Engineering Studies of Fluorescent Penetrant Inspection

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

Program Timeline

- 1999 – 2002 – Cleaning and Drying Studies performed as part of the Engine Titanium Consortium
- 2002 – 2006 – Engineering Assessment of Fluorescent Penetrant Inspection performed as part of Center for Aviation Systems Reliability effort

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Engineering Assessment of FPI

- Provide engineering data to support decisions regarding the safe application and relevant use of FPI
- Includes data to support changes in specifications
- Generate tools for use by airlines and OEMS that improve FPI processes
- Strong industry team with extensive experience

BOEING
Delta
delta.com
D&W Enterprises, LTD.
Consulting Services
General Electric Company
IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY
Pratt & Whitney
A United Technologies Company
Rolls-Royce
SHERWIN
INCORPORATED
UNITED

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Program Partners

Cooperative university/industry program which brings together aircraft and engine OEMs, airlines, vendors, as well as technical expertise from the NDE community.

ISU: Lisa Brasche, Rick Lopez, Dave Eisenmann, Bill Meeker

FAA: Al Broz, Paul Swindell, Dave Galella

Industrial Advisory Panel

- Boeing - Long Beach
  - Dwight Wilson, John Petty
- Boeing - Seattle
  - Steve Younker
- Delta Airlines - Atlanta
  - Lee Clements
- United Airlines - Indianapolis
  - Bill Nappi
- Pratt & Whitney - EH and WPB
  - Kevin Smith, John Lively
- Rolls Royce - Indianapolis and Darby
  - Pramod Khandelwal, Keith Griffiths, Bill Griffiths, Tom Dreher
- GE Aircraft Engines
  - Terry Kessler, Thadd Patton, Wayne Kitchen, Phil Keown
- Sherwin - Cincinnati
  - Sam Robinson
- D&W Enterprises - Denver
  - Ward Rummel

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Technical Approach

- Define factors for which engineering data is deficient
  - Change in process, e.g., environmental changes
  - Change in applications
  - Data not available in the public domain
- Design engineering study that provides quantitative assessment of performance
  - Brightness measurements
  - Digital recording of UVA indication
  - Probability of Detection
- Complete study using either lab or shop facilities as appropriate
- Distribute results through use of web
- Support changes to industry specifications as warranted
- Utilize results to update/create guidance materials
- Transition process to airlines for internal, self-assessment

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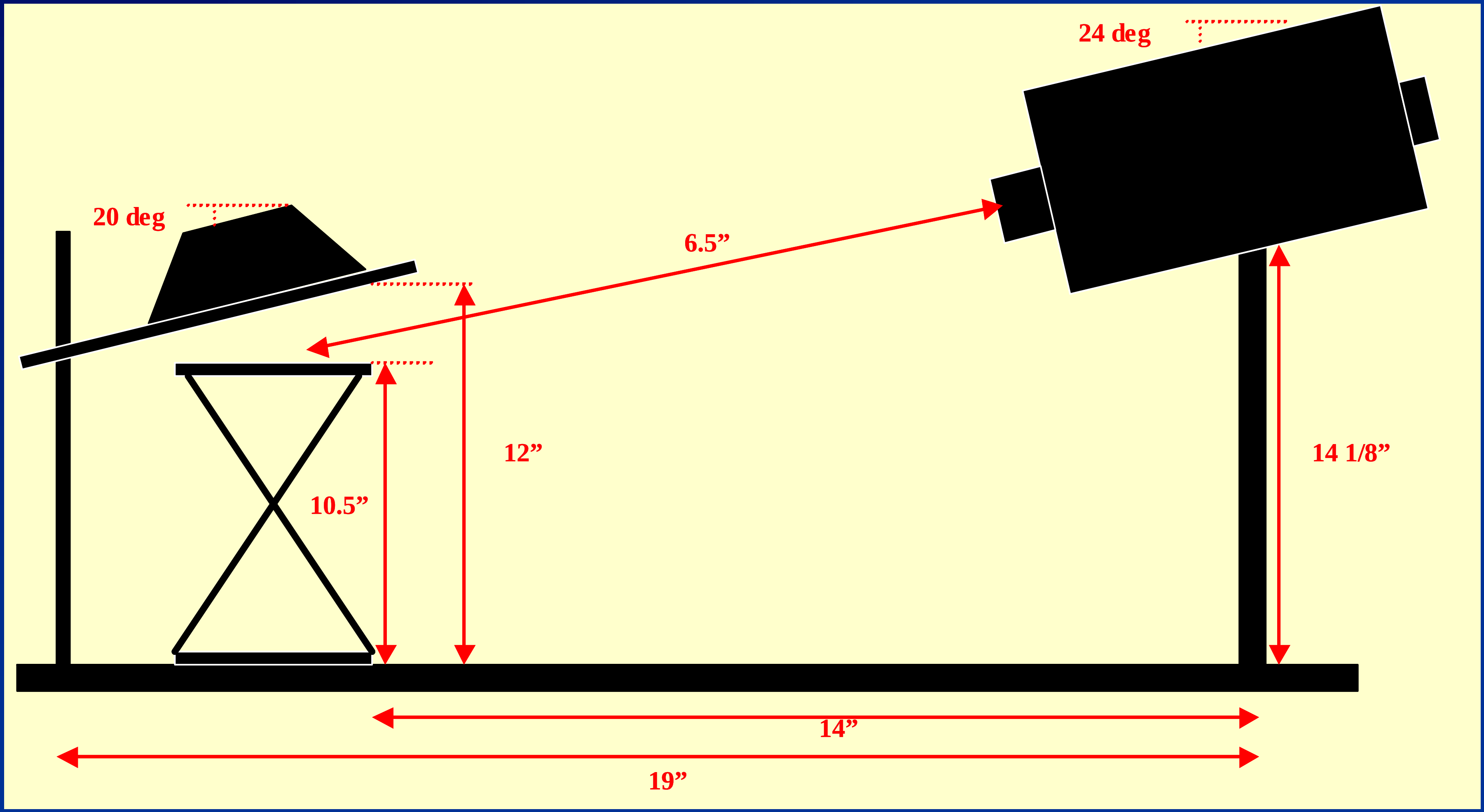
Brightness Measurement

- Used rigid fixturing to assure repeatability with transportability for brightness measurements
- Photo Research PR-880 Photometer used to record indication brightness in ft-Lamberts

Brightness Measurements



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Field Studies

- Requires access to typical drying, cleaning and FPI methods used in commercial aviation
- Several partners have provided access to their facilities
  - Access to cleaning lines for Ti and Ni as well as mechanical blasting facilities
  - FPI line for sample processing
  - Inspection booth for characterization and brightness measurements

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

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Field Studies

- Samples dried for 8 minutes at 150ºF
- Drag-through application of developer
- 10 minute development time
- Brightness reading using Spotmeter
- Length reading using UVA and image analysis software

Engineering Studies

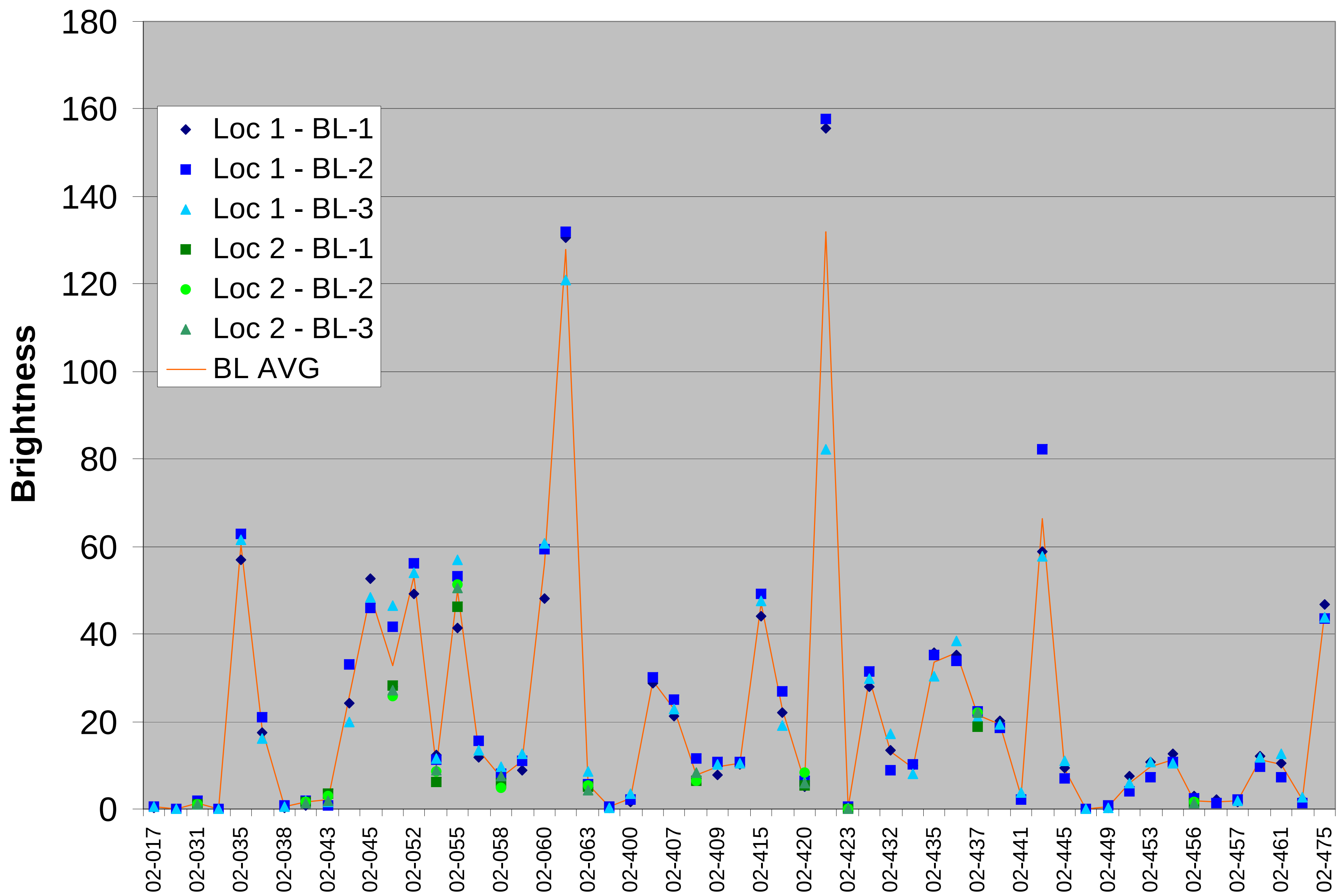
- Topics for engineering studies selected and prioritized by team
- Subteams developed for experimental design with review by the full team
- Experimental efforts to take place at various industry locations
- Definition currently underway

- ES – 1 – Developer Studies
- ES – 2 – Cleaning Studies for Ti, Ni and Al
- ES – 3 – Stress Studies
- ES – 4 – Assessment tool for dryness and cleanliness
- ES – 5 – Effect of surface treatments on detectability
- ES – 6 – Light level Studies
- ES – 7 – Detectability Studies
- ES – 8 – Study of Prewash and Emulsification Parameters
- ES – 9 – Evaluation of Drying Temperatures
- ES – 10 – Part geometry effects
- ES – 11 – Penetrant Application Studies
- ES – 12 – Relationship of part thickness to drying method

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 use through out

Baseline Characterization



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.

