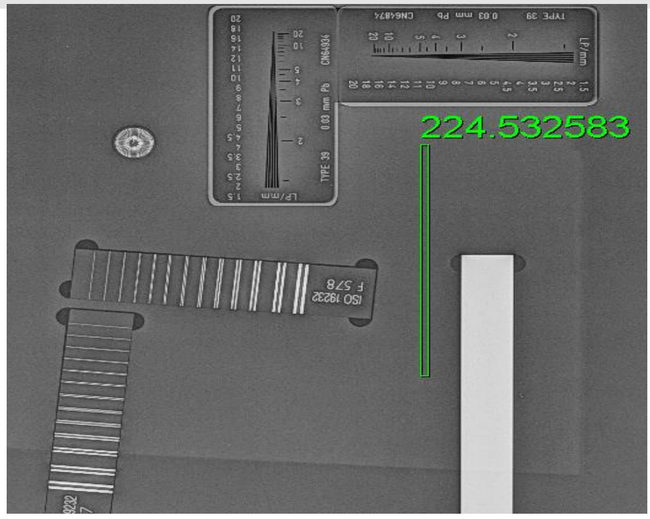
i.e. Capability to "window/level" to visualize a contrast step



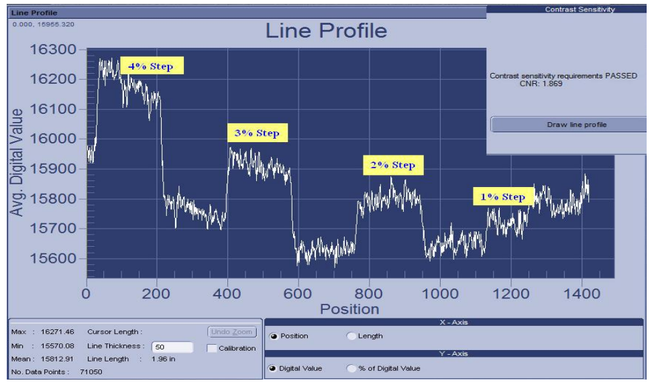
Ref: Digital and Film Radiography Comparison - Ken LaCivita

Primary Metrics for Image Quality in CR

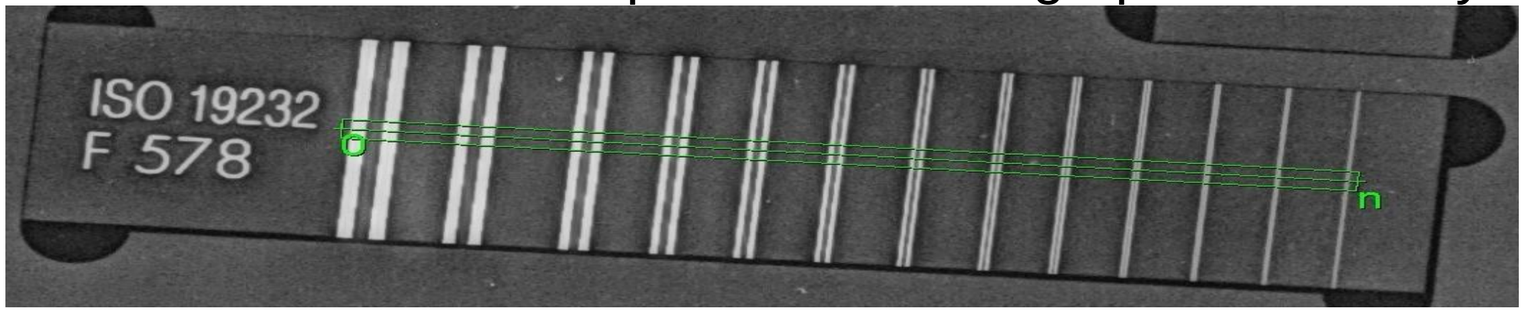
- **Primary metrics for establishing the performance are**
  - Signal-to-Noise Ratio (SNR)
  - Contrast-to-Noise Ratio (CNR)
  - Basic Spatial Resolution (SR_b)
  - Higher the SNR, CNR or smaller the SR_b, better the quality
  - In film radiography (RT) these are evaluated indirectly by image quality indicators (IQI)
  - No direct relationship between radiographic sensitivity and flaw size



SNR 226.273



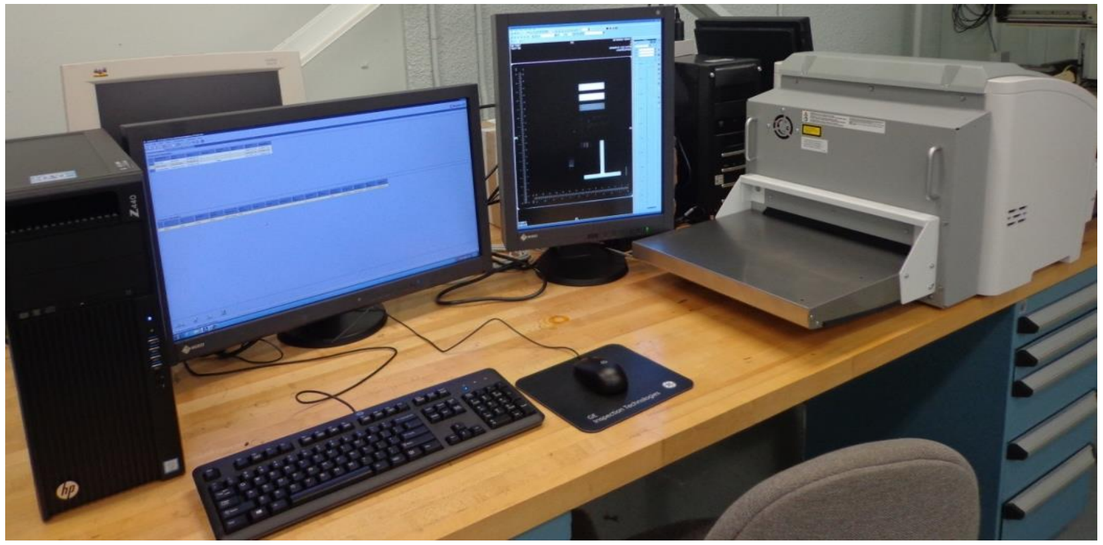
(CNR) < 2

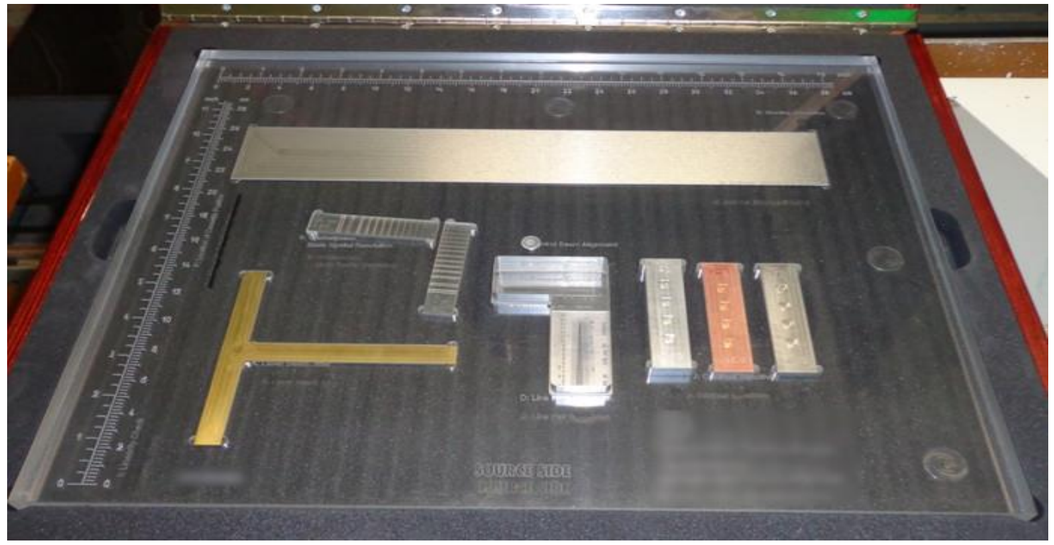


(SR_b)

NRC Computed Radiography

- Computed radiographic system (SR 70 µm, HR 35 µm)
  - Table-top flatbed scanner with contactless plate transport, inline erasure
  - 16 Bit, Scan width 14”, Throughput 90 plates/hr (SR), 28 plates/hr (HR)
- CR image acquisition/analysis software (DICONDE compliant
- HR & medium speed (IPS) and extreme HR and slow speed imaging plates (IPU)
- BAM certified highest system Class IP 1 / 80 according to ISO 16371-1 and ASTM E2446

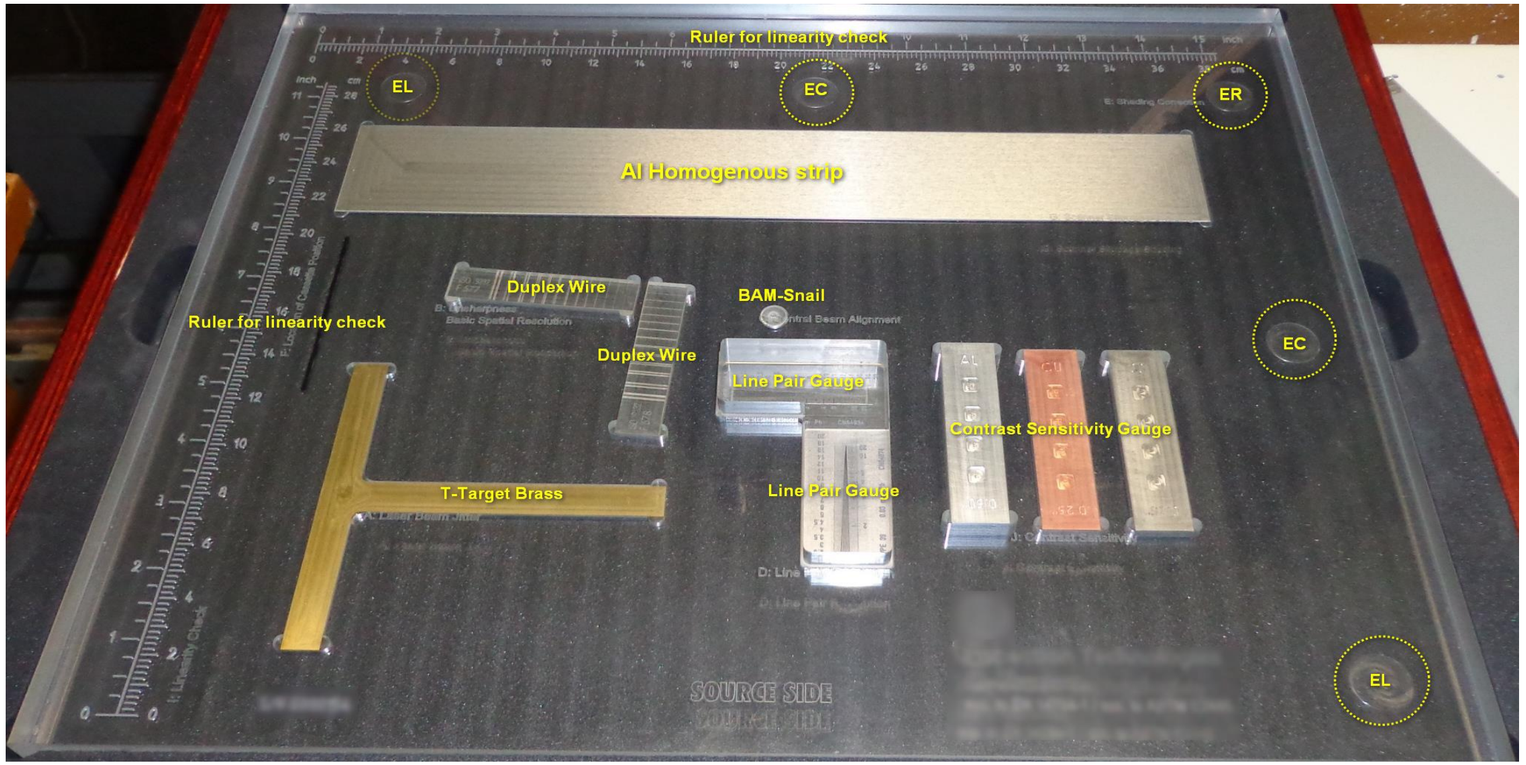




ASTM E 2445M-14 (Phantom)

