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CASR FPI – Engineering Studies: Developer Studies

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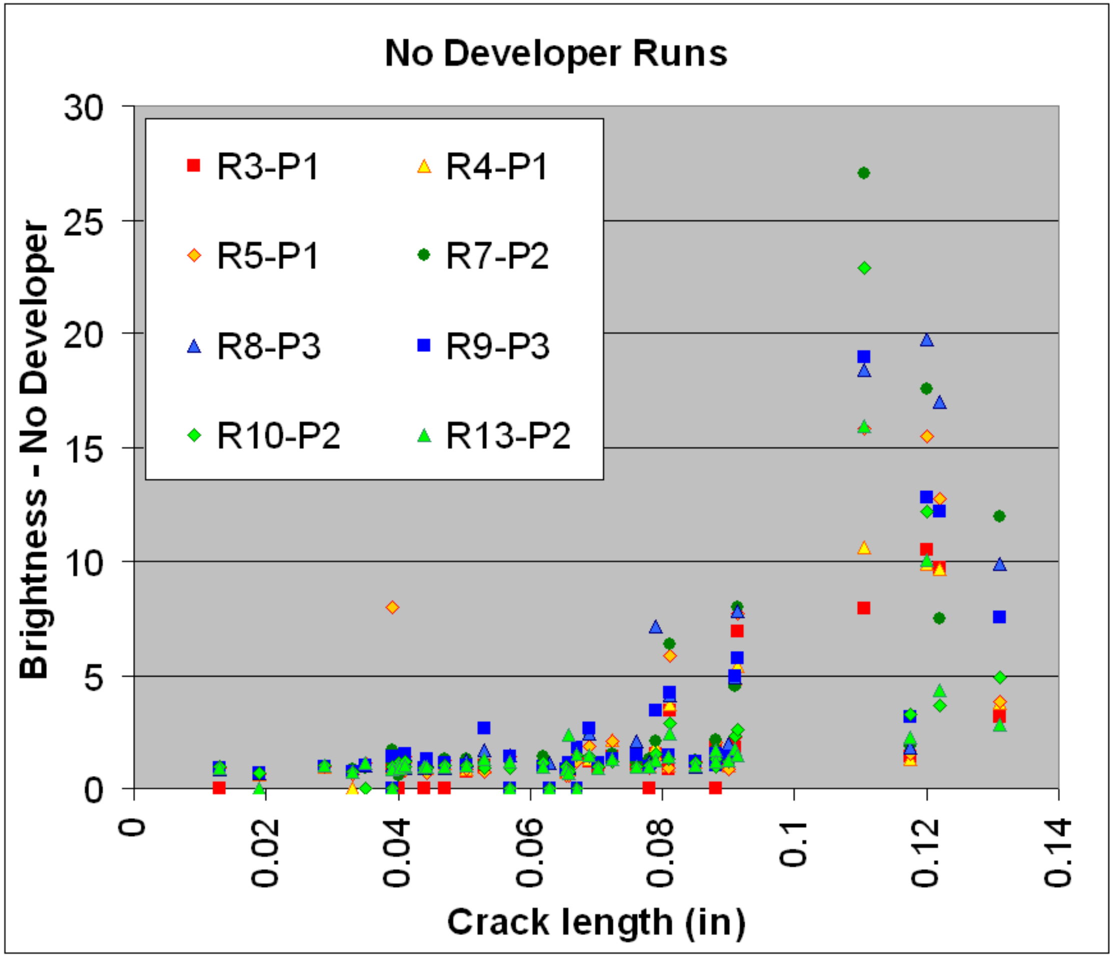
Developer Questions

- Do penetrants self-develop?
- How does dry powder developer compare to non aqueous wet developer?
- How do different penetrant/developer families compare?
- How do developer application methods compare (dust chambers, bulb, spray wand, electrostatic)?
- How do different developer forms compare?

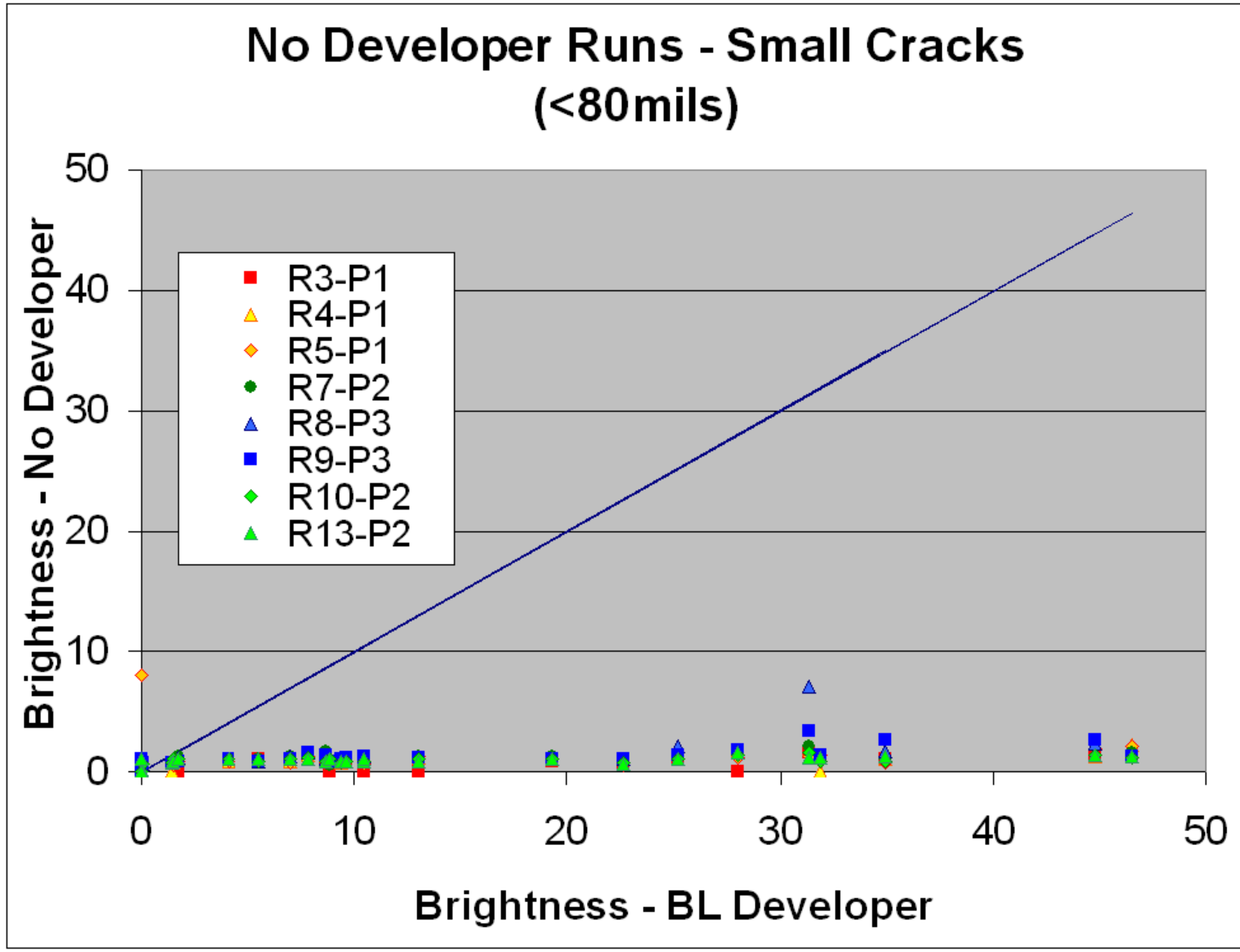
Need for Developer

- Brightness of three penetrants was evaluated without developer for cracks ranging from 13 to 130 mils
- While some larger cracks (> 80 mils) had acceptable brightness (>5), this was not true for all large cracks or for small cracks (< 80 mils)



Need for Developer

- No difference found in ability of penetrants to “self develop” for small cracks (< 80 mils)
- Effective inspection sensitivity requires developer



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Developer Questions

- Do penetrants self-develop?

- Without developer, the three penetrants tested did not provide sufficient brightness to suggest reliable inspection
- Developer is required

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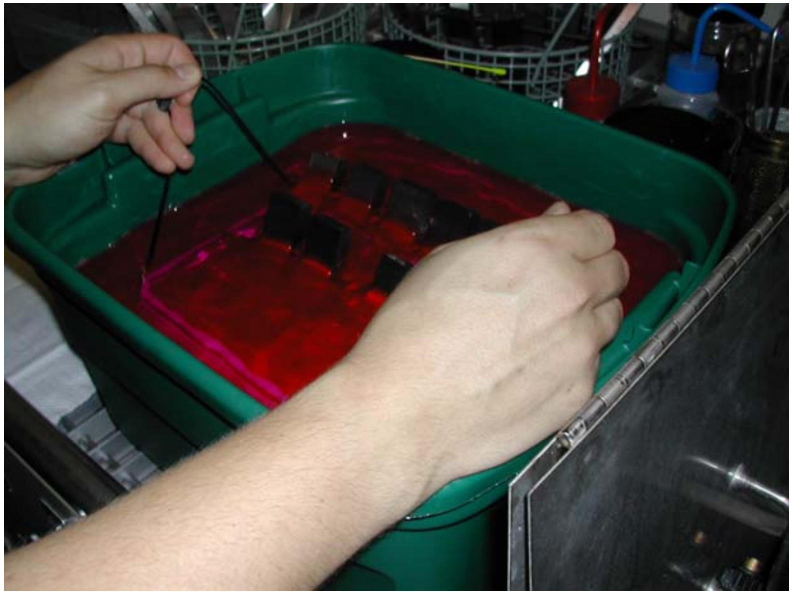
Developer Questions

- Do penetrants self-develop?
- How do developer application methods compare (dust chambers, bulb, spray wand, electrostatic)?
- How does dry powder developer compare to non aqueous wet developer?
- How do different penetrant/developer families compare?
- How do different developer forms compare?

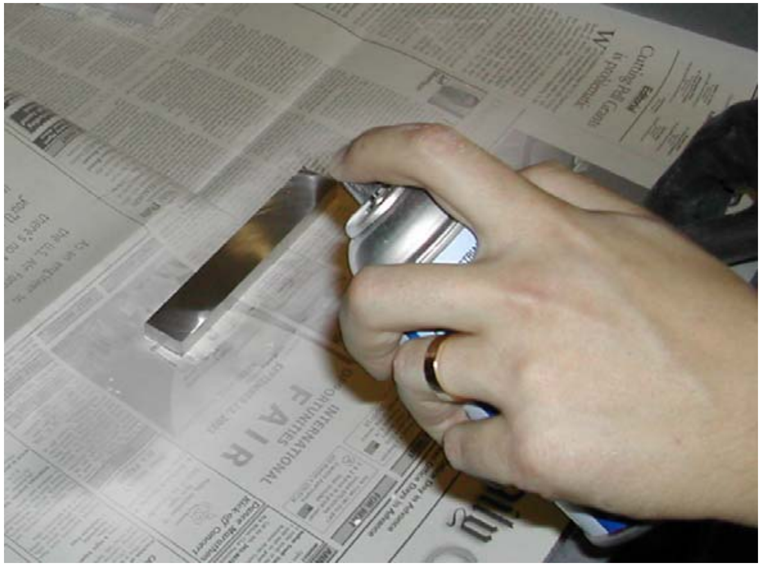
Dry Powder vs. NAWD Comparison

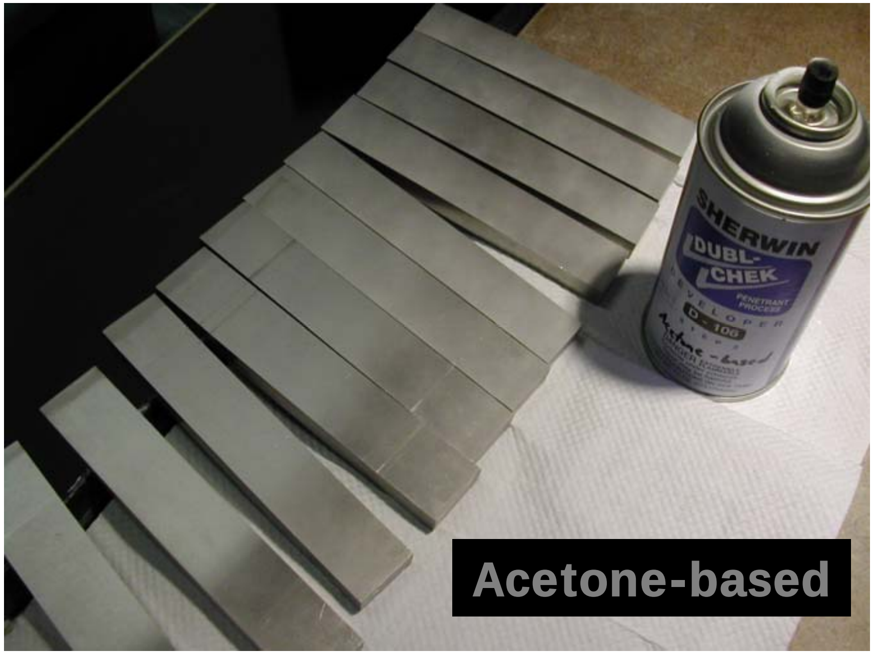
- Level 4 Penetrant – 20 minute dwell, 30 sec spray wash, 120 sec emulsification with agitation, 60 sec spray wash
- Dry powder developer (form a) with dip/drag application – Two penetrant products
  - DP1 used as baseline
  - DP2
- NAWD (form d) alcohol based
  - 2 applications
- NAWD (form d) acetone based
  - 3 applications



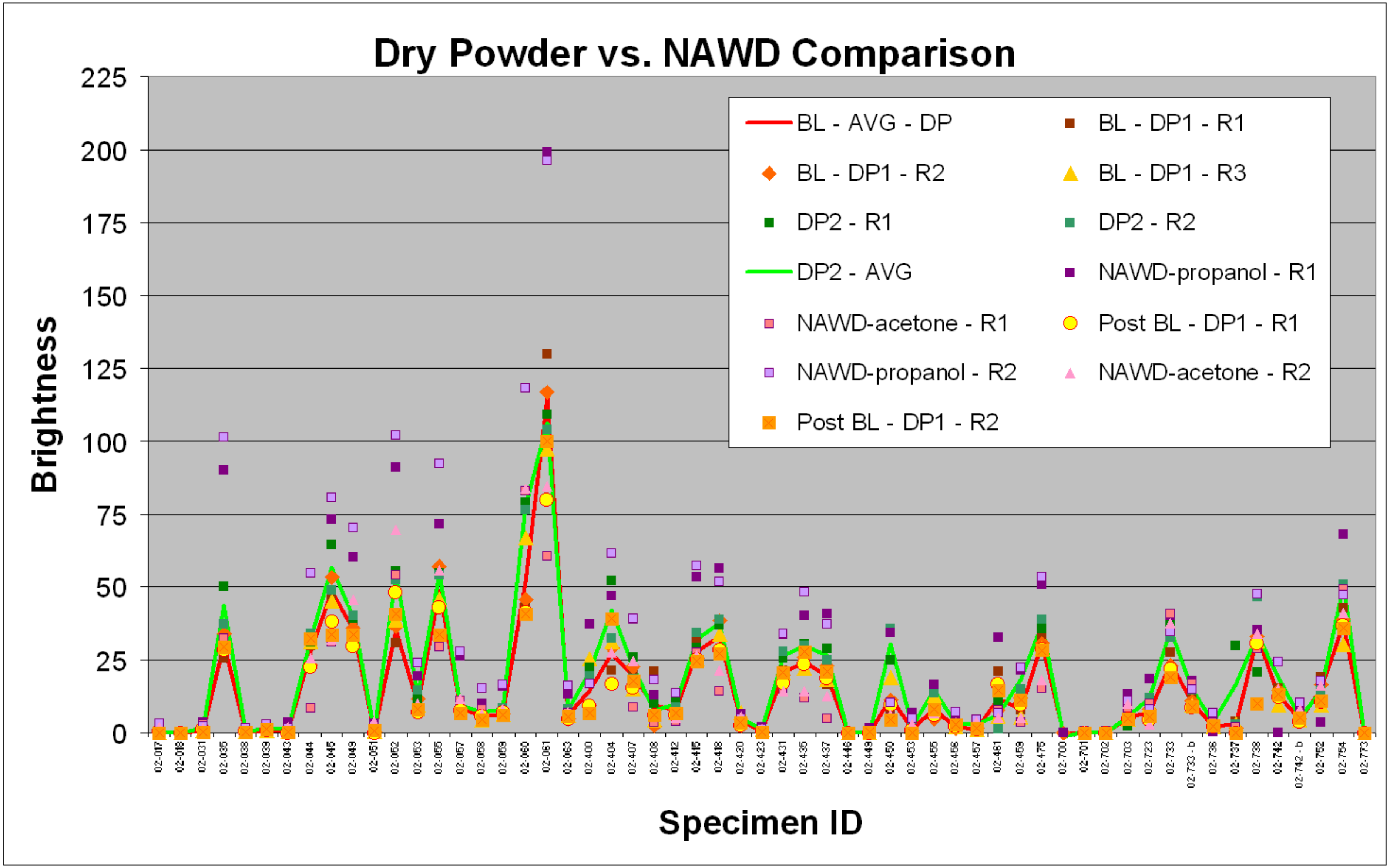
CASR Dry Powder vs. NAWD Comparison

- Followed manufacturer recommendation
- 10” distance
- 2 (across and back) or 3 (repeat across)





Form A vs. Form D Comparison



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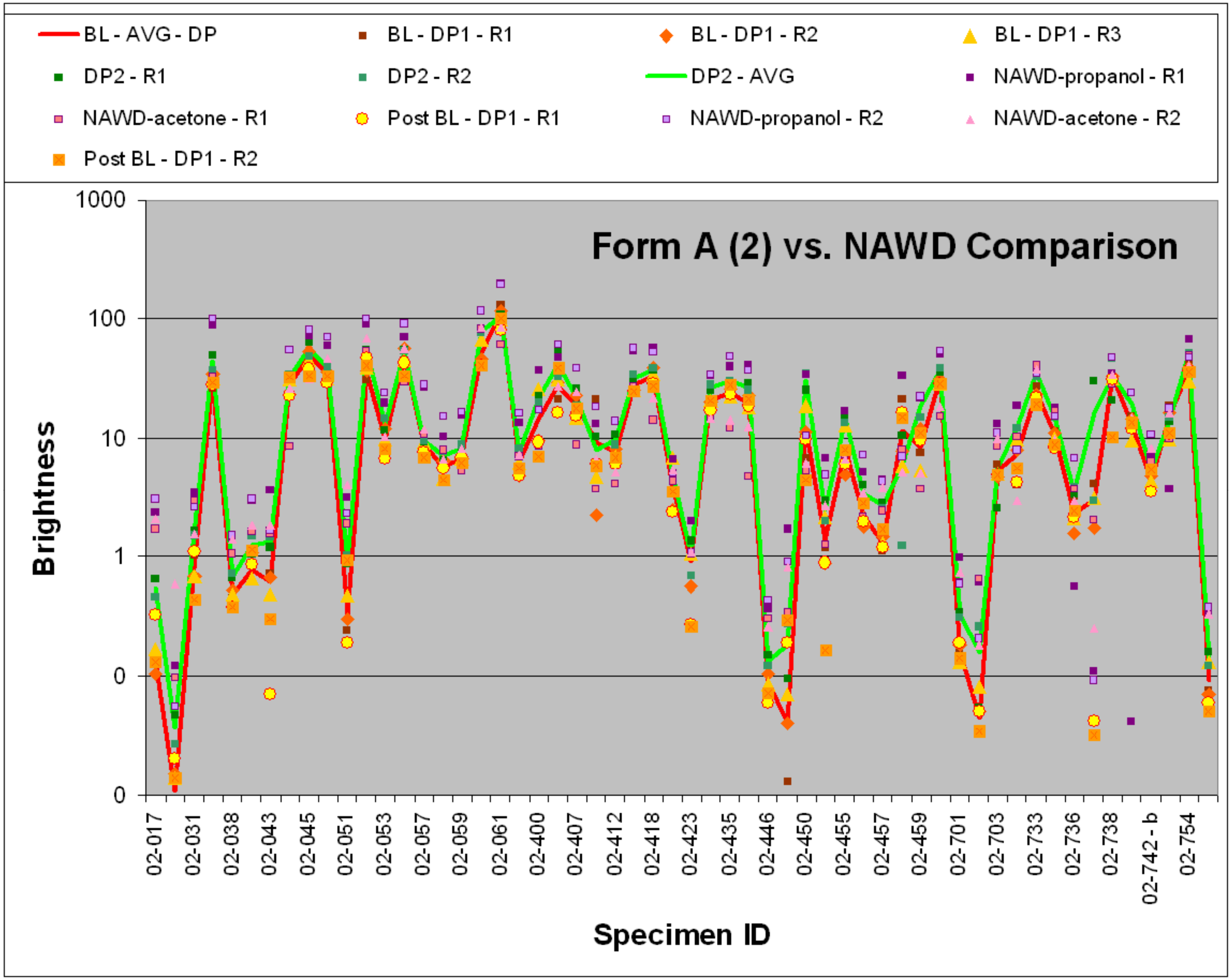
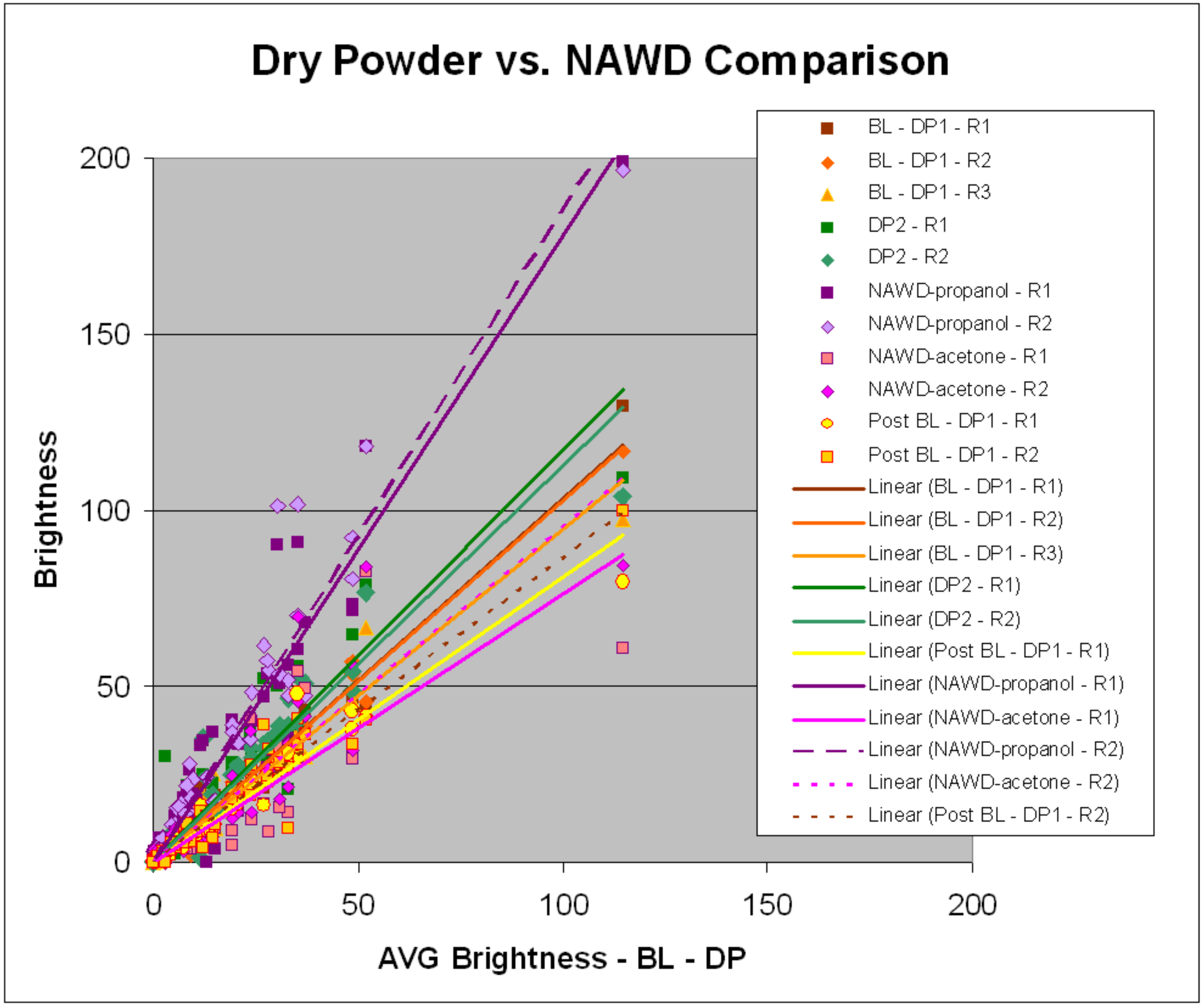
Form A vs. Form D Comparison



Dry Powder vs. NAWD Comparison

- Data shown for Al, Ti and Ni samples with some differences in surface condition associated with alloy
- DP2 yielded brighter indications than DP1
- Propanol-based NAWD yielded brightest indications which is a result of "blooming" of the indication
- Acetone-based NAWD yielded lowest brightness but also "crisper" images than propanol-based NAWD



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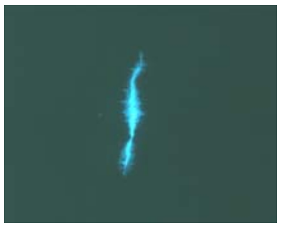
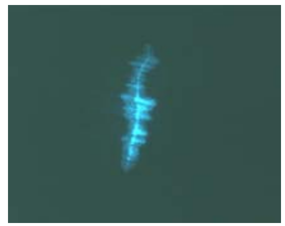
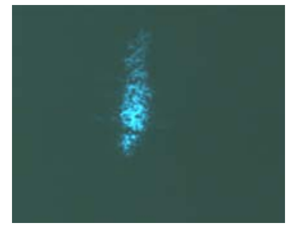
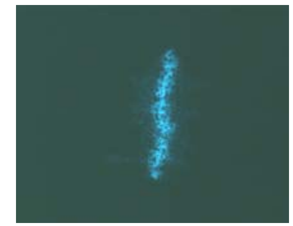
Aluminum Samples

	DP1	DP2	NAWD - Propanol	NAWD - acetone
02-733				
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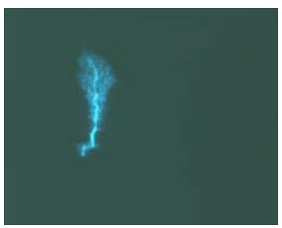
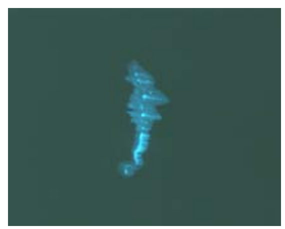
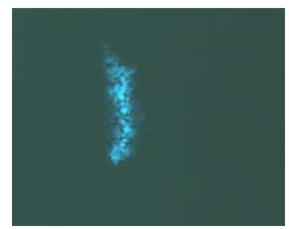
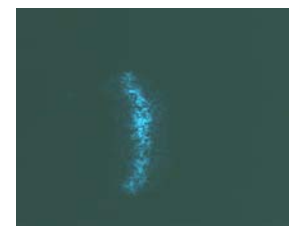
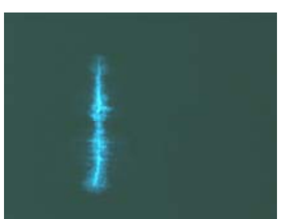
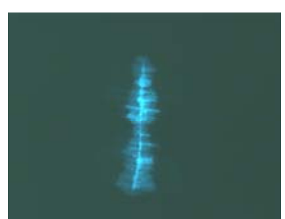
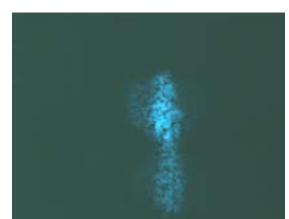
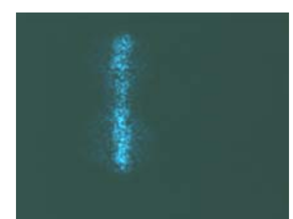
02-738				
	0.00230841	0.00263646	0.00256451	0.00260592
02-754				
	0.00248095	0.00358498	0.0043331	0.00363175