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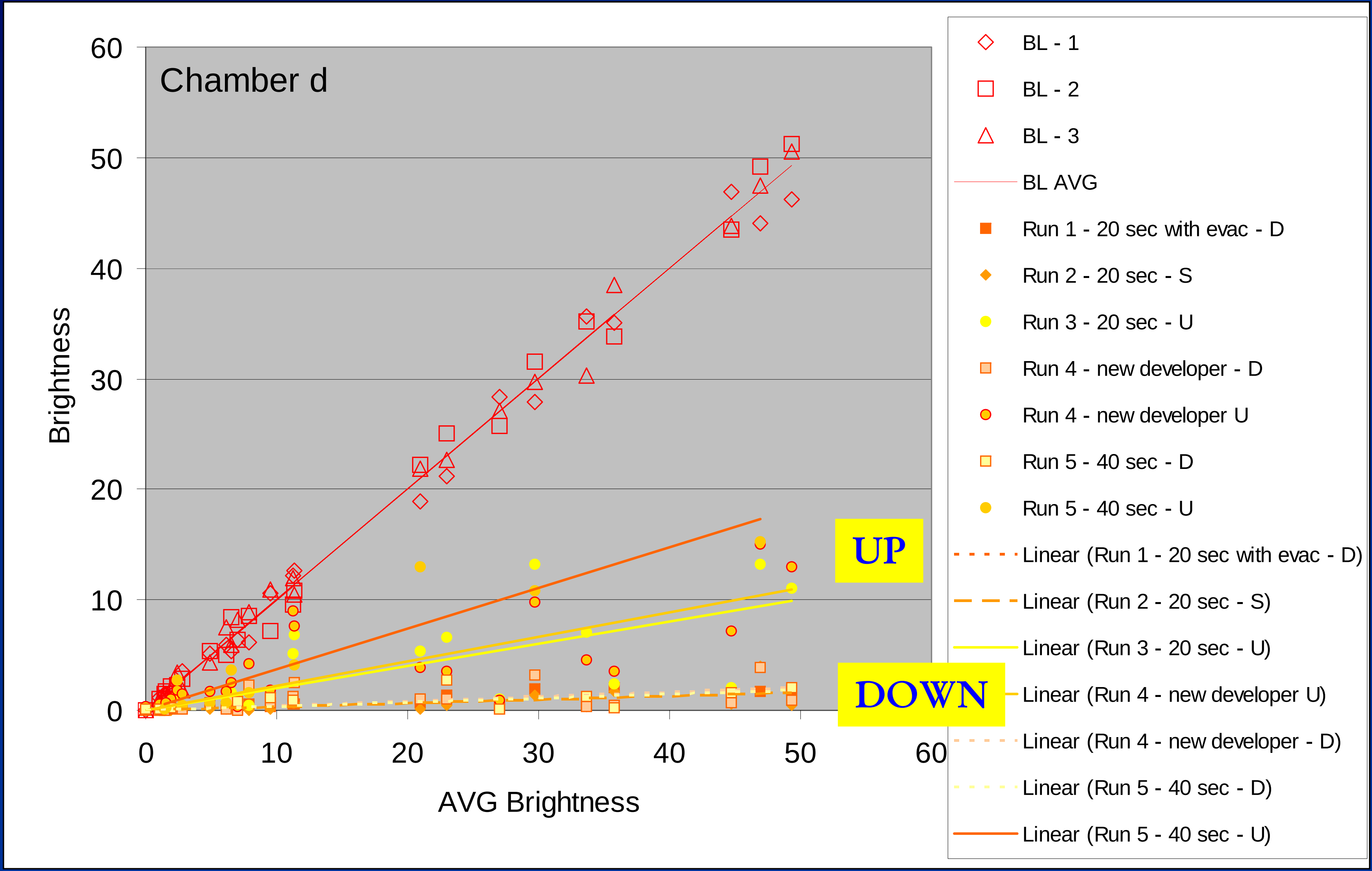
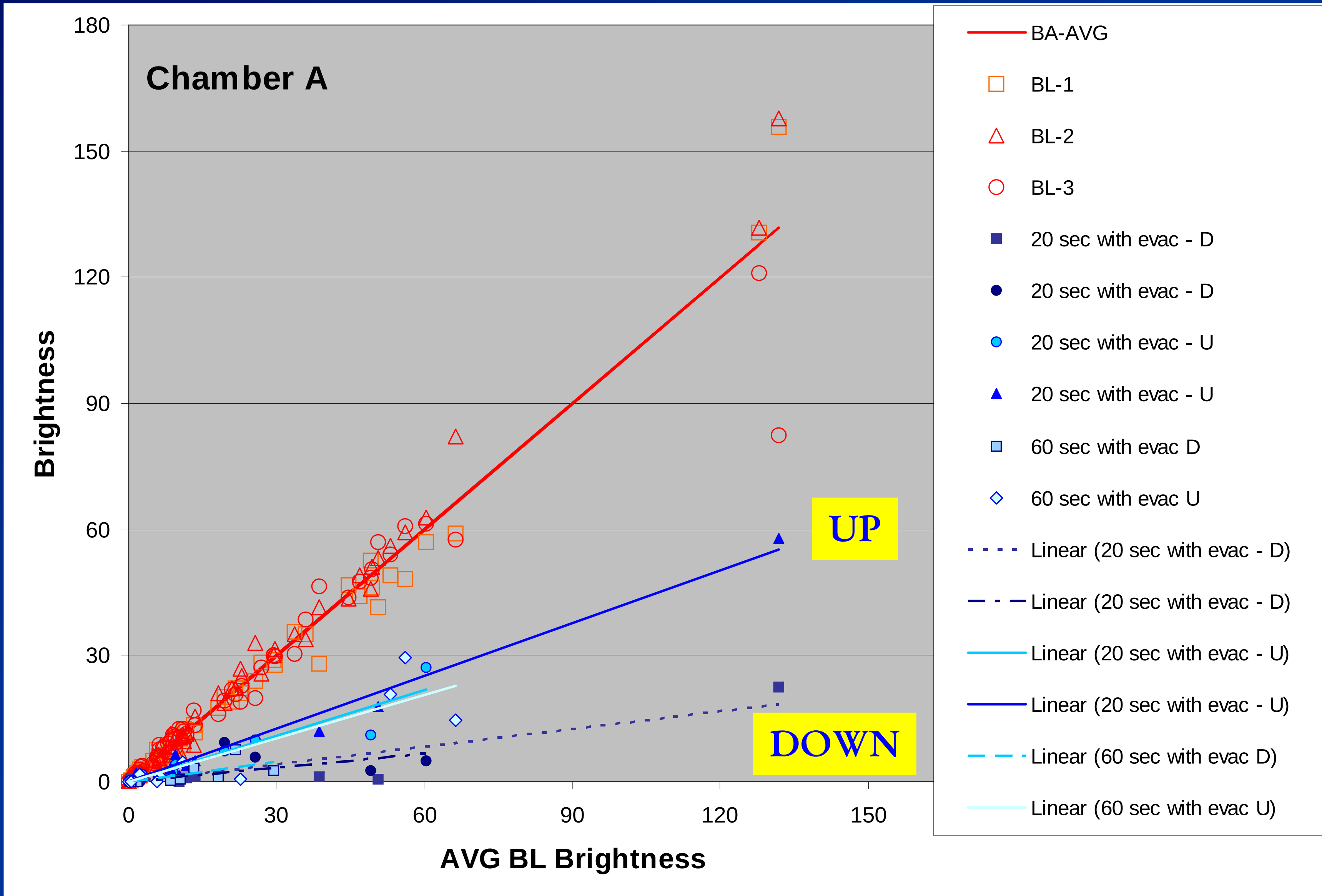
Chamber D Characterization

- 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

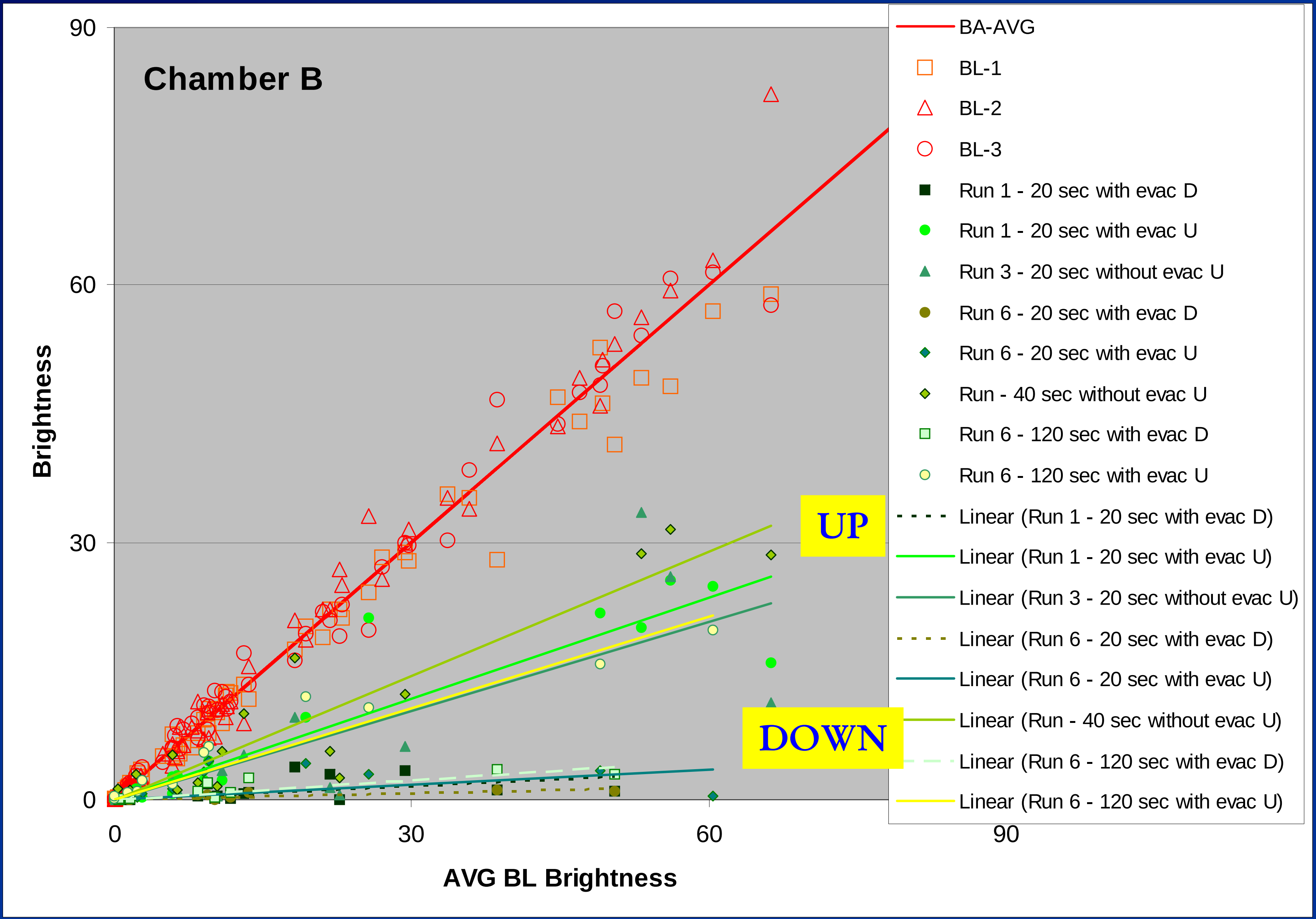
Chamber D Characterization



Chamber A Characterization



Chamber B Characterization



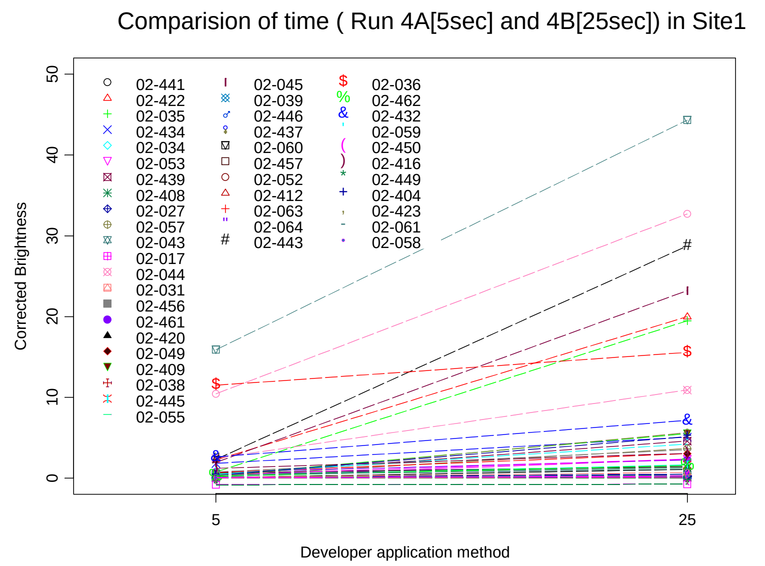
Manual Spray Application

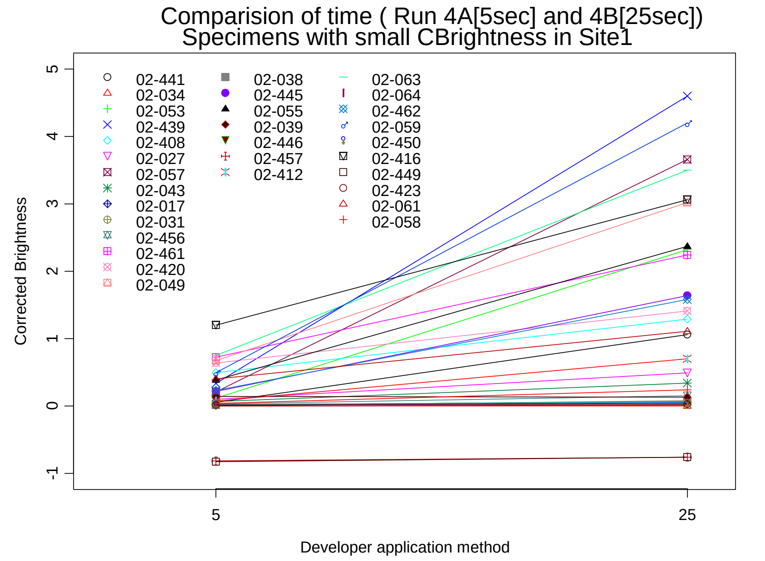
- Low pressure, high volume spray
- 5 and 25 sec runs completed using lobster cage with cracks in D, S or U position
- 60 and 120 sec runs completed with samples all in U position