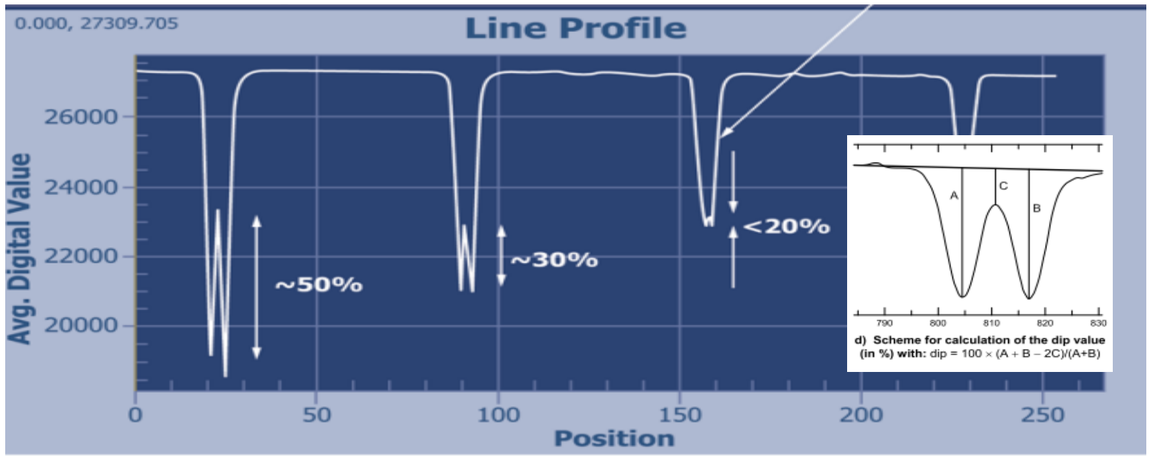
(Practice for Qualification and Long Term Stability of CR Systems)

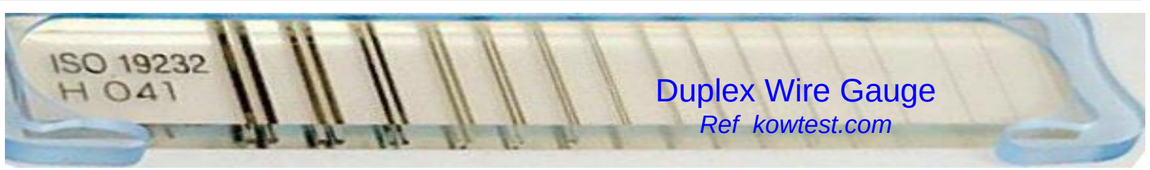
- Spatial Resolution and Unsharpness – Converging Line Pair
- Contrast Sensitivity (Contrast-to-Noise Ratio CNR)
- Spatial Resolution and Unsharpness – Duplex Wire
- Geometric Distortion
- Laser Beam Function
- Blooming or flare
- Slippage
- Shading
- IP Linearity
- Signal-to-Noise Ratio (SNR)
- EPS (Either SNR or EPS)



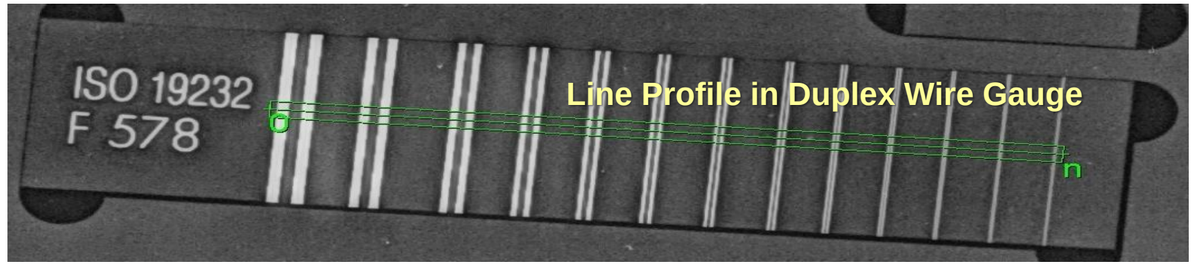
Basic Spatial Resolution (SR_B) (Duplex Wire Gauge)

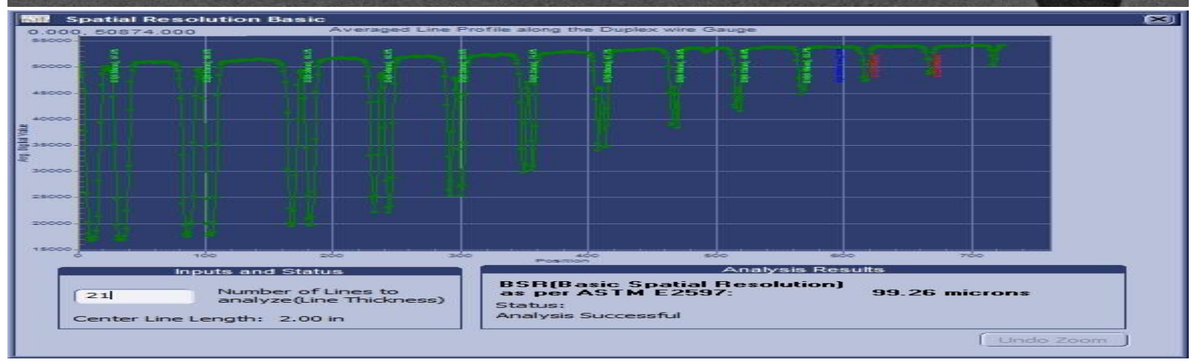
- SR_B - ability to clearly see abrupt changes in an object, resolve/separate smaller features
- Film has better SR_B (Film grain ~0.6-0.8µm vs CR IP grain ~ 3-5µm, scanning res., others)
- Duplex Wire IQI in accordance with ASTM E2597
- Resolution is determined by the first unresolved wire pair (modulation depth <20%)
- Profile line requires parallel to gauge and positon/width of line have effect on BSR
- Best result – IPU (blue plates) and lower scanning sampling rate (scanning time /



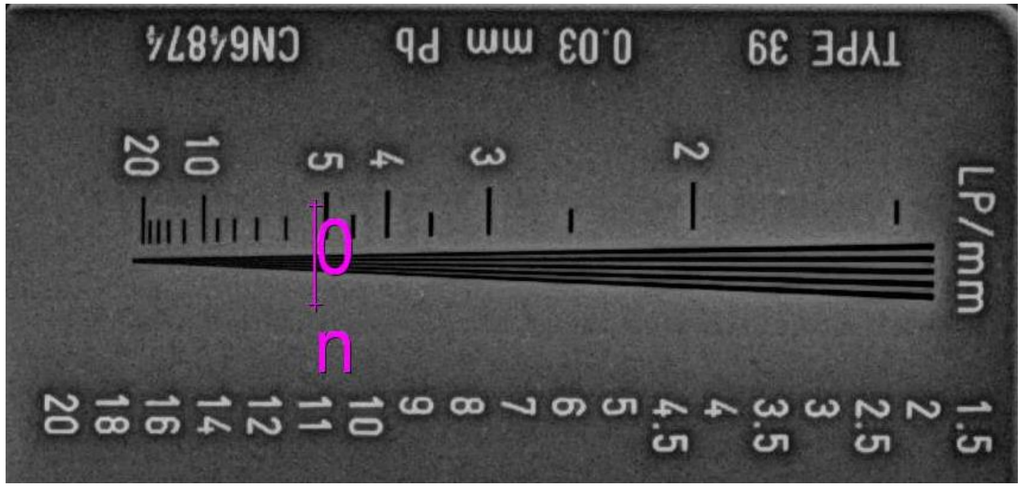


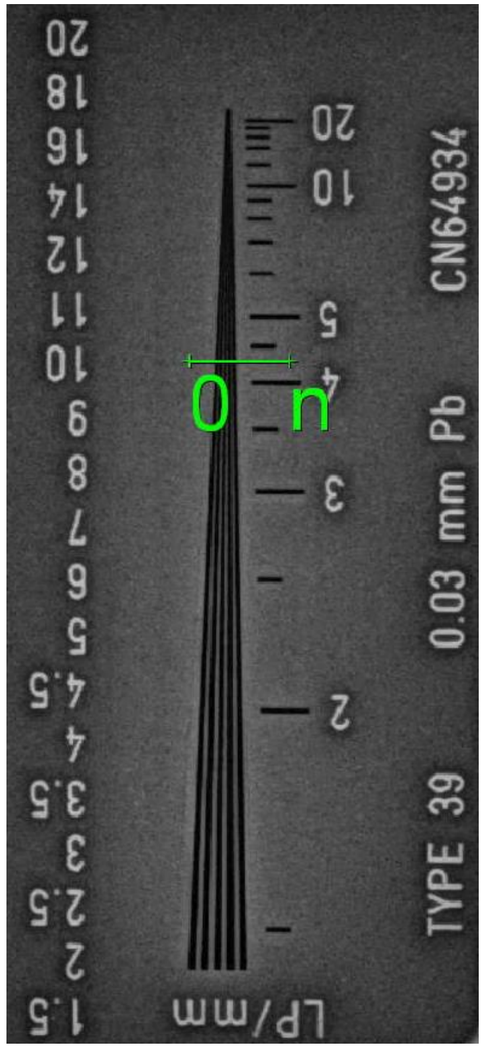
Duplex Wire Gauge
Ref kowtest.com

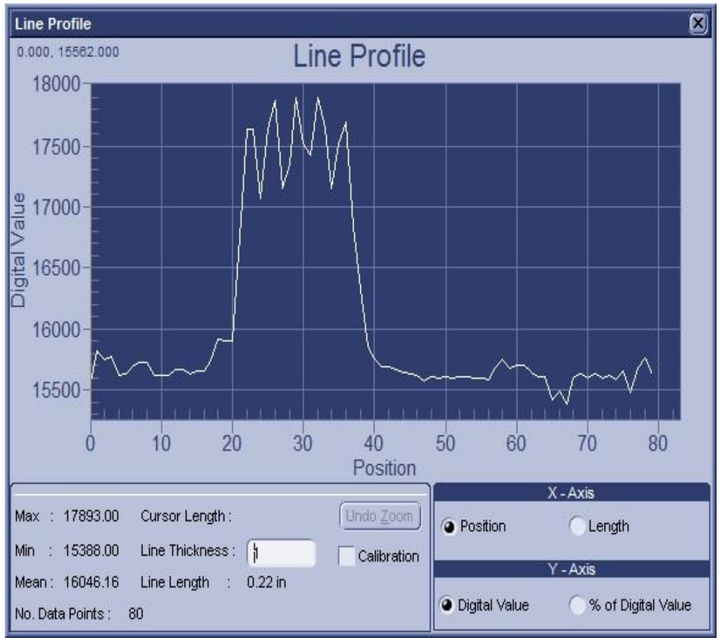




Basic Spatial Resolution (BSR) (Line Pair Gauge)







Fast Scan Direction 4.25 lp/mm 125 Micron

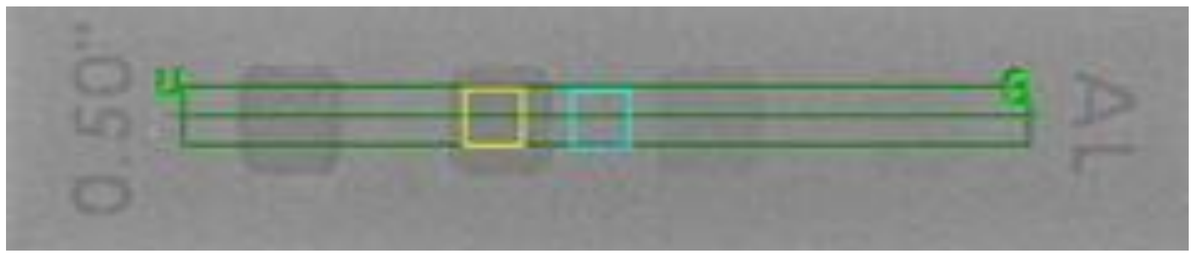
Slow Scan Direction 5.3 lp/mm (100 Micron)

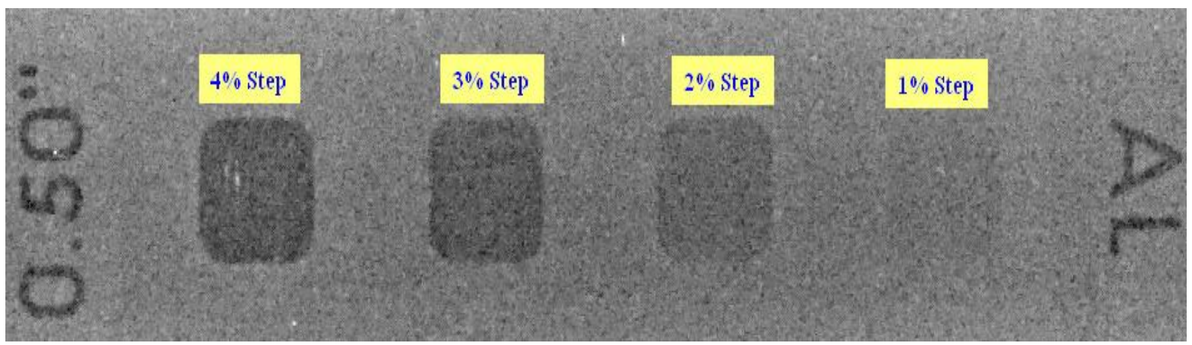
- ❑ Discrepancy in BSR (DW vs. LP)
- ❑ Human Factor, Aliasing
- ❑ ASTM E2445 lacks in instruction