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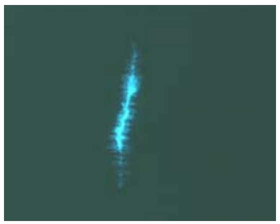
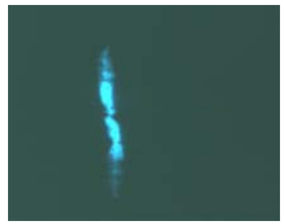
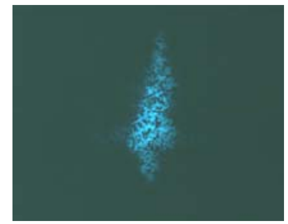
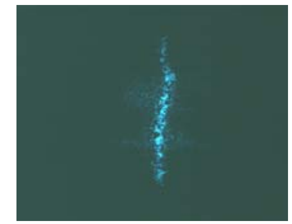
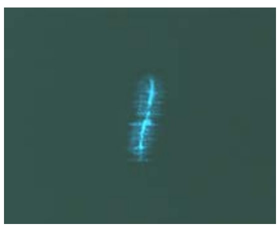
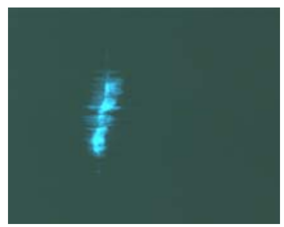
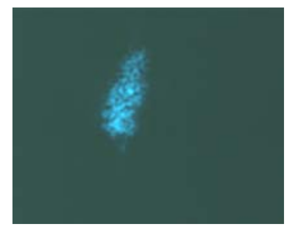
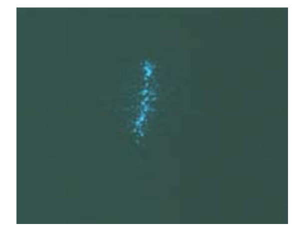
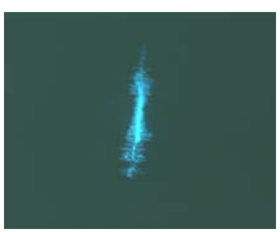
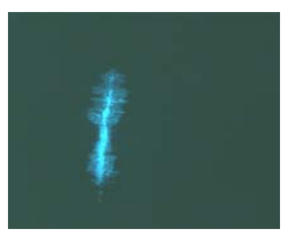
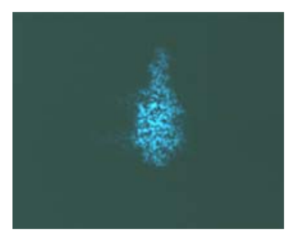
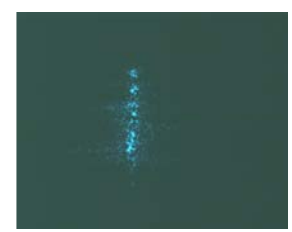
Titanium Samples

	DP1	DP2	NAWD - Propanol	NAWD - acetone
02-415				
Area →	0.0014715	0.00159755	0.00367583	0.00140007
02-431				
	0.00171245	0.0017963	0.00288122	0.00097764
02-475				
	0.00188998	0.00268864	0.0036684	0.0011268

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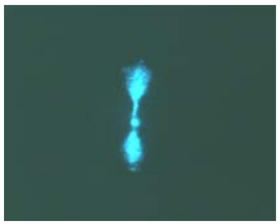
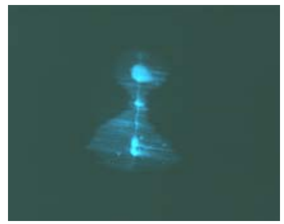
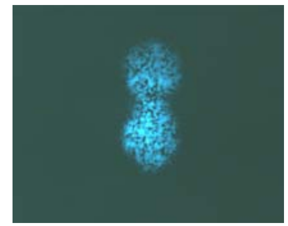
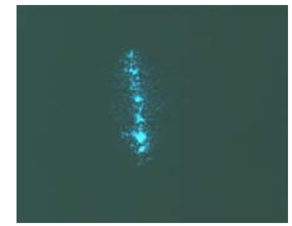
Nickel Samples

	DP1	DP2	NAWD - Propanol	NAWD - acetone
02-035				
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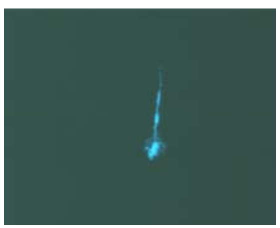
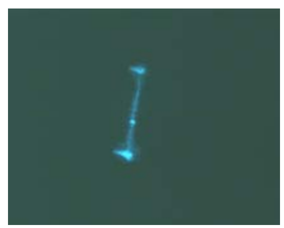
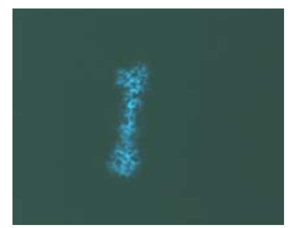
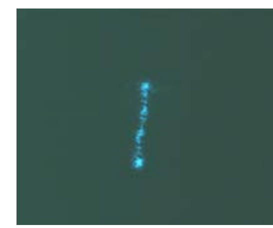
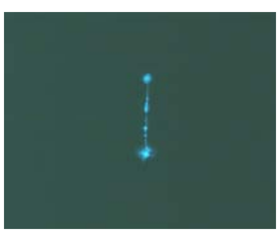
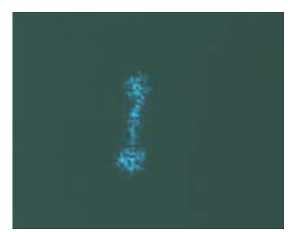
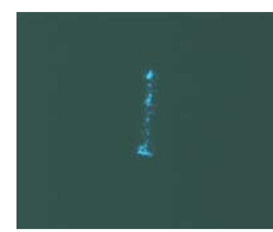
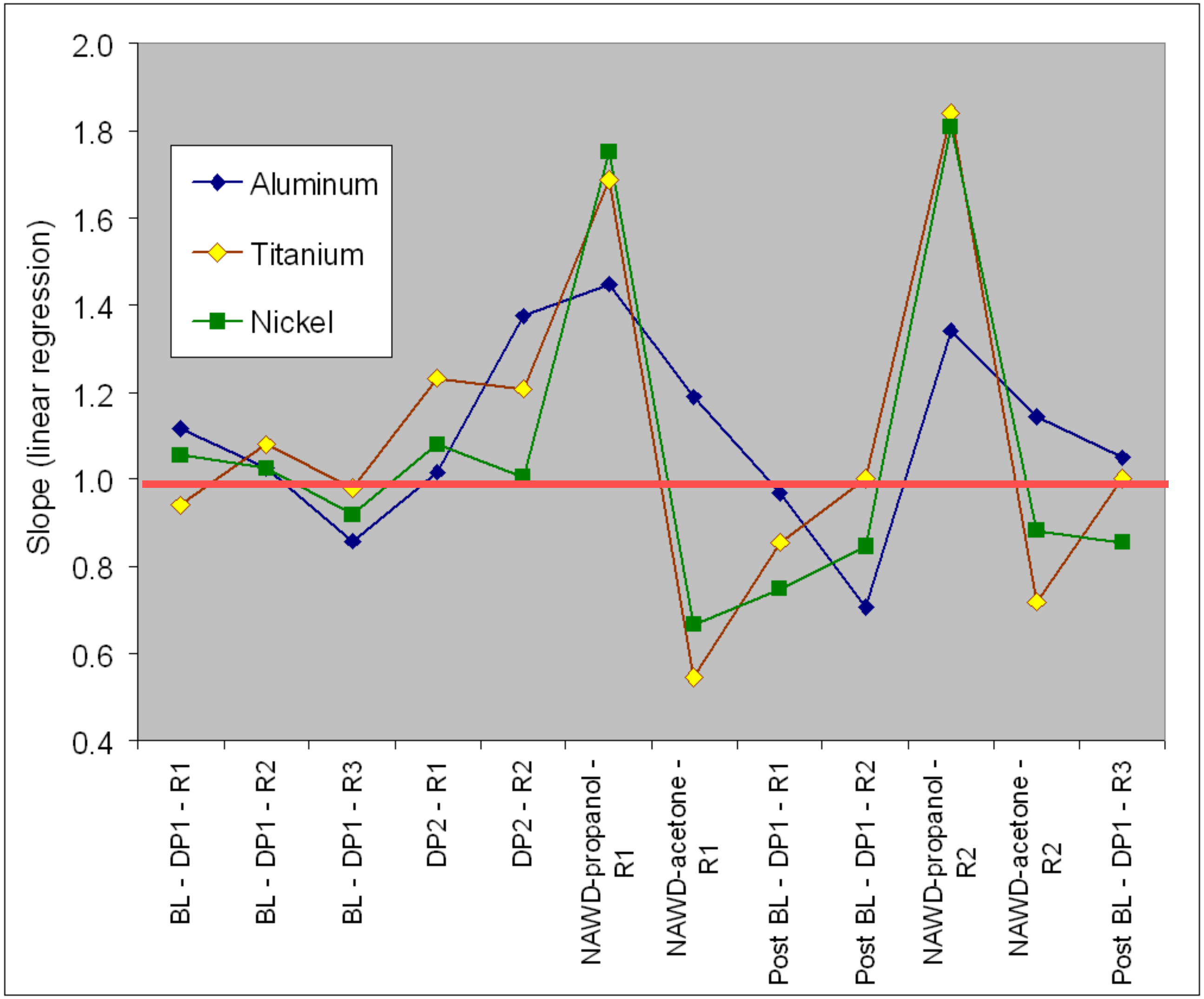
02-057				
	0.00051902	0.0011116	0.00285967	0.00073288
02-059				
	0.00046172	0.00090909	0.00194606	0.00045183

Dry Powder vs. NAWD Comparison

- Ni and Ti, in general, behaved similarly
- Recommend that differences in indication characteristics be included in training documents
  - "Blooming" that occurs with NAWD when compared to Form A developers



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Developer Questions

- Do penetrants self-develop?
- How do developer application methods compare (dust chambers, bulb, spray wand, electrostatic)?
- How does dry powder developer compare to non aqueous wet developer?
- How do different penetrant/developer families compare?
- How do different developer forms compare?

Comparative Study of Penetrant/Developer Combinations

Background

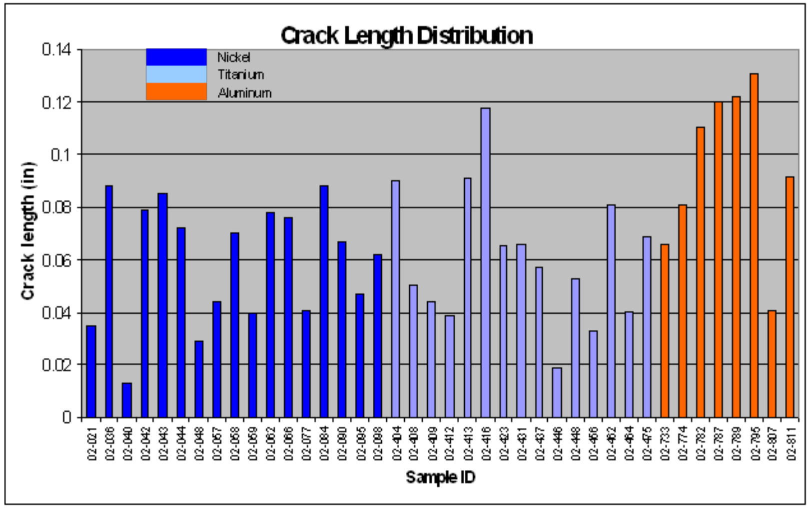
- A key step in the penetrant process is the application of penetrant with many commercial products to choose from. It is often suggested that penetrant families be used together. As a minimum, the penetrant/emulsifier are qualified as a system and shall be used together. However, developers can be selected separately. Data regarding the variation of penetrant brightness in combination with developer has not been published.

Purpose

- Compare three penetrants and three developers using two application methods (dip/drag and bulb) in a laboratory environment.
- Brightness and UVA indications were measured for each penetrant with it’s recommended developer and with the developer from the other penetrants.
- Emulsifier was specific to the penetrant.
- Baseline measurements will be interspersed in the study to track the performance of the samples and ensure sample degradation is not occurring.

Comparative Study of Penetrant/Developer Combinations

- Testplan and crack size distribution was determined using samples from three alloys
- Number of samples:
  - Ni – 17
  - Ti – 15
  - Al – 8



Run #	Penetrant	Developer	Application method	Notes
1	P-1	D-1	dip/drag	
2	P-1	D-1	bulb	
3	P-1	D-1	bulb	
4	P-1	D-1	dip/drag	
5	P-1	D-1	bulb	
6	P-1	D-1	dip/drag	
7	P-2	D-2	dip/drag	penetrant with it's own developer
8	P-3	D-3	bulb	
9	P-3	D-3	dip/drag	
10	P-2	D-2	bulb	
11	P-1	D-1	bulb	
12	P-1	D-1	dip/drag	
13	P-2	D-1	dip/drag	penetrant with baseline developer
14	P-3	D-1	dip/drag	
15	P-3	D-1	bulb	
16	P-2	D-1	bulb	
17	P-1	D-1	bulb	
18	P-1	D-1	dip/drag	
19	P-1	D-2	bulb	baseline penetrant with other developers
20	P-1	D-3	dip/drag	
21	P-1	D-2	dip/drag	
22	P-1	D-3	bulb	
23	P-1	D-1	dip/drag	
24	P-1	D-1	bulb	
25	P-2	D-3	dip/drag	other penetrants with other developers
26	P-3	D-2	bulb	
27	P-2	D-3	bulb	
28	P-3	D-2	dip/drag	
29	P-1	D-1	bulb	
30	P-1	D-1	dip/drag	
31	P-1	D-1	bulb	
32	P-1	D-1	dip/drag	

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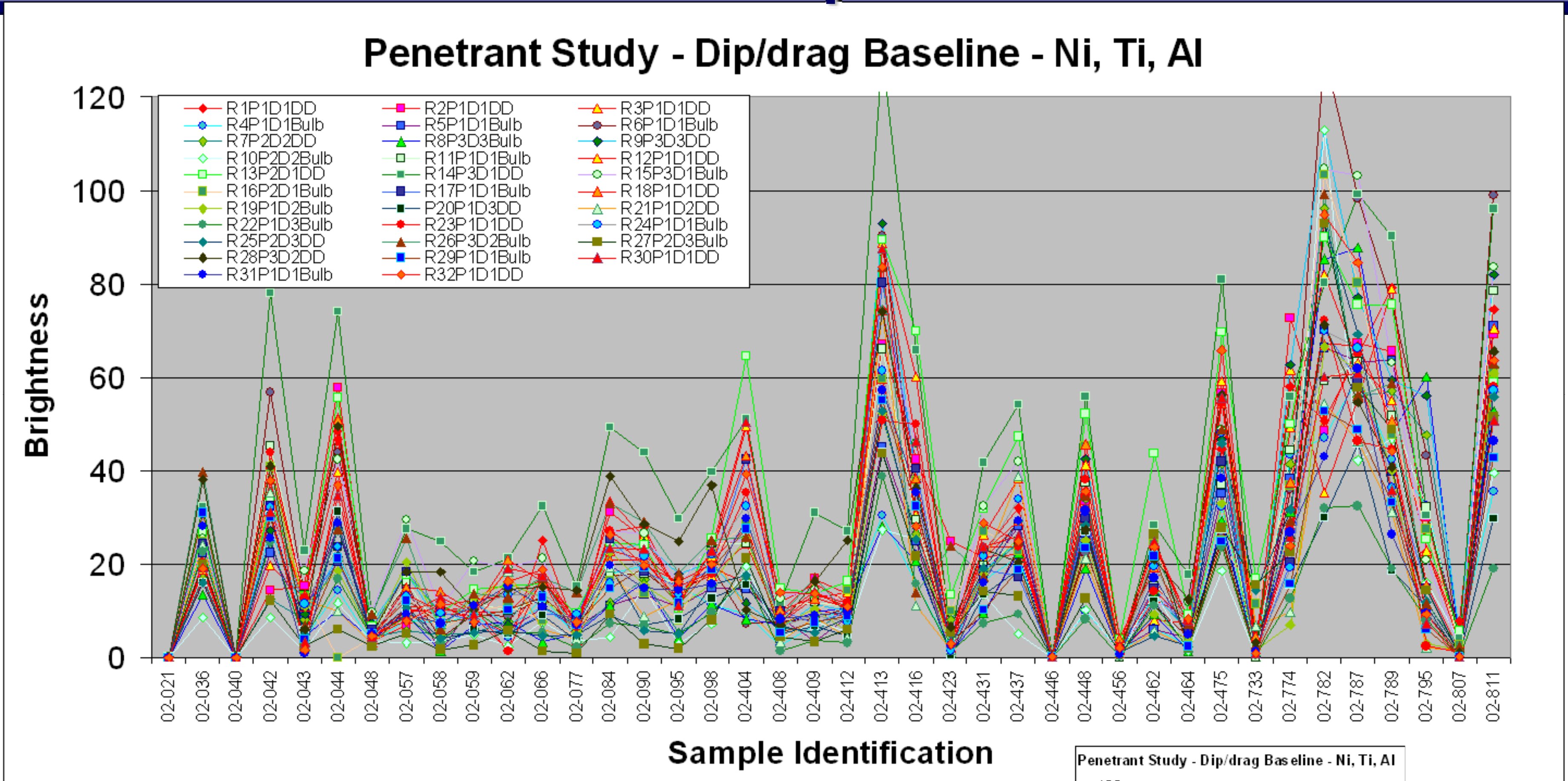
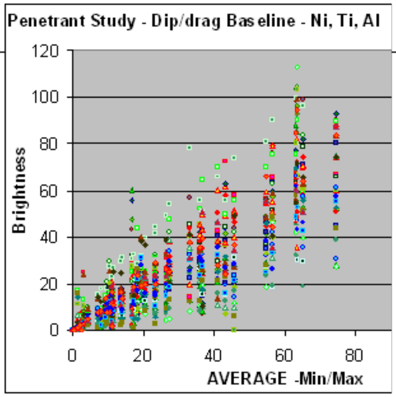
Comparative Study of Penetrant/Developer Combinations



- Over 1400 data points
- Red – baseline dip/drag
- Blue – baseline bulb
- Green – other penetrant/developer combinations

- Considerable variation found as evidenced by raw data and regression analysis



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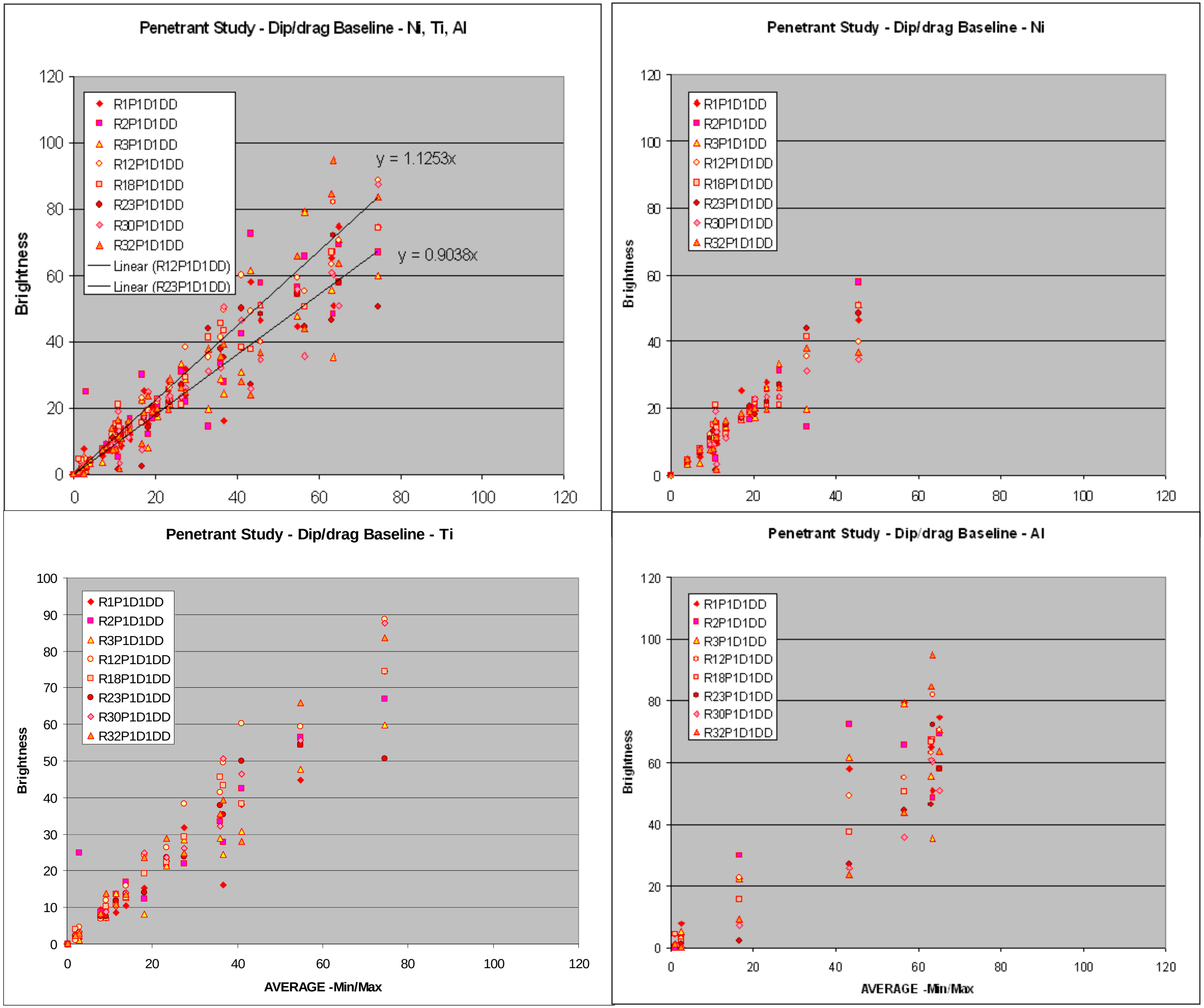
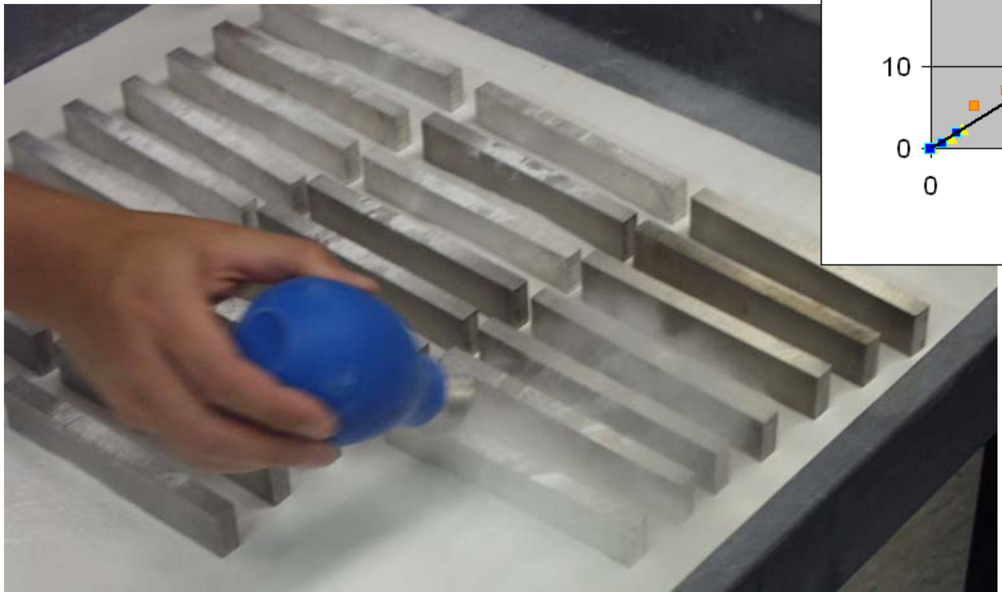
Comparative Study of Penetrant/Developer Combinations

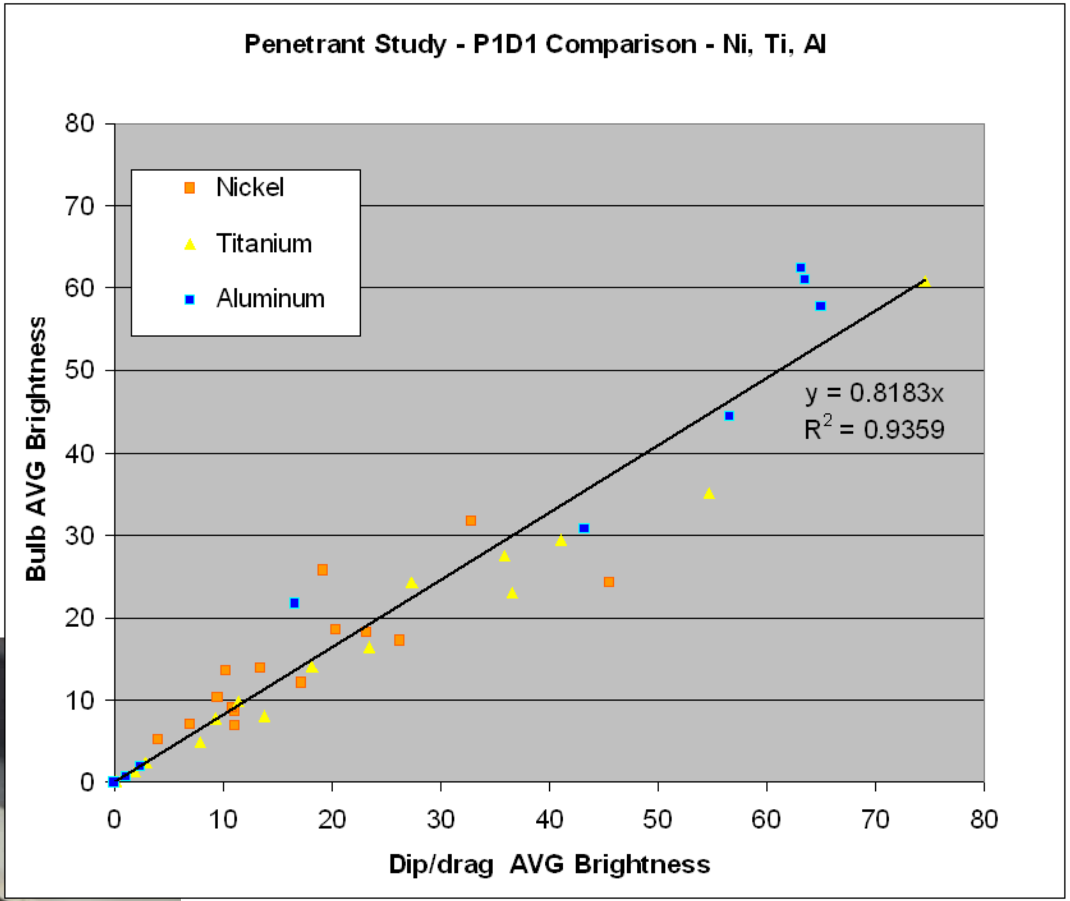
- Baseline comparison shows more variation with Al samples than Ti and Ni
- Al more susceptible to environmental changes, i.e., samples are more difficult to maintain



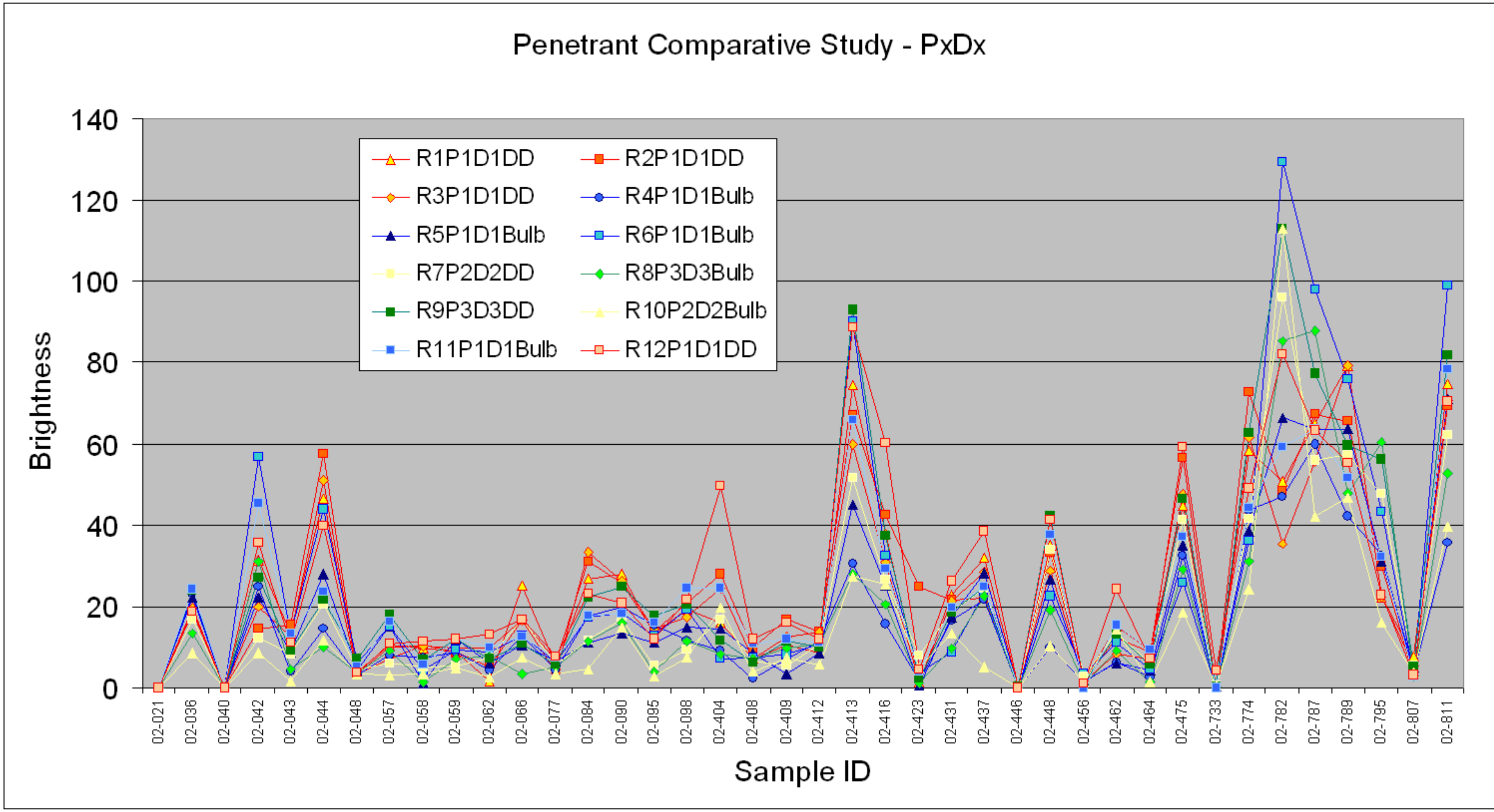
Comparative Study of Penetrant/Developer Combinations

