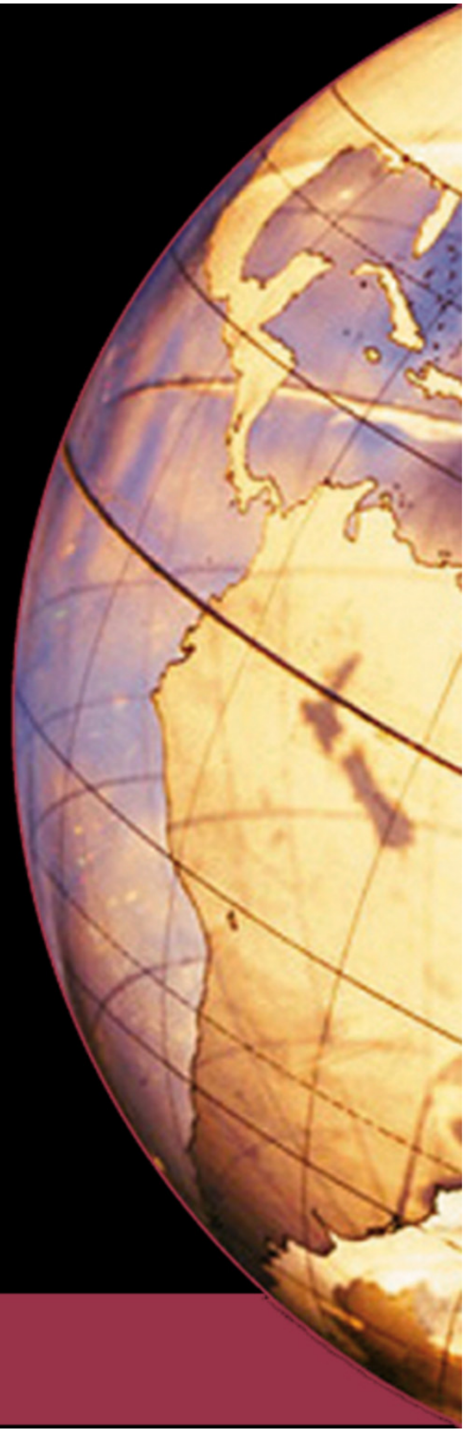
Computerized Radiography

Investigation as a Possible Replacement for Conventional Wet Film X-ray Technique of Aircraft Structure

Sponsored by
United States Air Force NDI Office
(AFRL/MLS-OL)



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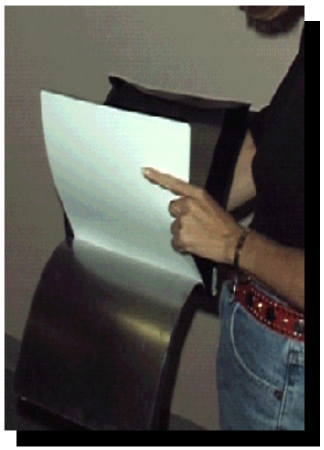
PURPOSE

Program was to provide the United States Air Force NDI Office with data to support making a decision on whether to replace film based radiography with computerized radiography (CR). Objectives of this study were to:

- Determine feasibility of replacing film based radiography with commercial off-the-shelf CR radiography for detecting cracks in aircraft structure
- Determine if CR systems can be used effectively in a field setting
- Determine if CR systems can cost effectively replace film techniques for field level operations

REPRESENTATIVE SYSTEM DESCRIPTION

Computed Radiography System Consists of Four Major Components

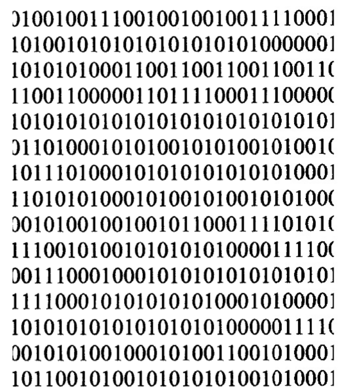


1

Imaging Plates "IP's"

2

Reader Unit "RU"



3

Software

4

Workstation

Images courtesy of: FUJIFILM I&I – Imaging & Information

SYSTEM EVALUATION PROGRAM

The Air Force contracted with ARINC to perform a controlled study to determine if CR technology could replace conventional wet film based techniques.

The program was designed to be completed in two parts:

- PART 1 – LABORATORY EVALUATION
- PART 2 – FIELD EVALUATIONS OF CR SYSTEMS

PART 1 – LABORATORY EVALUATION

- Fair laboratory testing methods to produce unbiased results
- Design of appropriate test specimens
- Recruitment of CR system vendor participation
- Use of approved mathematical evaluation tools
- Protocol development to maintain uniformity of test conditions

Test Methodology

Three test methods were used to collect detection capability measurement data for film and CR techniques.

- Circular artifacts
- Linear artifacts
- Wedges

Test Methodology

The results for film were compared to CR using three techniques:

- Probability of Detection (POD)
- Hit, miss, and false call analysis
- Measurement of the length of a long wedge

The POD program and hit, miss, and false call analysis are a pass/fail type of interpretation; an area either has, or does not have, an indication. The interpreter marks indications on a diagram matching the test specimen.

The wedge measurement was an alternative method to determine resolution capability of film and CR systems.

Test Specimen Design

The Problem of Designing a Test Specimen

Test standards and specimens used in the other common methods of nondestructive inspection rely on two dimensional artifacts – length and width, thickness and length, thickness and depth, or length and depth.

Radiography (and eddy current for corrosion) require three dimensional artifacts.

Test Specimen Design

ARINC designed a series of test specimens that partially mitigated the three dimension dilemma. Instead of having artifacts penetrating completely through the test specimen the depth of the artifact was controlled as a function of the specimen thickness. The length and width of the artifact were also controlled.