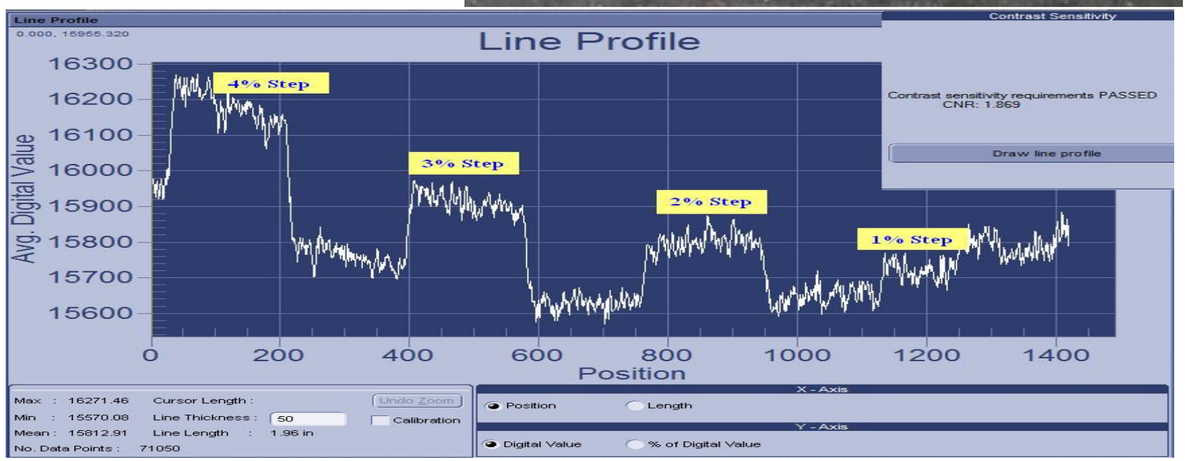
Contrast Sensitivity /Contrast-to-Noise Ratio (CNR)

$$CNR = (\mu_0 - \mu_B)/\sigma_B = \Delta\mu/\sigma_B$$

- Ability to detect variations in thickness/density
- Visual evaluation of targets Al, Cu, Steel
- CNR often requires 2 - 2.5 (TBD)
- 2% sensitivity was observed even when CNR < 2
- Automated procedure showed inconsistencies in CNR
- Contrast sensitivity is key for low res. Application (e.g. composite)

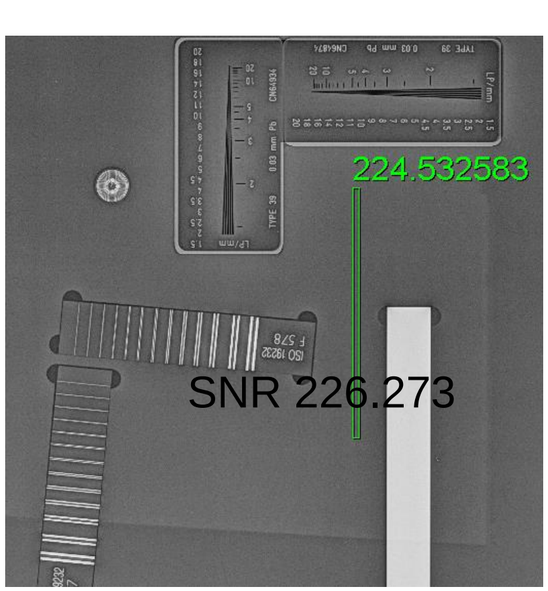


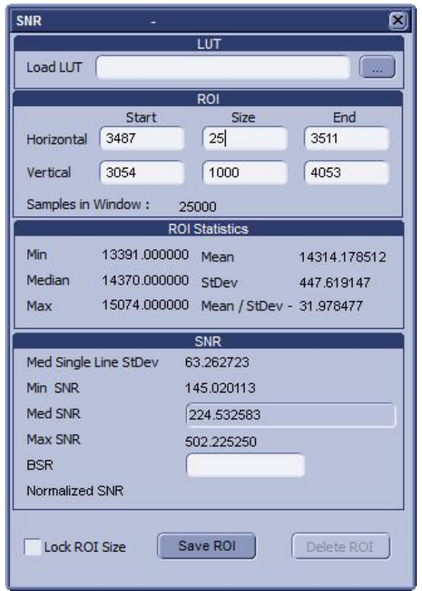




Signal-to-Noise Ratio (SNR) / Normalized SNR (SNR_N)

- SNR - Quantitative indication of noise level
  - (*Scatter, quantum nature of photon, IP inherent structure, PMT Gain, Laser Power, etc.*), higher the SNR, the less obtrusive the background noise
- Normalization by the effective pixel size gives an SNR_N (Independent of SR_B)
- SNR were found varied with size and location of Region-of-Interest (ROI)
- In general CR is more sensitive to scatter than film
  - Pre-filters, screens, collimator, short exposure may reduce scatter

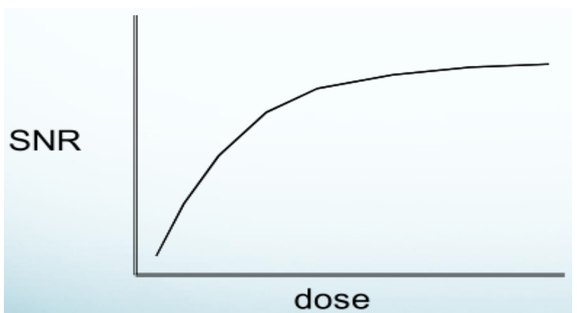


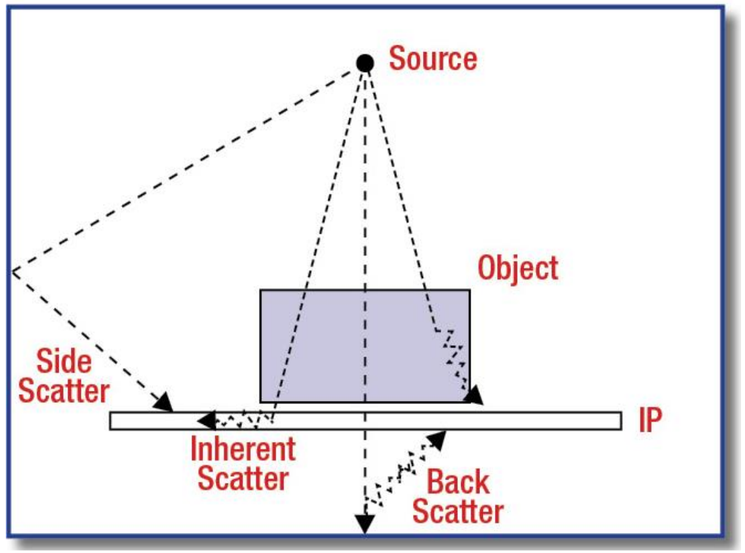


$$SNR_N = SNR_{meas} \frac{88.6\mu m}{SR_b}$$

$\mathrm{SNR}_{\mathrm{meas}}$ is measured SNR

SR_b is basic spatial resolution

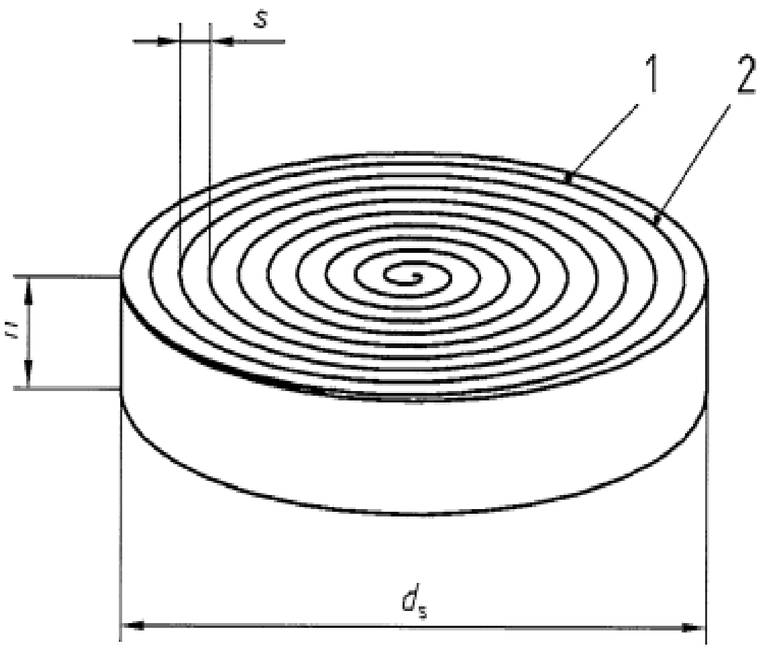




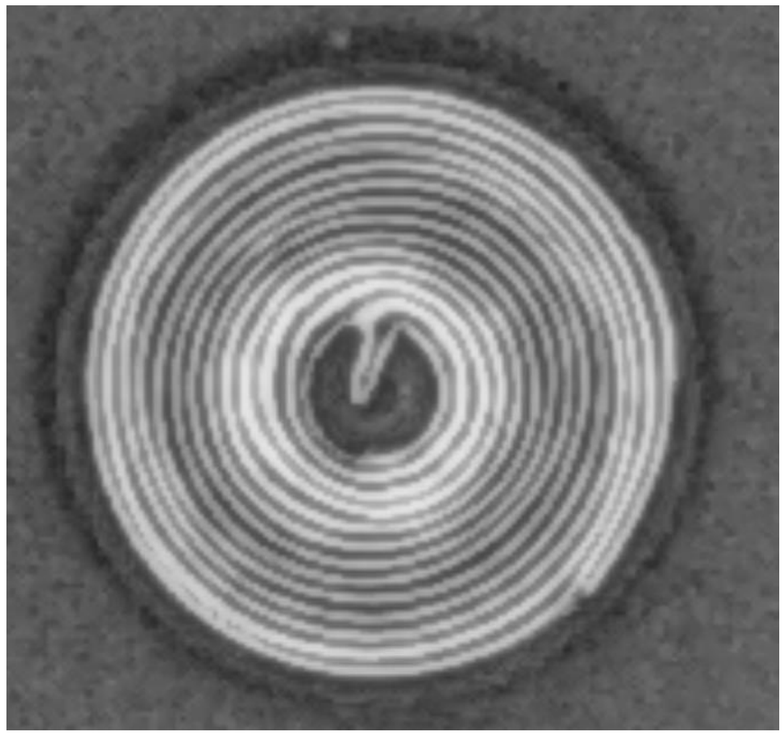
Ref: Digital and Film Radiography - Ken LaCivita

BAM Snail for Central Beam Alignment

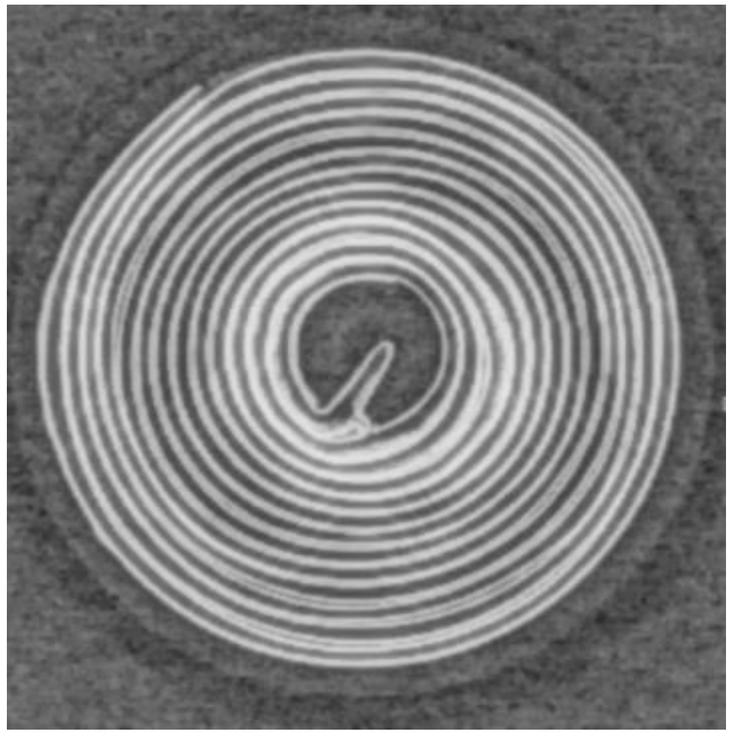
- Radiation beam aligned perpendicular to the center of the (BAM-Snail)
- CR image of the image quality indicator will be a regular spiral