- Use of bulb is on average, 20% less bright than dip/drag application of developer for baseline P/D combination

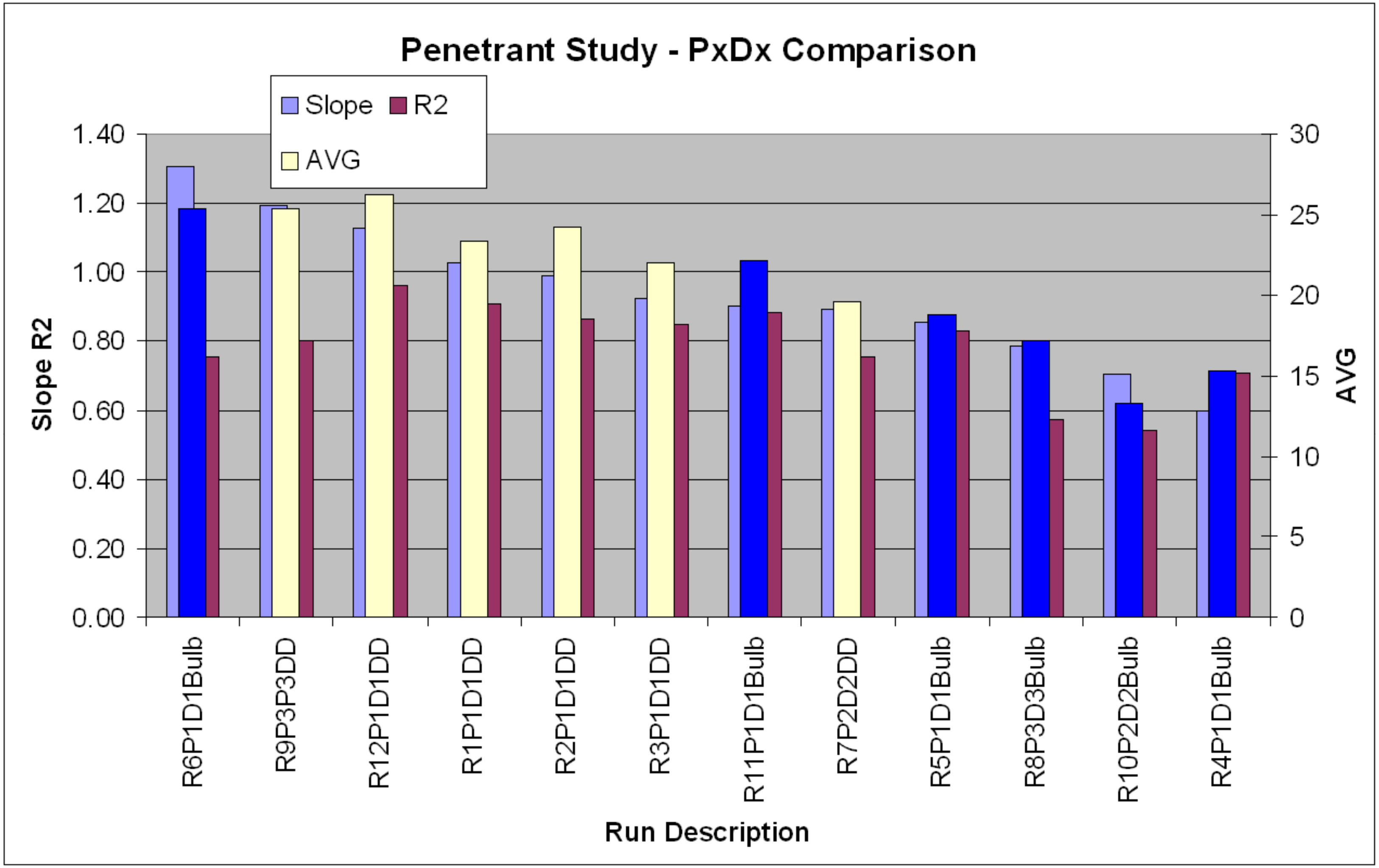




Comparative Study of Penetrant/Developer Combinations

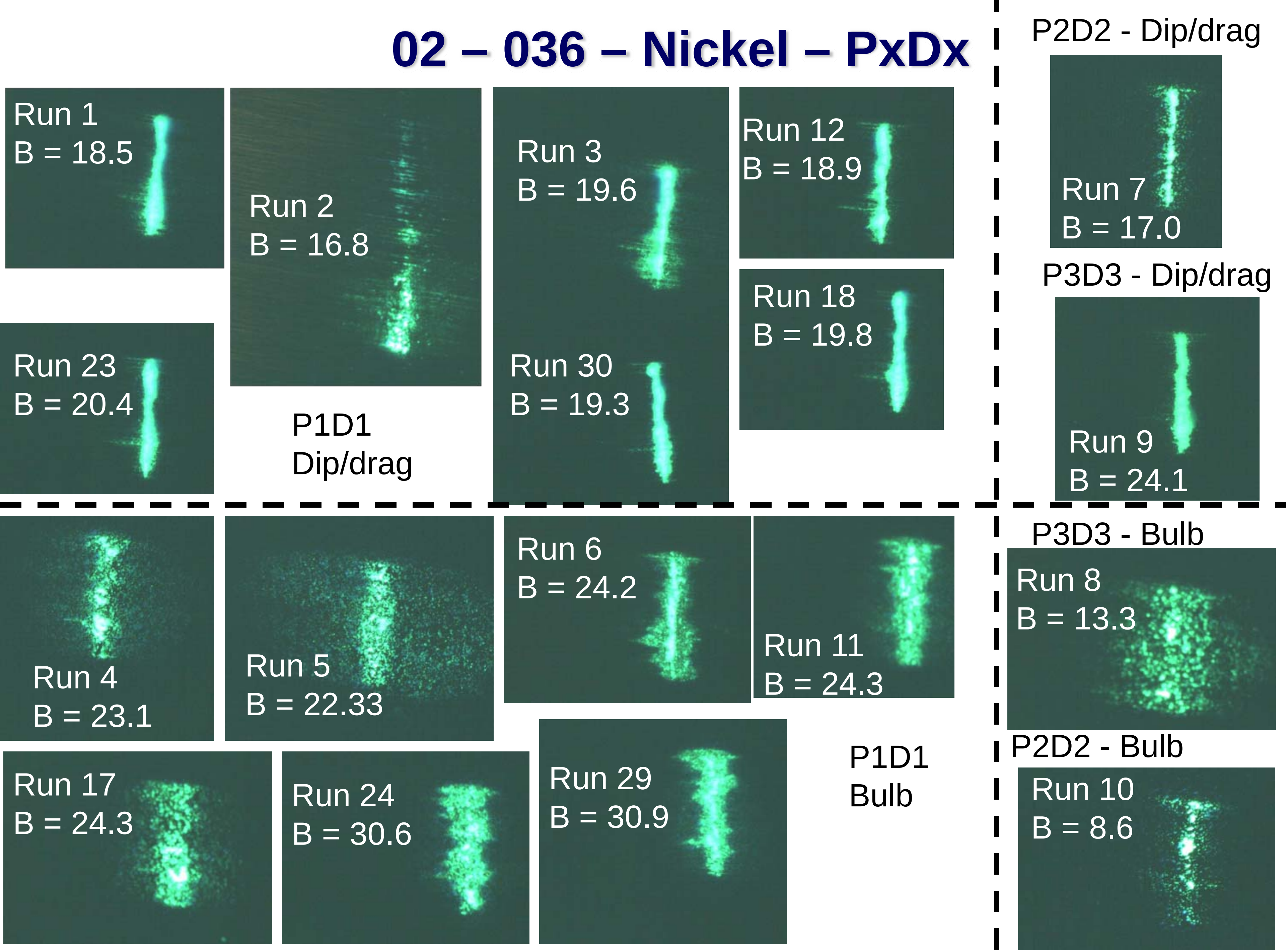


Comparative Study of Penetrant/Developer Combinations

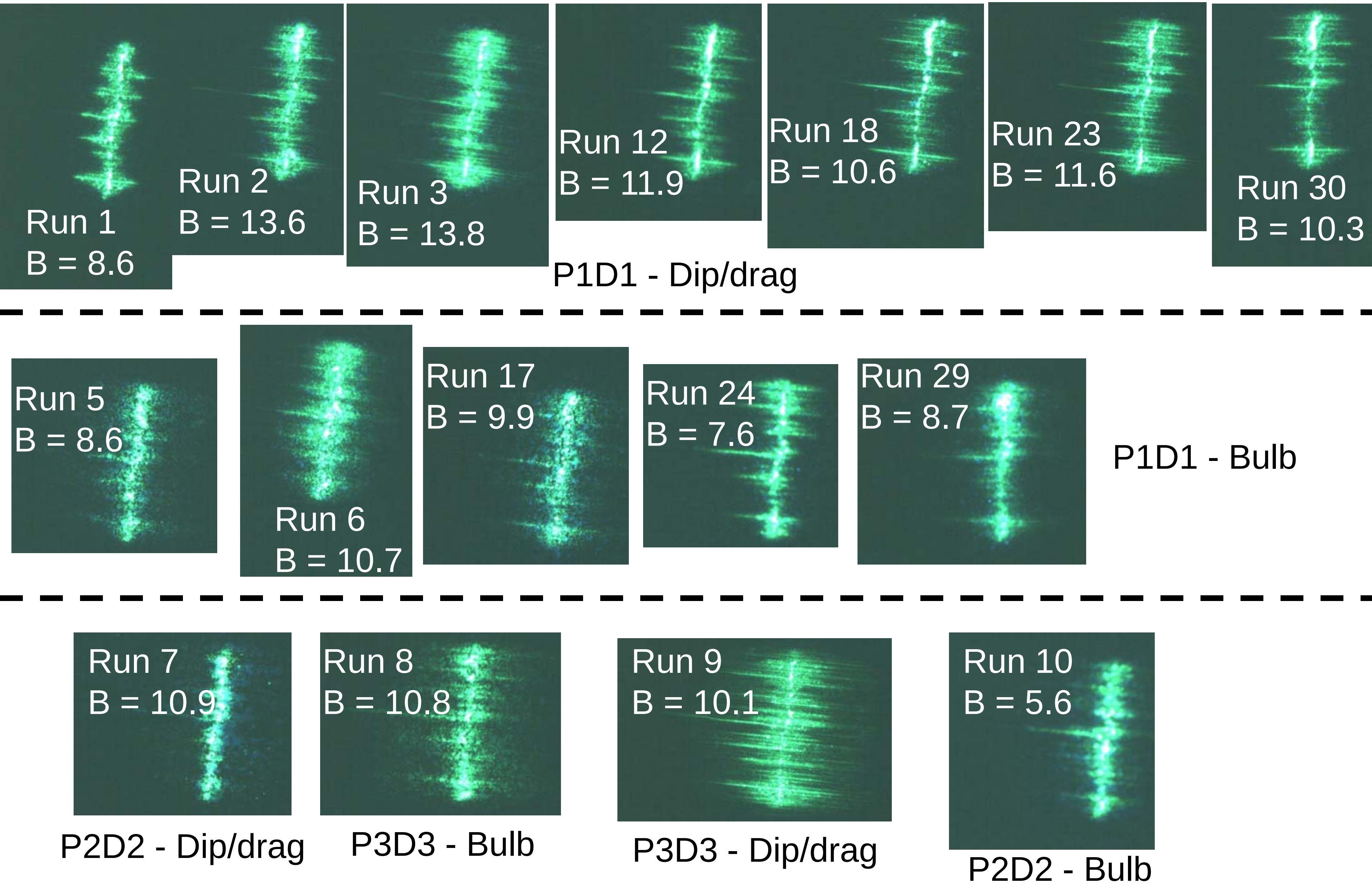


	R6P1D1Bulb	R9P3P3DD	R12P1D1DD	R1P1D1DD	R2P1D1DD	R3P1D1DD	R11P1D1Bul	R7P2D2DD	R5P1D1Bulb	R8P3D3Bulb	R10P2D2Bulb	R4P1D1Bulb
Slope	1.31	1.19	1.13	1.03	0.99	0.92	0.90	0.89	0.86	0.79	0.70	0.60
R2	0.76	0.80	0.96	0.91	0.86	0.85	0.88	0.76	0.83	0.57	0.54	0.71
AVG	25.35	25.40	26.25	23.41	24.21	22.03	22.15	19.62	18.81	17.14	13.33	15.35

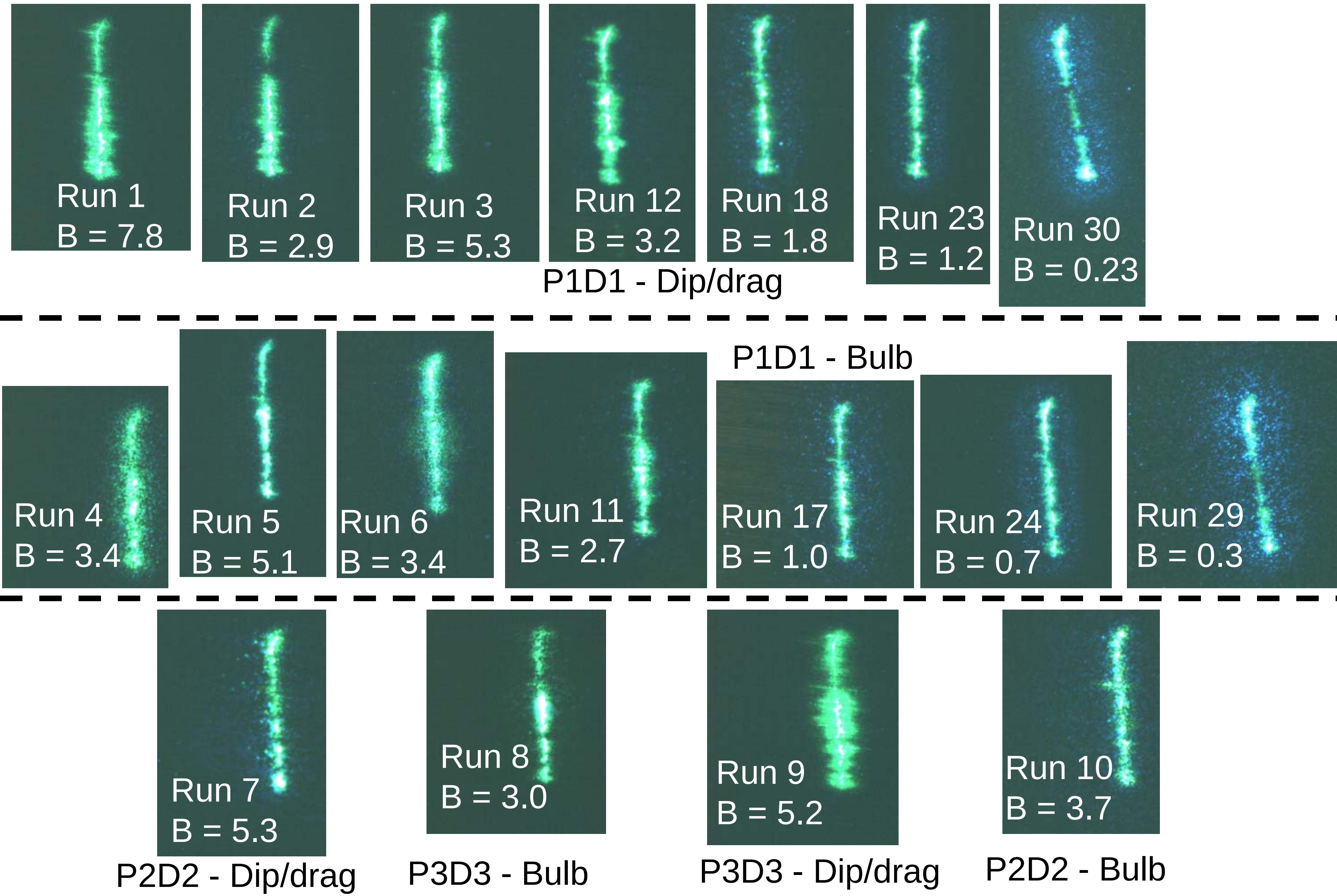
02 – 036 – Nickel – PxDx



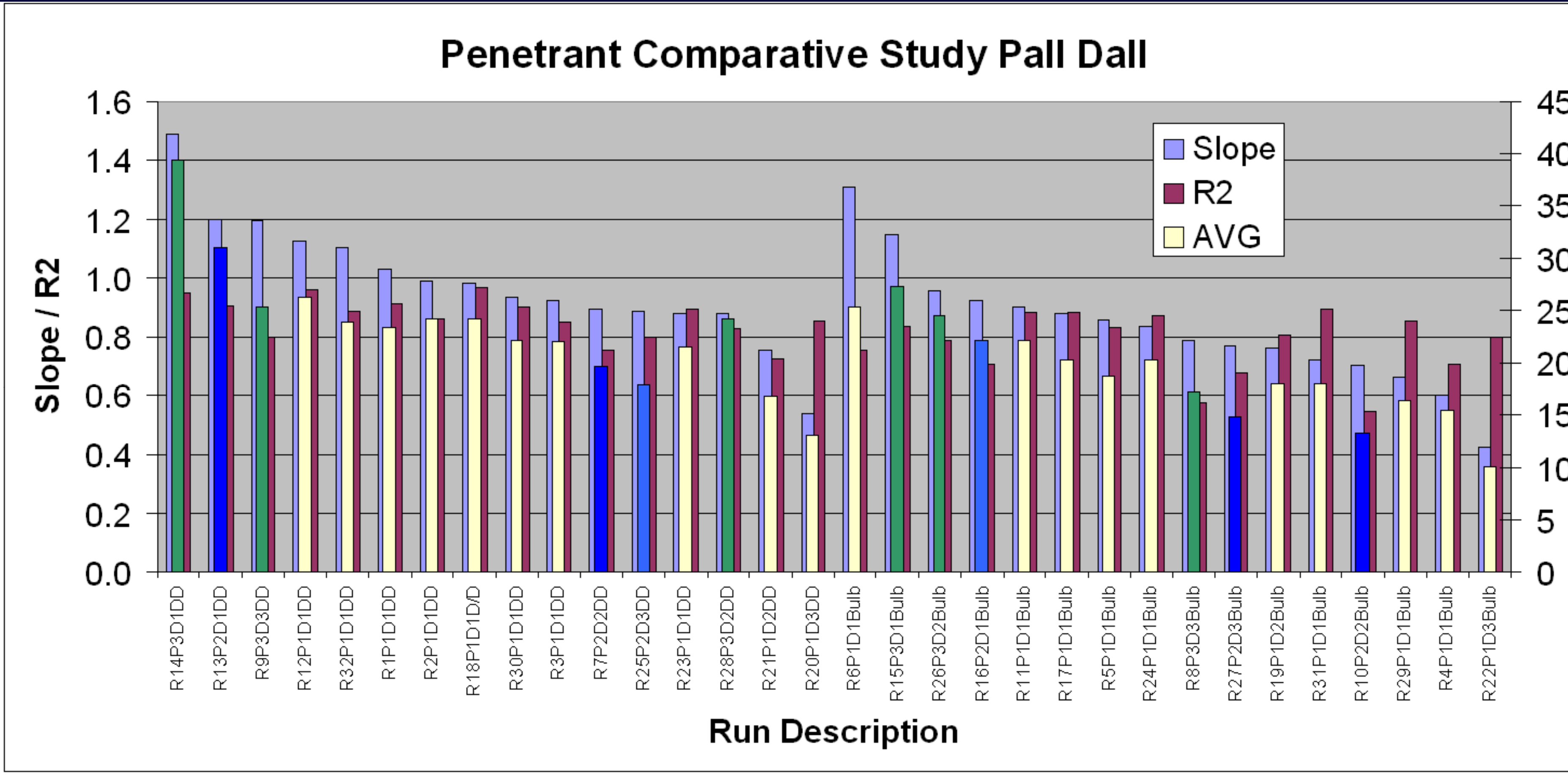
02 – 412 Titanium – PxDx



02- 807 - Aluminum – PxDx



Comparative Study of Penetrant/Developer Combinations



- Data sorted between dip/drag and bulb and then arranged in order of decreasing average brightness with P1Dx shown in white, P2Dx shown in blue, and P3Dx shown in green

Comparative Study of Penetrant/Developer Combinations

- Differences in penetrant/developer families are observed but all cracks gave acceptable performance
- In general, dip/drag gave better brightness values than bulb
- Linear regression analysis showed better performance for P3D3 followed by P1D1 and P2D2

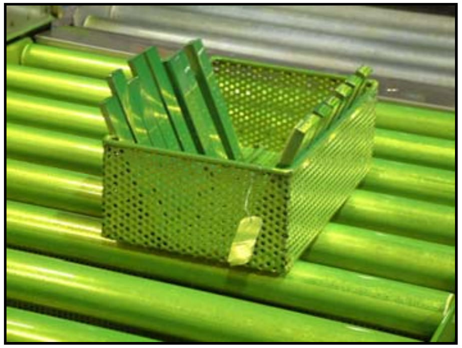
Developer Questions

- Do penetrants self-develop?
- How does dry powder developer compare to non aqueous wet developer?
- How do different penetrant/developer families compare?
- How do developer application methods compare (dust chambers, bulb, spray wand, electrostatic)?
- How do different developer forms compare?

CASR

Field Studies

- 15 - 20 samples per basket
- 20 minute penetrant dwell
- 90 second pre-wash
- 120 seconds emulsifier contact with vertical motion
- Two 30 second cycles of air agitated water rinse, then a 90 second post-wash



http://www.cnde.iastate.edu/faa-casr/fpi/index.html

Field Studies

- Samples dried for 10 minutes at 160ºF
- Drag-through application of developer
- 10 minute development time
- Brightness reading using Spotmeter
- Length reading using UVA and image analysis software

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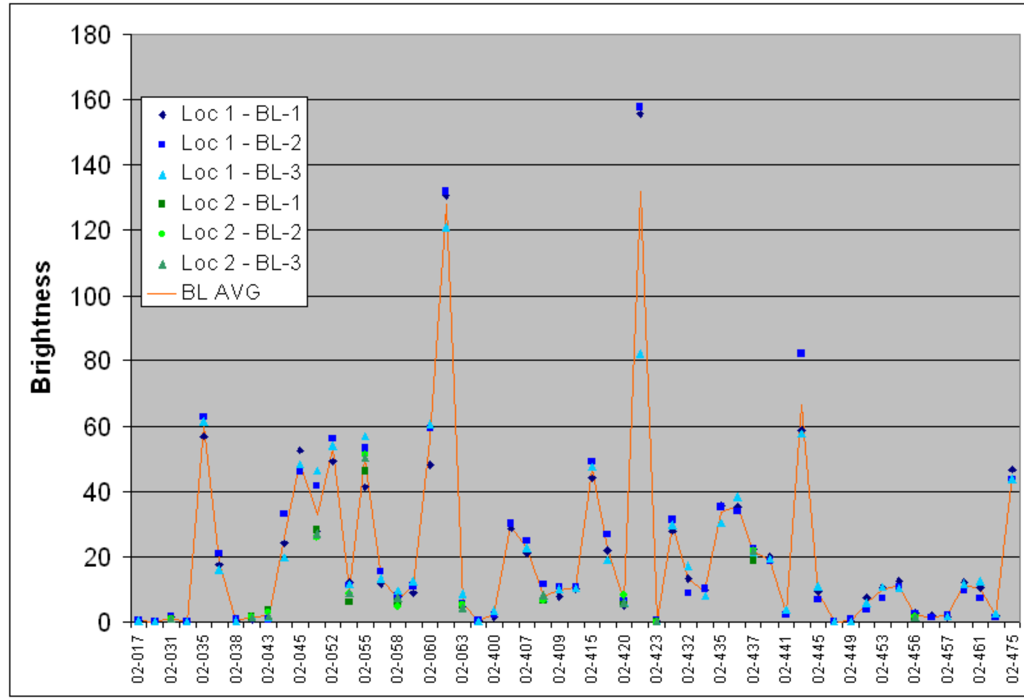
Developer Chamber Characterization

- Utilized standard sample process with baseline established using dip/drag method of developer application
- Evaluated four developer chambers and wand application methods at two locations
- Same penetrant process (level 4 PE) and chemistry used through out



Developer Application Methods

- Chamber a – Developer applied through linear diffuser located at top and bottom of chamber
- Chamber b – Developer applied from circular diffuser located at top and bottom of chamber
- Chamber c – Developer applied from circular diffuser located at top of chamber
- Chamber d – Developer applied from two nozzle diffusers located at bottom of chamber
- Manual spray – Low pressure, high volume manual application
- Dip/drag – Hand application of individual samples. Used for baseline measurements.

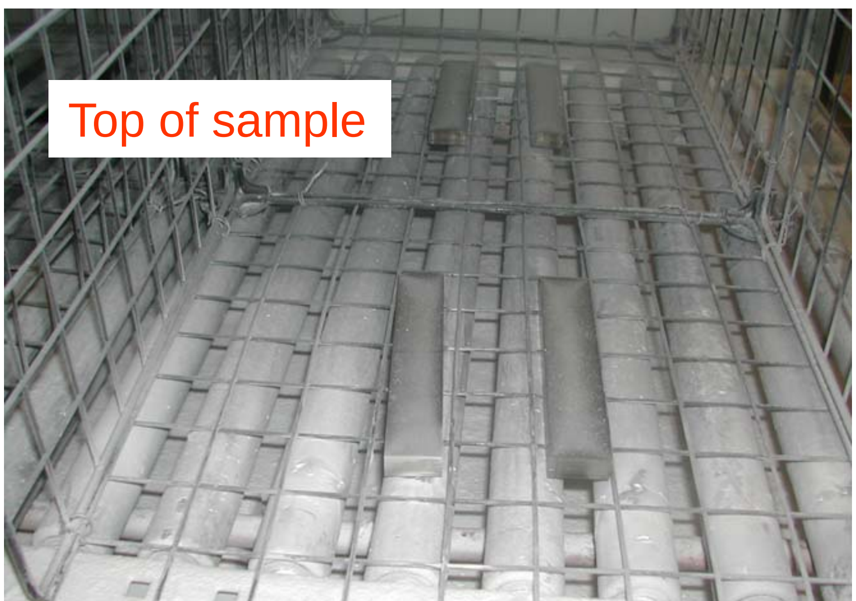
Chamber A Characterization

Chamber A Characterization

- Developer applied through linear diffusers located at top and bottom of chamber
- Developer time of 20 or 60 sec followed by 2 min dwell, 1 min evacuation and removal at 5 min
- Samples placed with cracks in up or down position

Linear diffusers

Samples prior to removal



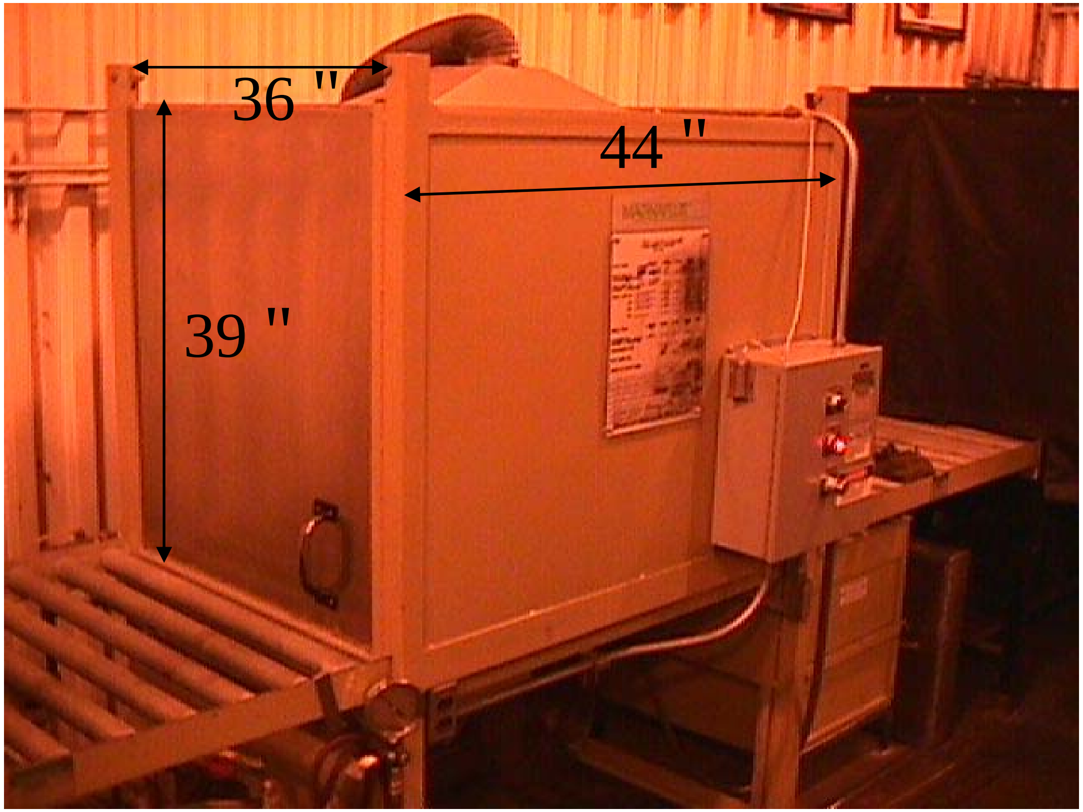
Chamber A Characterization

- New developer added to pot prior to study
- Run 8 – Samples placed in up or down position. Developer application for 20 sec.
- Run 10 – Samples in up or down position. Developer application for 60 sec.
- Run 12 – Samples placed in down or up (opposite of Run 8) position. Developer application for 20 sec.