Manual Spray Application

Manual Spray Application

- Increasing time of manual spray application from 5 to 25 sec showed significant improvements in brightness
- Emphasize as part of future training opportunities





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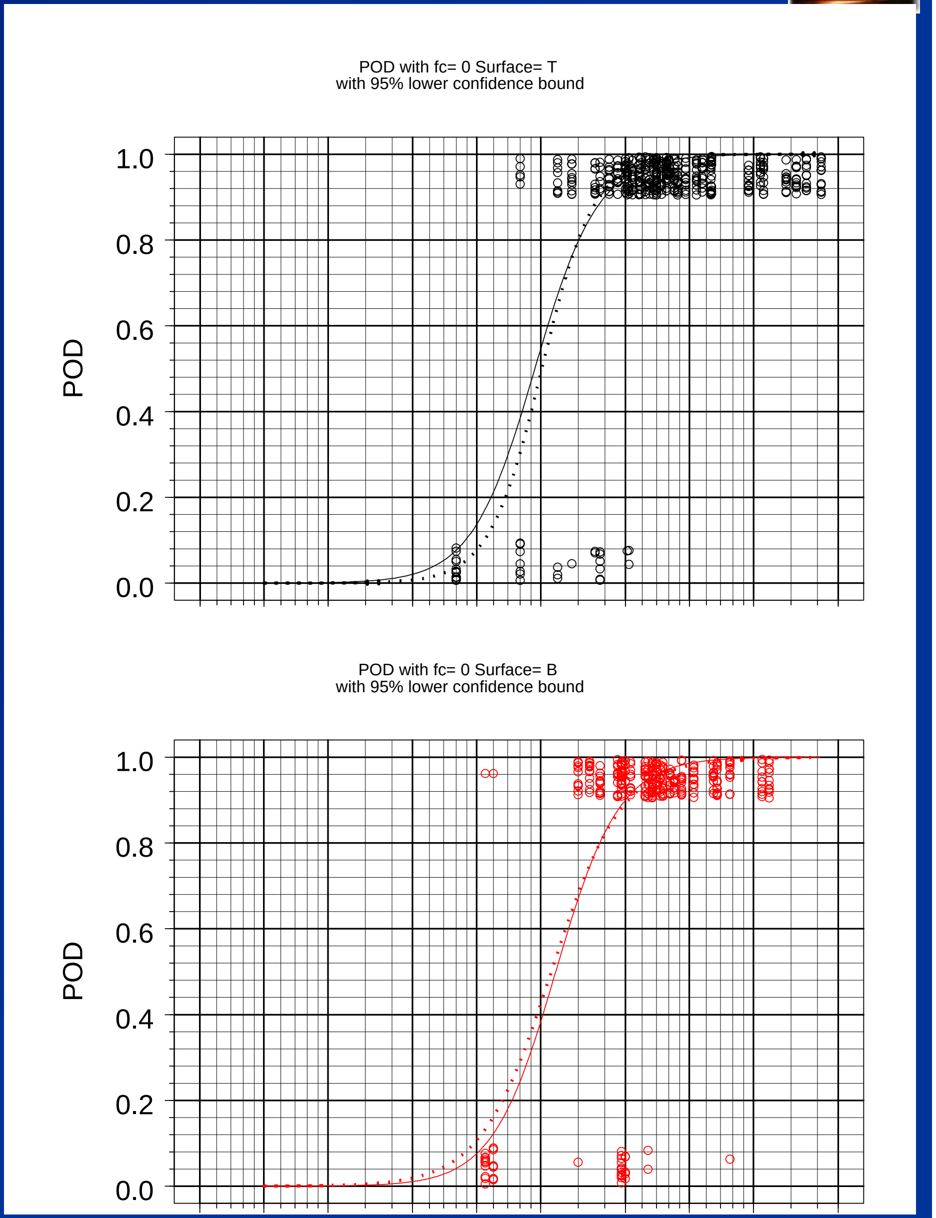
Statistical Analysis of Chamber Effects

- 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)

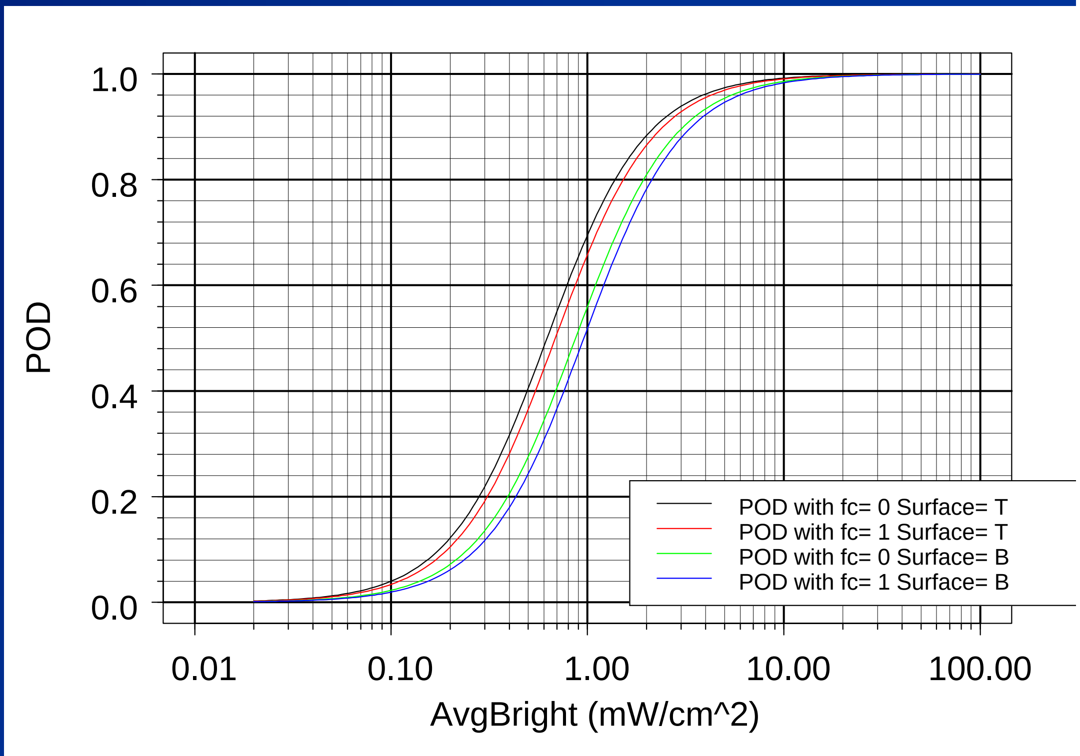
CASR Importance of Sample Orientation

- 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



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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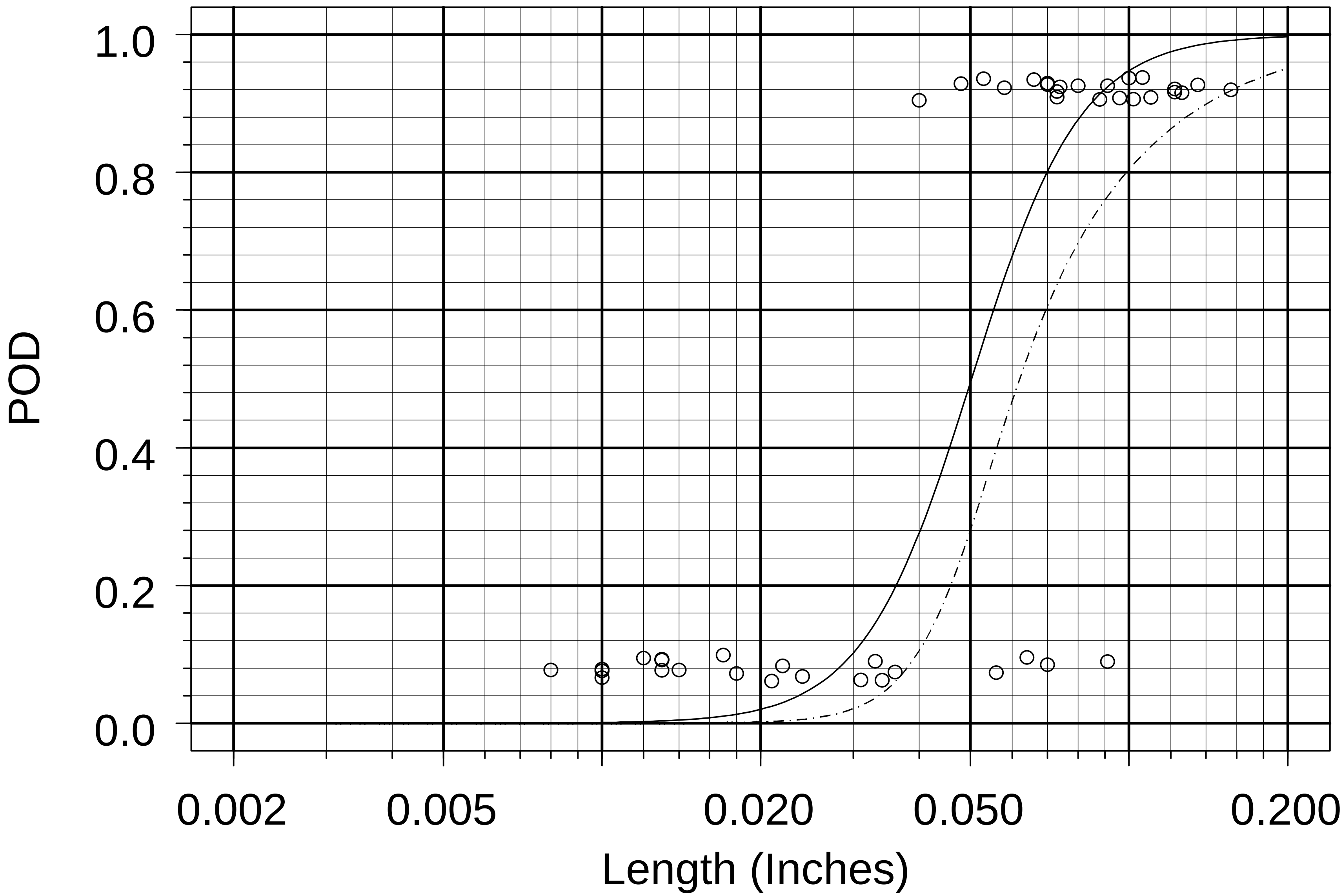
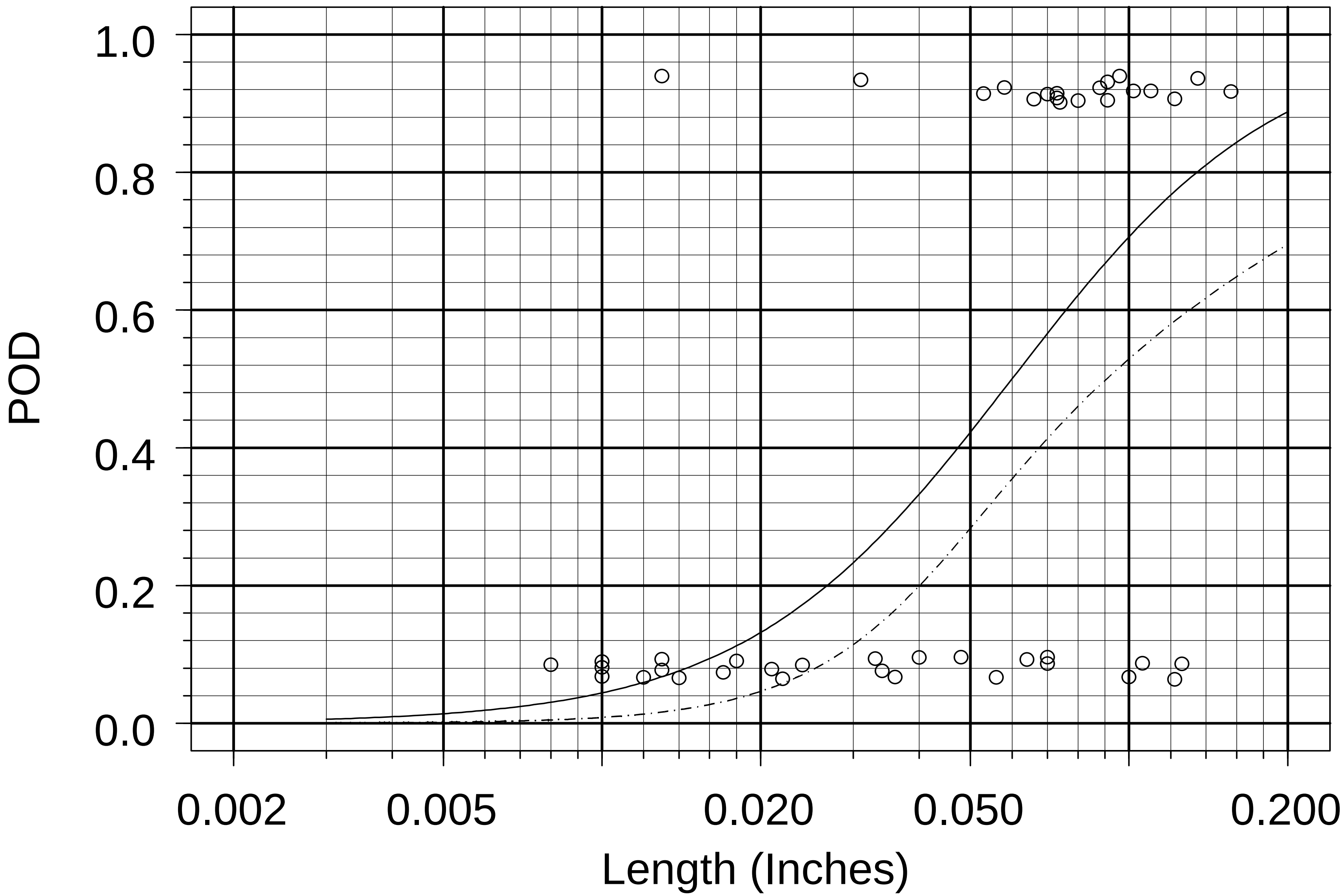
Hit-Miss POD with 95% lower confidence bound