Ref: ASTM E2445



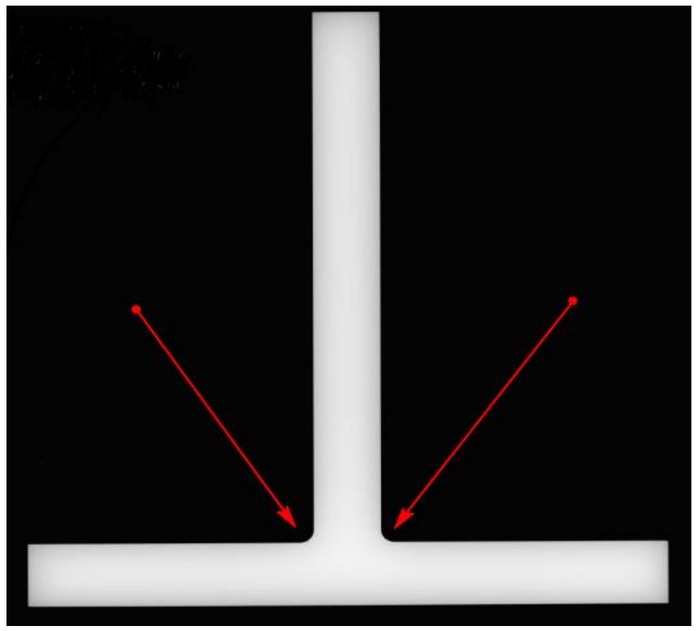
Central beam alignment @ 70 µm



Central beam alignment @ 35 µm

Laser Beam Jitter

- Jitter appears if the laser beam function is not working properly *(lack of smooth movement of the imaging plate/laser scanning device)*
- Dust on the laser or mirror is the probable causes of laser malfunction
- Examining the edges of the “T-bar” on the image
- Target edges should be straight and continuous



Examining edge of T-beam

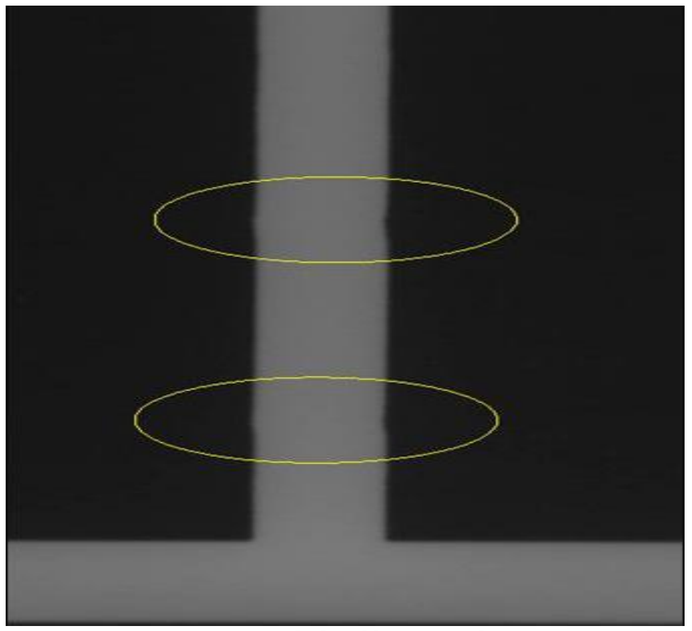


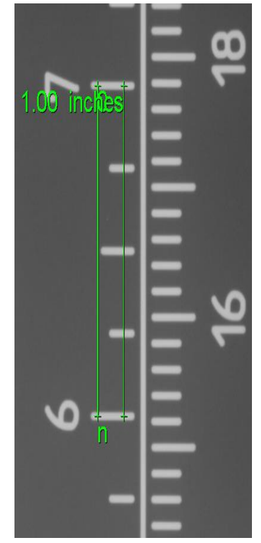
Image with jitter (sample)

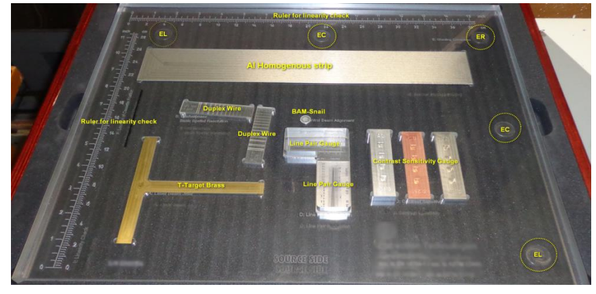
Ref: LaCivita, K.J, “AFRL-RX-WP-TR-2009-4069

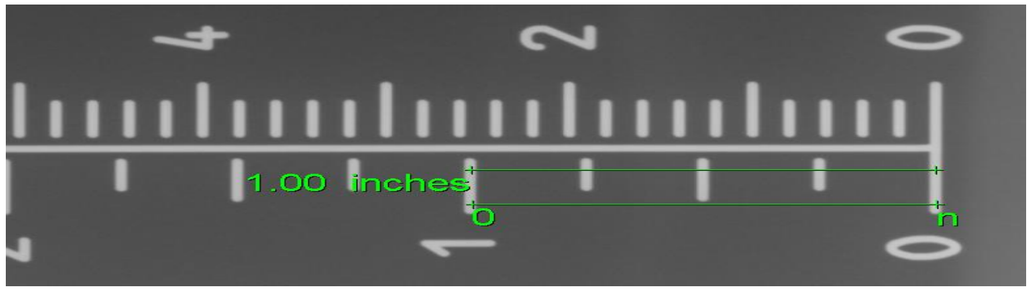
Image without Jitter (NRC)

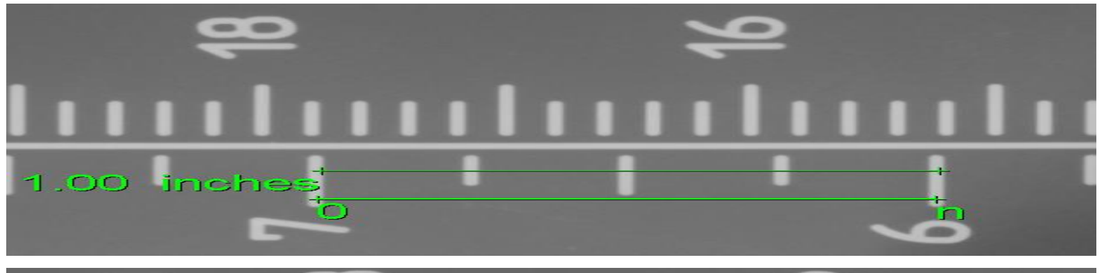
Geometric Distortion

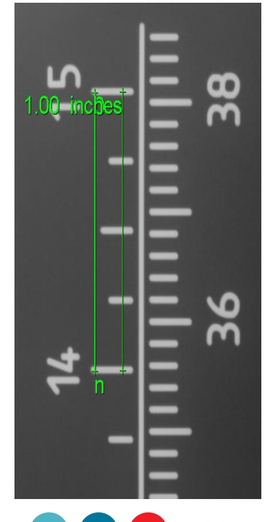
- Checks the <u>spatial linearity</u> of the CR system to find image distortion
- Ruler of high absorbing materials located in the perimeter (x- and y- direction)
- Tilting / twisting of IP during the scan
- Maximum geometric distortion was found <0.045% [Require < 5%]