Chamber B Characterization

- 20 sec of developer application followed by 3.5 min dwell and 2 min evacuation
- Other runs included:
  - 20 sec without evac
  - 40 sec without evac
  - 120 sec with evac

Chamber C Characterization

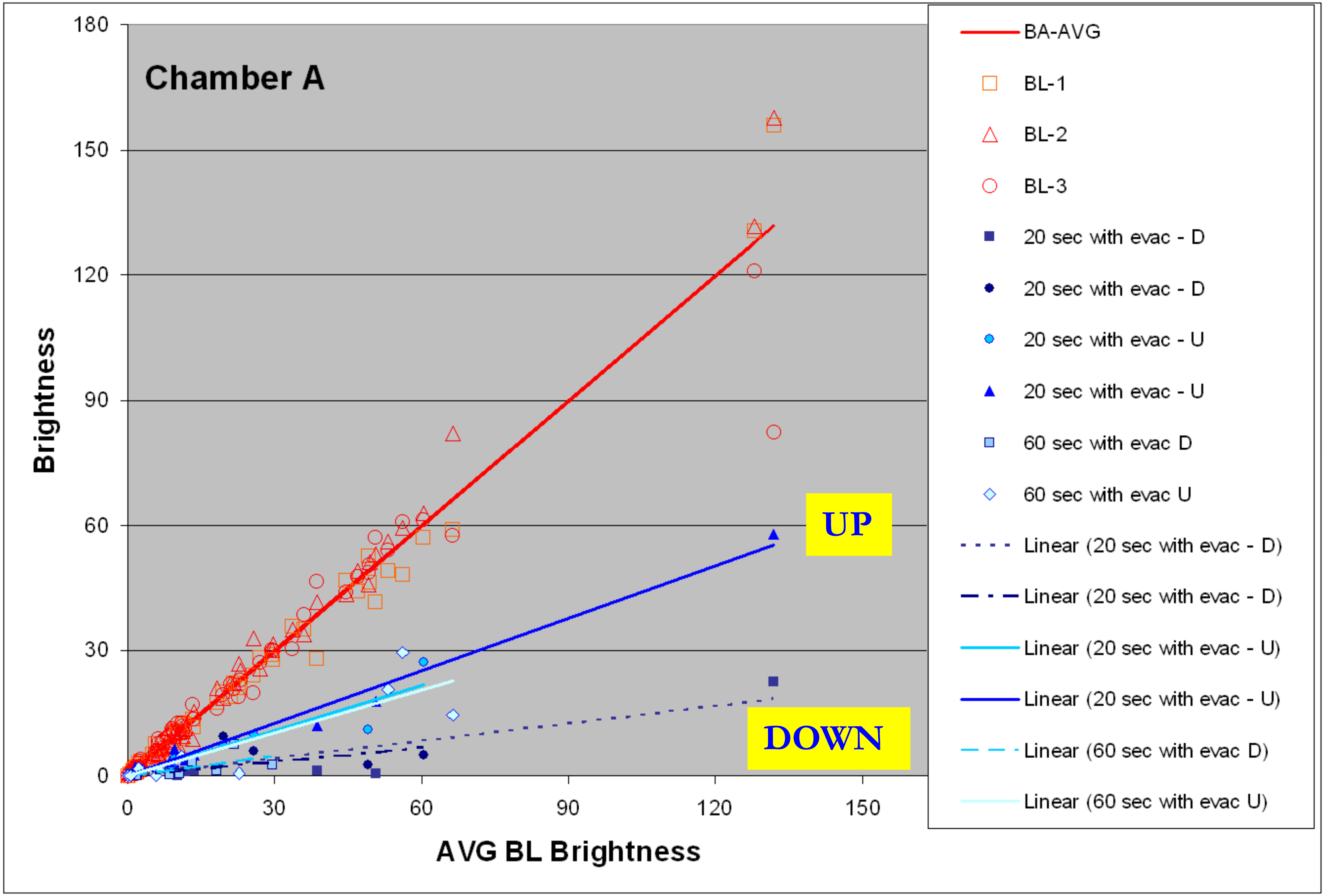


- Circular diffuser located in top of chamber
- 120 sec of developer followed by 110 sec dwell and evacuation of 60 sec

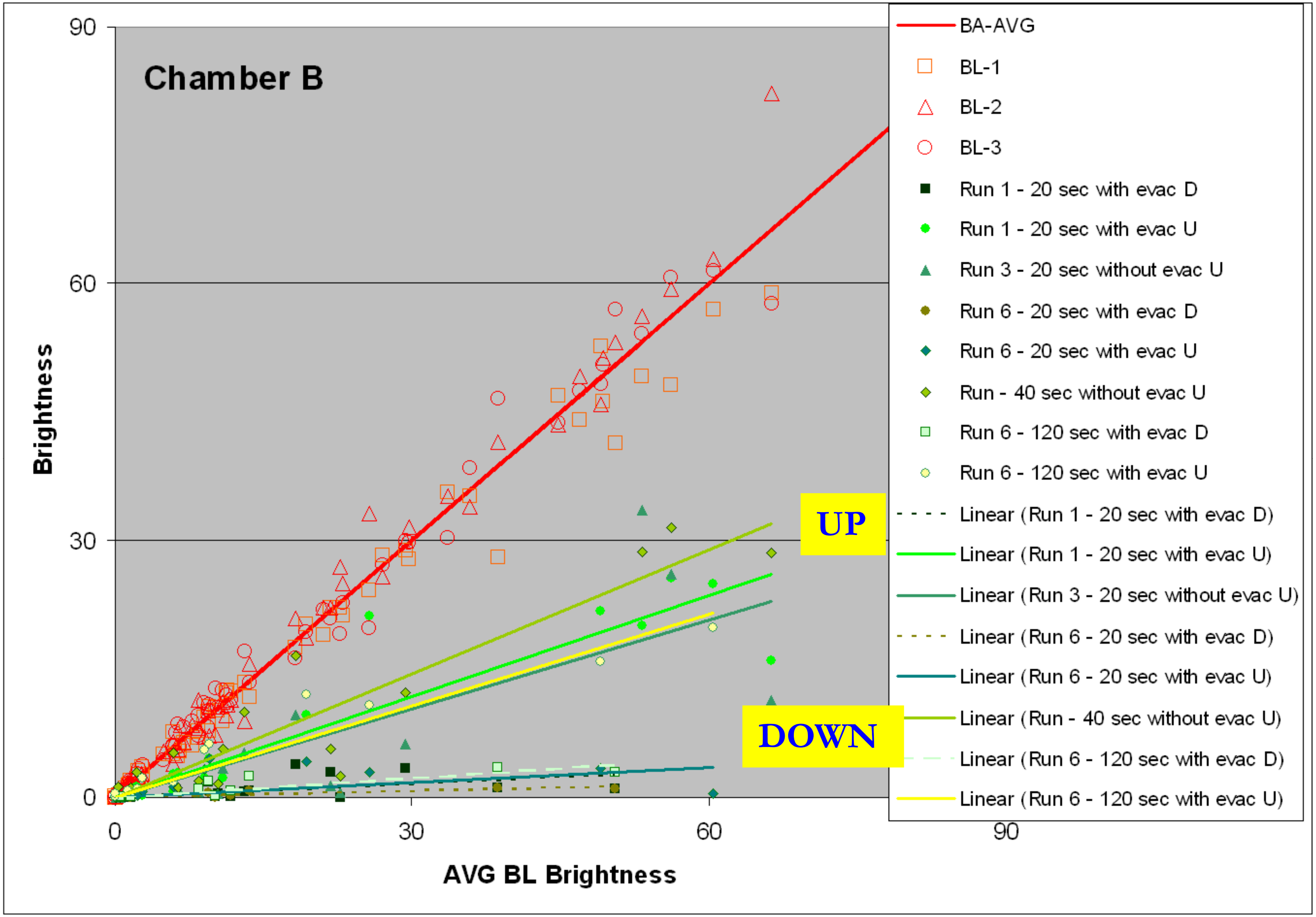
Chamber D Characterization

- Chamber contains two jets, at approximately ¼ and ¾ of the chamber length
- Jets located below rollers
- Typical operation of 5 sec developer application followed by 10 min dwell in chamber

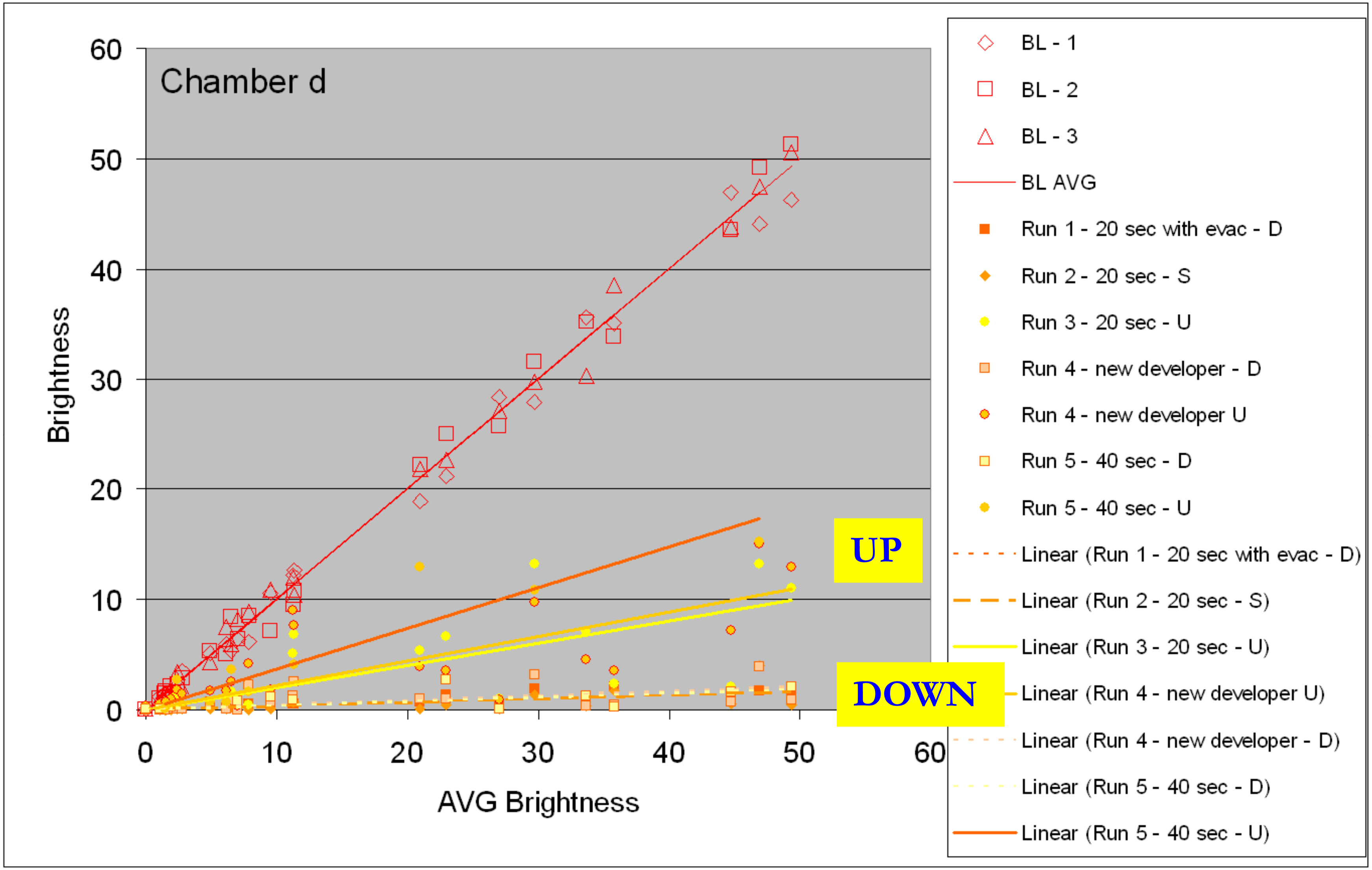
Chamber A Characterization



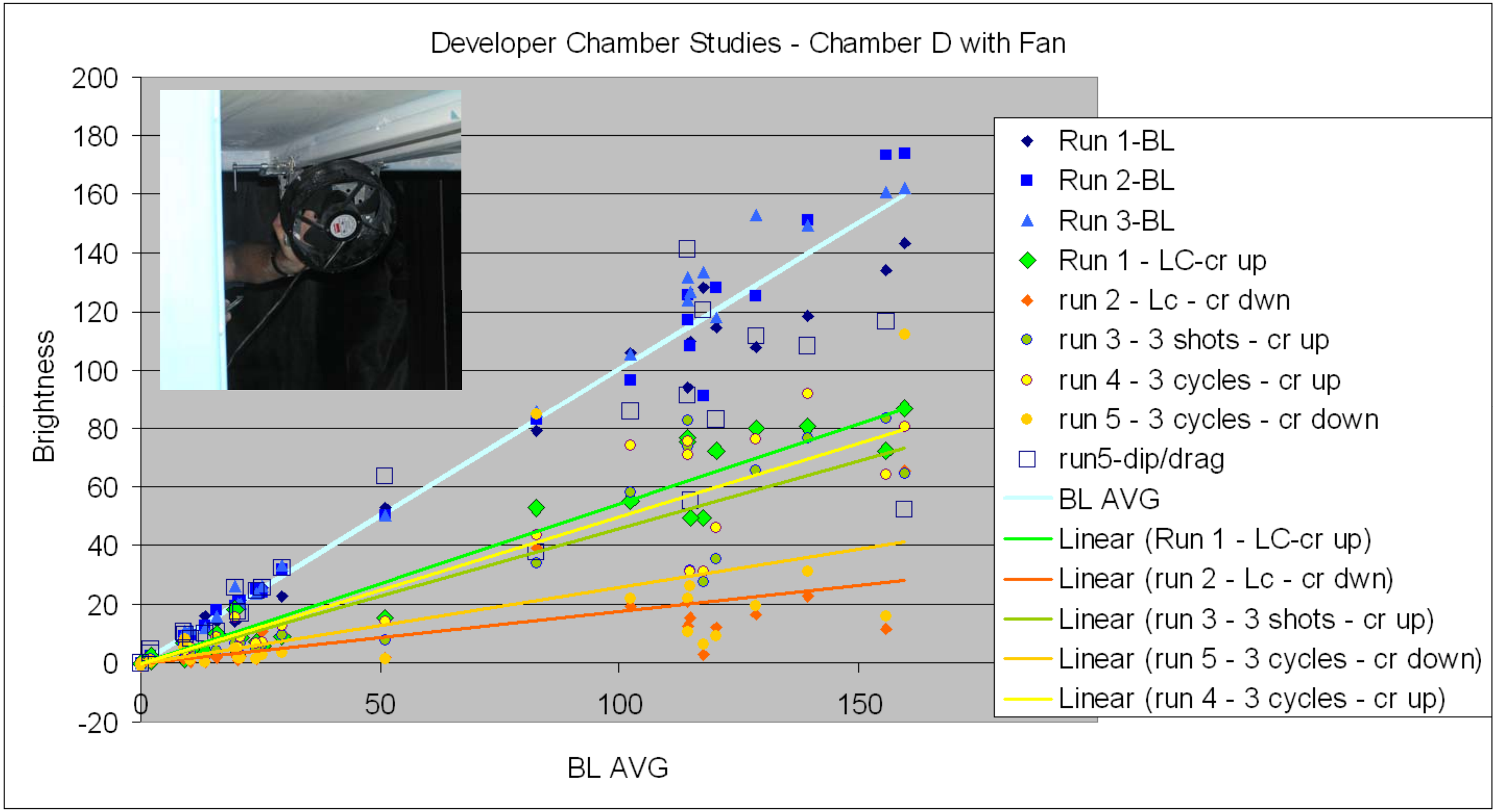
Chamber B Characterization



Chamber D Characterization

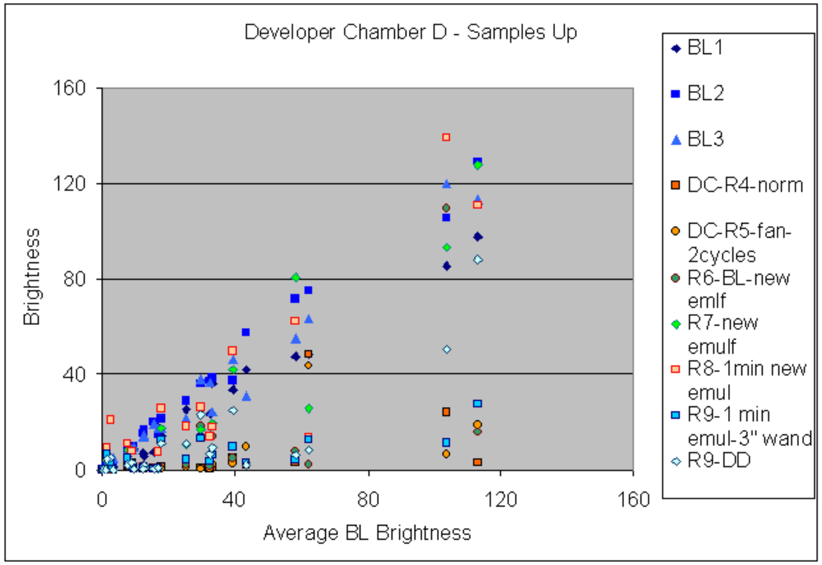


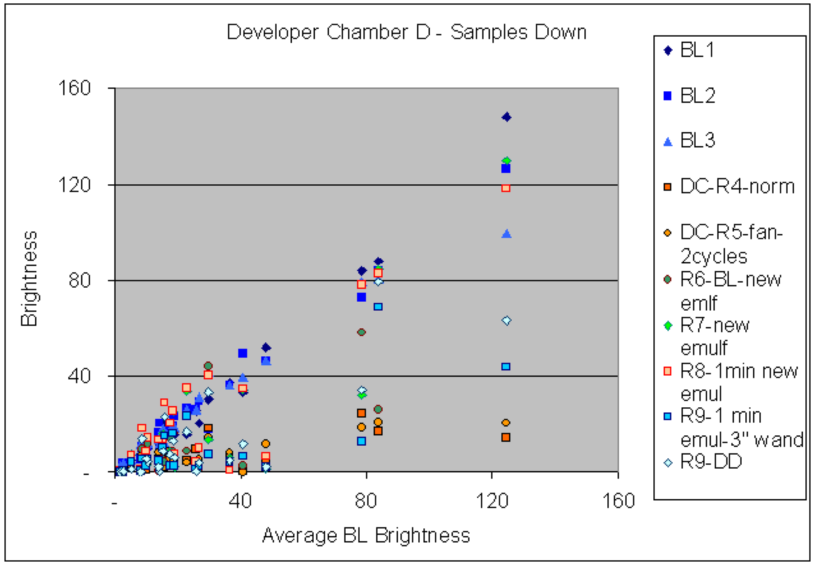
Chamber D – with Fan



CASR Developer Chamber Characterization

- Crack location (up, down, sideways) has significant effect on brightness
- Suggest consider approaches which enhance contact of the developer with potential crack locations
  - Localized developer in areas of concern
- Characterization of chamber performance needed for routine use in line maintenance
- Utilization of fan did not significantly enhance brightness
- Use of 3" wand has 10% better brightness performance than developer chamber but only 30% of that when samples were hand processed





	BL1	BL2	BL3	DC-R4-norm	DC-R5-fan-2cycles	R6-BL-new emlf	R7-new emulf	R8-1min new emul	R9-1 min emul-3" wand
Samples Up				0.1565	0.1837				
Samples Down				0.1767	0.1767				
Samples Dip/Drag	0.9918	1.0511	0.9571			0.6883	0.937	0.9582	0.2709

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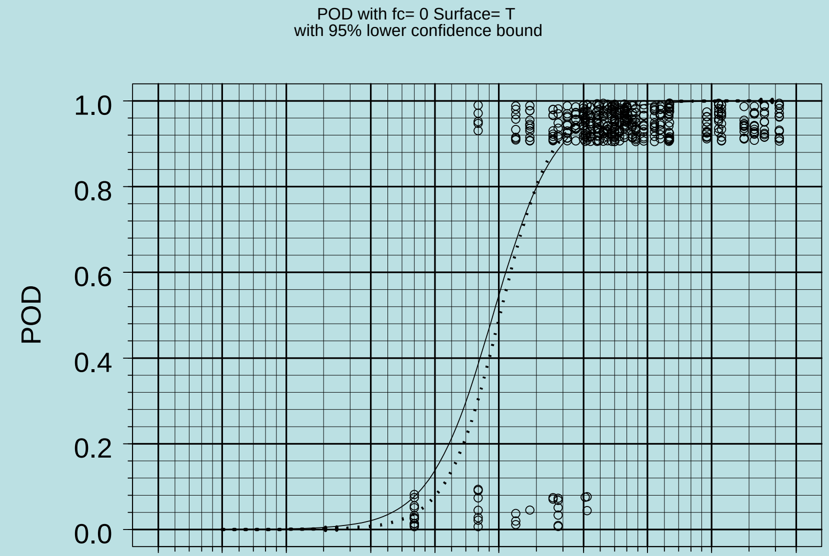
Statistical Analysis of Chamber Effects

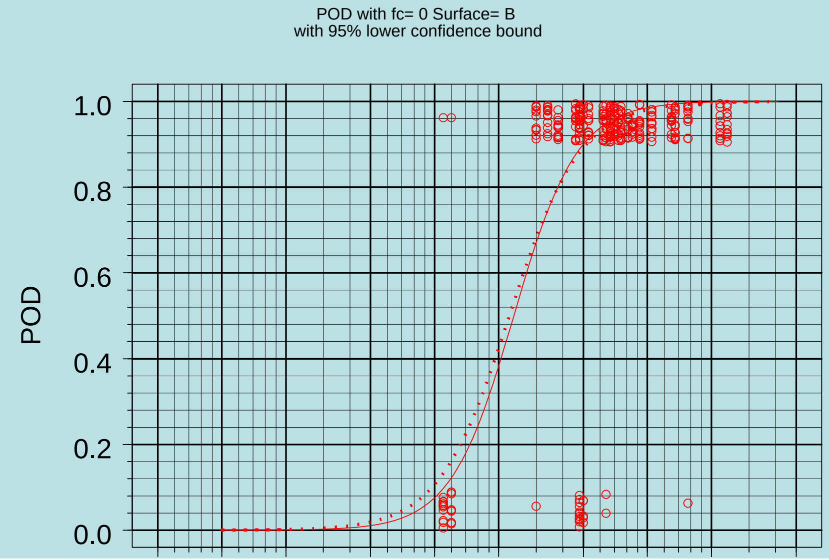
- Statistical analysis showed:
  - Differences were found in location within the chambers
    - Right/left effects in Chamber B but not Chamber A for cracks in up position
    - Improved brightness in middle of Chamber B compared to either end for cracks in up position
    - More variation at front of Chamber D than middle and back of chamber
    - No right/left, front/back or level effects for cracks in down position
    - No level (top, middle bottom) effect found in Chamber A, B or D
  - Most significant effect was crack orientation (up, down, sideways)
- Suggest consider approaches which enhance contact of the developer with potential crack locations
  - Localized developer in areas of concern
- Characterization of chamber performance needed for routine use in line maintenance

CASR

Importance of Sample Orientation

- Completed POD study which correlates brightness to detectability
- Used two sample sets, two inspectors under multiple UV intensity level, white light level combinations
- Evaluated indication location (top or bottom) of panel
- Significant differences can occur





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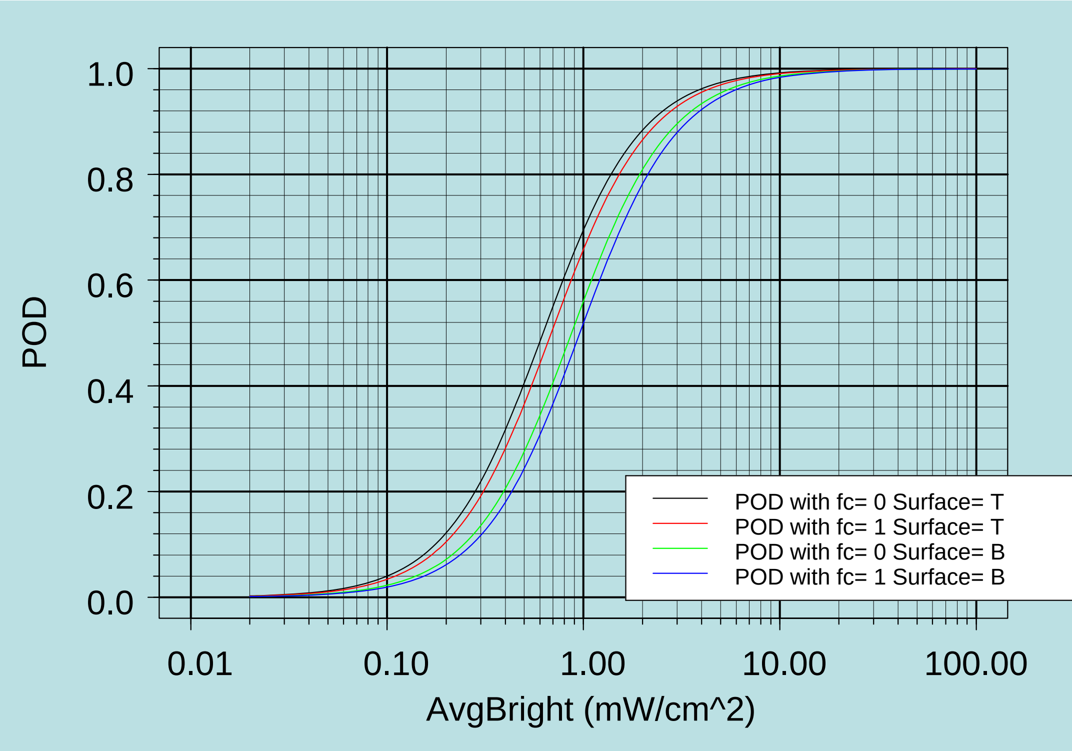
Importance of Brightness

- POD is correlated to brightness
- UVA intensity of 5000 μwatts/cm^2 lead to ~15 mil improvement in POD when compared to 1000 and 3000 μwatts/cm^2
- Increasing whitelight contamination led to significant reductions in POD in excess of 100 mils