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



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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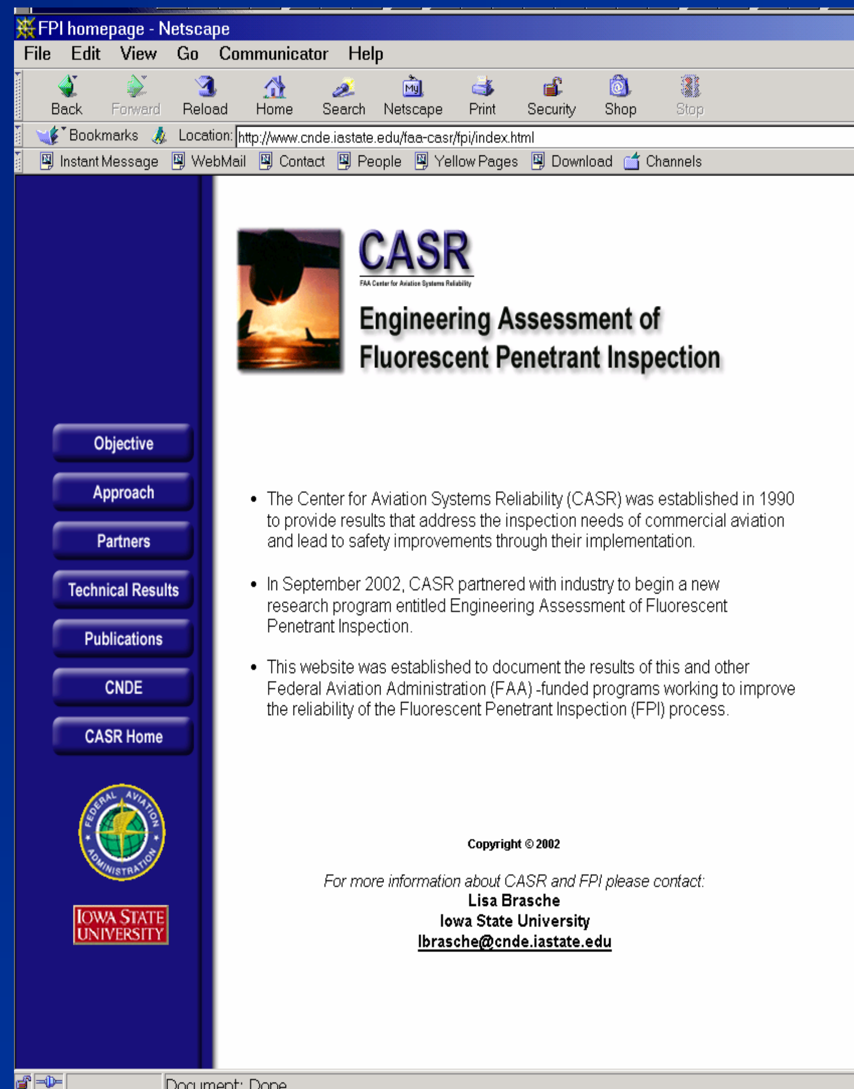
More information

- Website to provide background info and publish technical results
- Link to FAA Reports available



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

Study of Thermal Mass Effects on Drying Methods in Preparation for Fluorescent Penetrant Inspection

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ETC Drying Study

Drying study parameters

- Ultrasonic acetone clean 30 minutes
- Flash dry
  - Water bath at RT (82F – 28C)
  - Flash dry at 150F (66C)
- Oven dry
  - Water bath at RT (82F – 28C)
  - Oven dry at 225F (107C) for 30 minutes
- FPI Process
  - Cool to 40C prior to FPI
  - ZL-37 – UltraHigh Sensitivity Post Emulsified Penetrant
- Spotmeter brightness and digital recording of image

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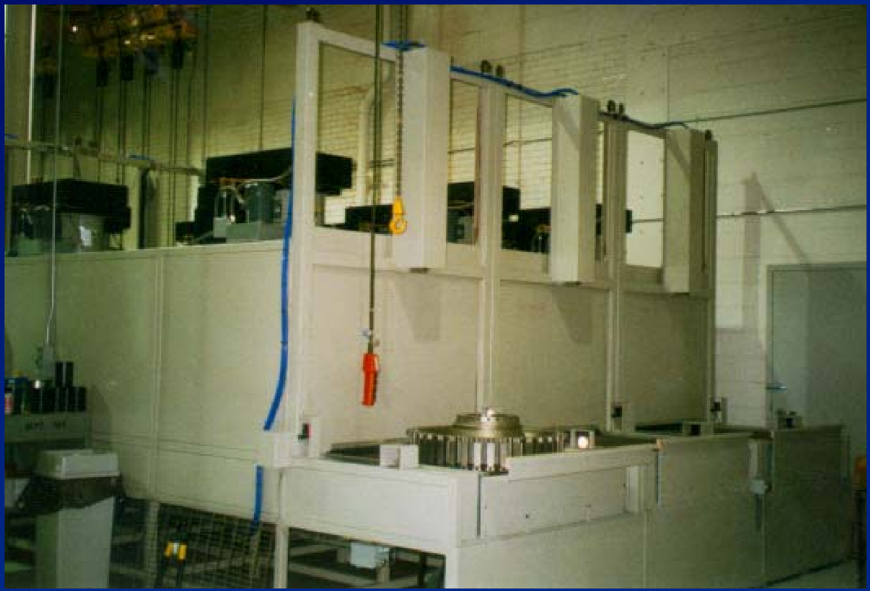
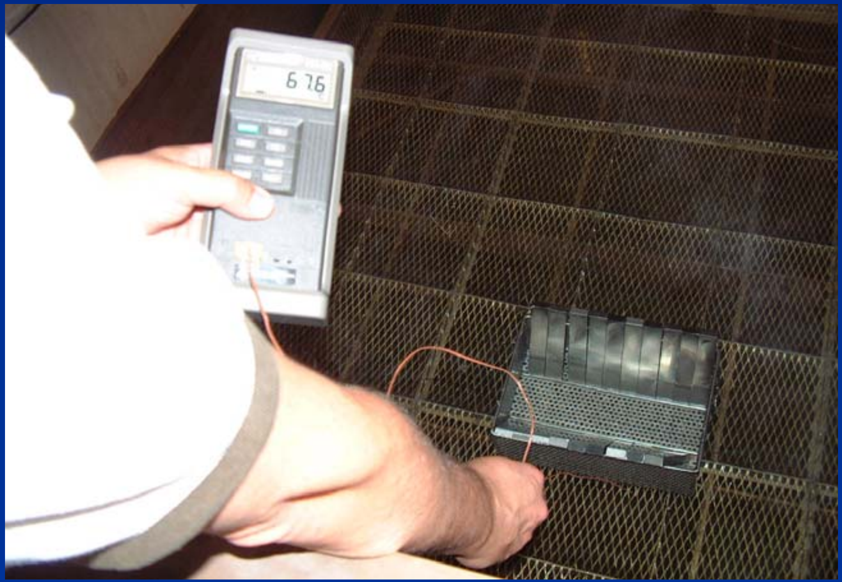
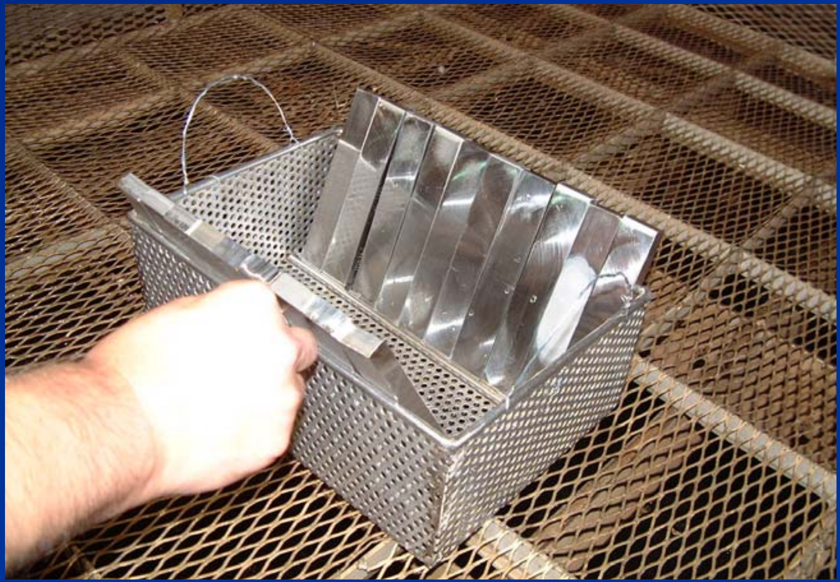
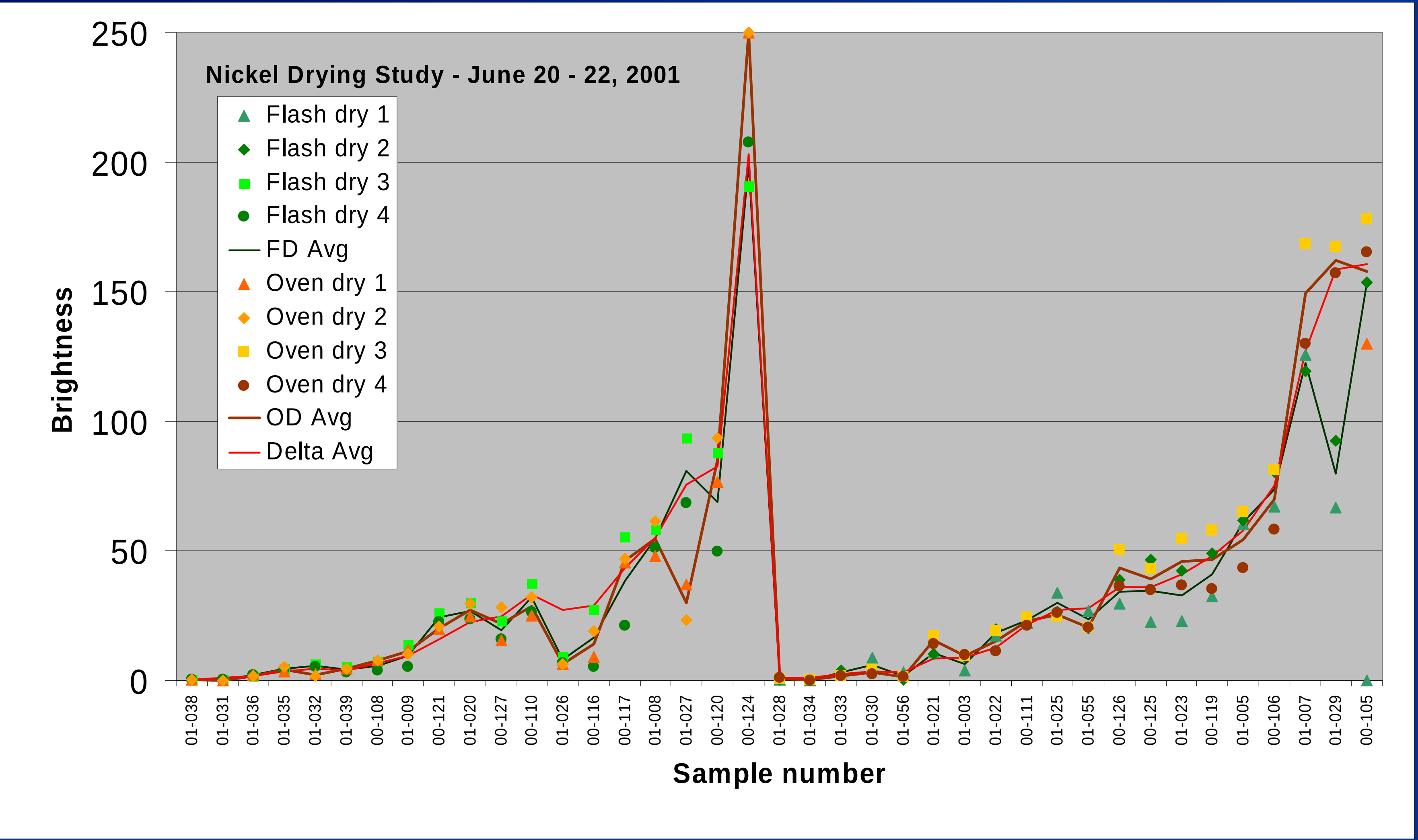
Drying Study