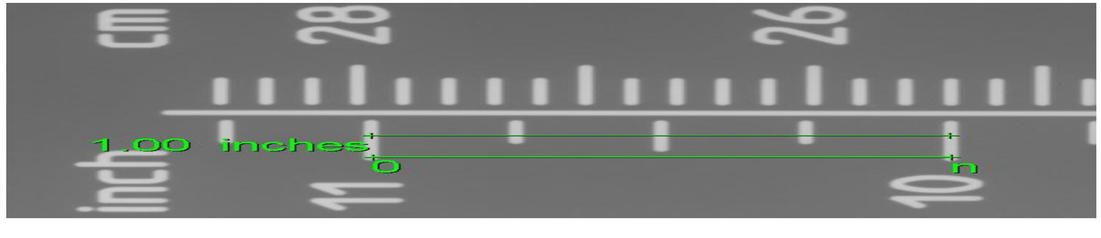






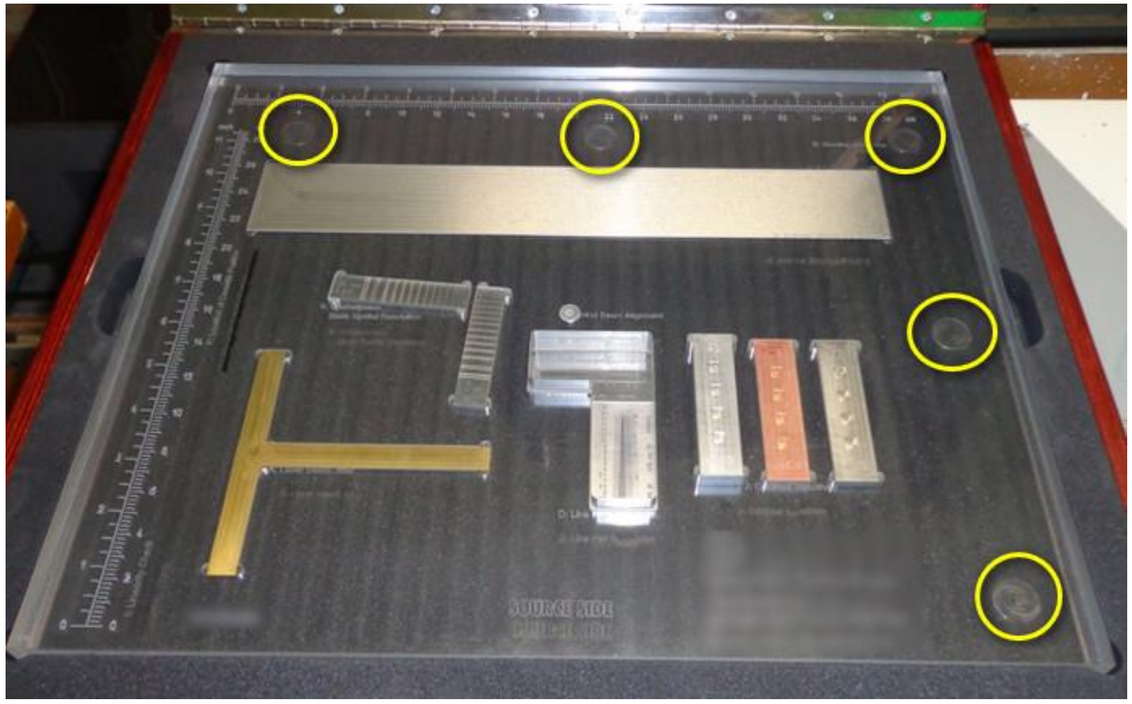


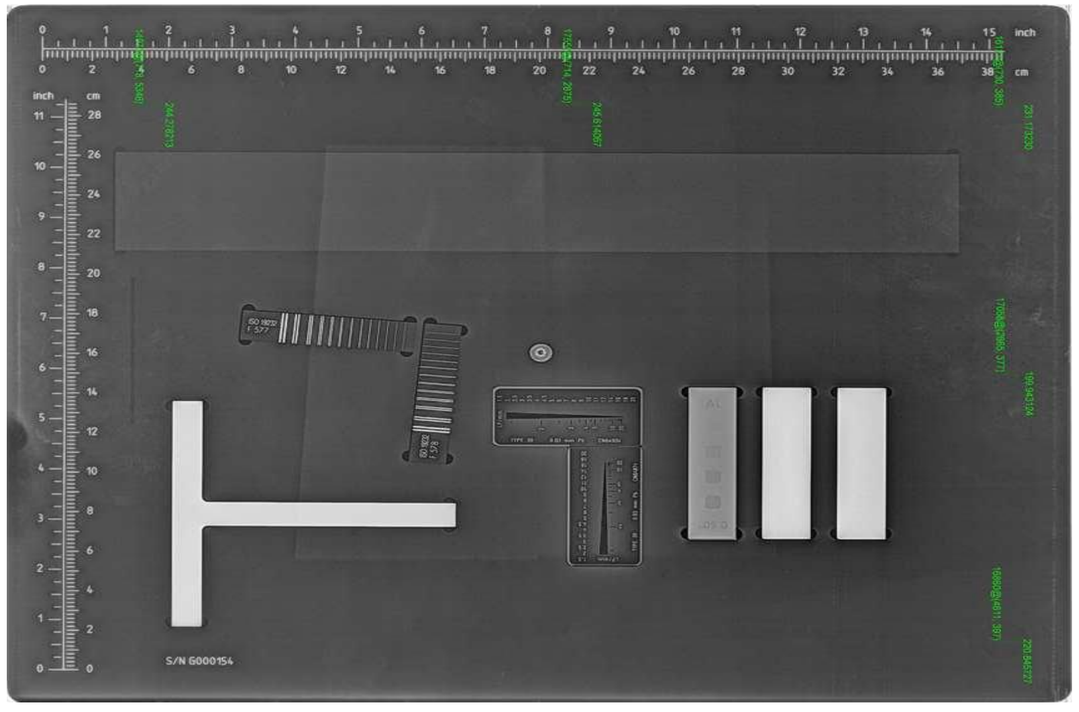




Shading Effect

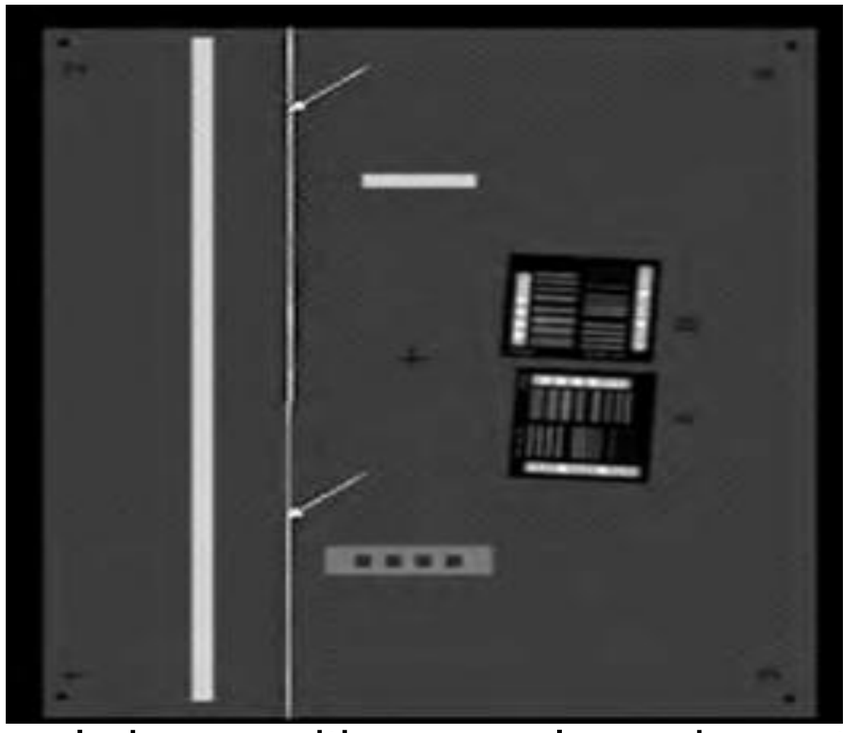
- Ensure scanning laser intensity is uniform across scanning width of IP
- Check for proper alignment of light-guide/photo-multiplier tube assembly
- ASTM E2445 ± 15%, Centre hole vs. Corner hole)
- NRC ± 1%, 8% and ± 3%, 1%





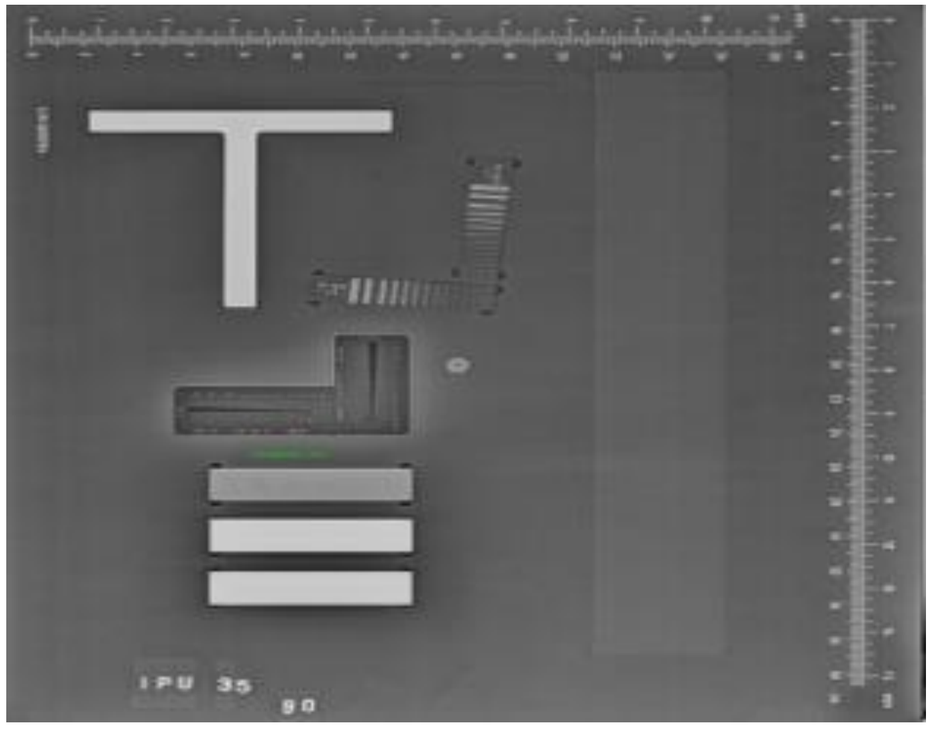
Scan Column Dropout

- No test object required
- Obserable as zero pixel value linear image artifact
- Straight bright white line parallel to the transport direction
- Probable cause is internal obstruction (e.g. contaminates]



Sample image with scan column dropout

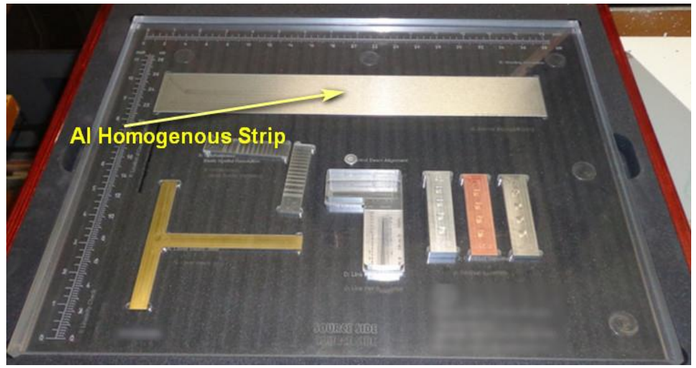
Ref: ASTM E2445M-14

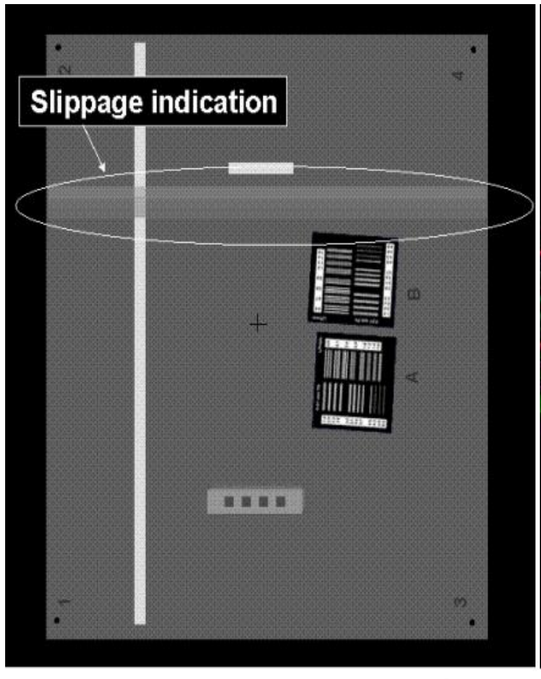


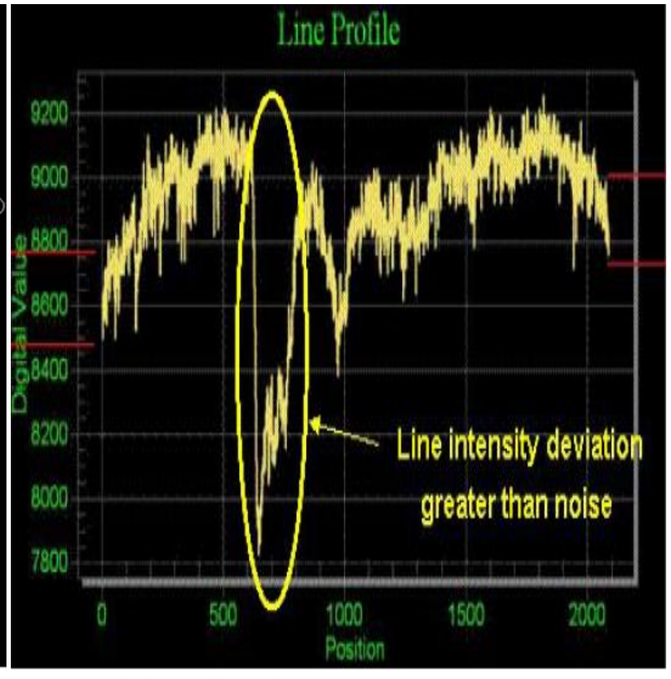
No scan column dropout white line (NRC study)

Scanner slippage

- Slipping of an IP in a scanner transport system
- Slipping would result in deviations in the intensity of scanned lines
- Distortion in homogeneity of scanning/reading system
- Deviation showed as intensity is greater than the system noise

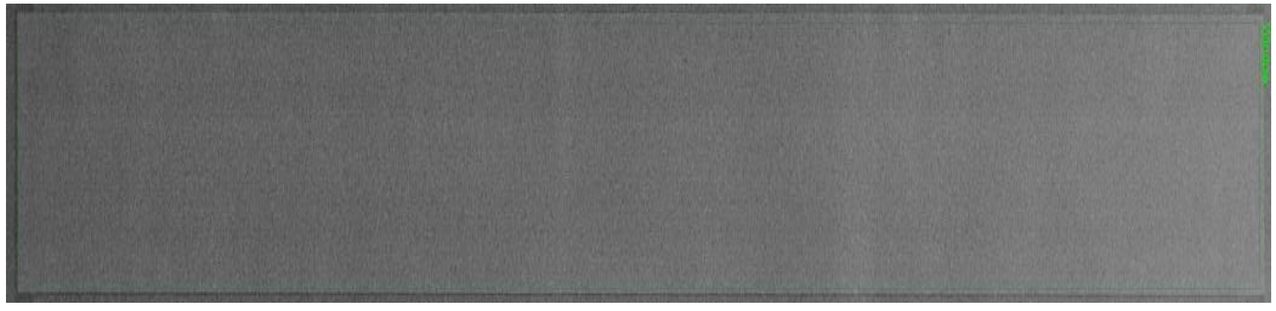


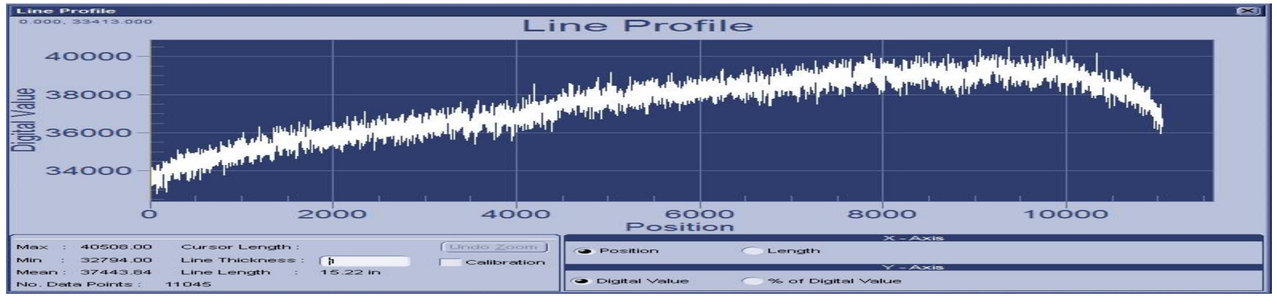




Sample Image with Slipping

Ref: LaCivita, K.J, “AFRL-RX-WP-TR-2009-4069”