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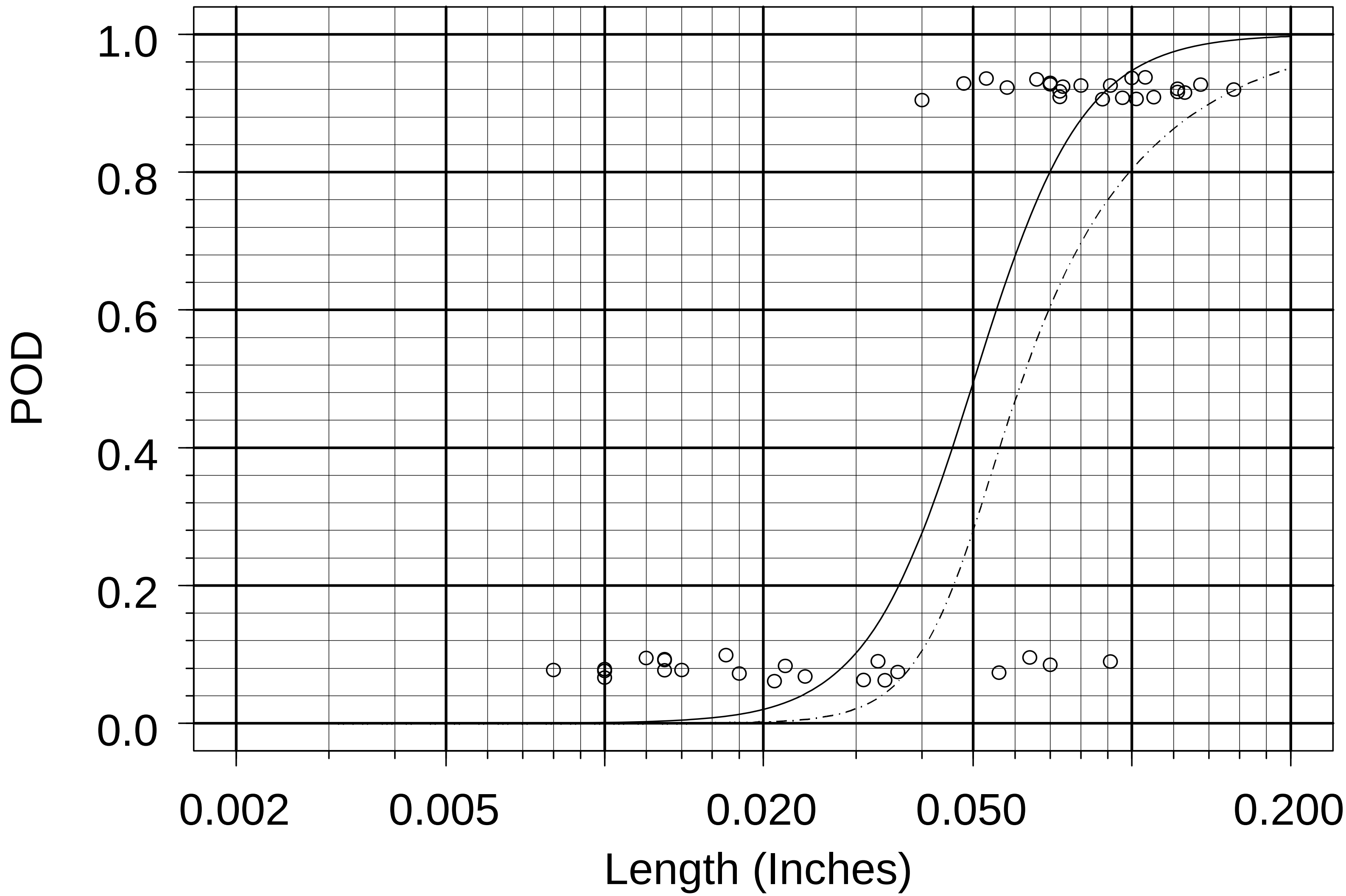
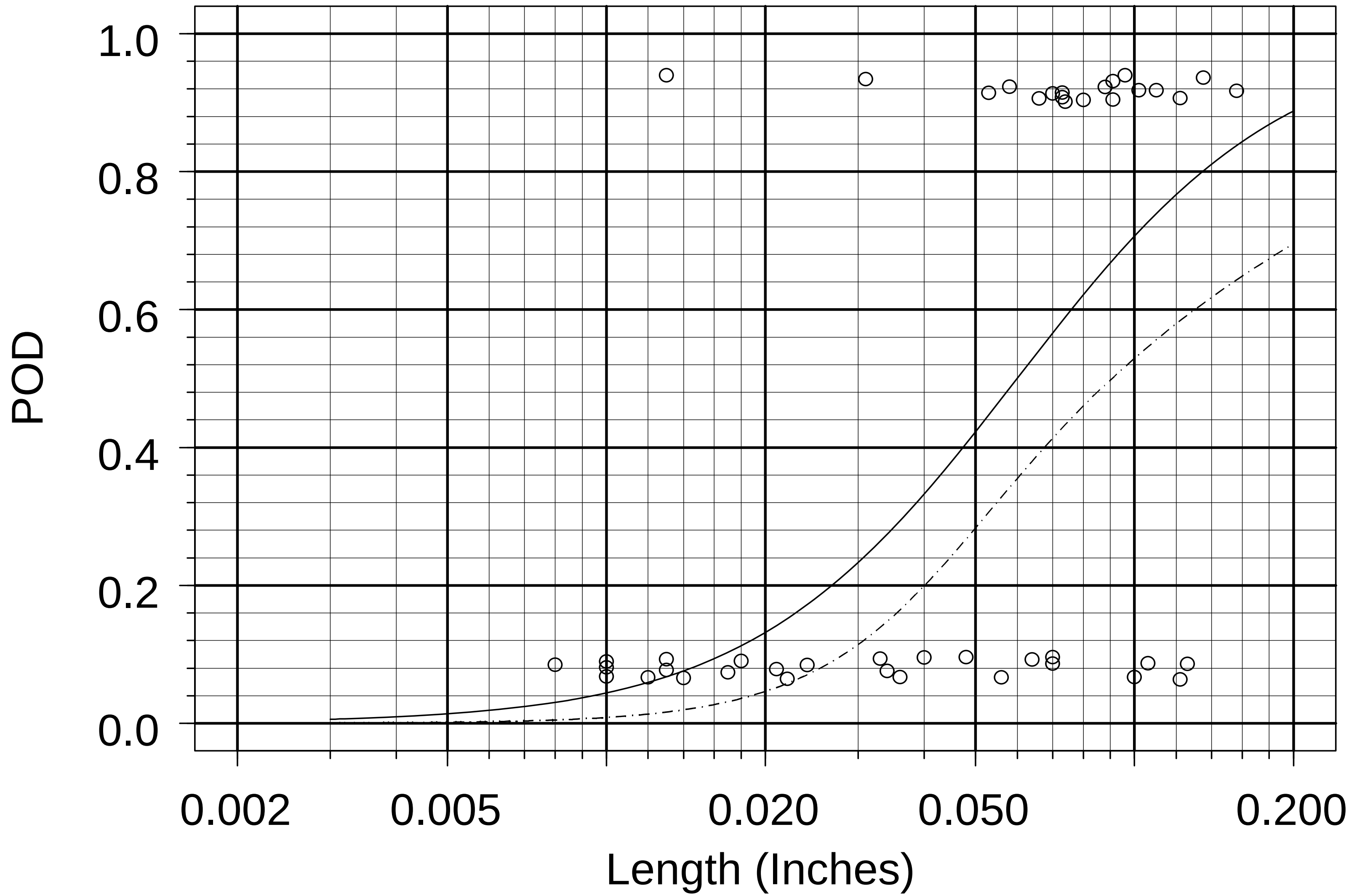
R3.I2.5kuva.0fc
Hit-Miss POD with 95% lower confidence bound



R4.I2.DevCh.5kuva.0fc
Hit-Miss POD with 95% lower confidence bound



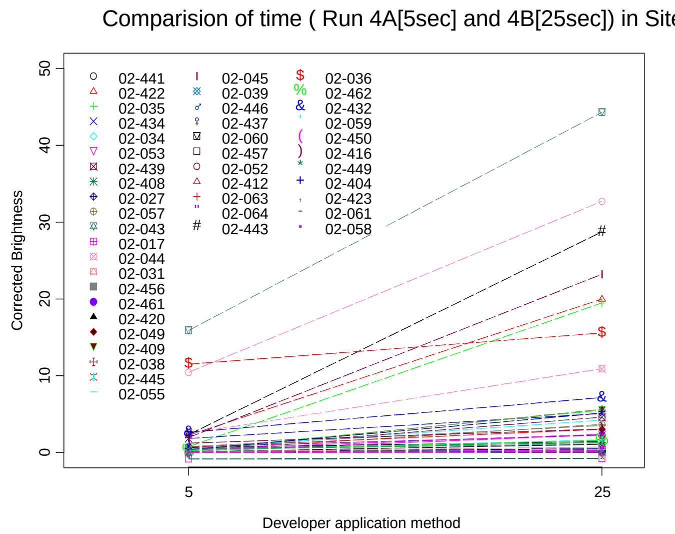
Manual Spray Application

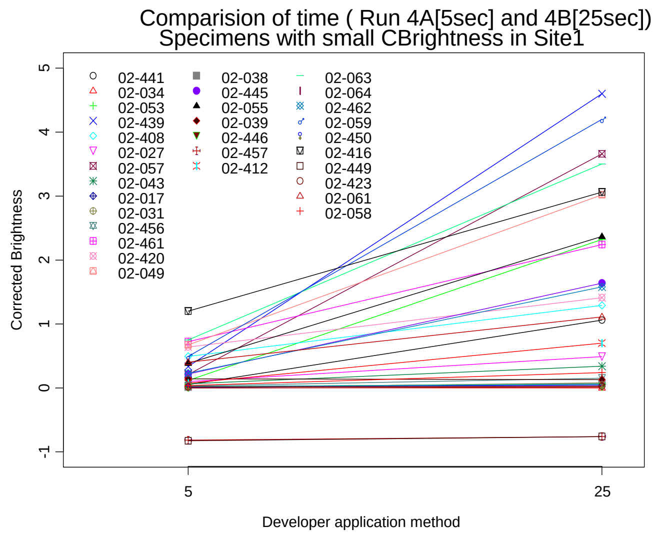
- Low pressure, high volume spray
- 5 and 25 sec runs completed using lobster cage with cracks in D, S or U position
- 60 and 120 sec runs completed with samples all in U position

Manual Spray Application

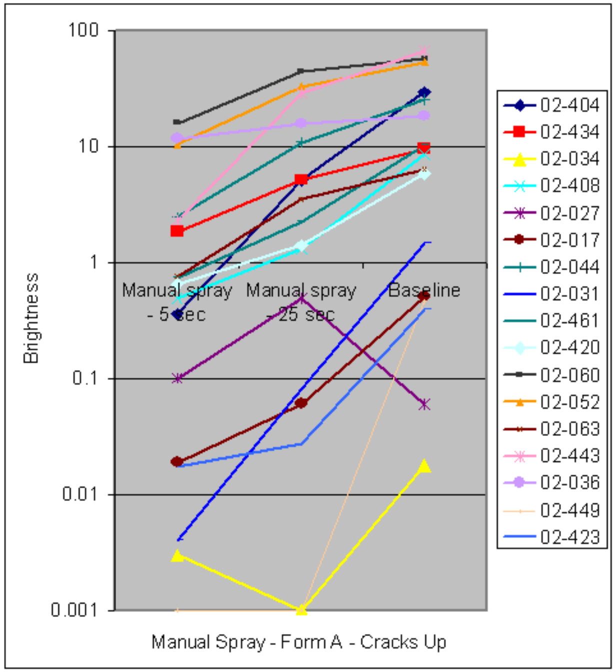
Manual Spray Application

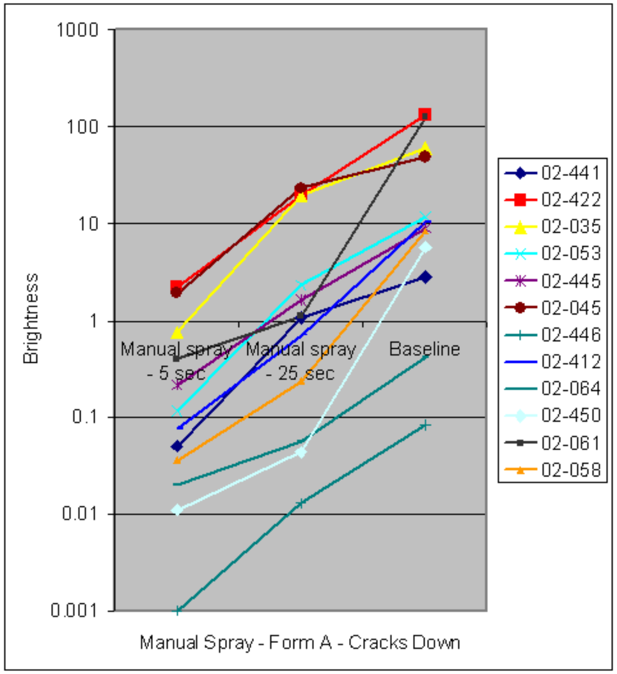
- Increasing time of manual spray application from 5 to 25 sec showed significant improvements in brightness

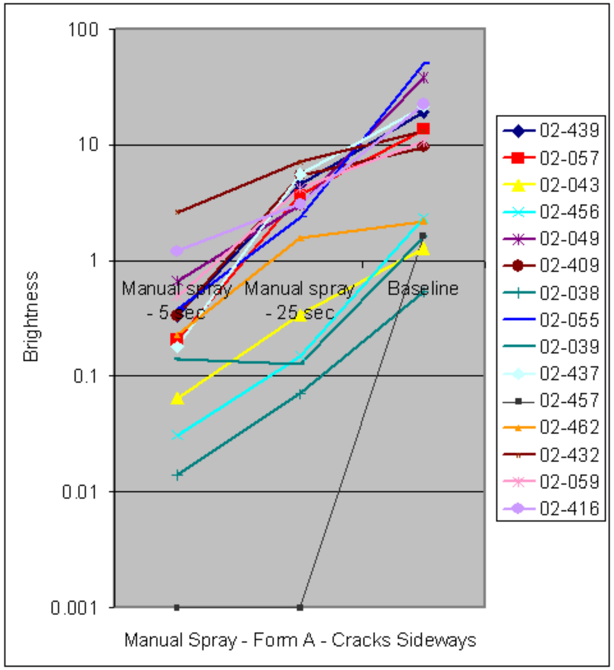




Manual Spray Application



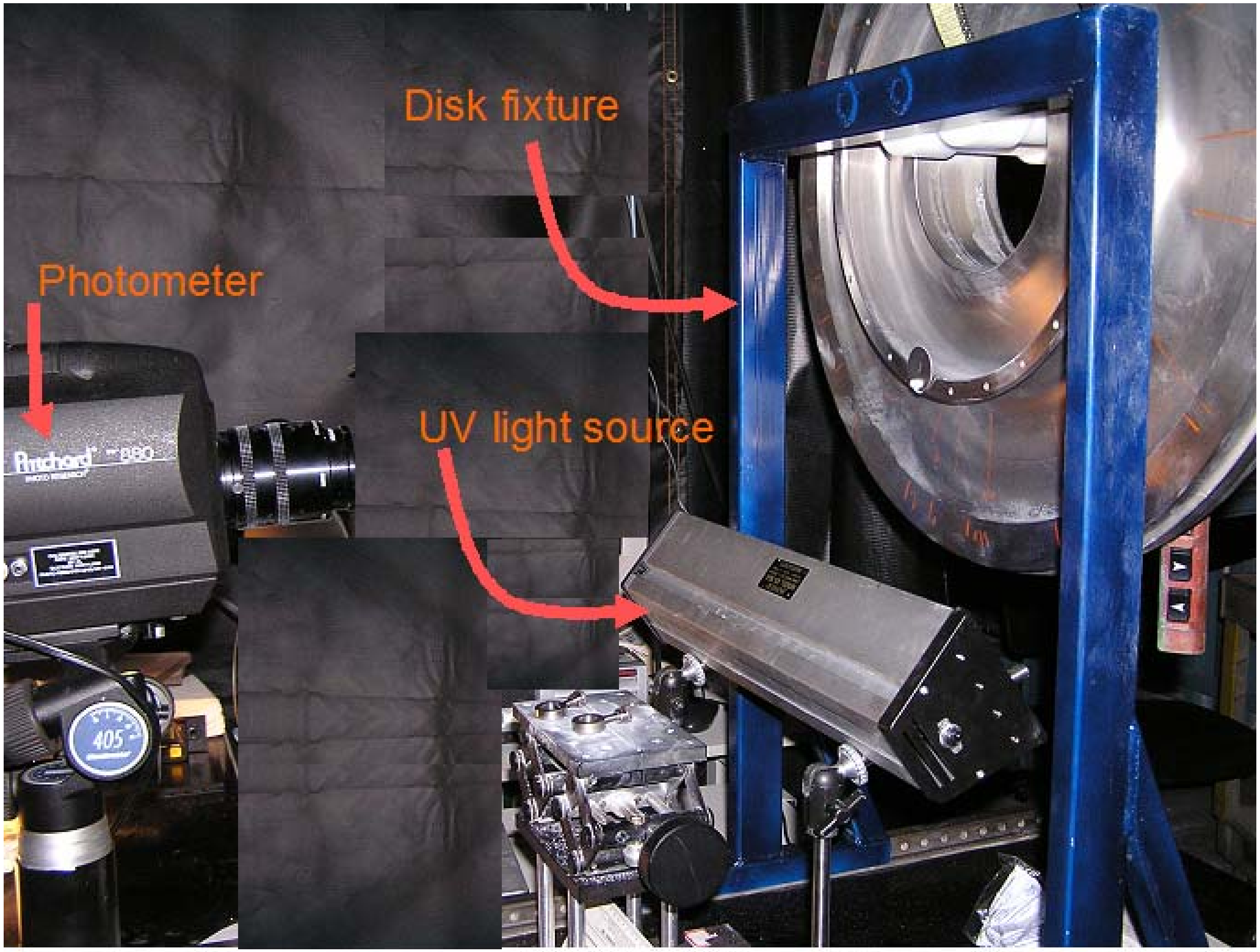




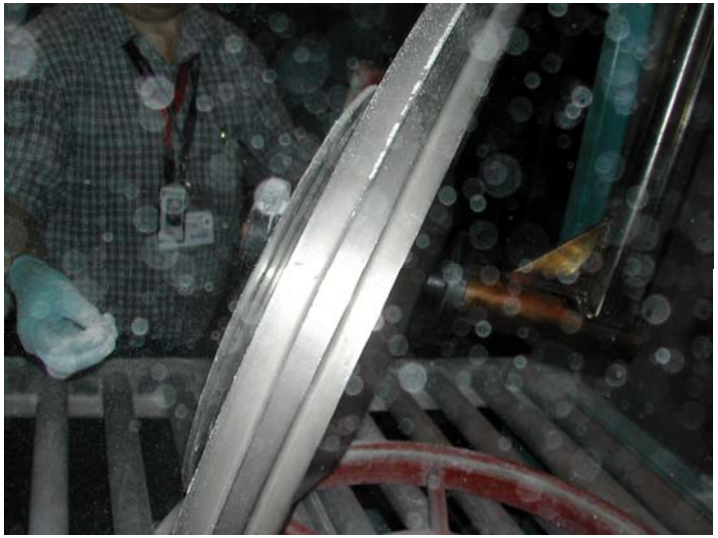
- Increasing time improves brightness for all orientations
- Runs made at 60 sec showed further improvements in brightness compared to 25 sec
- Runs made at 120 sec showed reduction in brightness for some samples

Brightness Measurement

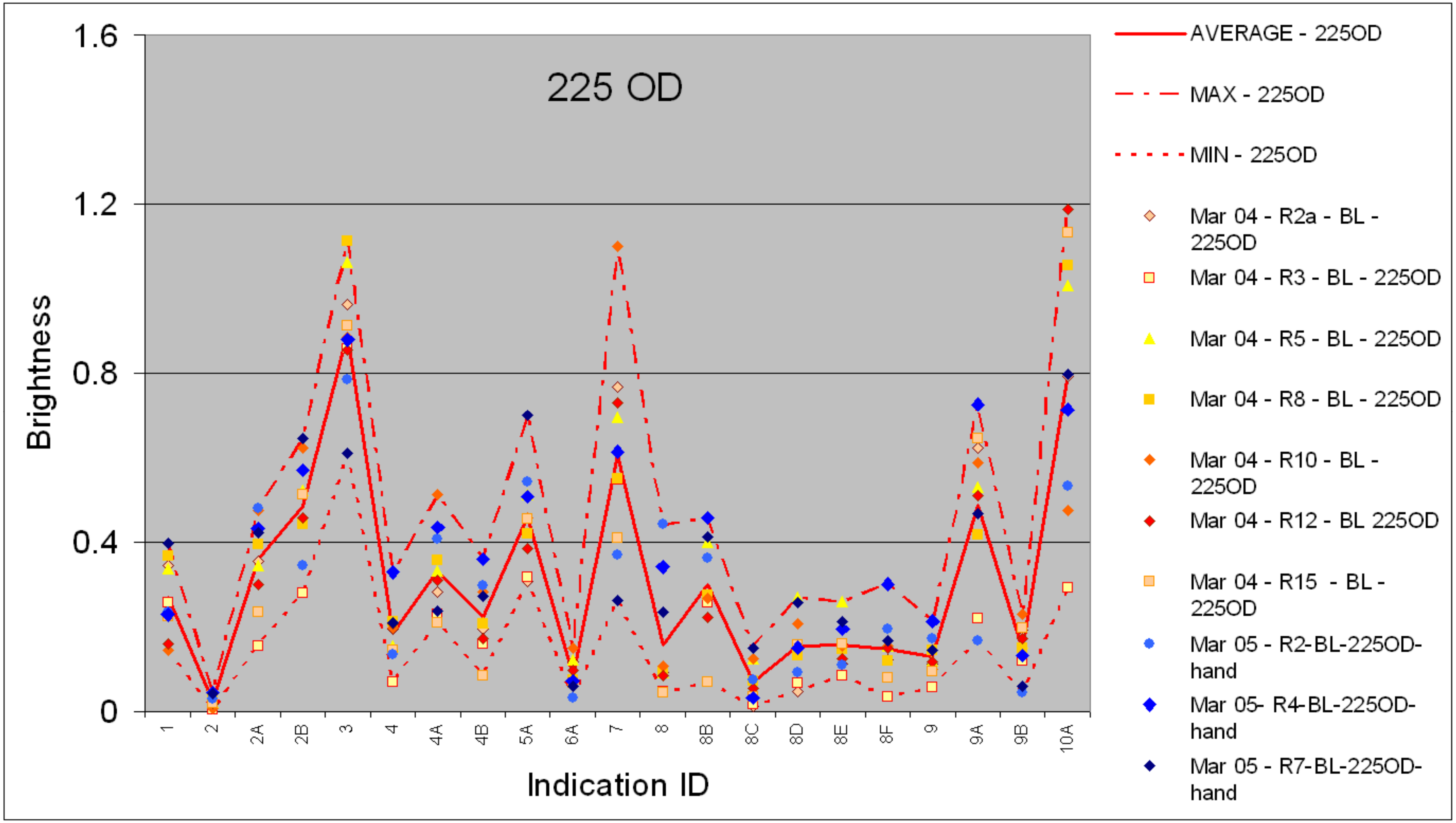
- Brightness measurements made with Photo Research PR-880 photometer
- UVP XX-BLB 17” fluorescent UVA source with 850μW/cm^2 at the part surface
- Fixtures used to maintain disk position
- Geared tripod head used to manipulate photometer position



Developer Application



Baseline Brightness Results



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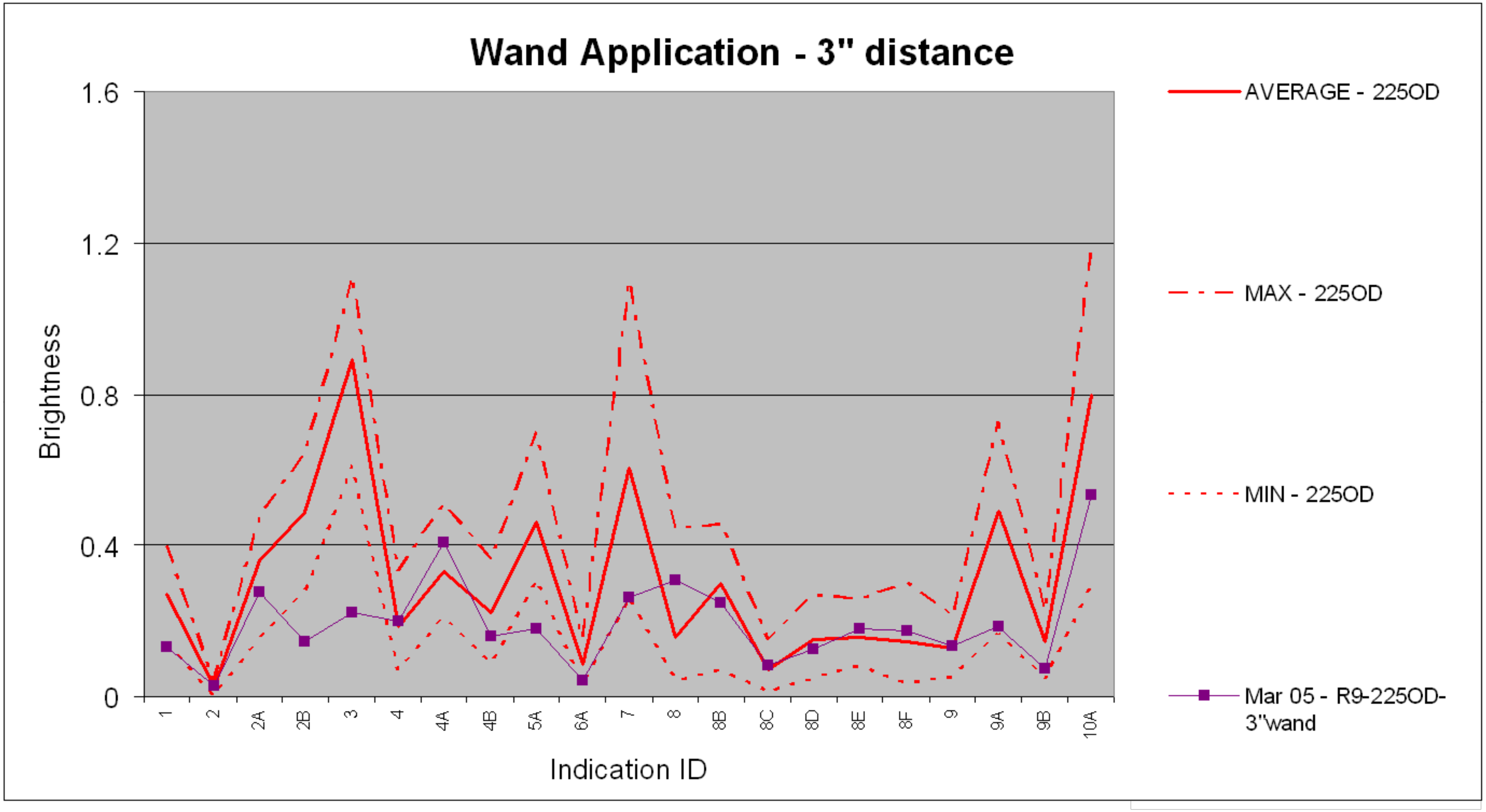
Developer Application - Wand



- Use of wand at 3” distance from part led to lower brightness than hand processing with brightness of 30% of the average brightness found with hand-processing

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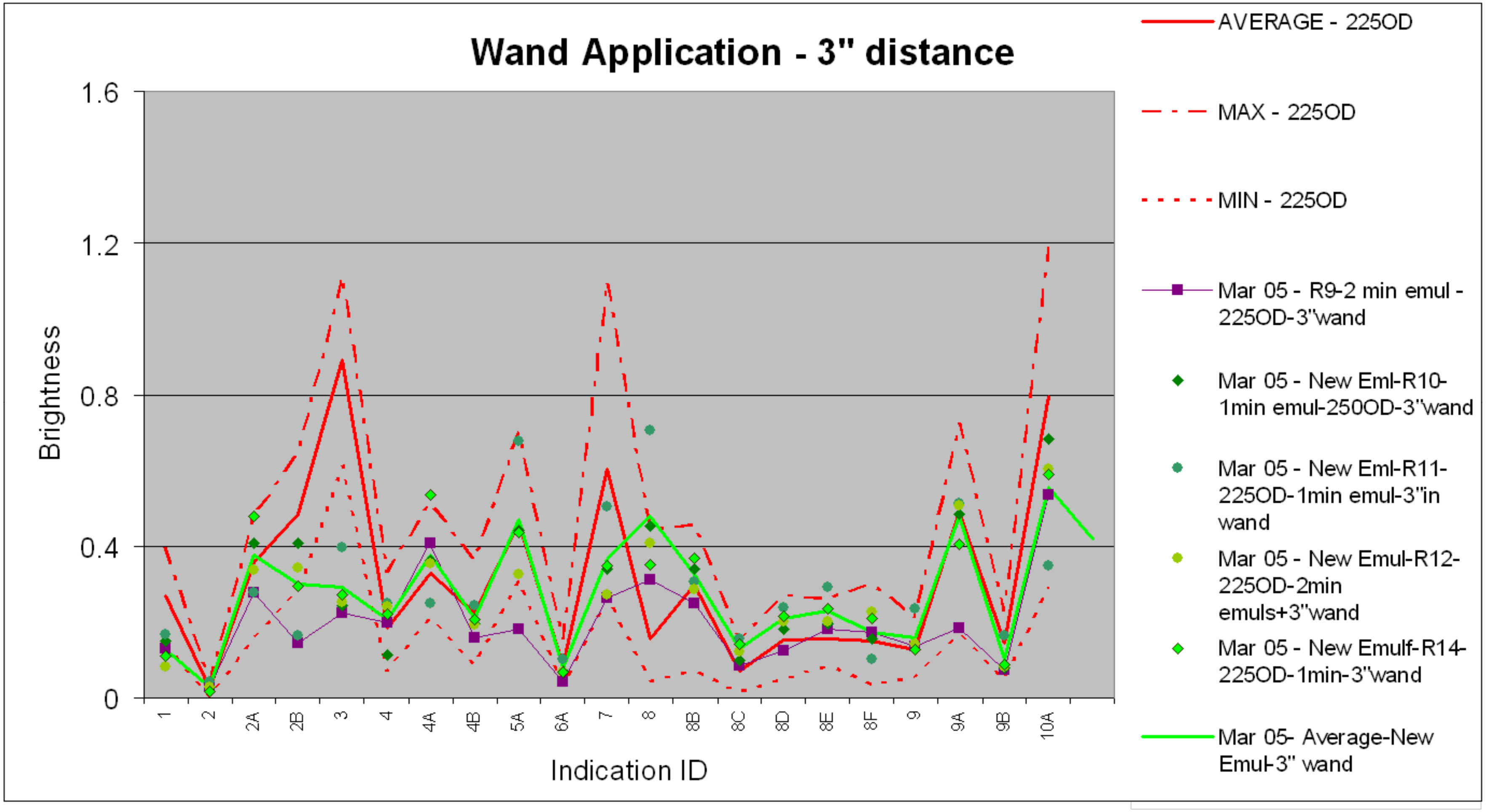
New Emulsifier