Three type of artifacts were generated:

- Circular holes (similar to penetrameter holes)
- Linear slots
- Wedges

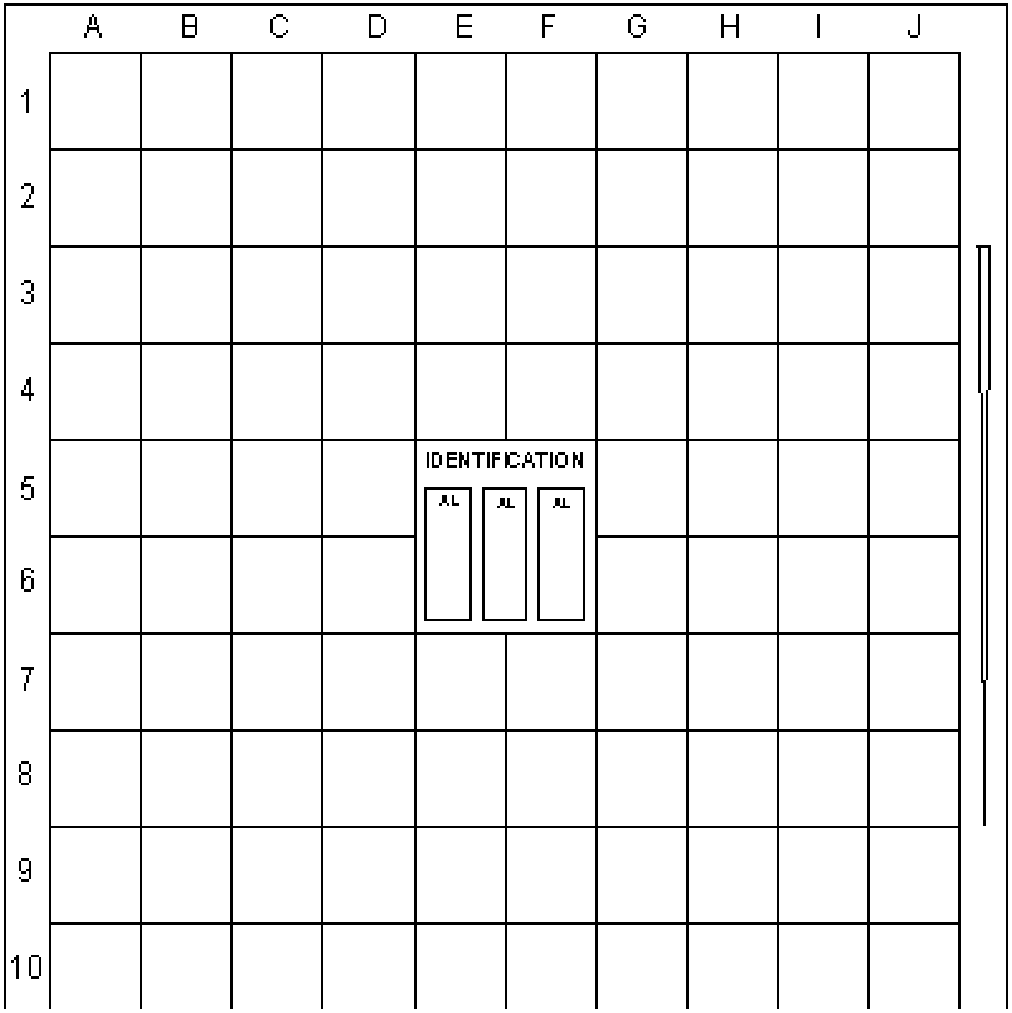
Test Specimen Design

The test specimen was constructed of two pieces of 7075 aluminum plate and a 0.004- to 0.007-inch foil artifact layer.

The foil was bolted between the plates for the evaluations.

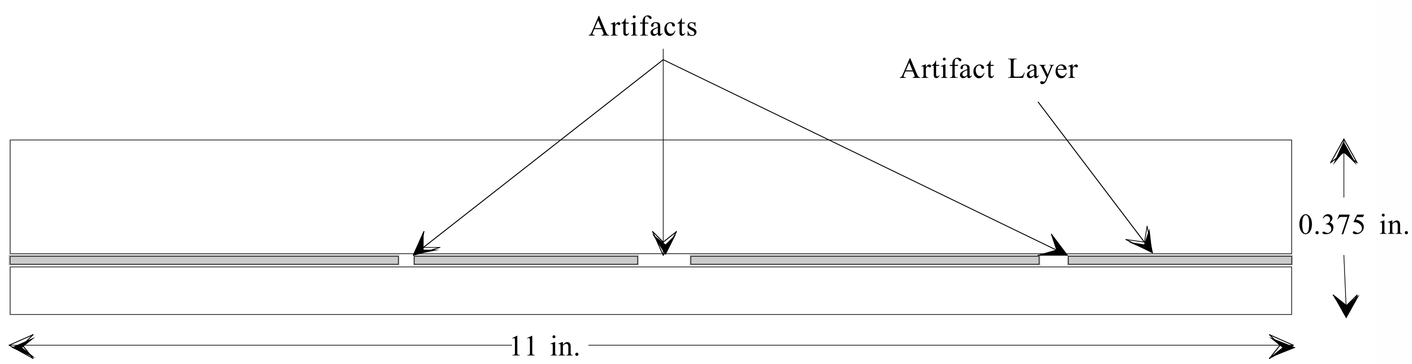
A spreadsheet type grid was engraved in the bottom plate.

Test Specimen Design



Specimen Design Showing the Engraved Decision Grid and Row/Column Identification.