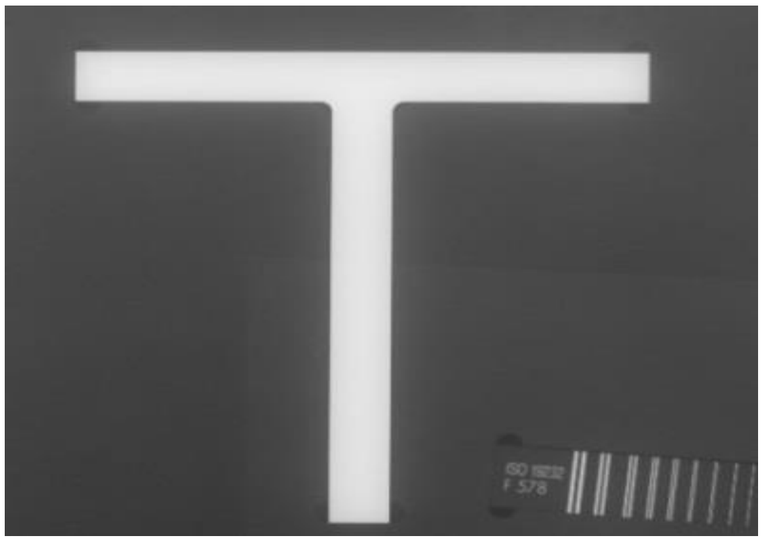




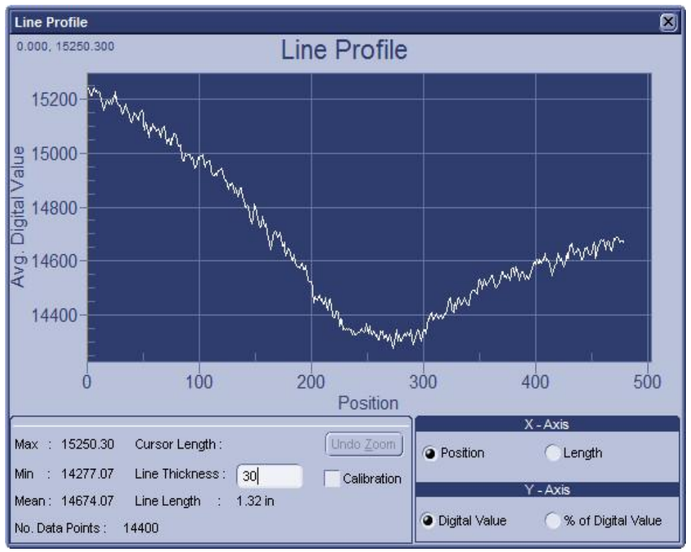
Blooming or Flare or Afterglow

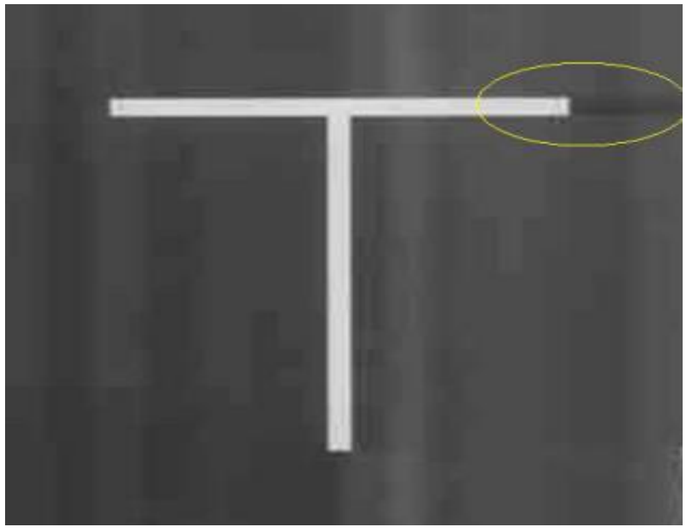
- Overshoot or streaking (dark shadow immediately adjacent of a high density target)
- IP oversaturated around target may leave a latest image or ghost
- Should not be visible, BAM okay 1.5 %, NRC no blooming
- Need to perform again with changed settings (High / Low PMT Gain)
- May require use of shielding or rotate IP to prevent local “blooming” artifacts and/or

latent images



NRC Experiment (No blooming)



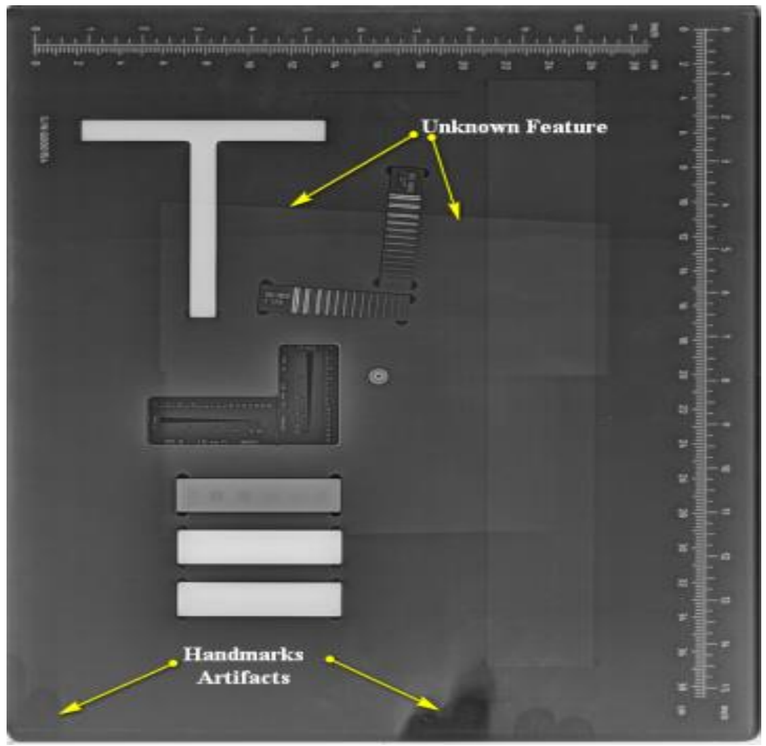


Sample Image with blooming

Ref: LaCivita, K.J, “AFRL-RX-WP-TR-2009-4069”

Image Artifacts (Ghost)

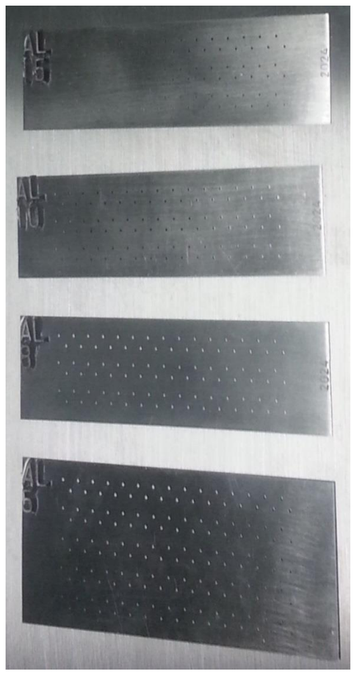
- **Unwanted image features (unanticipated and unexplainable)**
- **Hardware, cracked plates, laser beam head, wear/scratch or moisture**
- **Harm the quality and may obscure the area of interest**

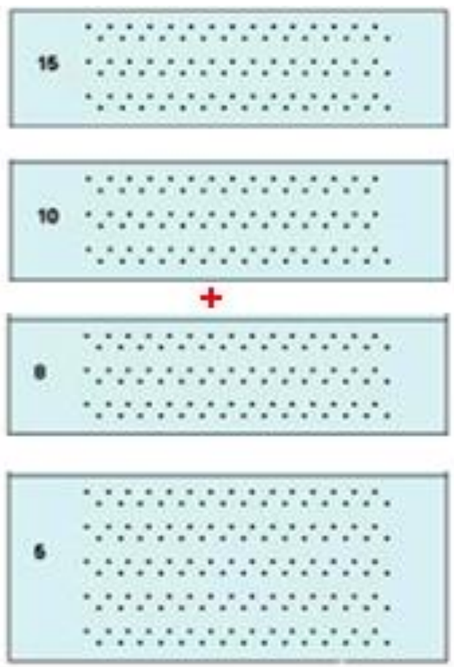


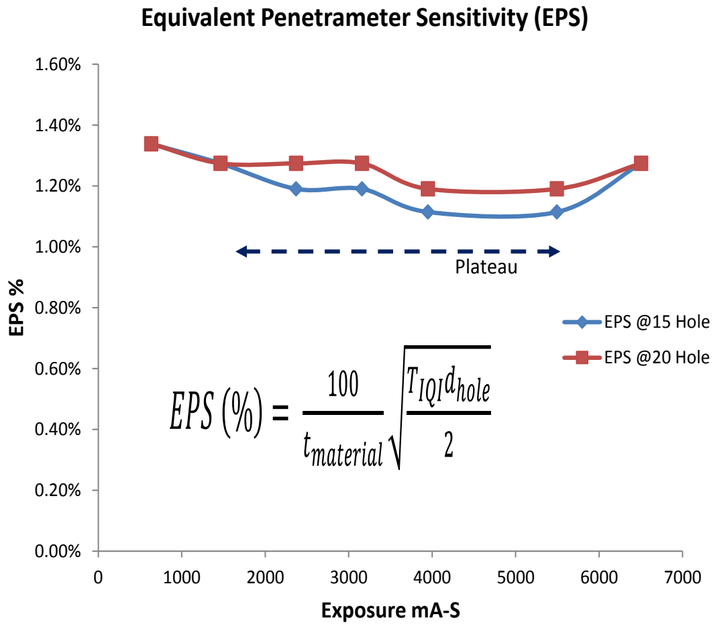
- Few artifacts were attributable to residual permanent image of reference specimen.
- High exposure in unshielded part of IP plate, scatter radiation, etc. which eventually contributed to form a hard to erase latent image
- Erasure test can help to determine if erasure is adequate
- Masking unexposed part with lead and additional erasure cycles are few options to remedy latent image

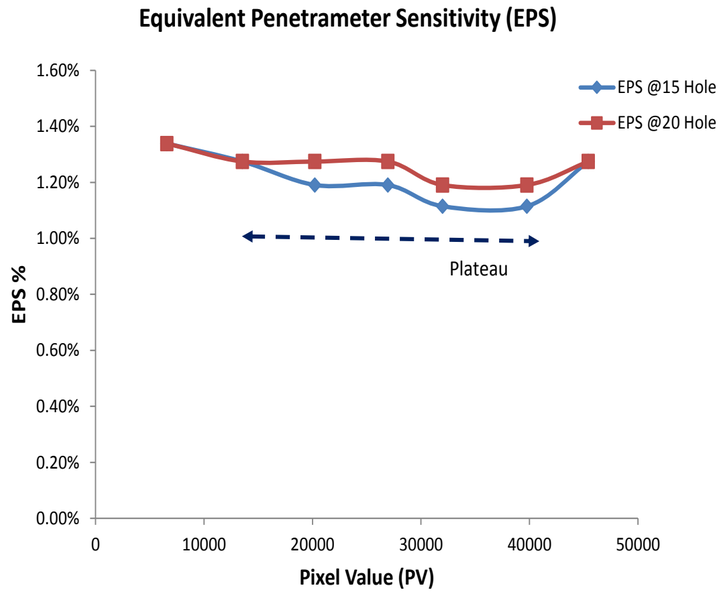
Equivalent Penetrameter Sensitivity (EPS)

- EPS plaques discern subtle differences in image quality as radiographic parameters are changed
- Determine the exposure levels necessary to ensure an adequate signal-to-noise ratio (SNR)
- Generate the acceptable gray value working range of the CR system and IP plate combination
- EPS is a subjective test (Related to inspector eye capability to view & count no. of visible holes)
- EPS curve is used for establishing & monitoring critical process control metric of CR/IP/procedure
- EPS is inversely proportional to SNR (See ASTM E2445 or E746 for details)