- Brightness increased with new emulsifier compared to original emulsifier
- Use of wand in general led to a reduction in brightness but less variability than with hand processing

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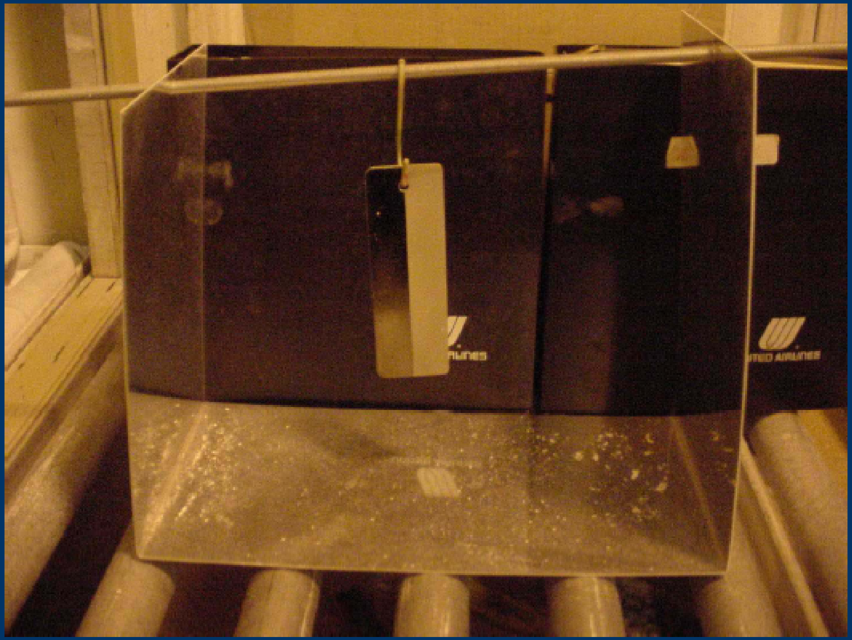
Characterization Methods

- Utilized “worst case” configuration for the sample for comparison to dip/drag
- Digital camera used to record indication response for comparison

Vertical Run Set-up



Ref: Tom Dreher ATA NDT Forum, 2004

UNITED SERVICES

Characterization Methods

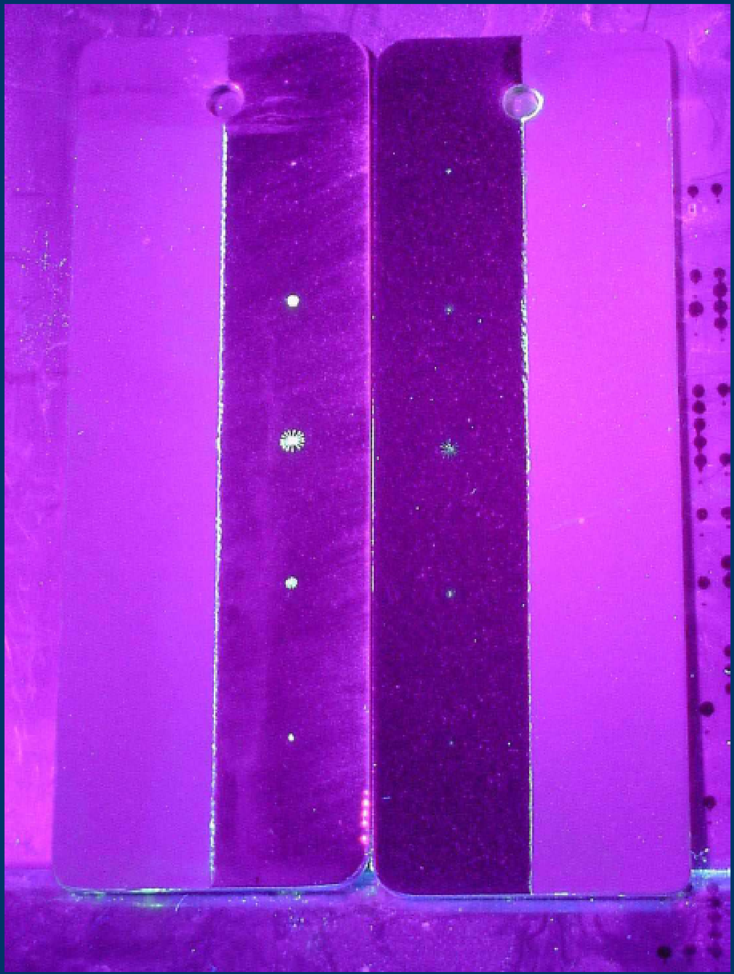
Ref: Tom Dreher ATA NDT Forum, 2004

KDS Panel 1st Baseline

Horizontal Cabinet Run

Dip vs. Cabinet 1

After Vertical Run



Preliminary Conclusions

- Developer application is critical to overall FPI performance
- Developer application by dip/drag yields brighter indication than with any of the developer chamber or wand application methods
- No indications were "lost" but detectability improves with brightness – optimal process will yield bright indications
- Sample orientation matters
  - Avoid barriers that prevent direct application of the developer
  - Ensure chamber configuration or part handling fixtures (rollers, baskets, etc.) don't hamper application
  - No metal-to-metal contact
  - May require multiple trips through the chamber to ensure adequate coverage on all surfaces
- White light contamination matters

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Developer Questions

- Do penetrants self-develop?
- How does dry powder developer compare to non aqueous wet developer?
- How do different penetrant/developer families compare?
- How do developer application methods compare (dust chambers, bulb, spray wand, electrostatic)?
- How do different developer forms compare?

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Introduction

- Current industry standards allow the use of several developer forms, including:
  - Dry powder (Form a)
  - Water soluble (Form b)
  - Water suspendible (Form c)
  - Non-aqueous wet developer (Form d)
- Past studies have shown that application of dry powder using a dust storm cabinet produces an indication brightness that varies between cabinets, and with defect location
- Spray or dip application of water suspendible or water soluble developer has the potential of avoiding this defect location sensitivity

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Objectives

- To compare the brightness of form b (water soluble) and form c (water suspendible) developer processes to baseline dip/drag processing using form a (dry powder)
- To compare performance results to previous studies of dust chamber performance

Introduction

- Dry powder developers are accepted into the qualified products listing (QPL-SAE-AMS-2644) through a dip/drag processing procedure at Wright Patterson AFB
- Acceptance of Forms b and c developers is based on immersion results (dipping sample into stirred bath) using the manufacturer's recommended concentration
- It is known that
  - NAWD produces very bright indications, but full coverage of large components is not realistic.
  - Powder application using a dusting bulb produces results similar to that obtained using a dust storm cabinet
  - Immersion of large specimens into a vat of Form b or c is not always feasible in industry, so spray application is typical

Note: This study is not intended to be an exhaustive comparison of penetrant products, nor is it a qualification process study. Rather its purpose is to provide data from representative products which are typical of aerospace use.

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What Work Was Done

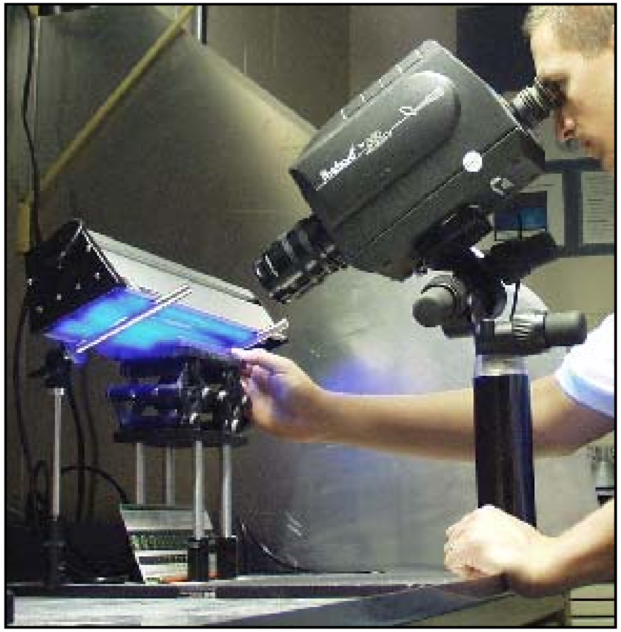
This work monitored the change in FPI indication brightness while varying:

Developer Type

- Dry powder
- Water soluble
- Water suspendible
- NAWD

Developer Concentration (for soluble/suspendible)

- Recommended
- Low



Developer Application Method

- Immersion
- Spray (performed at Tinker)
- Dip/drag
- Bulb

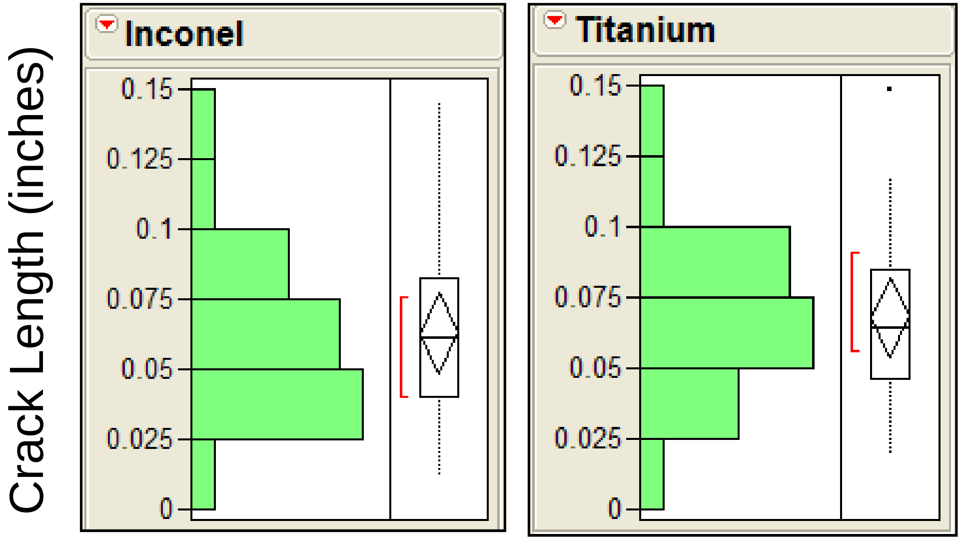
Crack Orientation (for Bulb application)

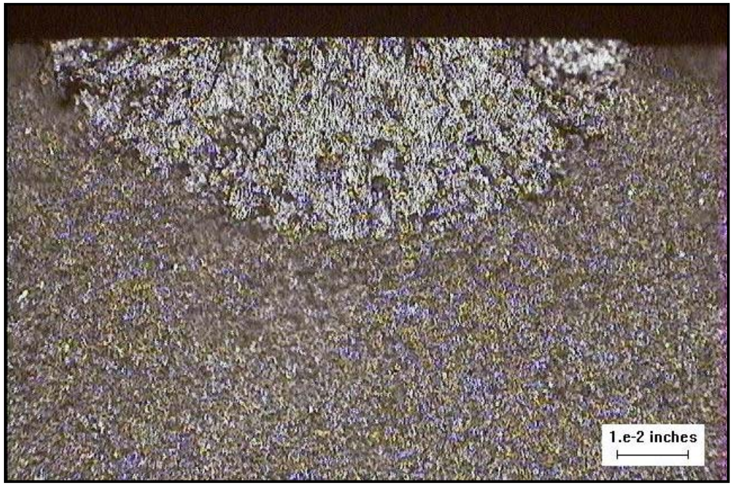
- Facing up
- Facing sideways

How Was It Performed

Low-cycle fatigue (lcf) crack samples

- (20 pcs) Inconel-718 and (20 pcs) Titanium 6-4
- Dimensions: 1 - 1.5″ wide X 0.5″ thick X 6″ long
- EDM starter defect propagated under 3-point bending
- Crack lengths ranged from 0.013″ to 0.145″ (0.066″ aver.)
- Aspect ratio (surface length : depth) ≈ 2.6 : 1





Example Aspect Ratio

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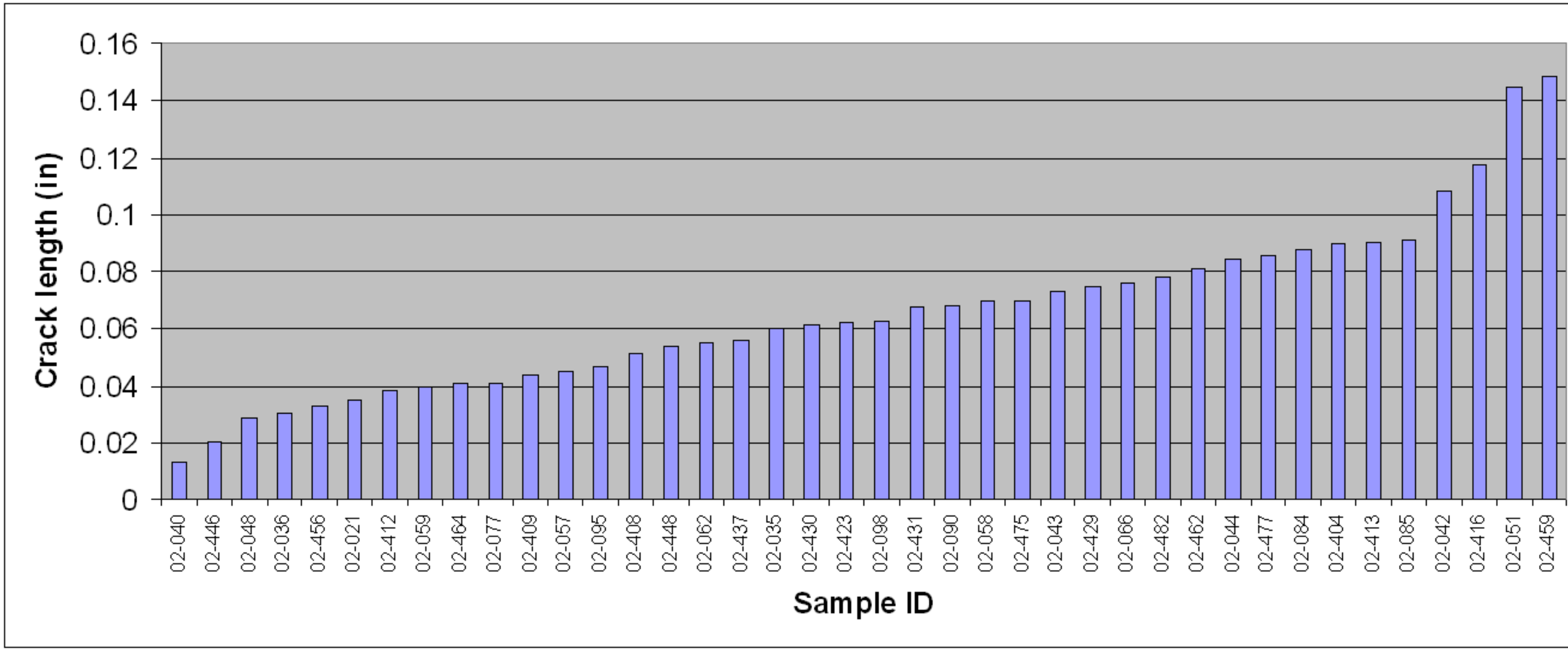
Sample description



- 39 samples (Ti, Ni) selected with crack sizes shown in the distribution above
- Included 16 samples from prior emulsification studies completed at ISU

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How Was It Performed

Inspection Process

- 20 minute penetrant dwell
- 90 second pre-wash
- 120 second emulsification (15-second agitation interval)
- 90 second post-wash
- ➢ developer apply (soluble or suspendible)
- 10 minute dry @ 155°F
- ➢ 10 minute development (dry powder)
- photometer brightness and UVA microscope imaging
- NAWD Application and 10 minute development
- photometer brightness and UVA microscope imaging
- 30 minute UT-agitated acetone clean
- 60 minute dry @ 155°F

Variation depending upon experimental run

How Was It Performed

When divided by developer form, experimental runs included:

Dry powder developer

- Dip/drag application
- Crack facing upward – Bulb application
- Crack facing sideways – Bulb application

Water suspendible developer

- Recommended concentration – immersion application
- Low concentration – immersion application
- Low concentration – spray application (Tinker)

Water soluble developer

- Recommended concentration – immersion application
- Low concentration – immersion application
- Low concentration – spray application (Tinker)

NAWD

- Applied as a follow-up to any developer combination above

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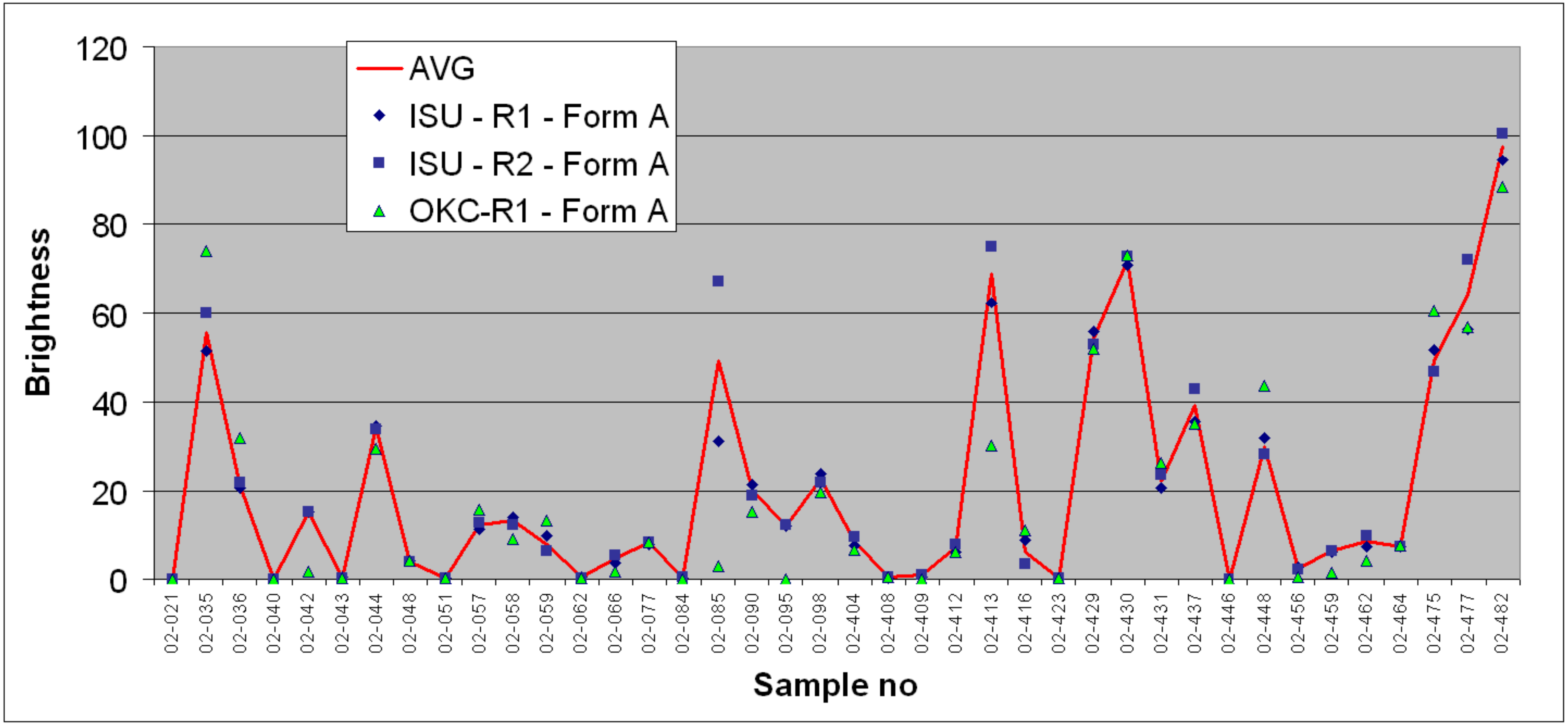
Study Summary

- Baseline runs completed at ISU using dip/drag processing
- Shipped emulsifier, penetrant and dry powder developer to Tinker for use in baseline processing
- One baseline run at Tinker to verify good compatibility between ISU baseline and OKC results
- Three runs each with Form B and Form C processes
  - Two runs with baseline penetrant/emulsifier and form b/c developer
  - One run through inspection line using penetrant/emulsifier/developer
- More detailed runs completed at ISU

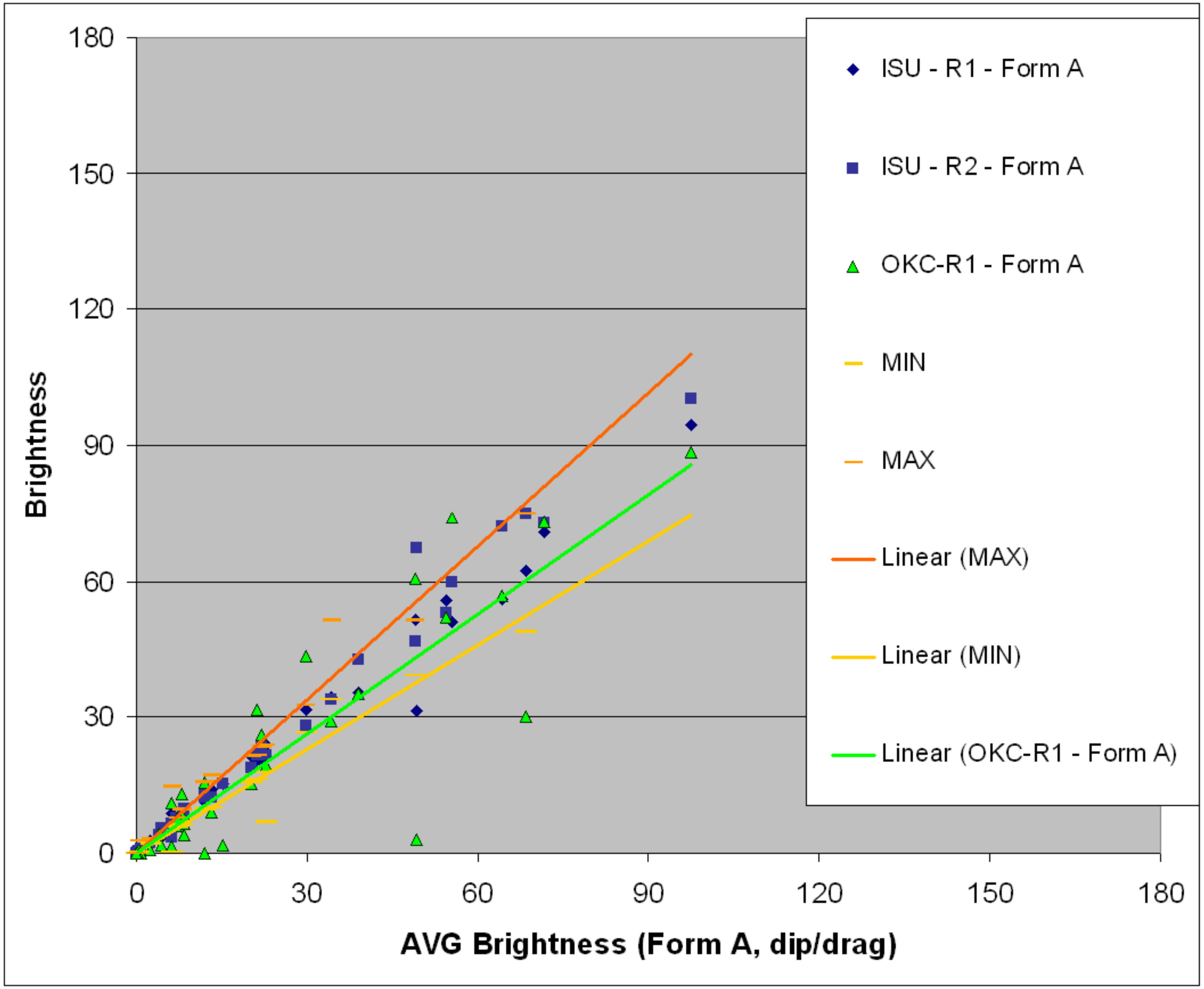
Baseline Comparison



- Reasonable agreement between baseline runs at ISU and OKC

Baseline Comparison

- Linear regression results for baseline showed OKC results within the normal variability of baseline processing at ISU



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Sample Processing

- Penetrant
  - Applied with applicator over crack location
  - Dwell time of 20 minutes
- Pre and Post-rinse
  - 90 sec each
- Emulsification
  - 120 sec total contact time
  - Mild agitation every 15 sec, 30 sec for transition to rinse station

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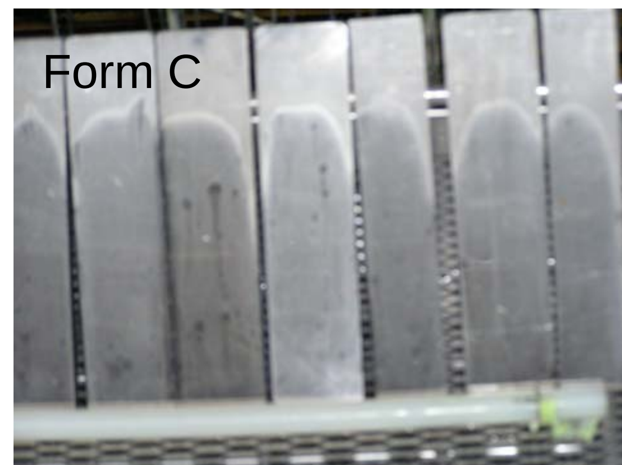
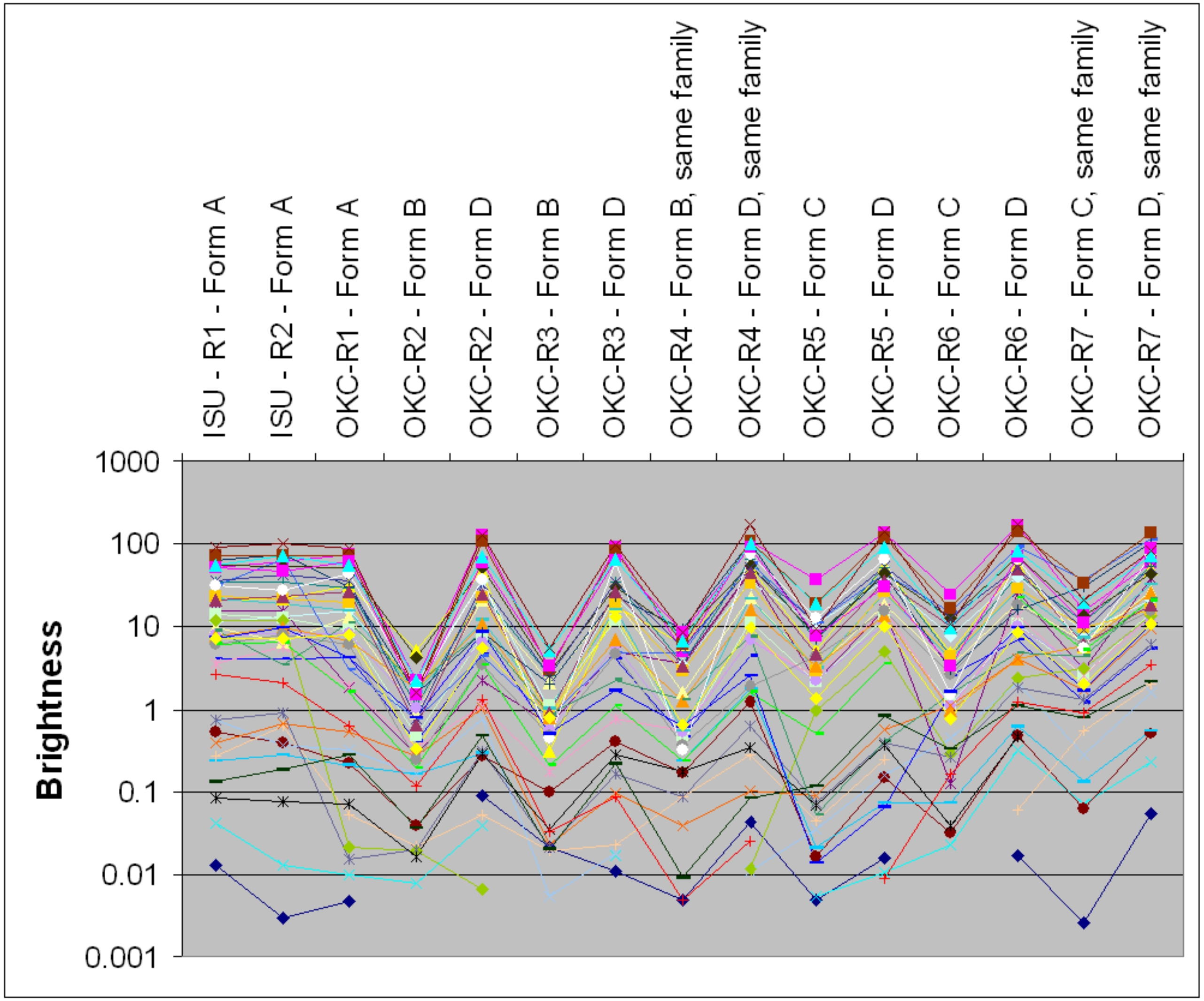
Sample Processing – Developer Application

- Form A – Dip/drag processing using baseline materials
- Form B – Water soluble applied with spray system
- Form C – Water suspendible applied with spray system
- Form D – NAWD, isopropanol-based spray can, single pass