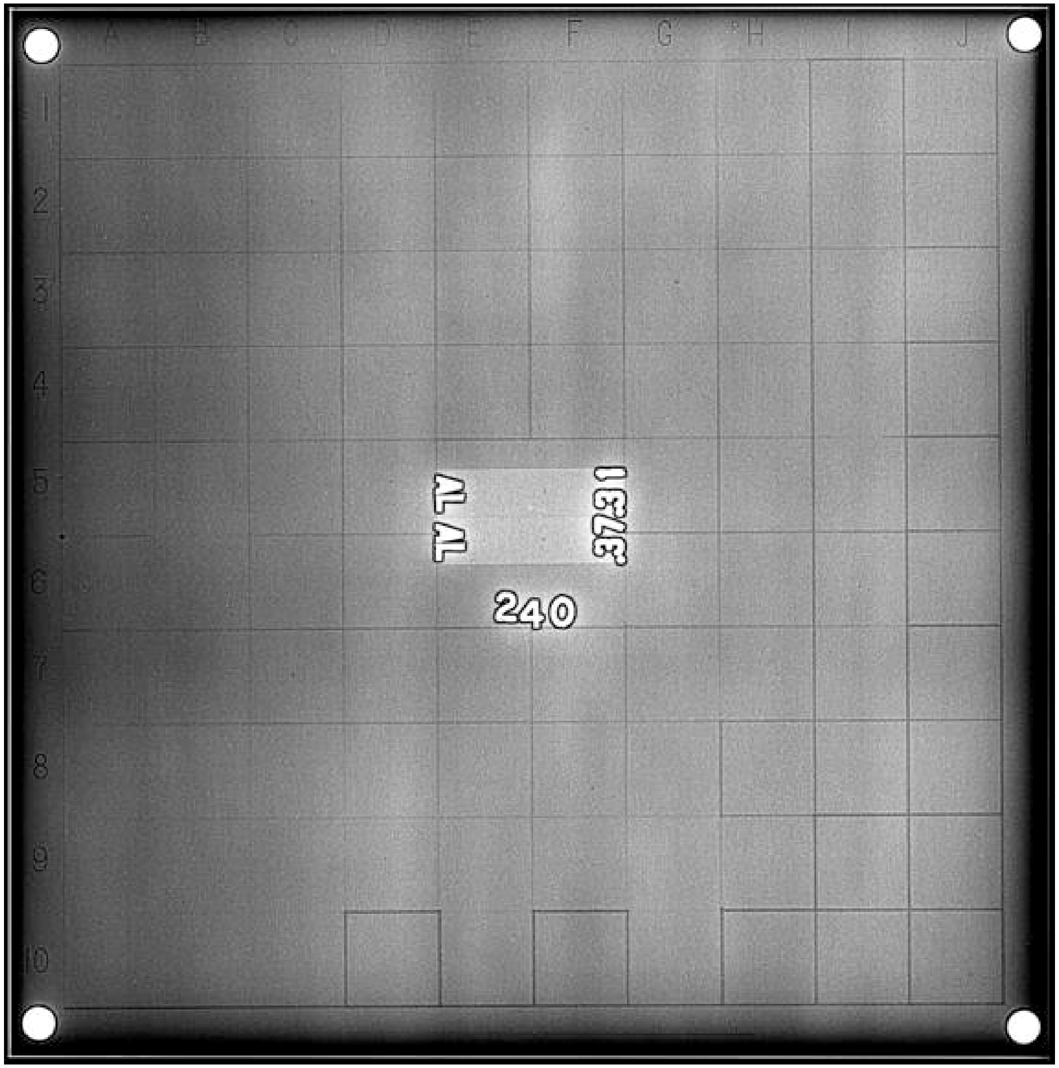
Test Specimen Design



Edge view of the test specimen showing the sandwiched foil with embedded artifacts.

The foil thickness ranged from 0.004 to 0.007 inches.

Test Specimen Design



CR Radiograph of Assembled Test Specimen.

Circular Artifact - Measurement

The POD program used requires a unitary flaw dimension as data input. In the case of circular artifacts or holes, an equivalent Image Quality Indicator (IQI) was calculated for each artifact and used as the unitary dimension alias.

The IQI equivalent sensitivity level was determined using the variables of section thickness, hole size, and hole depth or thickness in accordance with ASTM E 1025-98, Standard Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators Used for Radiology. The following equation was used to determine the IQI detection sensitivity for holes:

$$\alpha = (100/X)\cdot(TH/2)^{0.5}$$

Where:

α = equivalent IQI sensitivity, %

X = section thickness to be examined, inches

T = IQI or artifact layer thickness, inches

H = hole diameter, inches

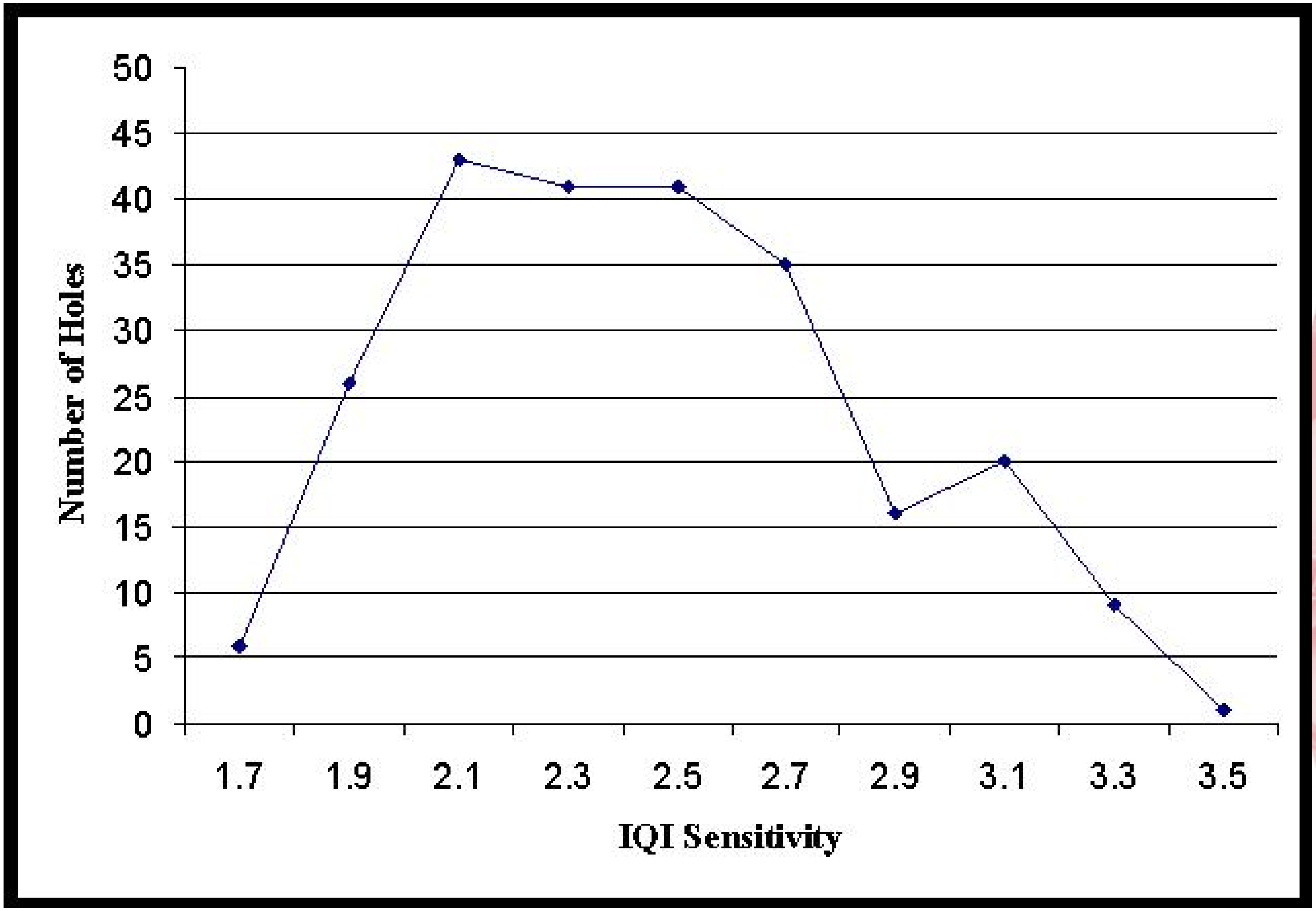
Circular Artifacts

Circular artifacts were round holes as small as 0.0138-inch diameter and ranging up to 0.057-inch.

These sizes provided some holes that were too small to be seen and some too large to be missed.

The following histogram shows the distribution of holes in the foils expressed as equivalent IQI sensitivity.

Circular Artifacts – IQI Distribution



Distribution of Circular Artifacts in Test Specimens.

Linear Artifacts - Measurement

An appropriate unitary flaw dimension alias could not be determined for linear artifacts (slots). Examination of detection data showed that foil thickness, slot width, and slot length contributed equally to overall detectability.

A hit, miss, and false call analysis was used to evaluate the inspection data for slots.

Foils were manufactured using slots as narrow as 0.002-inches and varying from 0.030-inch to 0.500-inch long.

Wedge - Measurements

The measurement of the observable length of a wedge cut out was used to calculate the width detection threshold of the imaging medium. Both horizontal and vertical wedges were cut out of each foil.

Interpreters measured their observable length using rulers or computer software imaging tools.

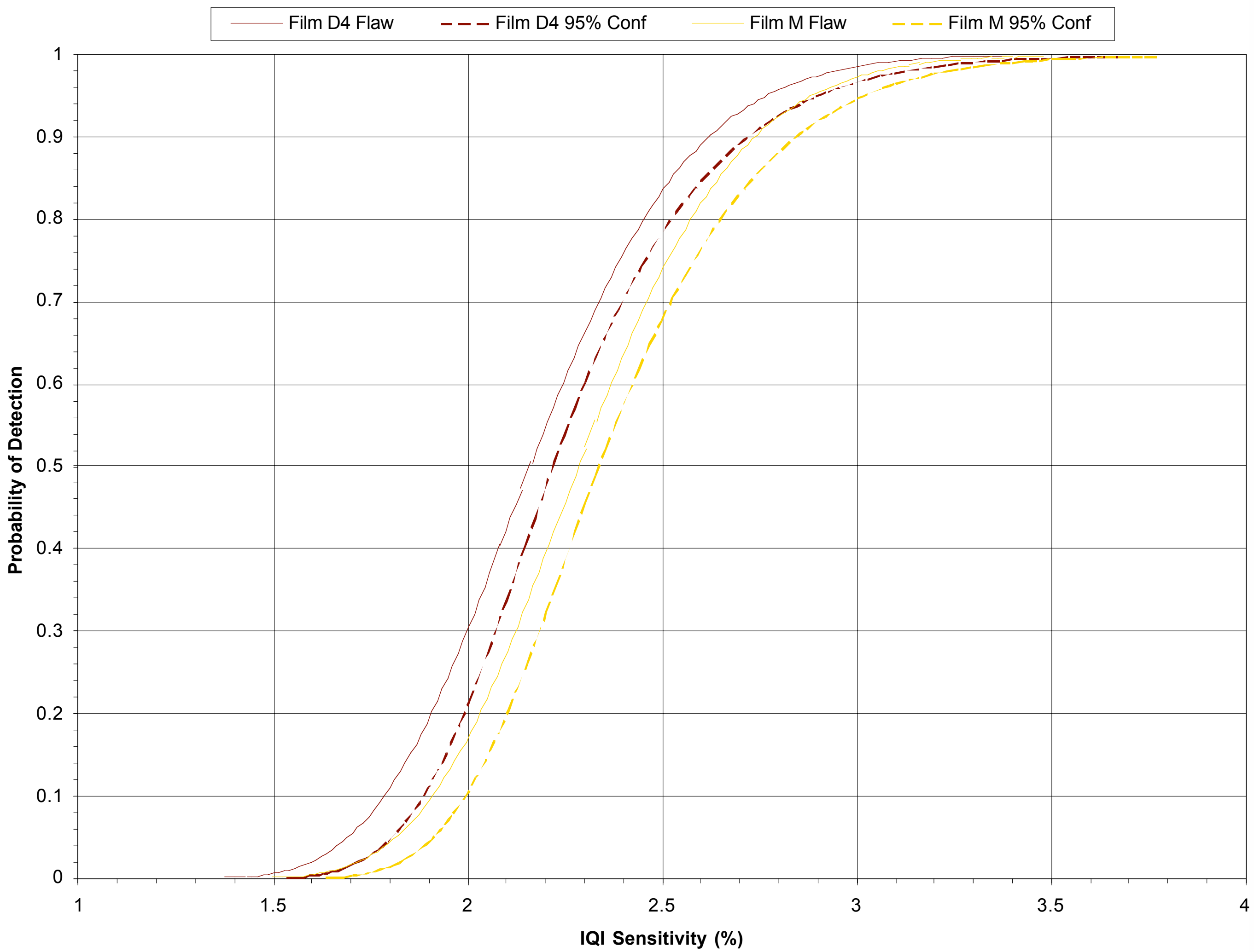
Wedge-shaped cut outs were made in the foils, 5 inches long, tapering from 0.0160 inches to less than 0.001 inch wide.