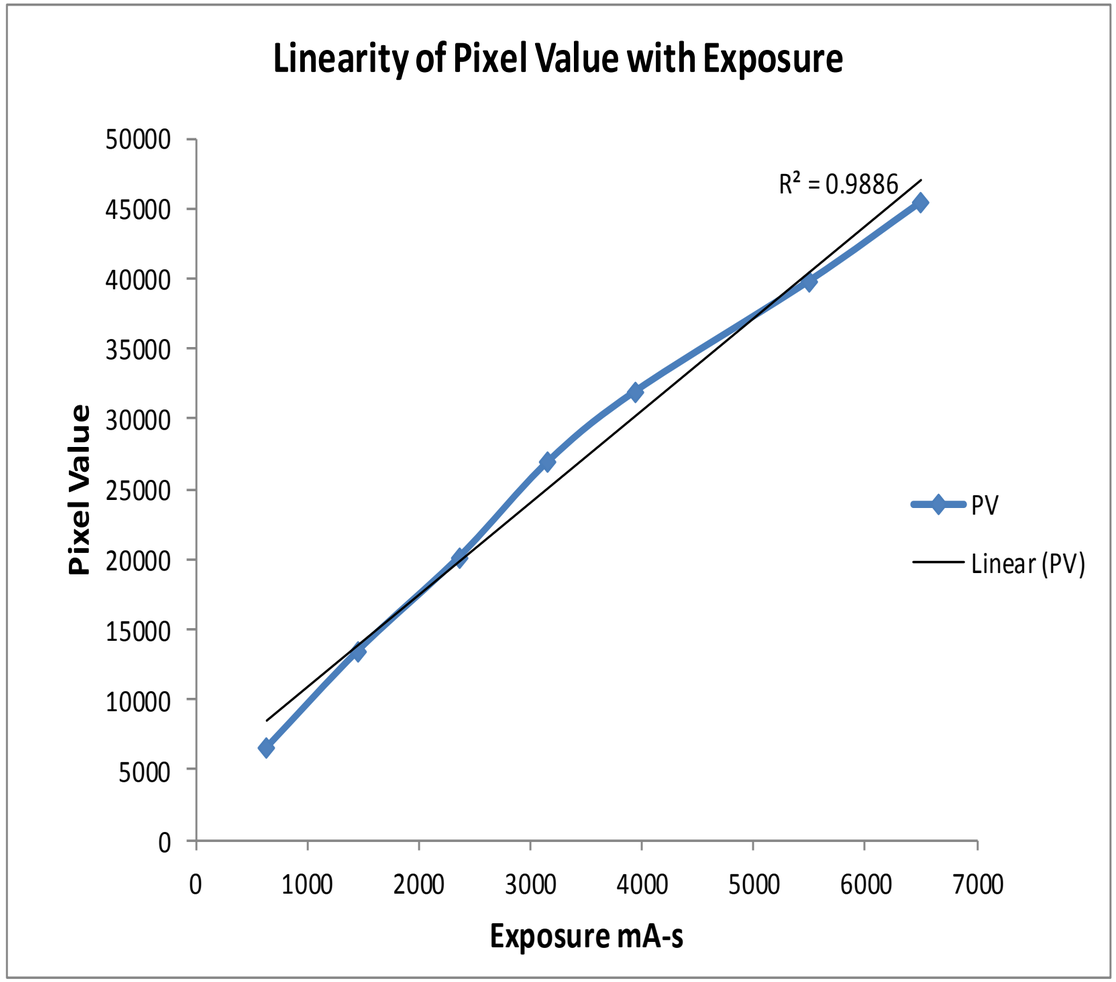




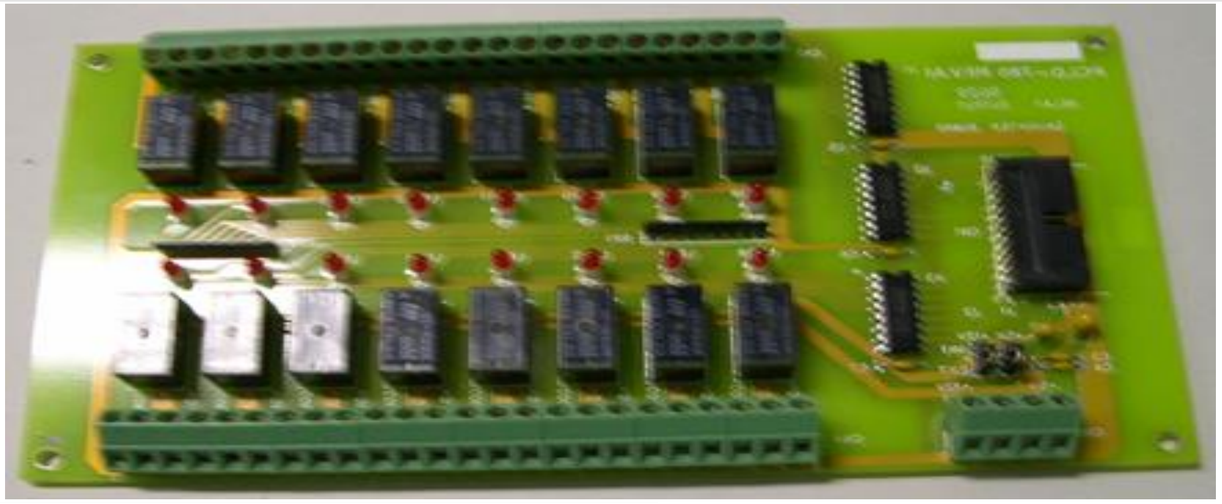


Pixel Value Linearity

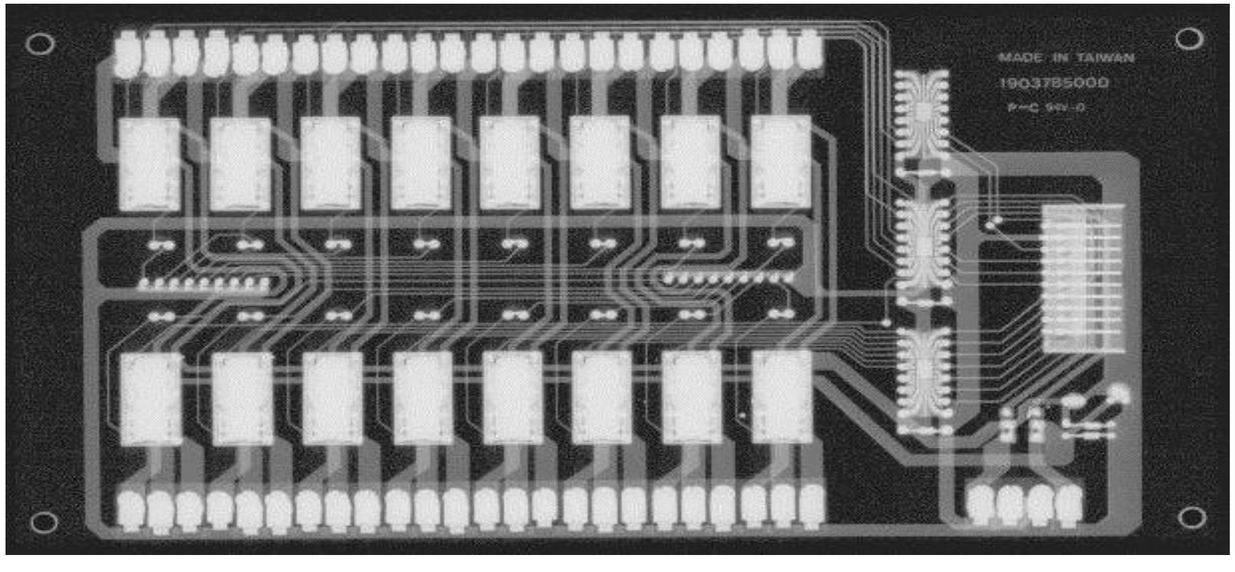
- Signal//Pixel value required to be proportional to the radiation dose or exposure
- Data point is within ± 10% of a straight line best fit
- ASTM E2445 lacks in guideline



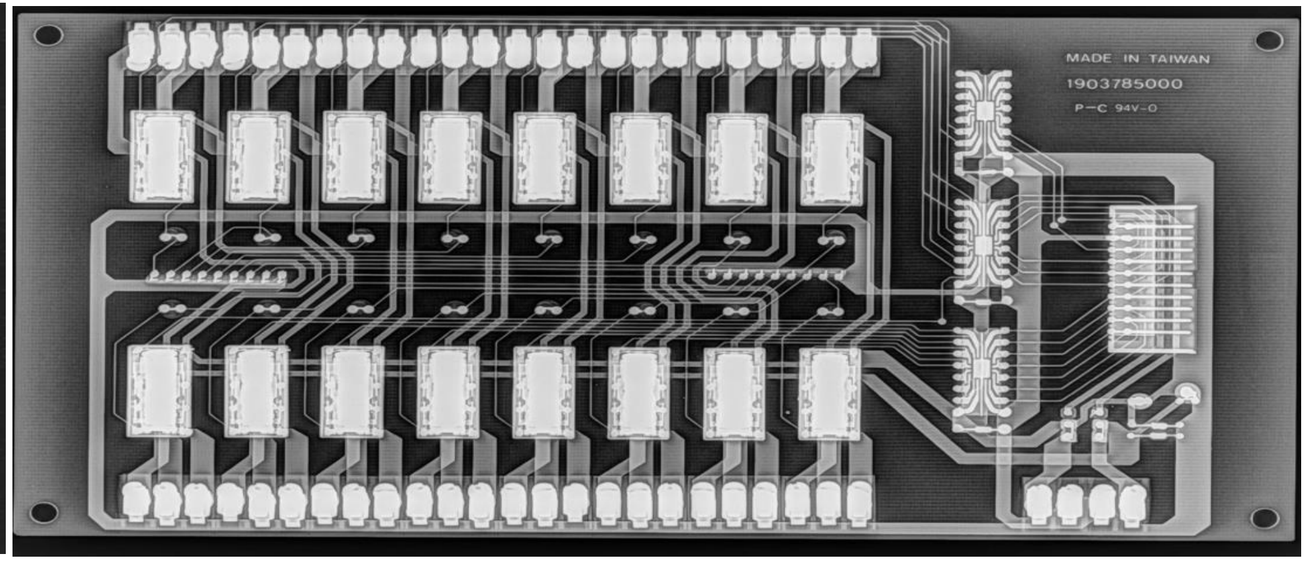
CR Comparison (Electronic Board)