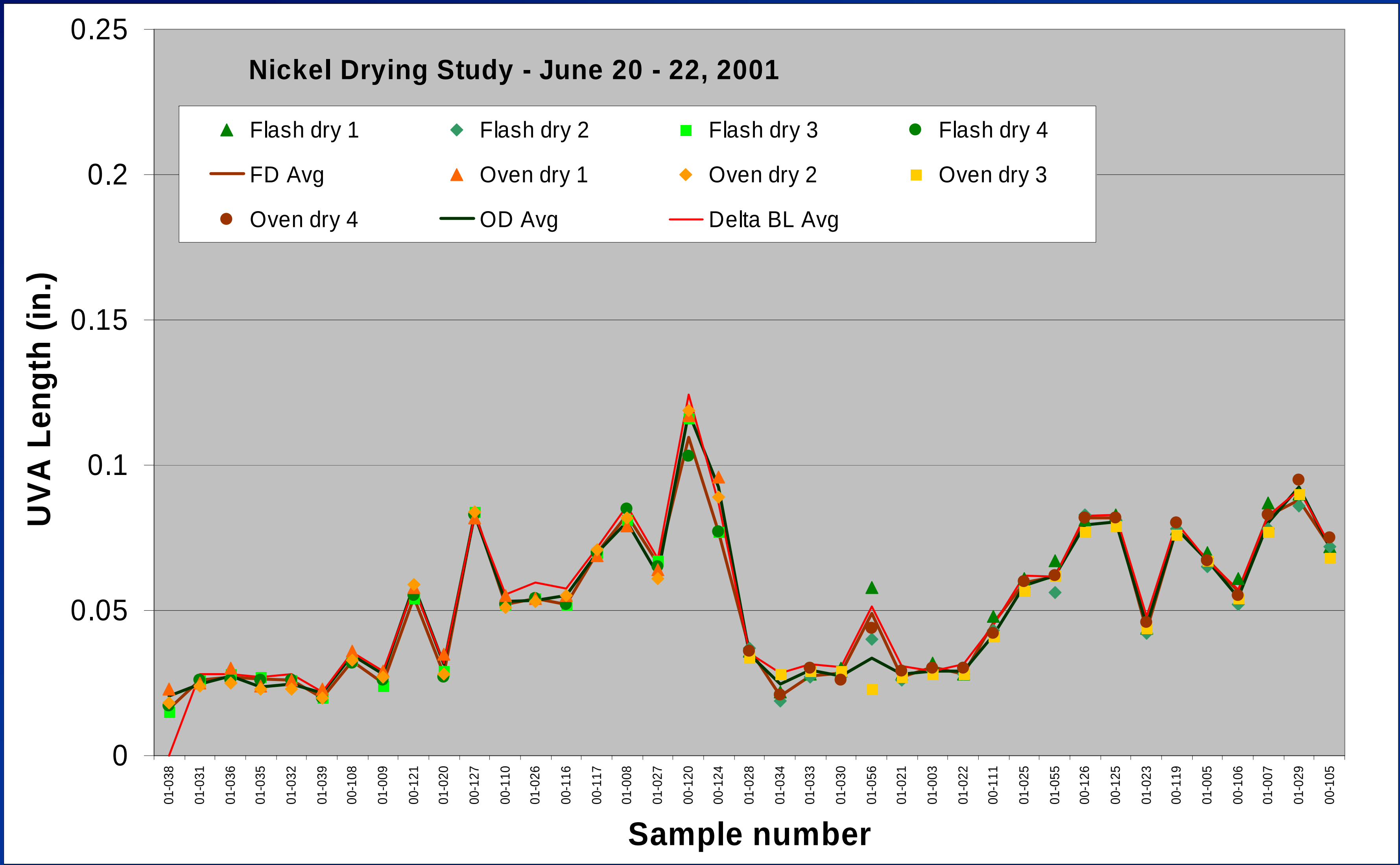




Drying Study



Drying Study



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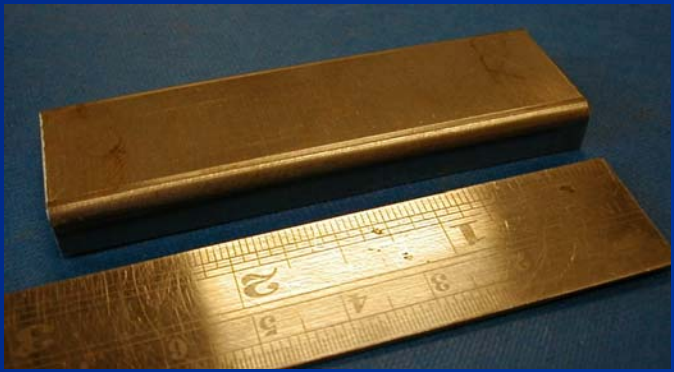
ETC Drying Study

- Statistical analysis of brightness and UVA lengths did not reveal significant differences between the two drying methods at the temperatures used in this study, i.e., flash drying at 150°F and oven drying at 225°F
- Potential factors not considered in the current study are the effect of thermal mass, potential differences in penetrant level, and a range of drying temperatures. Additional studies that explore these factors are underway.
- While significant differences were not found between the two methods, the importance of process monitoring and control for either method should be emphasized in specifications, standard practice documents, and training/guidance materials. Without careful adherence to the recommended practices, reductions in detectability can occur with either method.
- A comparison of the results of quantitative brightness measurements such as completed in this program and the more traditional POD study is underway

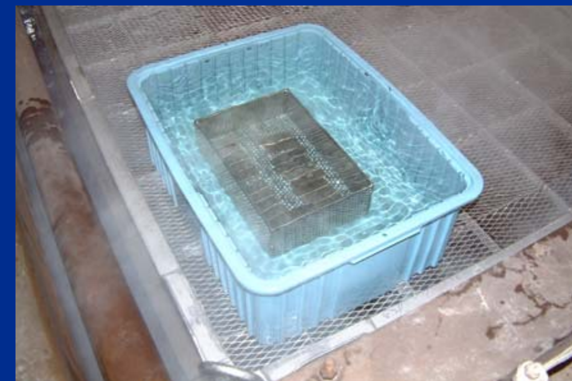
CASR Drying Study – ES -9

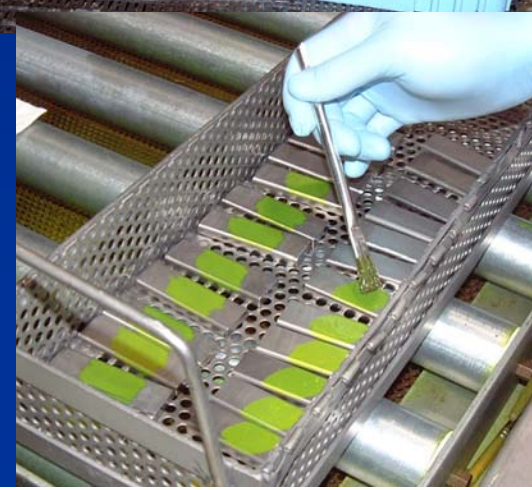
- Samples included shot peened and as machined surfaces
- Penetrants
  - Level 4 ultrahigh postemulsifiable: Magnaflux ZL – 37
  - Level 3 surfactant based water wash: Magnaflux ZL – 67
  - Level 2 oil based water wash: Magnaflux ZL – 60D
- Additional drying parameters
- POD data generated



CASR Drying Study – ES - 9

- Ensure "wet" cracks
- Apply penetrant solution and allow to dwell for 20 minutes
- Level 4: Spray wash for 60 sec, emulsifier for 120 sec, spray wash for 60 sec
- Level 3: Spray wash of 120 sec
- Level 2: Spray wash of 60 sec
- Dry specimens at 150°F for 10 minutes
- Apply dry developer using a drag through technique and a clean, dry container. Dwell 10 minutes prior to inspection.





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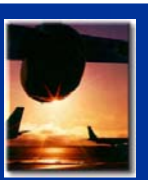
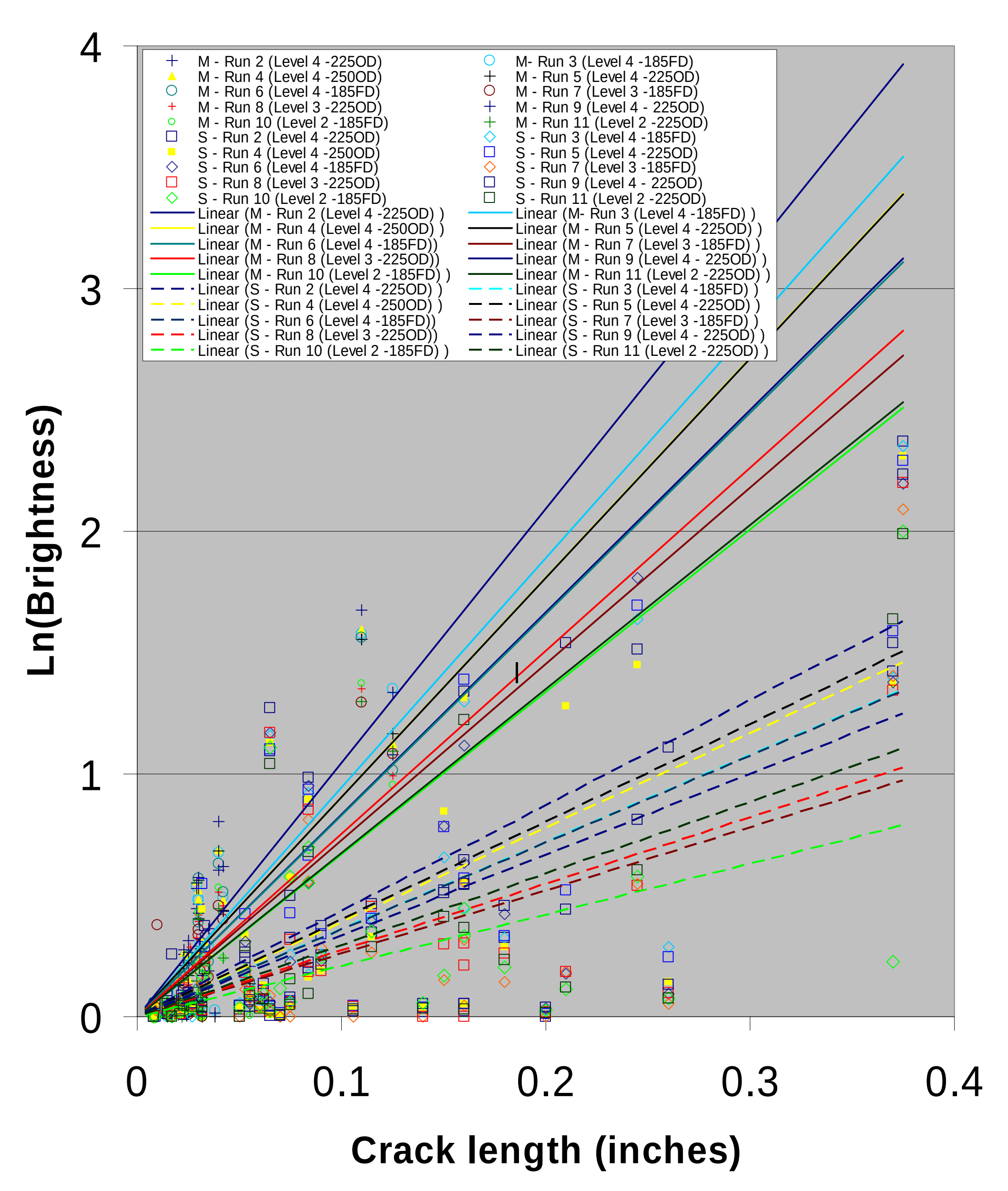
Drying Study Results

- Results analyzed as function of penetrant method, drying parameter, and surface finish
- Strongest factor was surface finish
- Expected differences found between penetrant levels





Conclusions

- For sample size and crack size used, differences were not found between the two drying methods. Factors not considered include thermal mass which will be accessed as part of future studies using real parts and appropriate fixtures.
- Differences were found between the two surface finish conditions. Detectability in shot peened surfaces present on these samples was lower than machined surfaces.
- Differences were found between penetrant method with Level 4 found to be more sensitive than Levels 3 or 2. Differences between levels 2 and 3 were not significant for the rinse times used in this study.