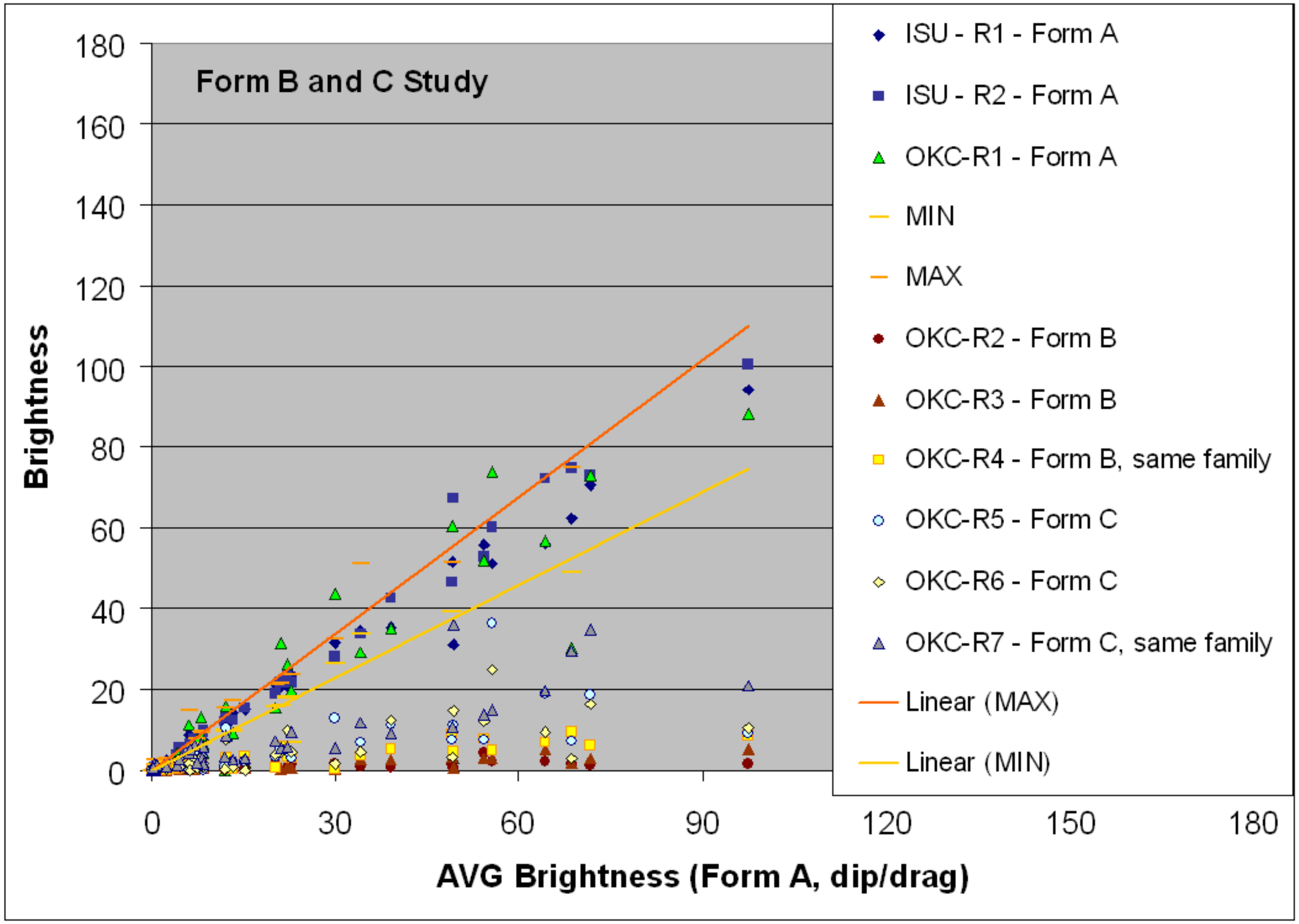


Data Summary

- Brightness results plotted on log scale
- Form B and C results on average show lower brightness than Form A or Form D
- Form C slightly better than Form B

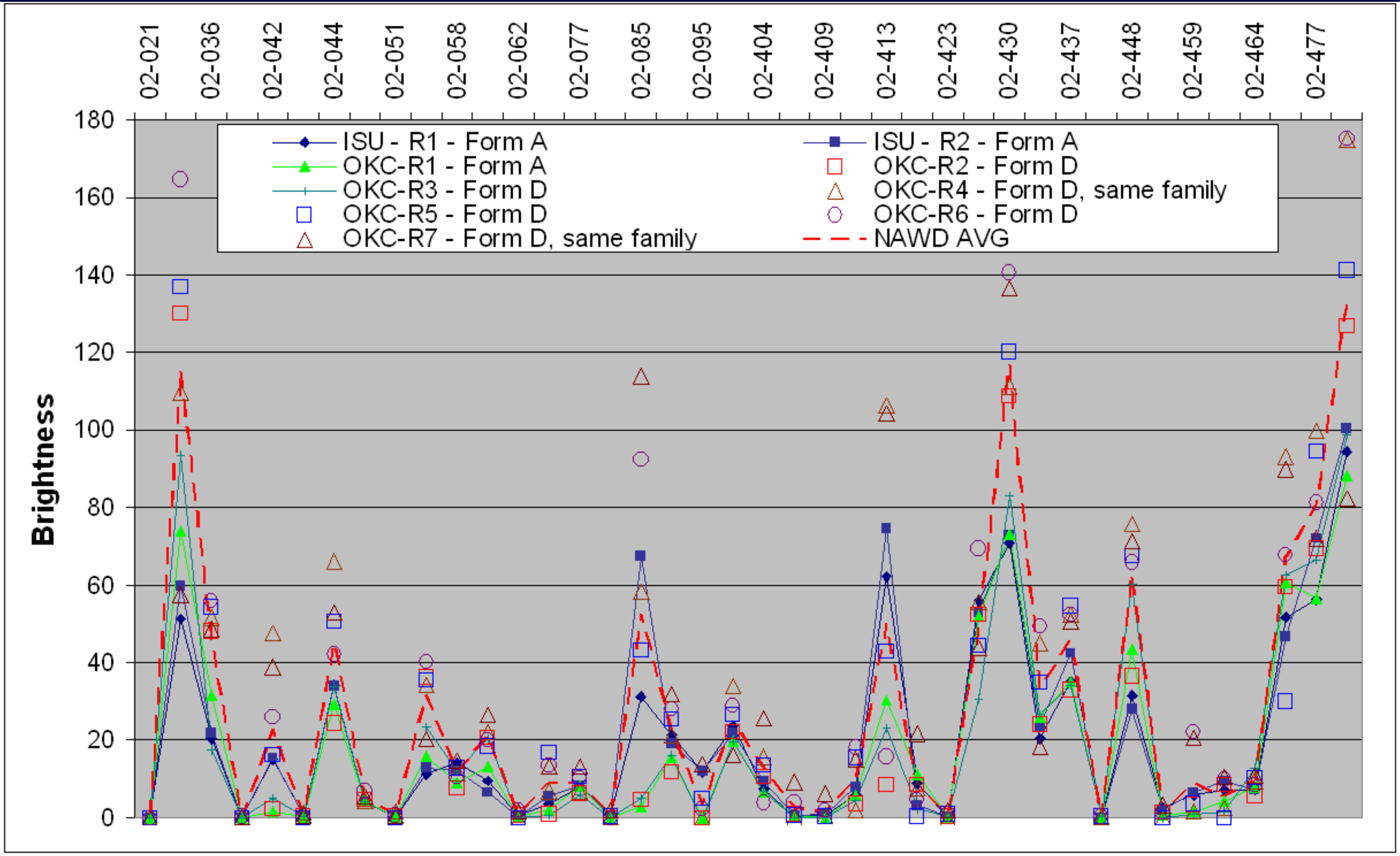


Data Summary



- Linear regression analysis shows significant reduction compared to dip/drag Form A

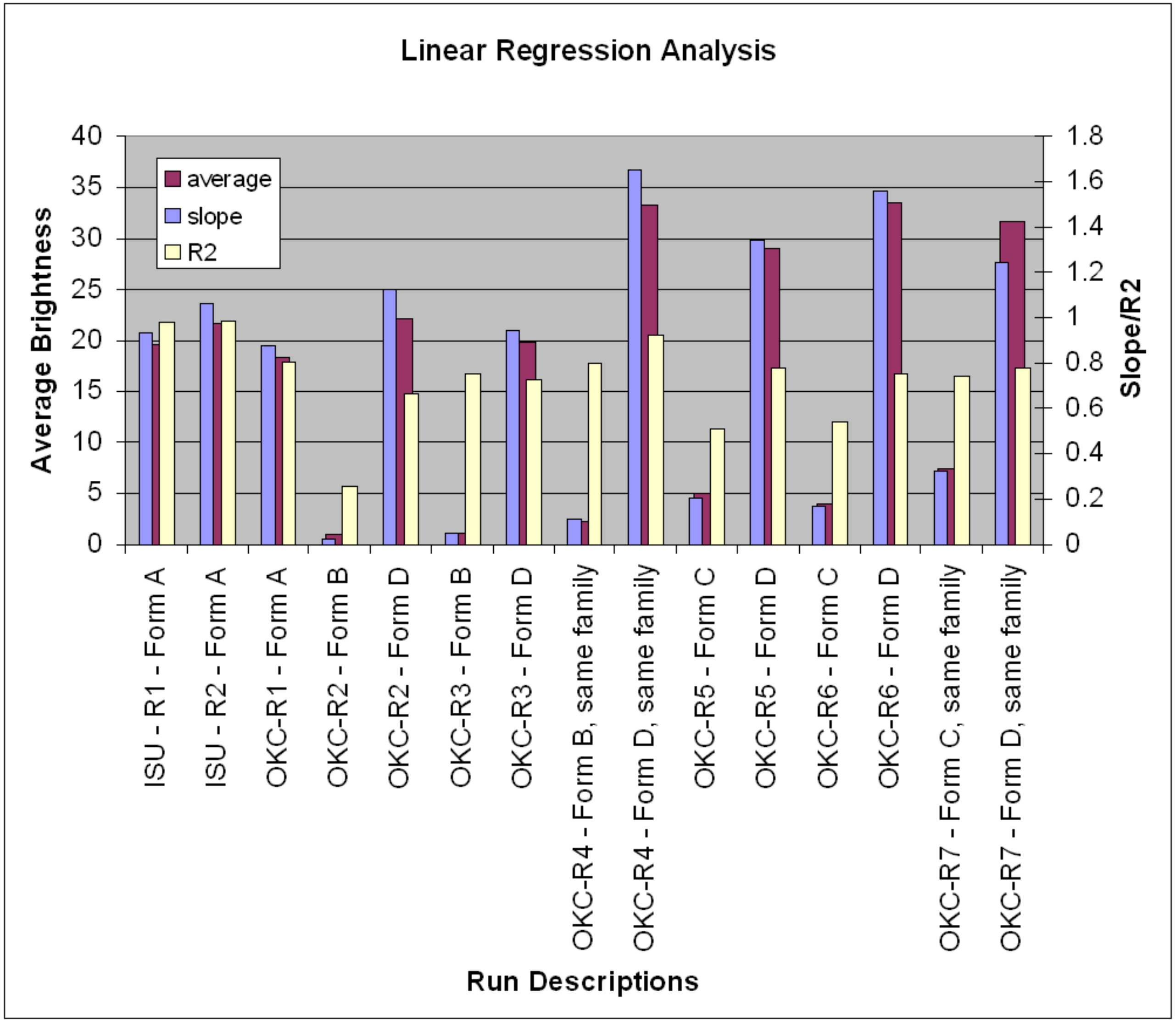
Data Summary



- Form D (NAWD aerosol) used after each run
- Verified penetrant entered cracks

Data Summary

- Form C slightly better than Form B
- Developer combined with same penetrant/ emulsifier slightly better than developer used with baseline p/e



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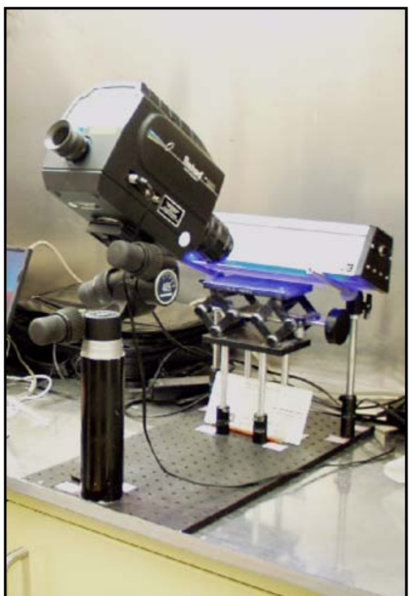
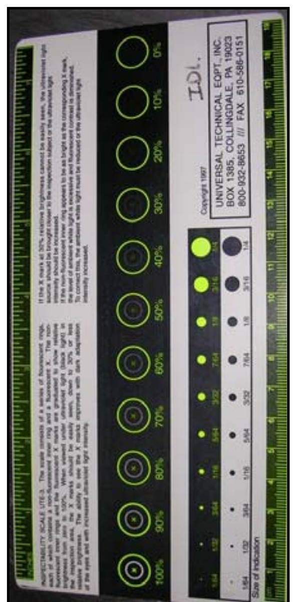
Post Baseline Characterization

- Repeat baseline runs at ISU using dip/drag followed by NAWD
- Repeat baseline runs at ISU using bulb application followed by NAWD

How Was It Performed

- Brightness measurements were made with a Pritchard PR-880 photometer by Photo Research
- UV-A intensity measured with Spectroline DSE-100X and broadband DIX-365 sensor
- UV-A irradiation provided by twin 40W fluorescent bulbs (3,000 μW/cm^2)
- Indication images captured using a Leica MZFLIII UV-A binocular microscope and QImaging Retiga 1300 cooled camera





½-degree spot size

How Was It Performed

Surface Appearance After Developer Application at ISU

Dip / Drag

CASR

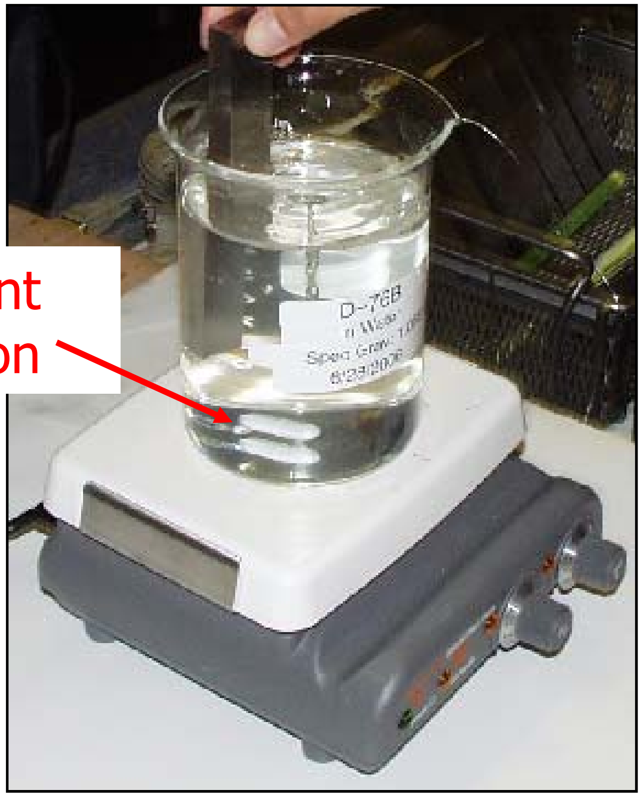
How Was It Performed

Surface Appearance After Developer Application at ISU

Bulb

How Was It Performed

Surface Appearance After Developer Application at ISU



Constant Agitation

Water Soluble

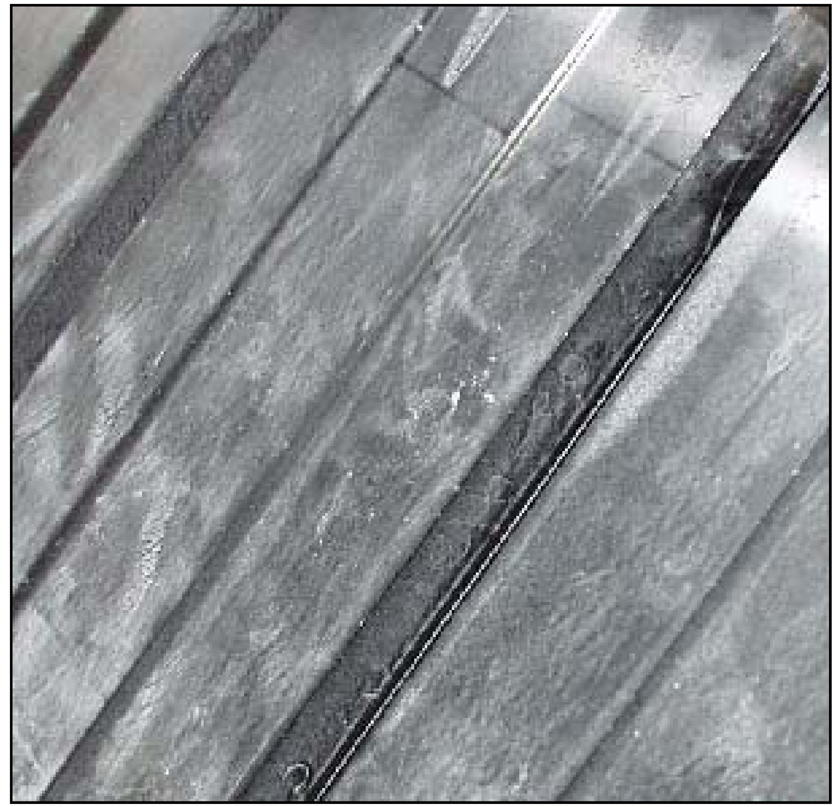
Dipped Once per End

CASR

How Was It Performed

Surface Appearance After Developer Application at ISU

Constant Agitation

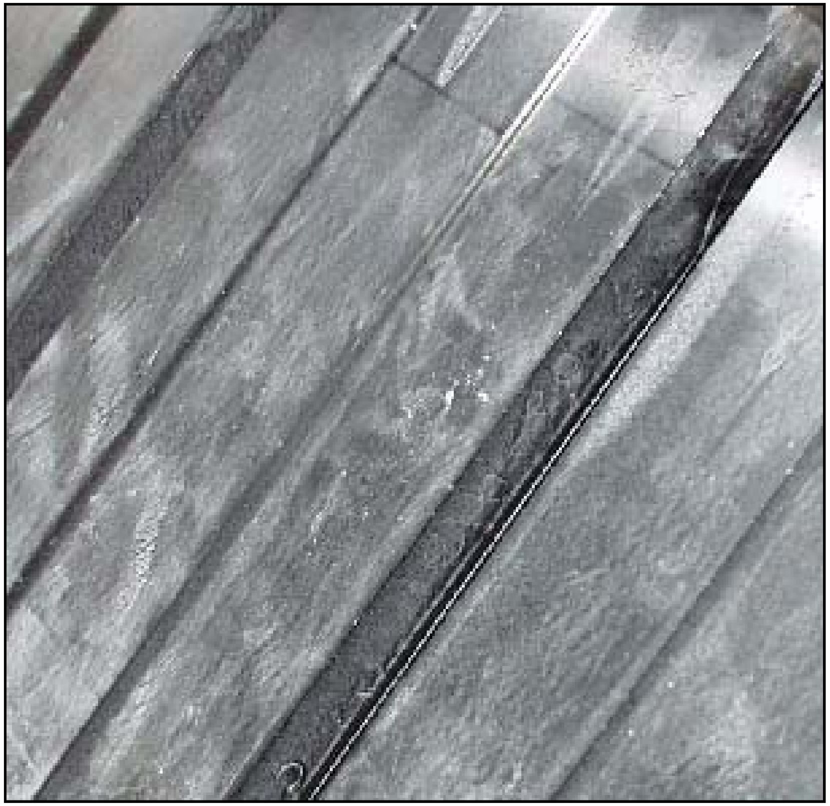


Water Suspendible

Dipped Once per End

Comparison of Surface


Form B


Form C

How Was It Performed

Surface Appearance After Developer Application at ISU

NAWD

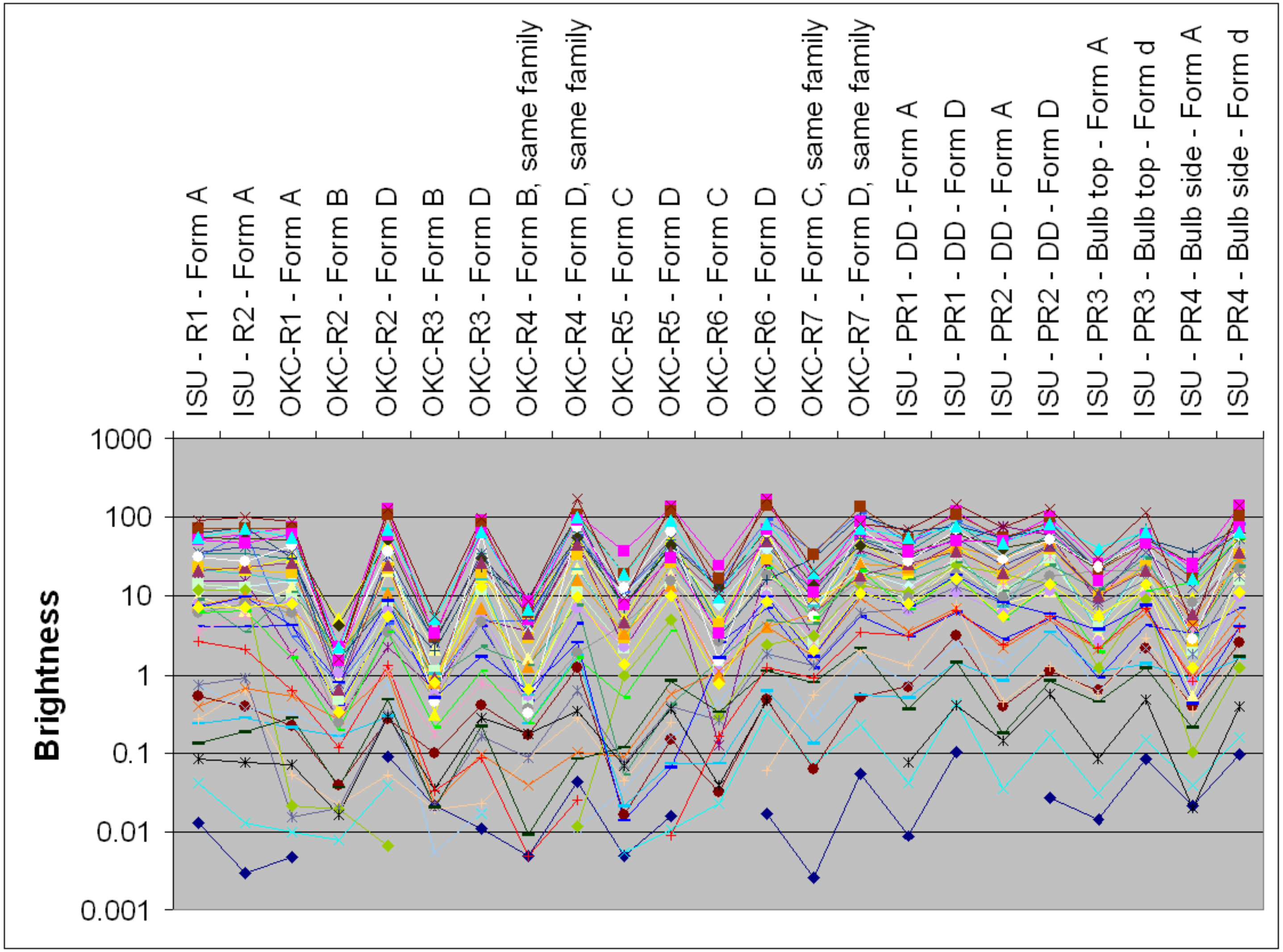
Applied Over Initial Developer

How Was It Performed

Water Soluble/Suspendible developers used at acceptable concentration, and at a lower concentration to determine the relative effect on indication brightness

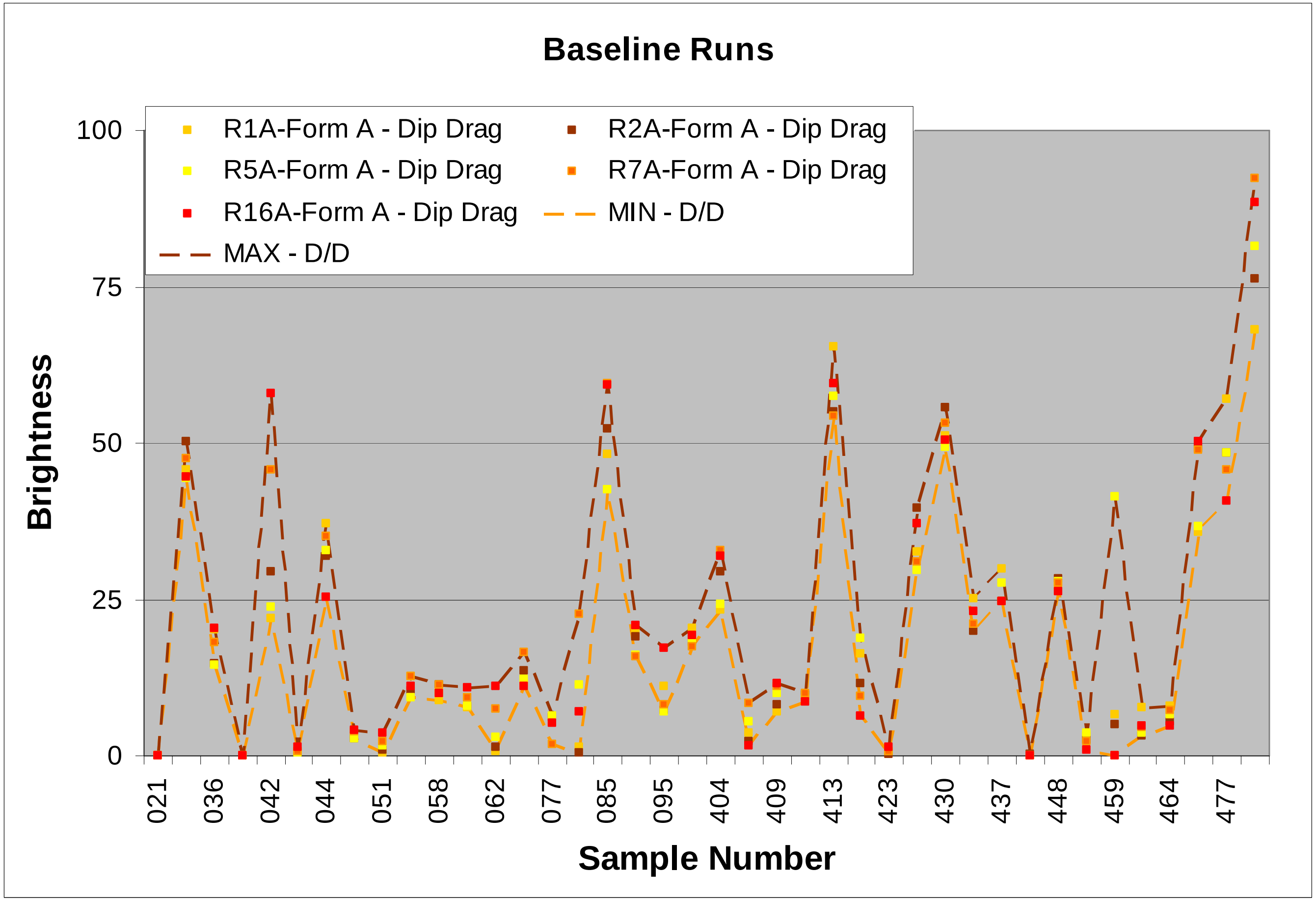
QPL Listed and Manufacturer's Recommended	Form B	2.0 lbs/gal 1.055 sp. grav.
	Form C	0.5 lbs/gal 1.035 sp. grav.
Lower than Standard	Form B	0.25 lbs/gal 1.01 sp. grav.
	Form C	0.25 lbs/gal 1.008 sp. grav.