Specimen

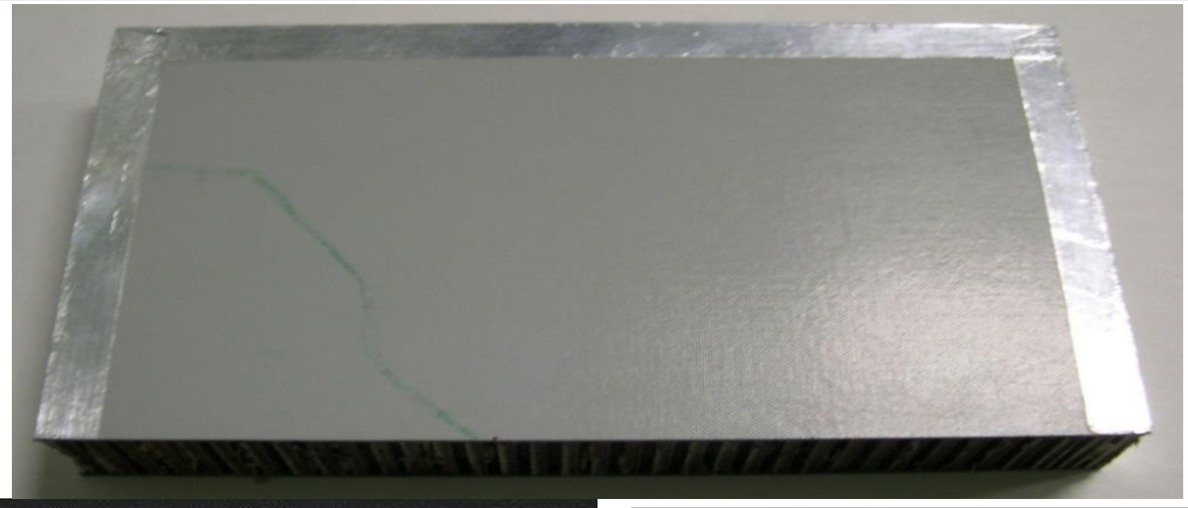


Film

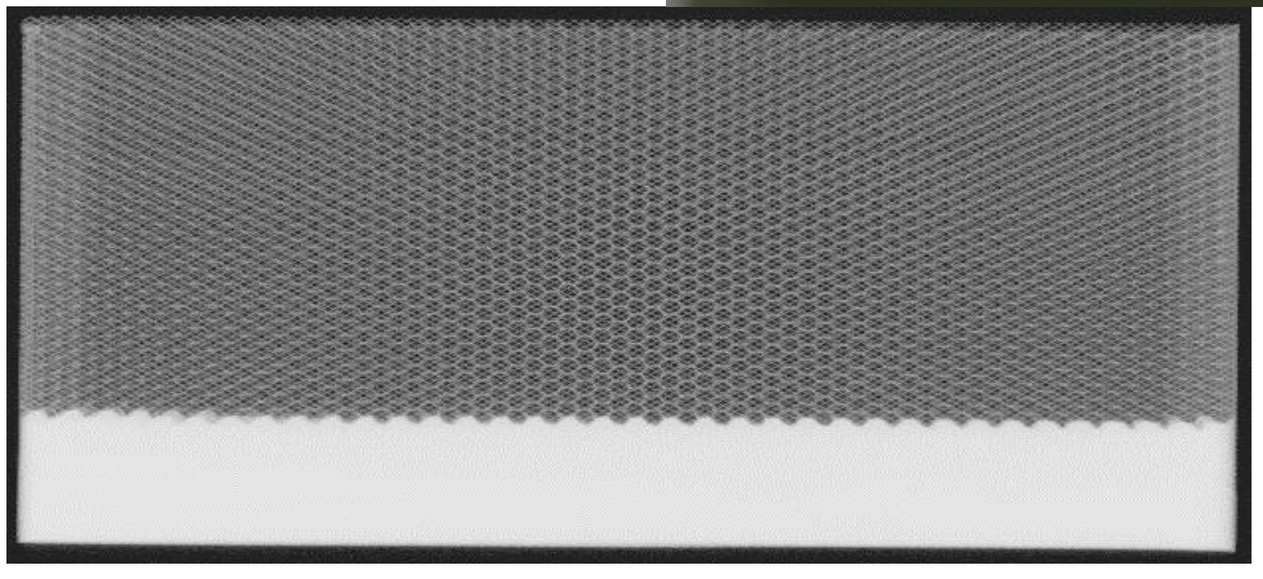


CR

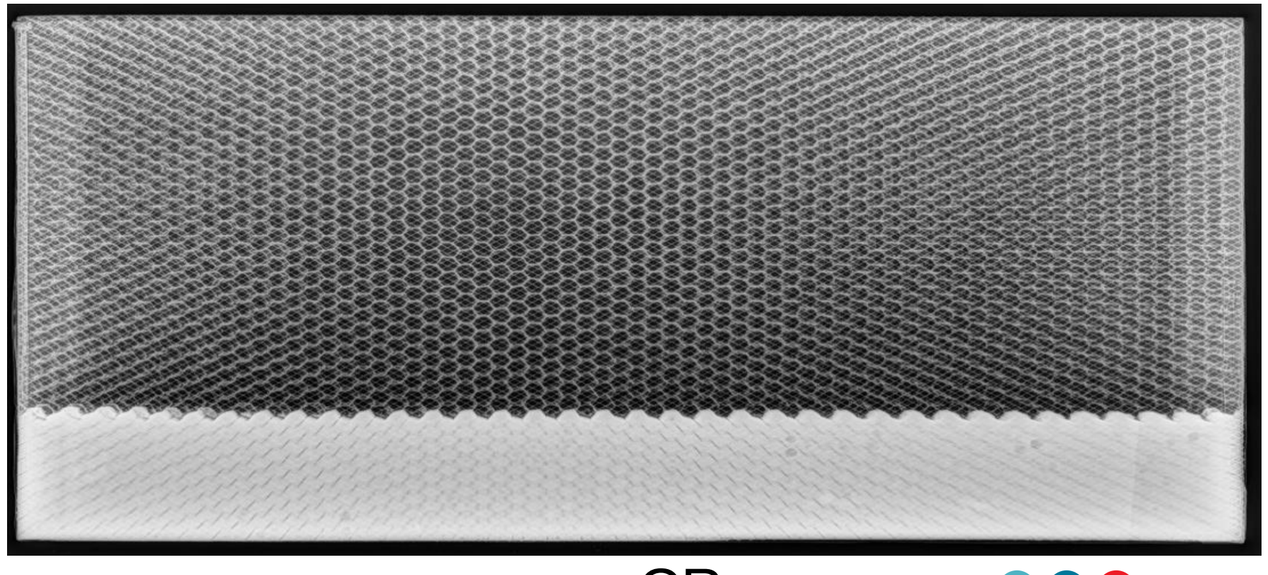
Film vs CR (Sandwich honeycomb core panel cupper mesh



Specimen



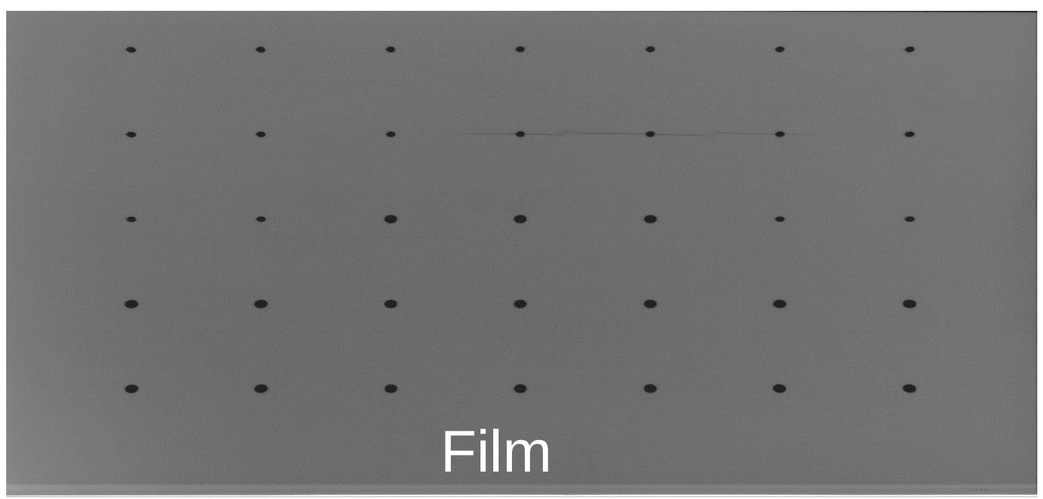
Film

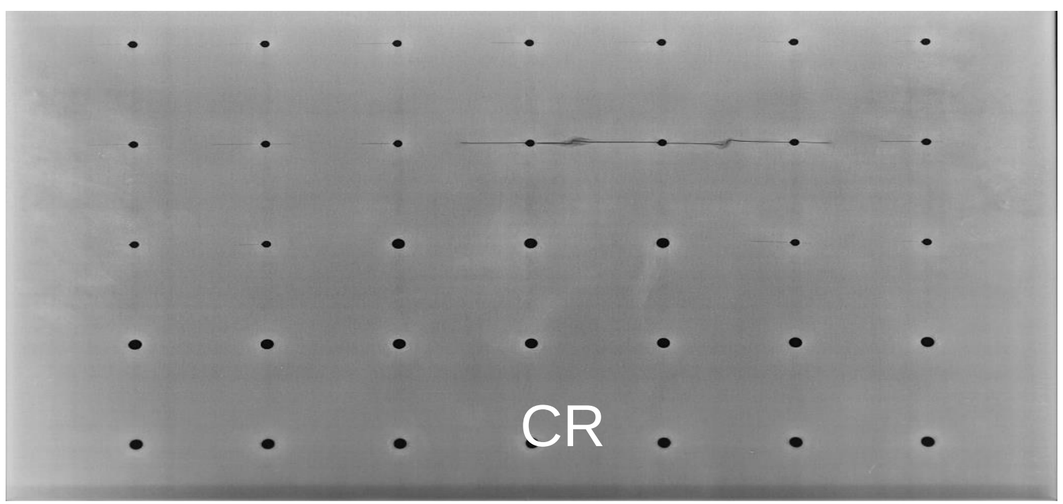


CR

CR for High Resolution Application (Cracks, Weld Defects)

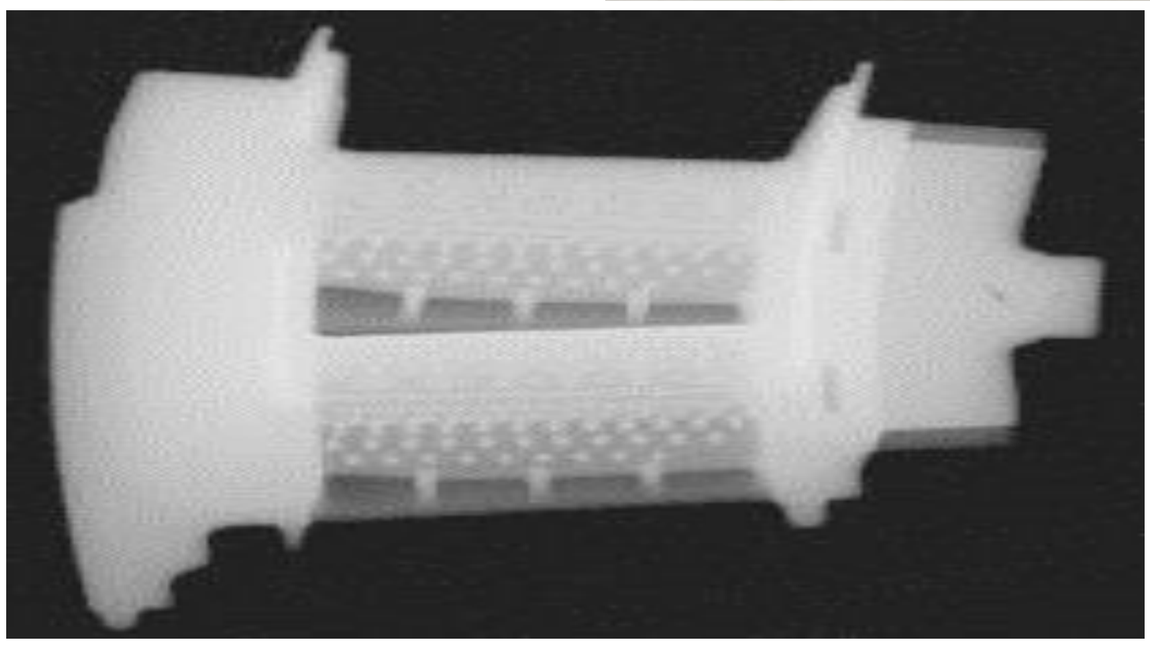
- **Much more challenging to match detection limits of film!**
  - Should have good contrast sensitivity
  - Spatial resolution and image noise are also critical
  - Spatial resolution (primarily affected by sampling rate or scanning resolution (100µm, 50µm, 25µm), imaging plate grain size
  - Image noise primarily affected by imaging plate characteristics, exposure (mA x time)



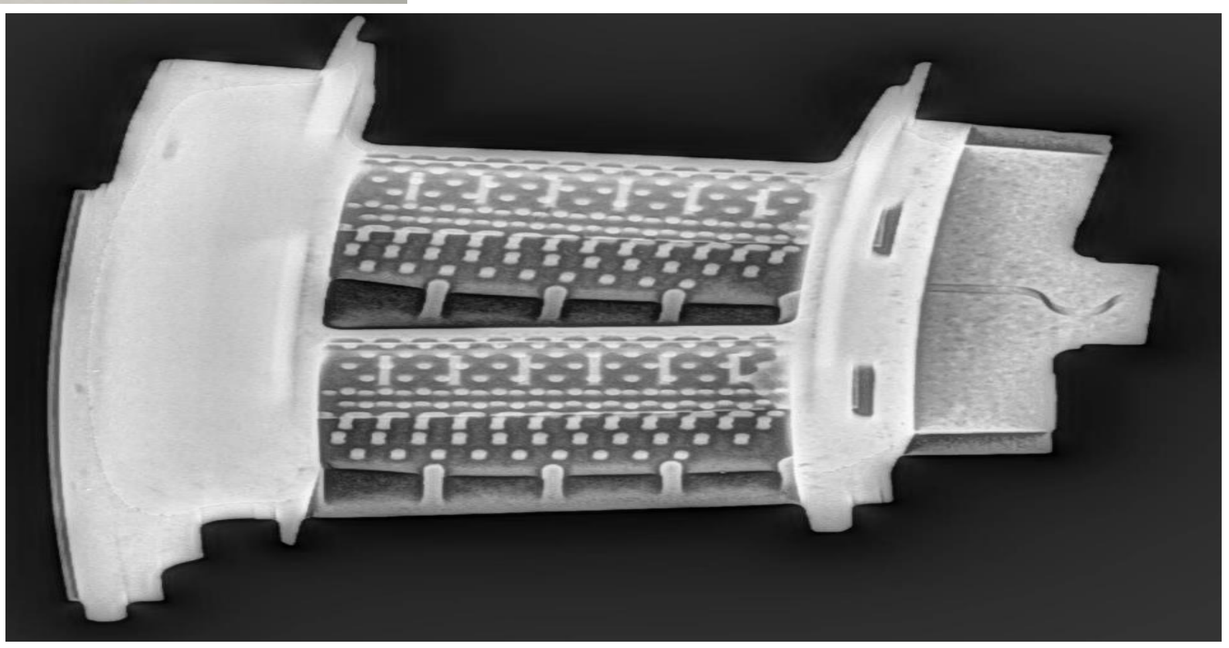


Film vs CR (Nozzle Guided Vane)

Specimen



Film



CR

Summary

- **SNR_N exceeded the ASTM highest system class (130 IP special)**
- **Resolution, contrast, SNR, shading, beam alignment, jitter, slippage, geometric distortion etc.) met the current ASTM requirements**
- **SNR or EPS improves with exposure up to certain point.**
- **Best image resolution – blue plates & lower scanning resolution**
- **Ghosting-like artifacts were observed which required engineering judgement to overcome**
- **EPS curve is not typical but identify min. exposure (key requirement)**
- **CR image is not the same as film, many variables affect image quality and many unique phenomena need to consider**

Thank you!

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