Results - Circular Artifacts

Vendor/Process	a_{50} IQI	a_{90} IQI	$a_{90/95}$ IQI
Agfa D4 Class 1 Film	2.157364	2.614103	2.716079
Kodak M Class 1 Film	2.281706	2.732941	2.840290
All Film	2.2200805	2.6797364	2.7858504
Vendor A	2.2598510	2.6832430	2.7808330
Vendor B	2.2598570	2.6351400	2.7246950
Vendor C	2.0421650	2.3287510	2.3997461

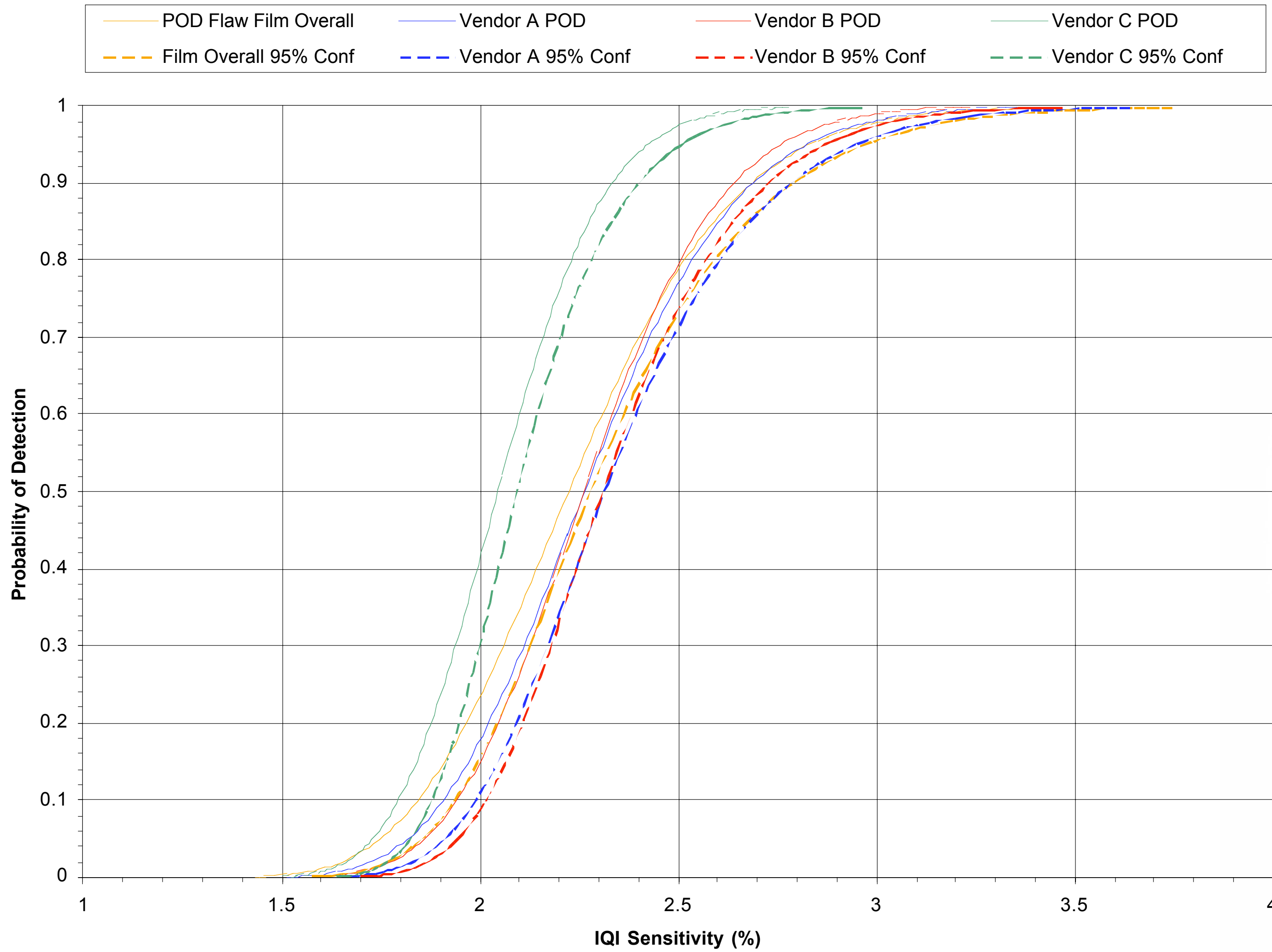
Results of POD Calculations using IQI Sensitivity.