Objective

- Evaluate geometry and high thermal mass effects on brightness in response to changes in processing parameters.
- Utilized real part with fatigue cracks generated during spin pit test and provided for use by Rolls Royce.
  - Weights approx. 300 lbs
  - Waspaloy material
  - Changing geometry
  - High mass to volume ratio
  - Shot peened surface

Part Preparation

Vapor degrease at 183F for 15 min

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Drying Methods

Oven dry for 30 min at 225 or 250F

Flash dry for 15 min (150 – 185F)

Oven dry temperature measurement

Flash dry temperature measurement

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FPI Processing

Level 4, PE Penetrant, 20 min dwell

Emulsification with agitation, 120 sec

Final spray rinse, 60 sec

Developer Application

Developer application in dust chamber

Hand application by tossing of dry powder

Removal of excess developer powder

Developer Application

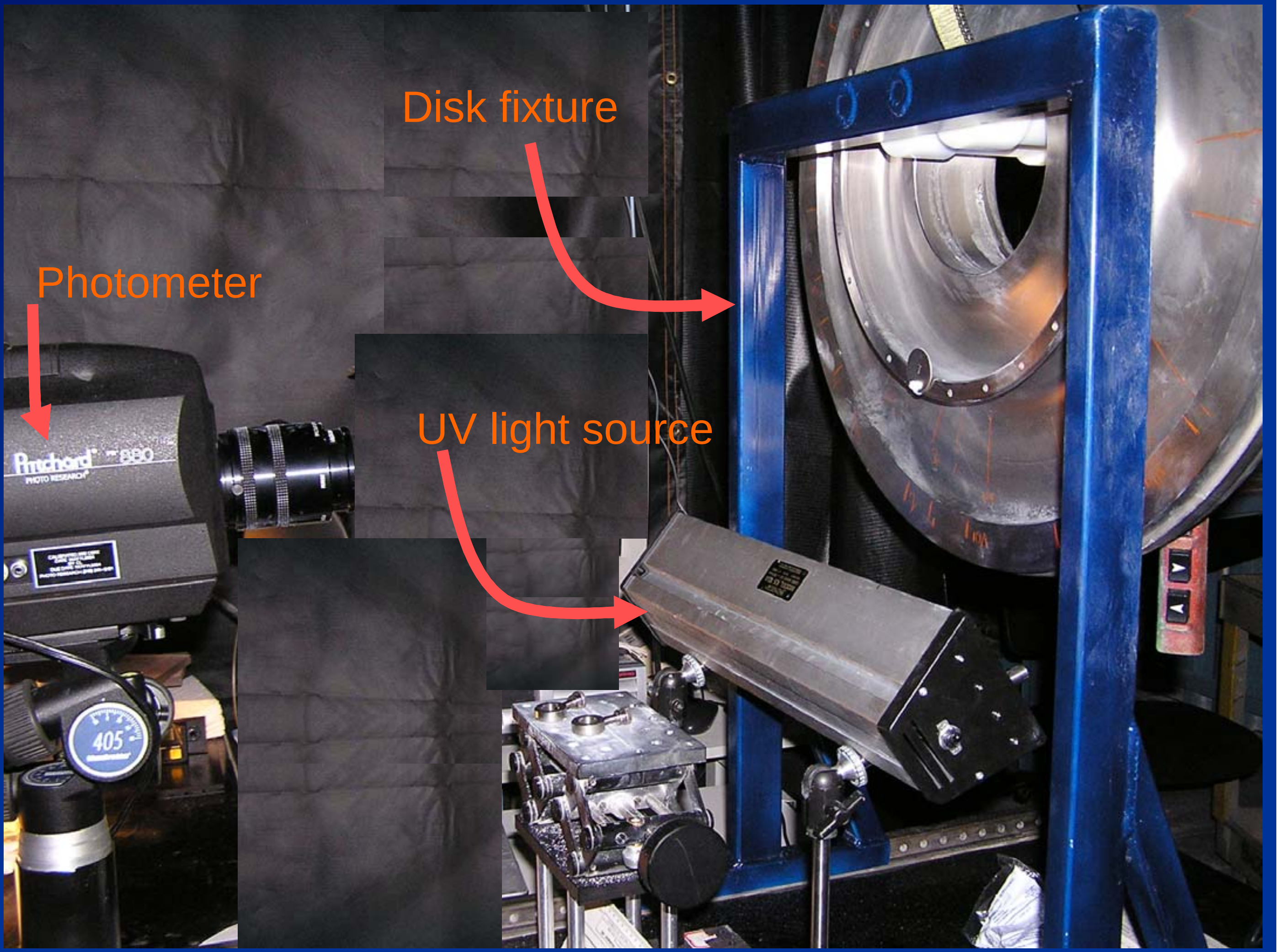
Wand application at 3” distance

Wand application at 3” distance

Bulb application of dry powder developer

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

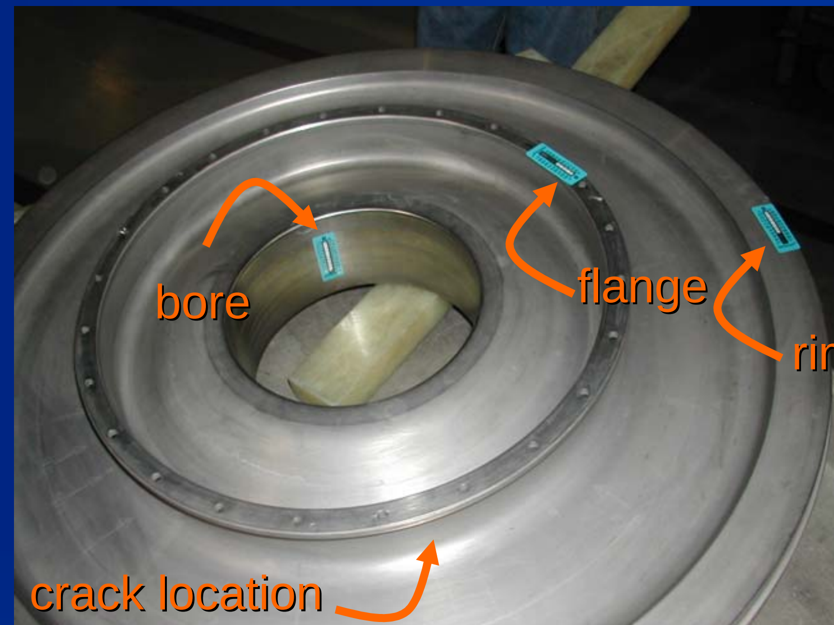


Baseline Process

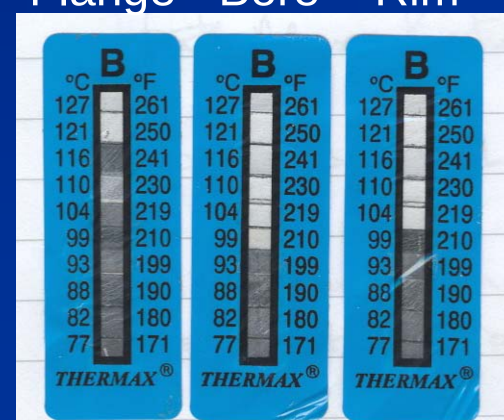
- Vapor degrease 5 mins @ 183F (This increased to default of 20 mins due to persistent FPI indications).
- Oven dry @ 225F for 30 mins
- Cool to 104F (forced air cooled using fan)
- Level 4, PE penetrant (ZL-37), dipped and dwelled for 20 mins
- Wash 60 seconds
- Emulsify using ZR-10B with agitation for 120 seconds
- Wash 60 seconds
- Pre developer dry @ 160F for 20 minutes
- Dry powder developer, ZP-4B, hand processed 10 minute dwell

Temperature Monitoring

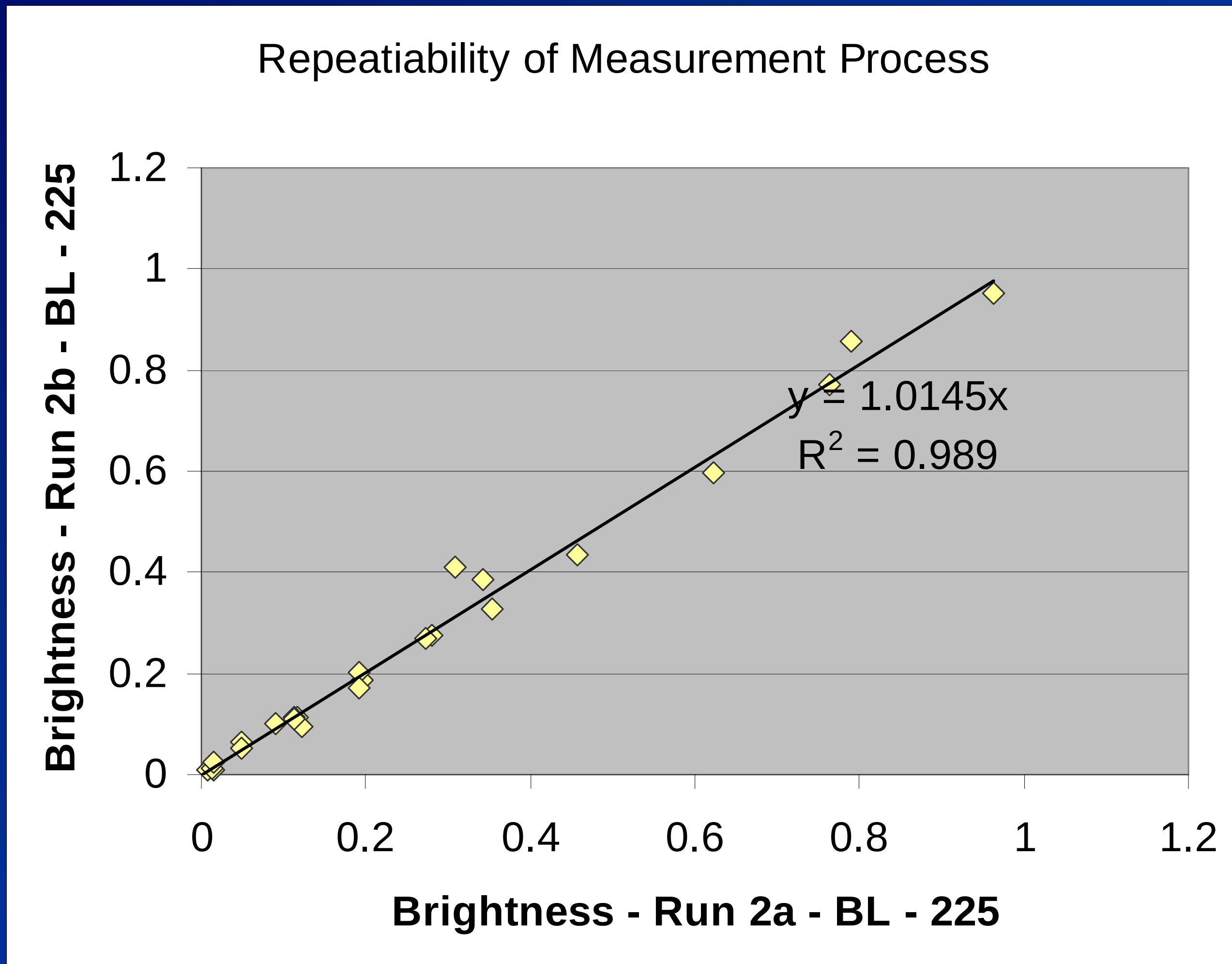
- Temperature gages used to determine variation with part geometry
- Order of increasing temperature:
  - Inner (bore)
  - Outer (rim)
  - Middle (flange)