Post Baseline Results



Laboratory Results

- Form A dip/drag runs made through out study to monitor sample progression



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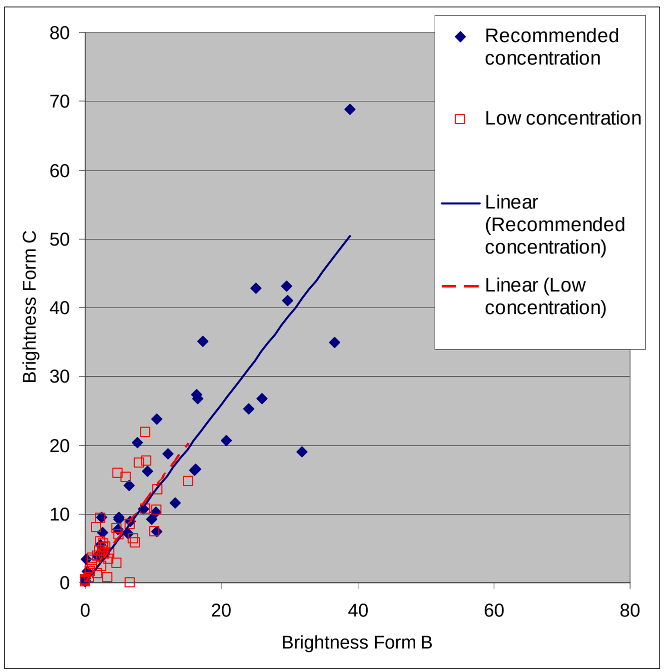
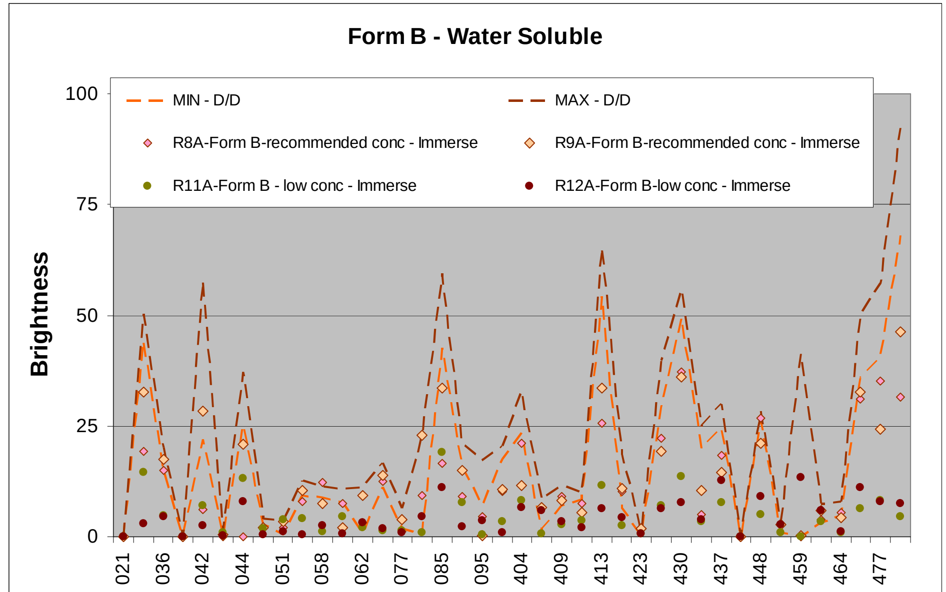
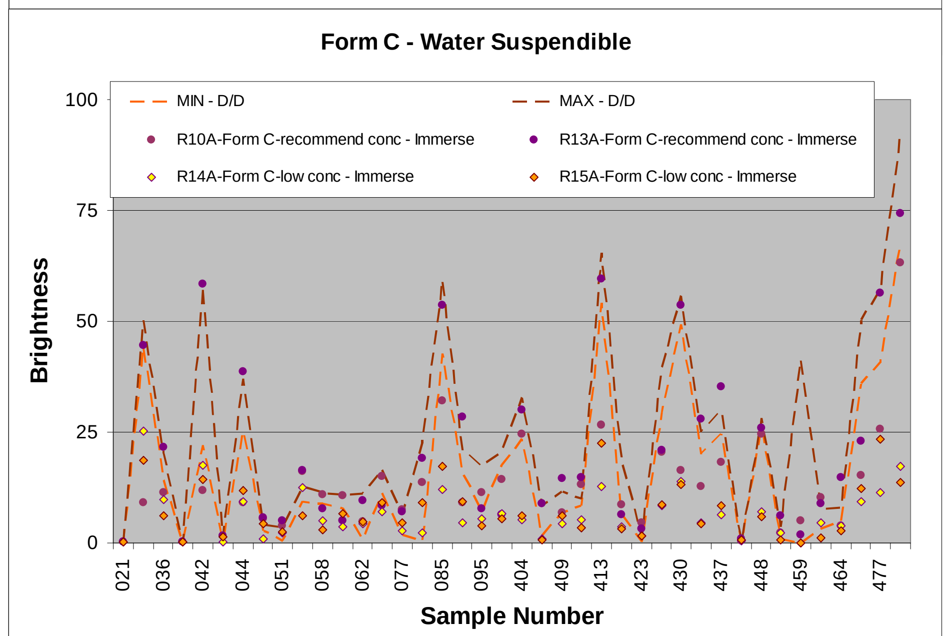
Laboratory Results

- Form C on average 30% brighter than Form B

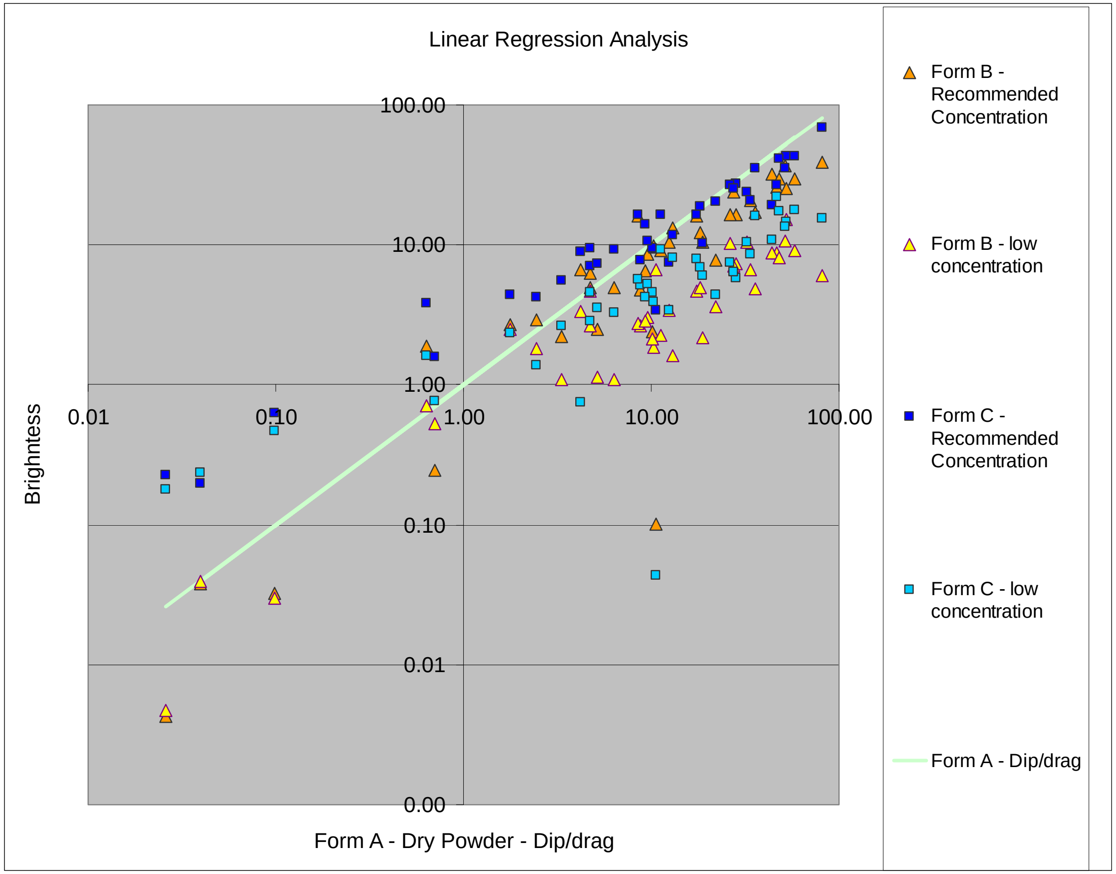






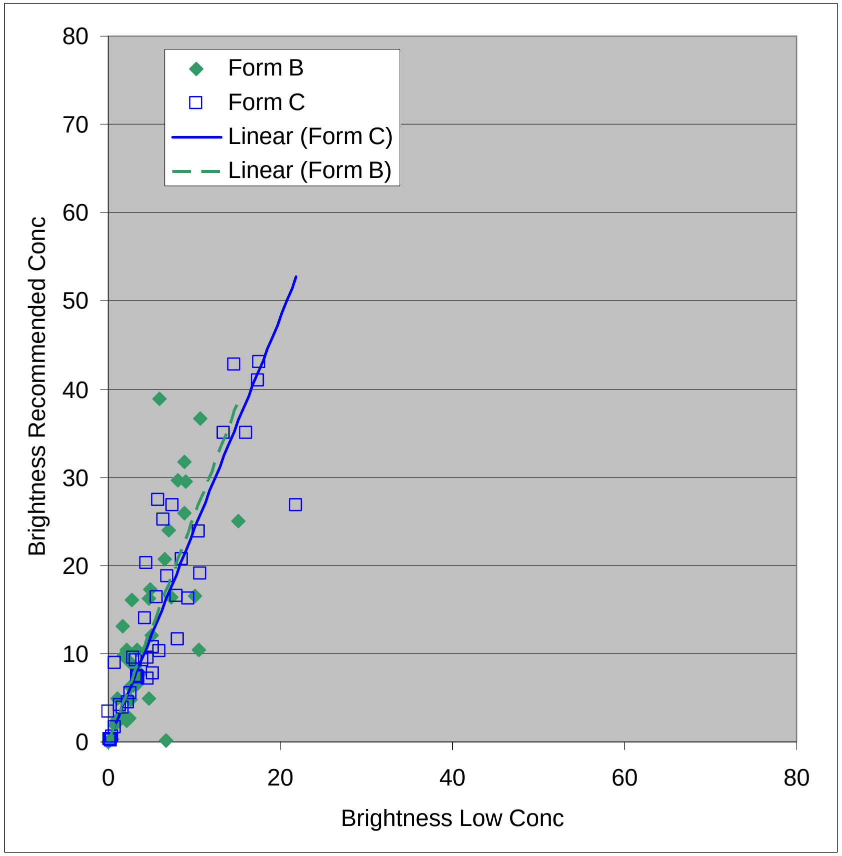
Laboratory Results

- Form C brightness similar to Form A with enhanced brightness at "smaller brightness" range



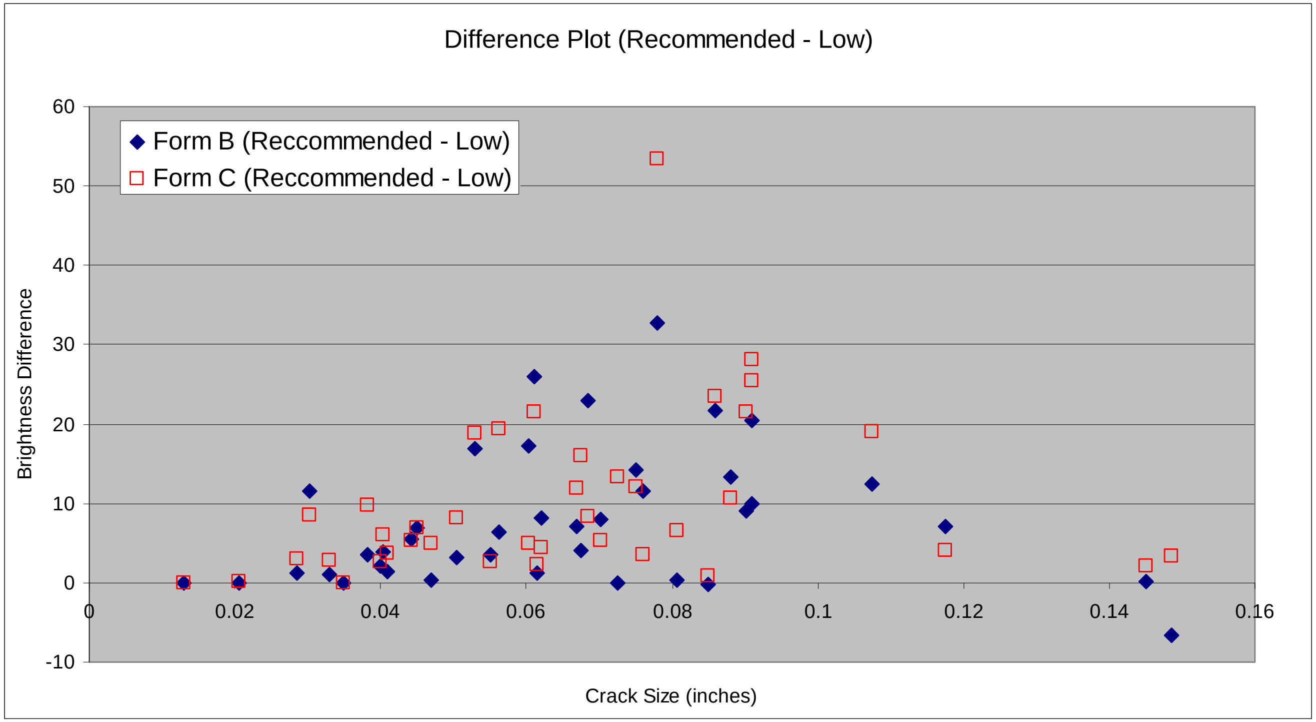
Laboratory Results

- Using the recommended concentration led to significant improvements in brightness for both Form B and C



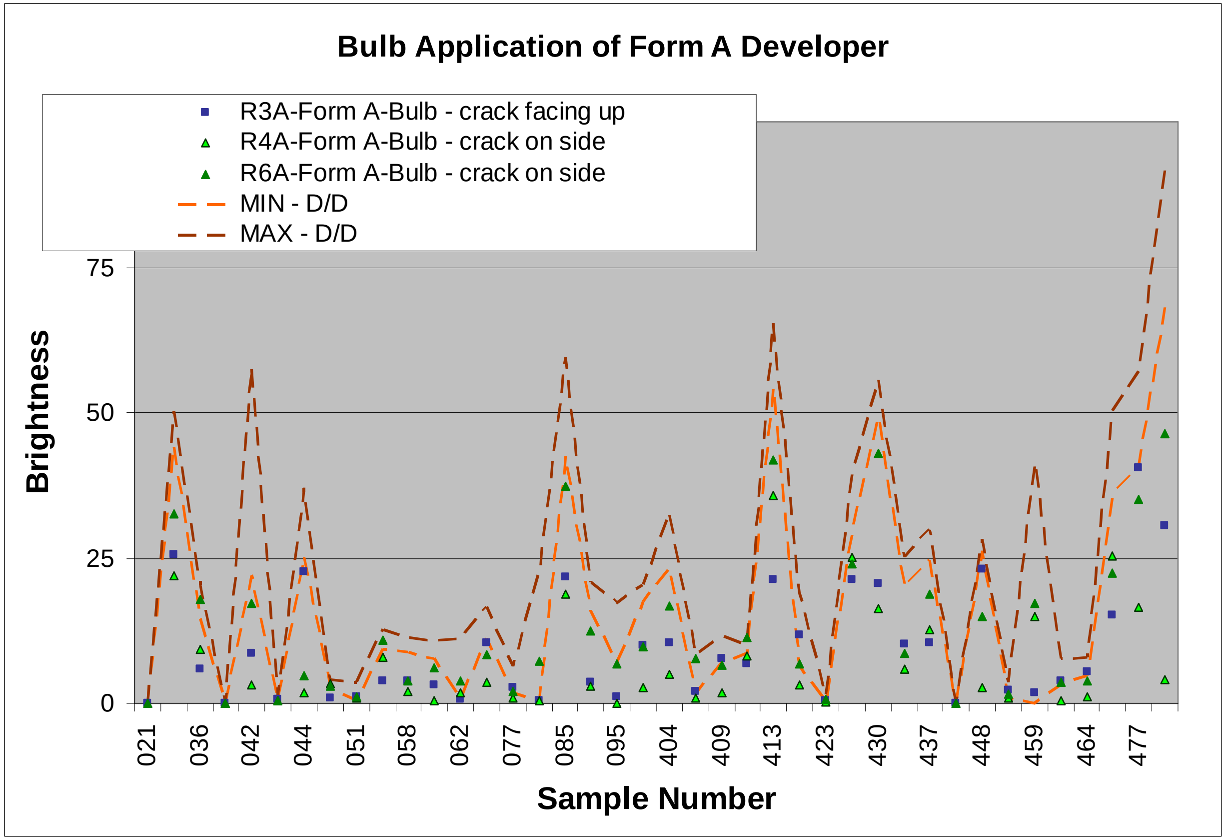
Laboratory Results

- Question ask about better performance using the lower concentration at smaller crack sizes
- Generating difference plot did not find advantage



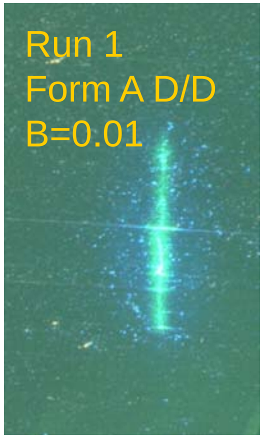
Comparison of D/D to Bulb Application

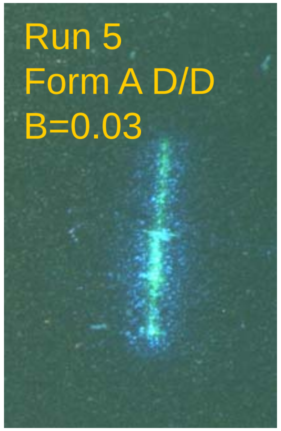
- Bulb application lower than dip/drag application

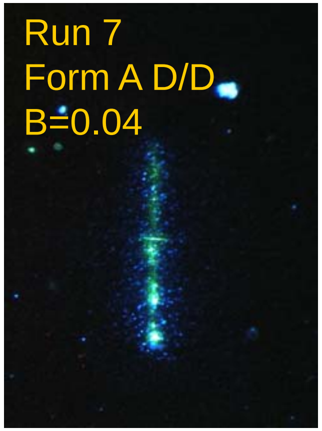


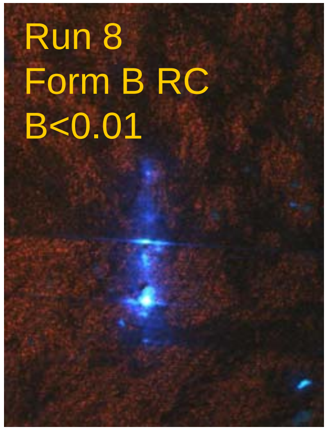
CASR

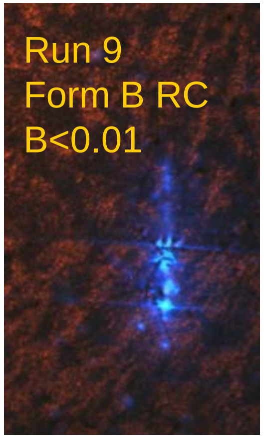
Sample 021 – 0.035”

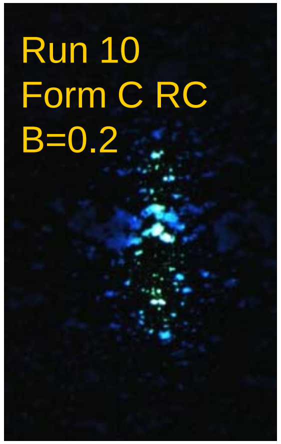


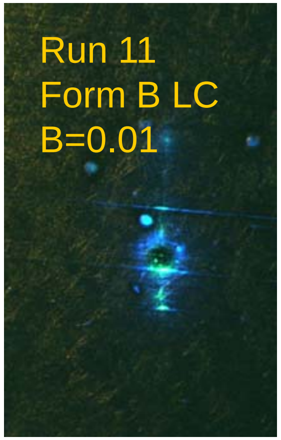


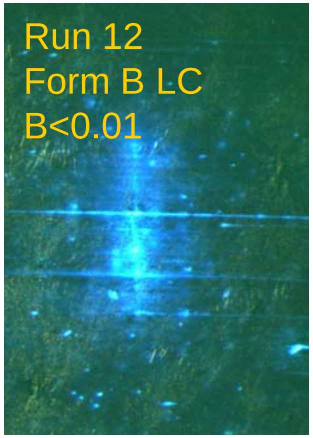


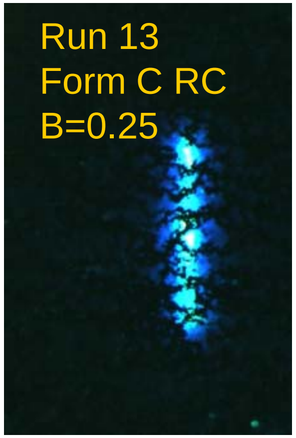


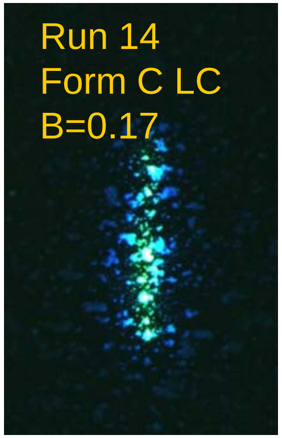


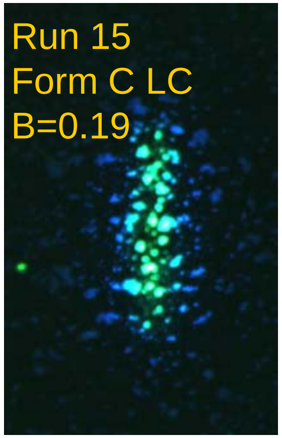


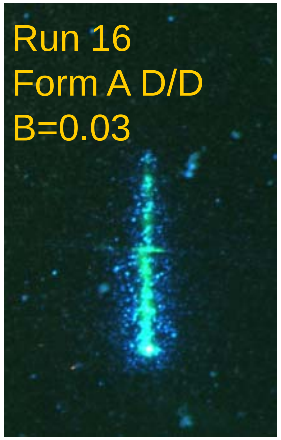






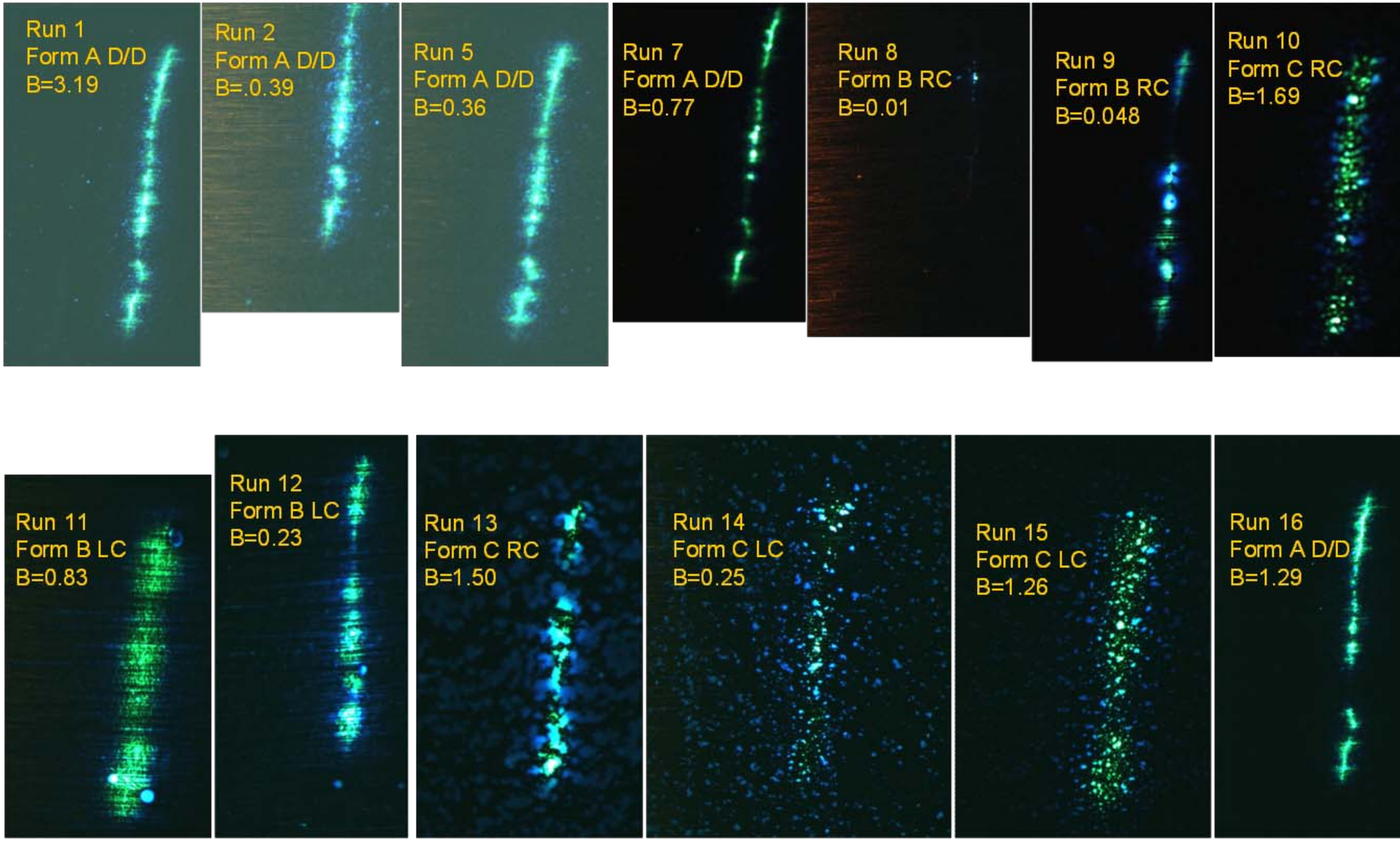




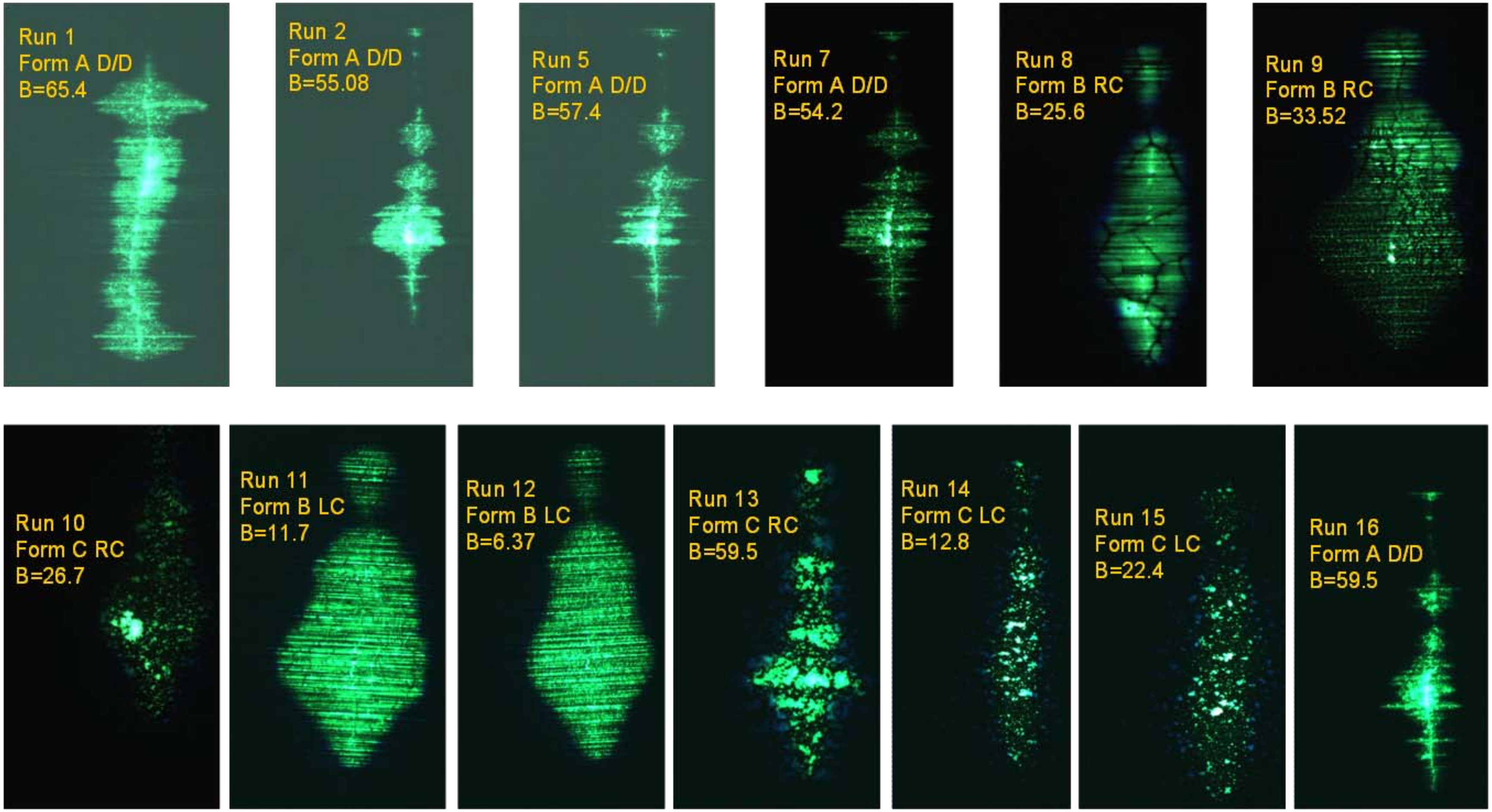


CASR

Sample 043 – 0.073”



Sample 413 – 0.091”



CASR

Conclusions

- Use of Form B and Form C developers at the recommended concentration lead to a 240% increase in brightness.
- Masking of small cracks was not evident at either the recommended or low concentration for this data set.
- Form B and Form C indications were more diffuse in nature, particularly when compared to the linear indications generated by the Form A developer. It is important that inspectors be aware of these differences and the implications for detectability. Consideration should be given to the implications for training.