Results - Circular Artifacts

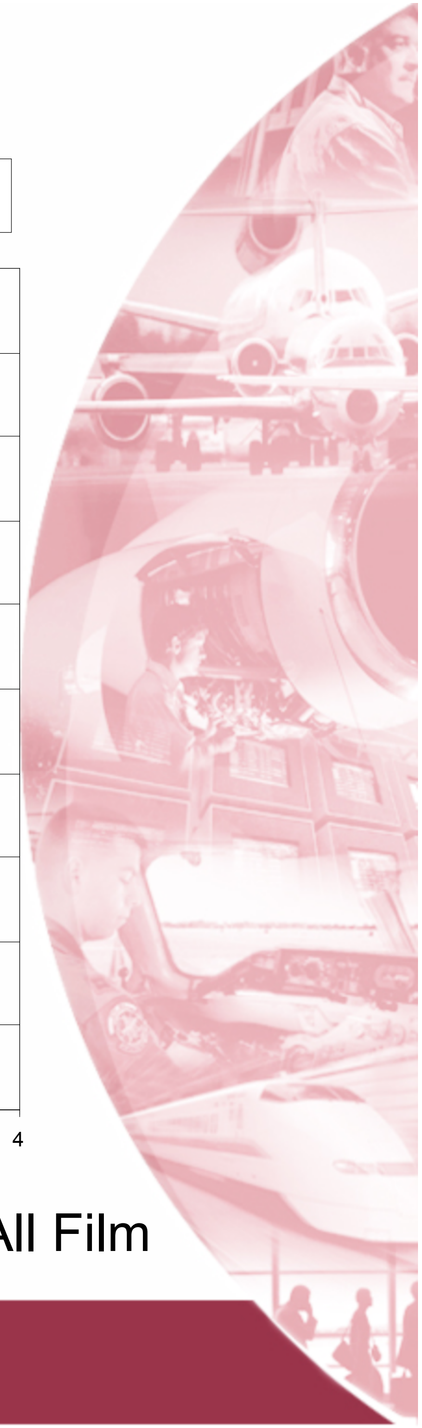


POD Results using IQI Sensitivity for Two ASTM Class I Films.