Flange Bore Rim

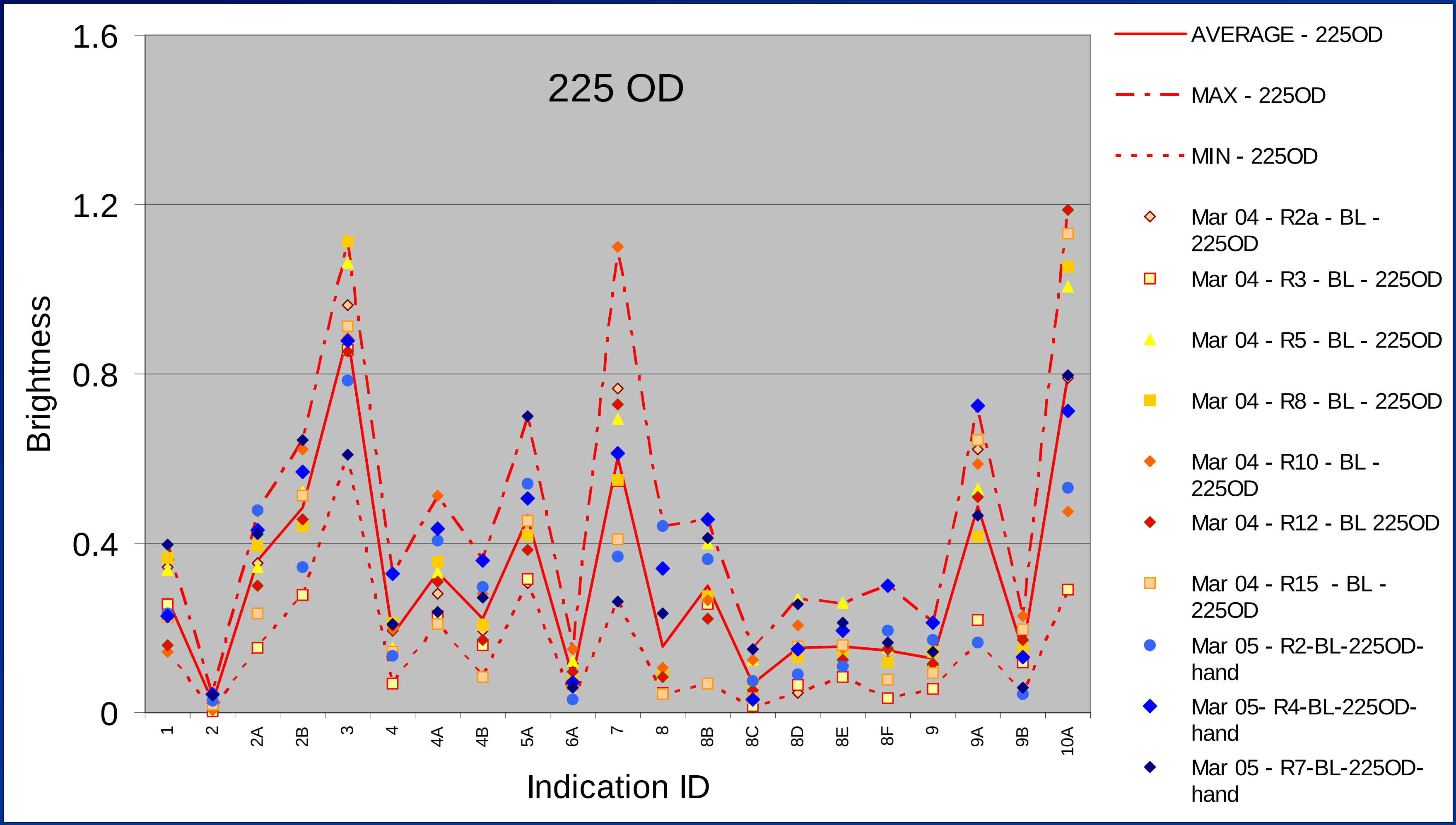


Repeatability

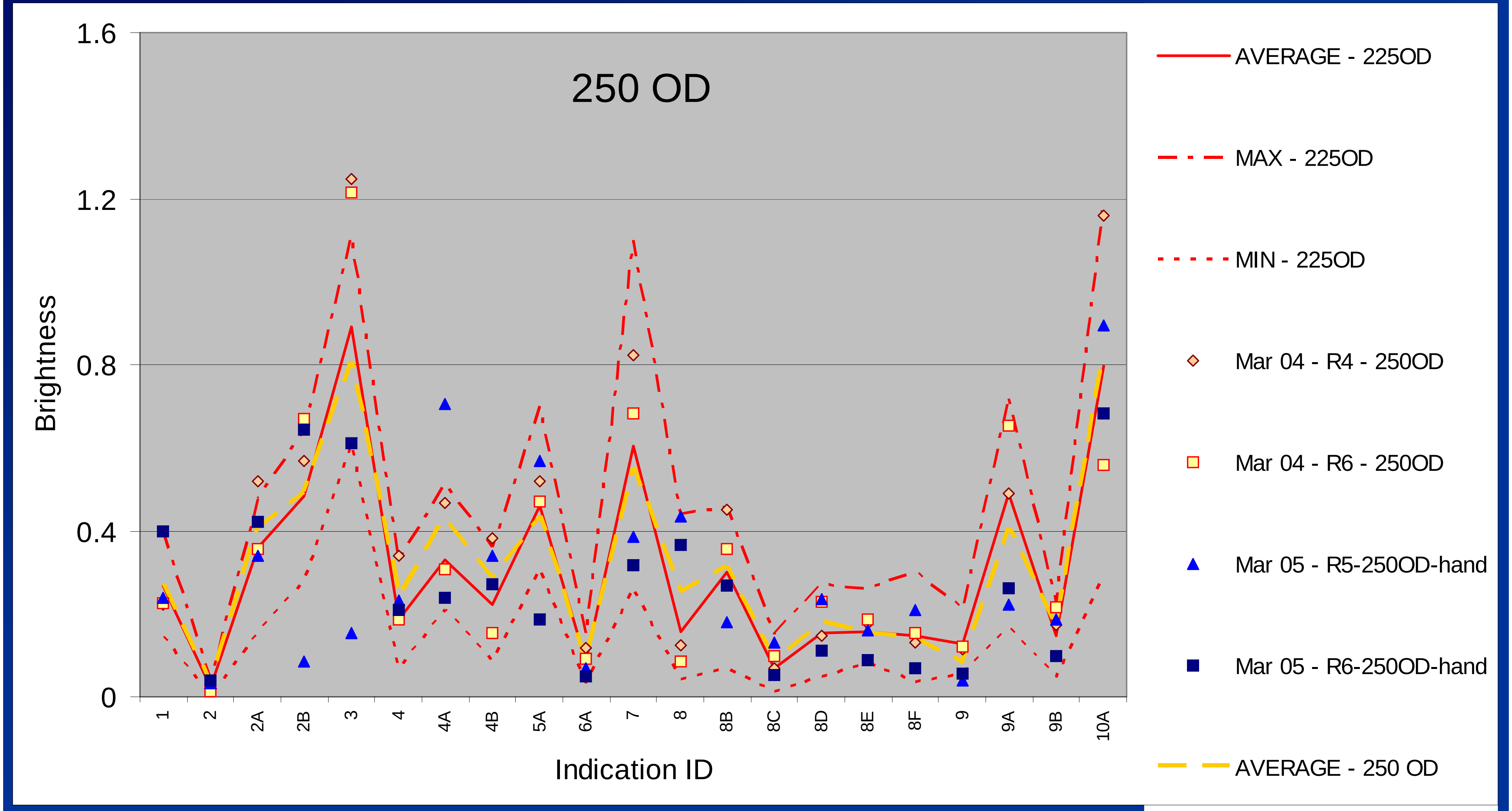


- Brightness measurements were repeated on the same process run to evaluate repeatability of the measurement process

Baseline Brightness Results

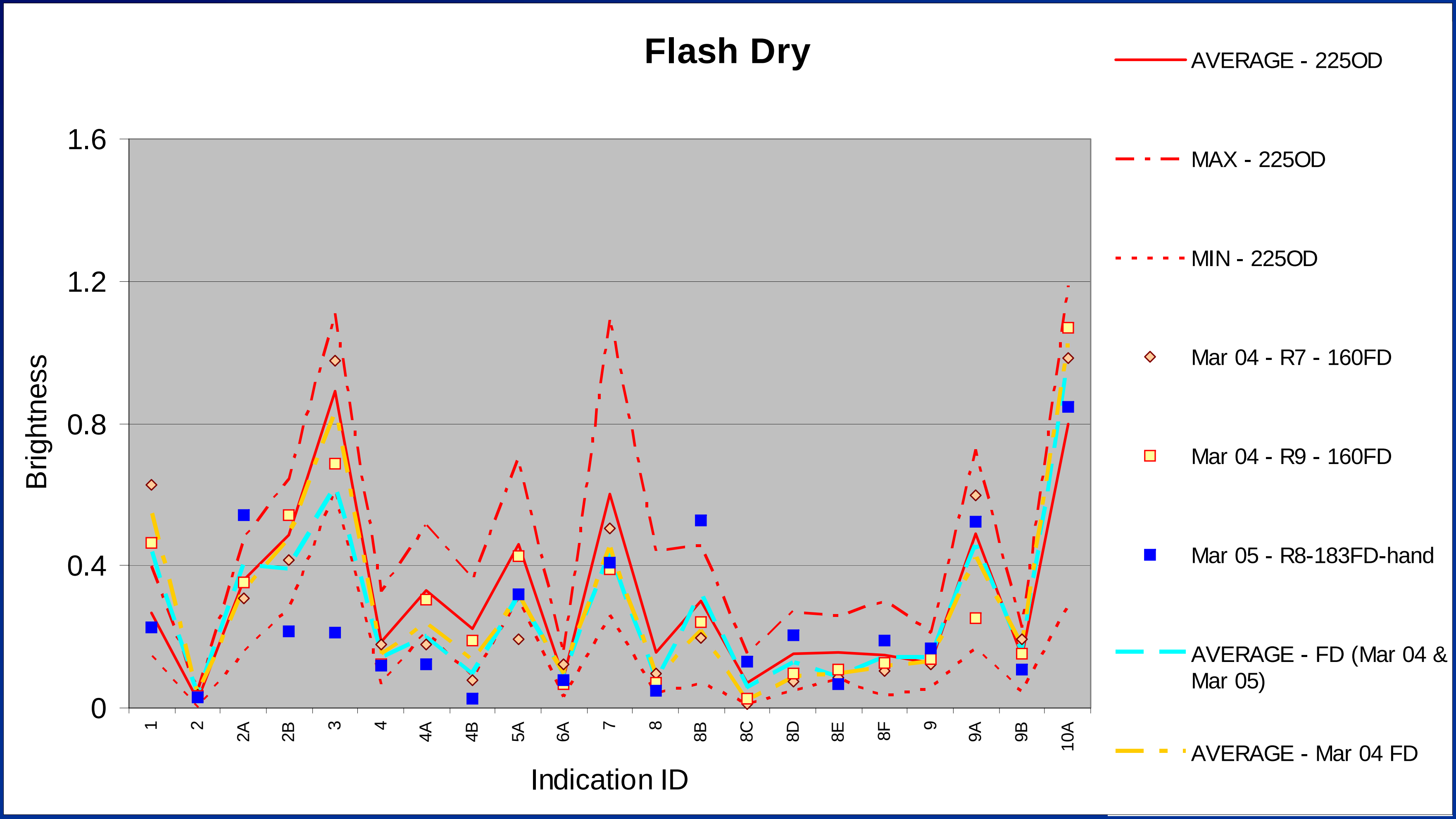


Comparison of 250 to 225 OD



- More variability found with 250OD than 225OD
- Average brightness essentially the same for both OD temperatures