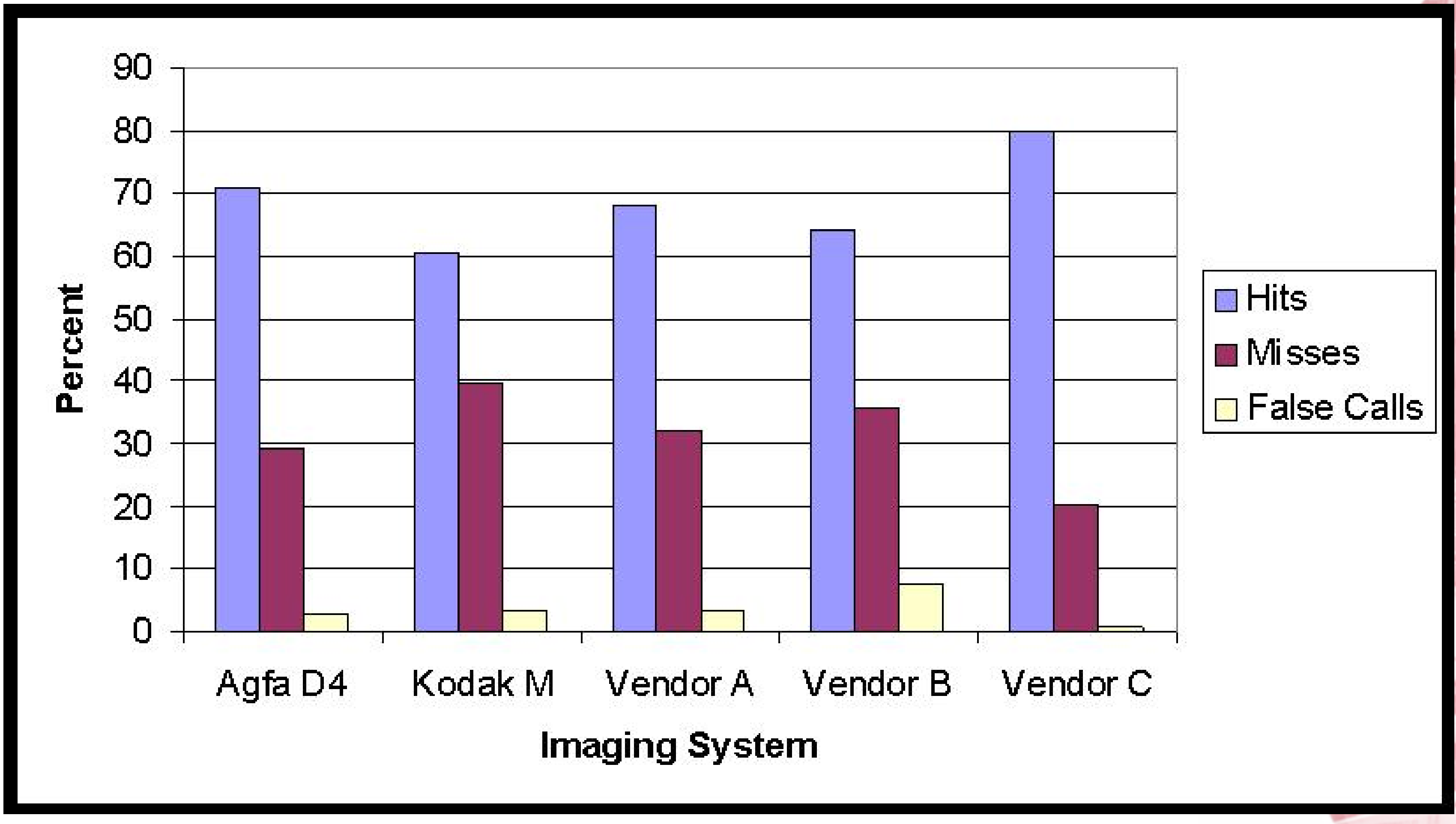
Results - Circular Artifacts



POD Results using IQI Sensitivity for Vendor Systems and All Film

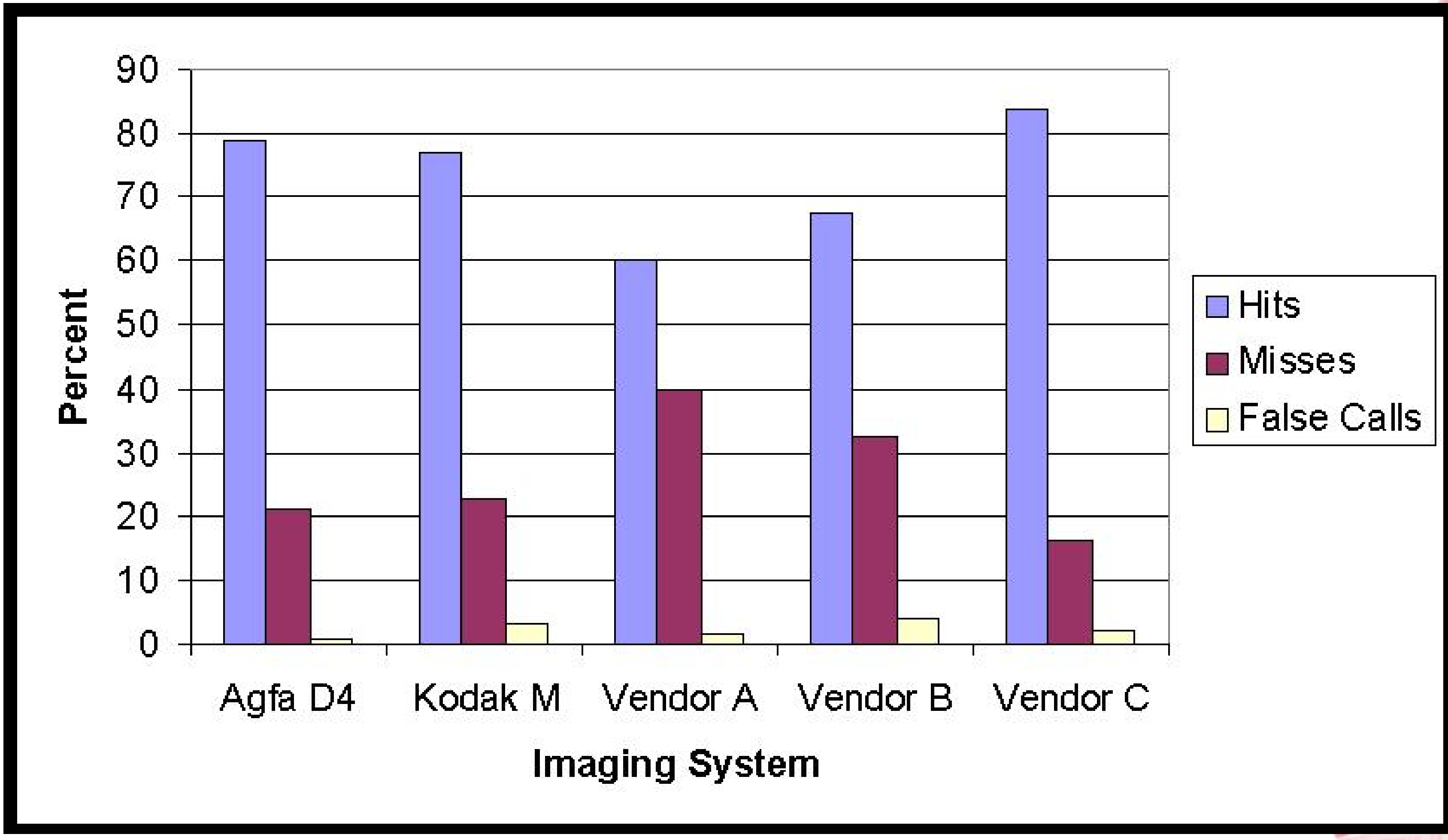


Results – Circular Artifacts



Hits, Misses, and False Calls - Circular Artifacts

Results - Linear Artifacts



Hits, Misses, and False Calls - Linear Artifacts

Hits, Misses, and False Calls Evaluation Results Summary

System	Reader	Lorad 160							
		Circular artifacts				Linear slots			
		I	H (%)	M (%)	FC (%)	I	H (%)	M (%)	FC (%)
Agfa D4	D	237	74.7	25.3	1.6	123	79.7	20.3	0.8
	E	237	57.8	42.2	2.8	123	76.4	23.6	0.4
	F	237	82.3	17.7	6.4	---	---	---	---
	G	237	67.9	32.1	0.9	n/d	n/d	n/d	n/d
	All	948	70.7	29.3	2.9	246	78.9	21.1	0.6
Kodak M	D	237	62.4	37.6	2.5	123	76.4	23.6	0.4
	E	237	48.9	51.1	4.8	123	66.7	33.3	1.5
	F	237	69.2	30.8	4.8	123	87.8	12.2	8.0
	G	237	60.3	39.7	0.2	n/d	n/d	n/d	n/d
	All	948	60.2	39.8	3.1	369	77.0	23.0	3.3
All Film		1896	65.5	34.5	3.0	615	77.7	22.3	2.2
All Readers	D	474	68.6	31.4	2.1	246	78.9	21.1	0.6
	E	474	53.4	46.6	3.8	246	72.4	27.6	1.0
	F	474	75.7	24.3	5.6	246	89.8	11.2	26.4
	G	474	64.1	35.9	0.6	n/d	n/d	n/d	n/d
A		237	67.9	32.1	3.2	123	60.2	39.8	1.5
B		237	64.1	35.9	7.6	123	67.5	32.5	4.2
C		237	79.7	20.3	0.7	123	83.7	16.3	2.3

Results Of Wedge Measurements

Wedge (foil) Thickness (Inches)	System	Average Length (Inches)	Calculated Observable Width (Inches)
0.004	Agfa D4 Class 1 Film	4.567	>0.0025
	Kodak M Class 1 Film	4.615	>0.0025
	Vendor A	4.389	>0.0030
	Vendor B	4.349	>0.0030
	Vendor C	4.980	>0.0015
0.005	Agfa D4 Class 1 Film	4.804	>0.0020
	Kodak M Class 1 Film	4.644	>0.0025
	Vendor A	4.599	>0.0025
	Vendor B	4.620	>0.0025
	Vendor C	4.850	>0.0015
0.006	Agfa D4 Class 1 Film	4.758	>0.0020
	Kodak M Class 1 Film	4.999	>0.0015
	Vendor A	5.158	>0.0010
	Vendor B	5.050	>0.0010
	Vendor C	4.990	>0.0015
0.007	Agfa D4 Class 1 Film	4.935	>0.0015
	Kodak M Class 1 Film	4.757	>0.0020
	Vendor A	4.596	>0.0025
	Vendor B	4.997	>0.0015
	Vendor C	5.000	>0.0010

PART 2 – FIELD EVALUATIONS OF CR SYSTEMS

- Purchase of three different systems for different locations
- On-aircraft demonstrations at each location on different aircraft types
- Cost breakdown
- Benefit analysis

System Purchases

Three different CR systems were purchased. Each system purchased was placed at a different Air Force Base working on different aircraft types:

- Base A (trainer aircraft)
- Base B (bomber and cargo aircraft)
- Base C (fighter aircraft)*

*This CR system was moved to Base D during the study.

On-aircraft Demonstrations

Side-by-side CR and film images of aircraft structure were obtained and compared.

- All geometric settings were untouched as the IP was substituted for the film.
- In most cases shooting time was reduced, in some cases shooting power levels were also reduced, as the IP was substituted for film.
- The image product of each system was compared to that of film by qualified radiographic interpreters.
  - All field units reported systems were easy to use.
  - All field units reported finding defects in aircraft with CR that had been missed using film.

Cost Breakdown

The cost breakdown obtained the following information:

- The number of chemical film radiographs that are taken during normal operations.
- The number of radiographs that could not be taken with the CR system and reasons explaining why.
- The total amount of time taken to radiograph and interpret inspection locations using film and CR methods.
- The cost of radiographic expendables replaced by CR system.
- The cost of disposing of the hazardous materials associated with local film radiography requirements.
- The number of service calls required to support repair and operation of the CR system.

Results - Cost Breakdown

- The cost for a new film operation is approximately $45,750.
- The cost for of the CR systems used in this study ranged from $127K to $139K.
- The cost for a 14x17 inch IP is $500-$650; it can be reused.
- Material savings averaged approximately $3.77 per film shot replaced by CR – this is due primarily to film costs.
- Time savings for CR compared to film is about 7 minutes per exposure using a 2 shot average – this is due primarily to film development time savings.

Operating Location	Aircraft Type	Annual Exposures	Exposure Savings		Annual Savings
			Material	Manpower	
Base A	Trainers	13,258	$49,983	$79,338	$130,270
Base B	Bomber, Cargo	5,050	$20,586	$11,312	$32,835
Base C	Fighter	24,000	$65,326	$53,760	$120,054
Base D	Fighter	26,400	$93,060	$59,136	$153,146

Benefit Analysis

Attributes observed included the following:

- Portability of the Equipment
  - Ease of transportability to the test site
  - Equipment weight
  - Number of packages
  - Cubage
- Equipment Set up Time
  - Time to set up the computer and reader systems
- Film Replacement
  - Does detector effectively substitute for film using same set-up?
- Ease of Image Capture Input
  - Usefulness of the flexible cassettes
  - Readability of the phosphor screens from the flexible cassettes
  - Is a light controlled area required?
- Exposure Times
  - Compared to film under identical conditions
- Exposure-to-read time
  - Transit time back to reader not be included
- Image quality
  - Compare the electronic image to the film image

Results - Benefit Analysis

- Portability of the Equipment
  - More portable than chemical systems
- Equipment Set up Time
  - Set up in less than 20 minutes
- Film Replacement
  - IP effectively substitutes for film using same basic set-up, settings, and using existing film holders
- Ease of Image Capture Input
  - Image capture as easy or easier than film
- Exposure Times
  - Less than film at same energy levels, same as film at reduced energy levels
- Exposure-to-read time
  - CR is faster due to development time savings
- Image quality
  - CR compares favorably to film

CONCLUSIONS

- CR system detection capability is as good as or better than film based radiography.
- CR systems can be used effectively in field setting
- CR systems can cost effectively replace film techniques for field level operations

CONCLUSIONS (Continued)
ADVANTAGES OF DIGITAL IMAGING

- Reduced Operating Costs
  - Elimination of Film as a Recurring Cost, IP is Reusable, Demonstrated Capability for Over 30,000 Shots in Commercial Use
  - Elimination of Wet Film Processors and Recurring Chemical Costs
- Increased Production Rate
  - Reduction of Shooting and Processing Times
- Increased Personnel and Environmental Safety
  - Reduction of Radiation Exposure – Personnel Hazard
  - Elimination of Hazardous Materials – Chemicals
- Increased Confidence in Results
- Reduction of Mobility Footprint
- Increased Flexibility of Data Results – Electronic Processing
  - Communication
  - Archiving
  - Data Mining
  - Aircraft Battle Damage Evaluation and Resolution

Where Do We Go Now?

Additional Work Must be Accomplished:

- ✓ Obtain Authorization from Technical Authorities at MAJCOMs and SPOs – to date five SPOs have approved CR to inspect for FOD and cracks in aircraft.
- ✓ Purchase Systems for USAF NDI Shops, 200+.
- ✓ Provide System Training for NDI Personnel.
- ✓ Update Technical Orders, General and Weapon System Specific.
- ✓ Produce Process Control Device (PCD) to be used by field units to verify proper CR system function.
- ✓ Produce program control auditing system to test proficiency of NDI offices.