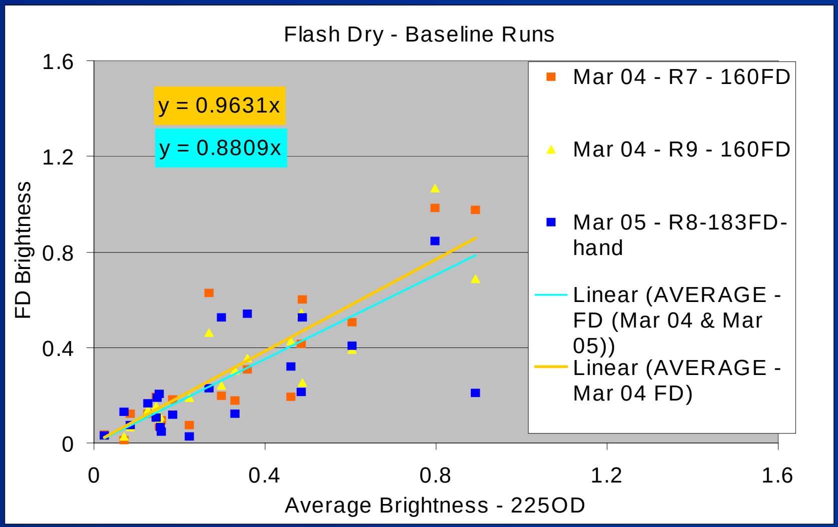
Results of Flash Dry Comparison

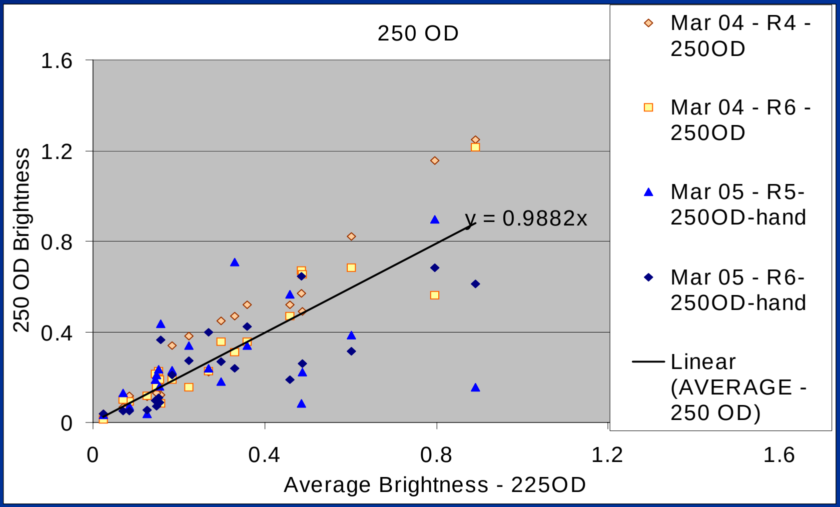


- Similar average brightness between FD and OD in Mar 04
- More variability and lower average brightness found with FD in Mar 05 than 225OD, possibly due to emulsifier effects

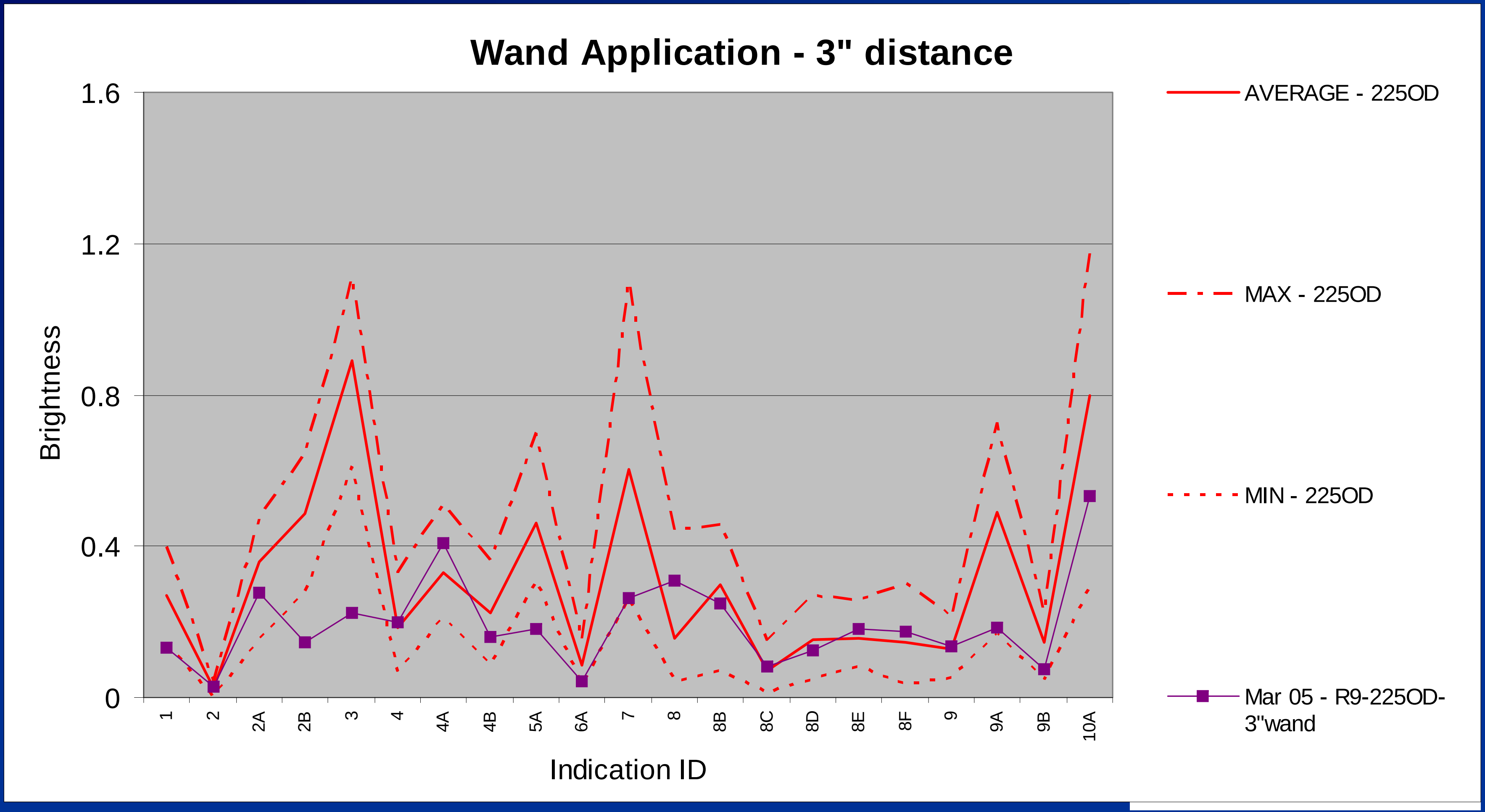
FD to OD Comparison

- Average brightness of 250 OD very similar to 225 OD (slope = 0.99)
- Average brightness of FD somewhat lower than OD when considering Mar 05 data (slope = 0.88)
- Average brightness of FD very similar to 225OD when consider only Mar 04 data (slope = 0.96)
- Difference between Mar 04 and Mar 05 could be related to emulsifier contamination
- Statistical significance being assessed





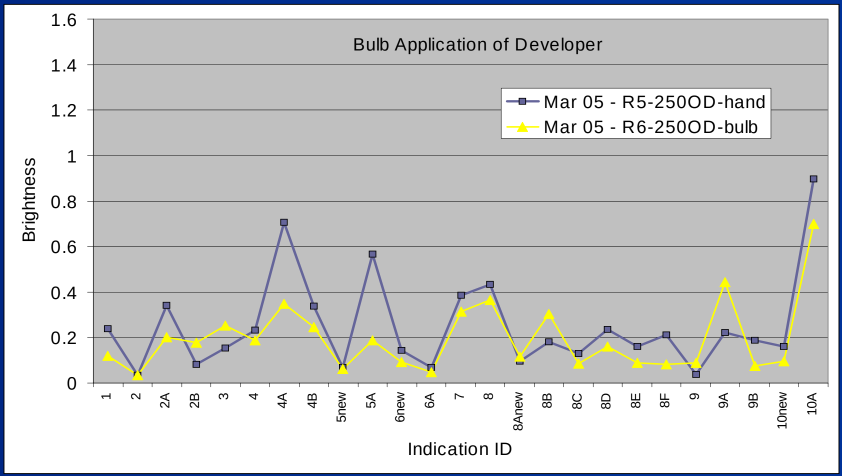
Developer Application - Wand

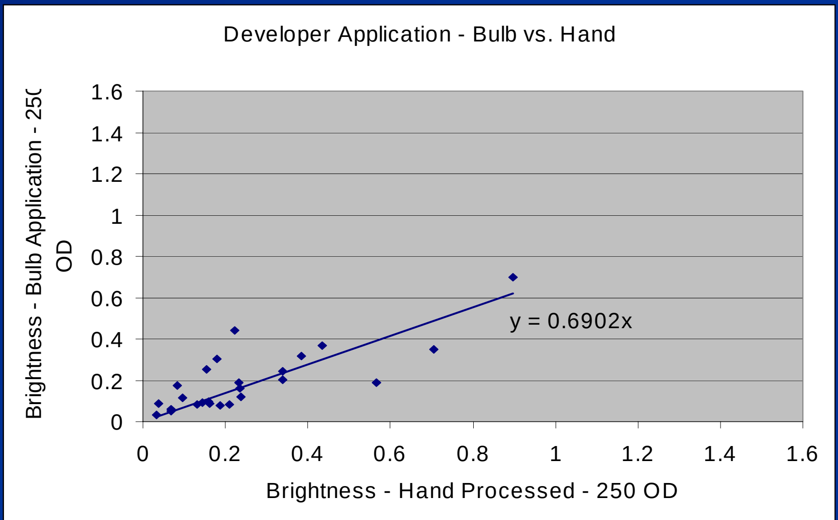


- Use of wand at 3" distance from part led to lower brightness than hand processing with brightness of 30% of the average brightness found with hand-processing

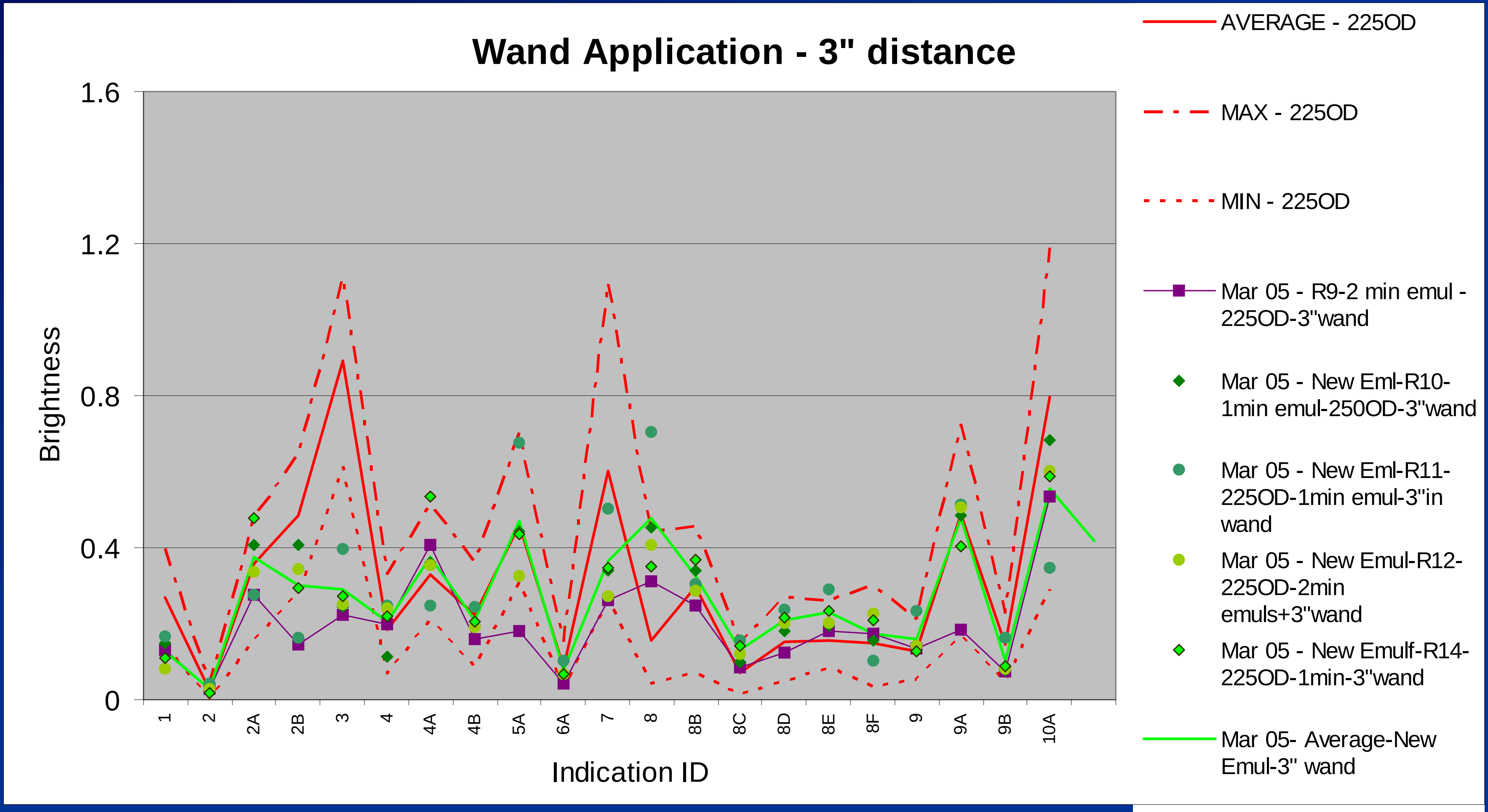
Developer Application - Bulb

- Comparison of developer application using a bulb led to lower brightness than most hand processed indications
- Linear regression shows brightness values of 69% for the bulb processing compared to hand processing



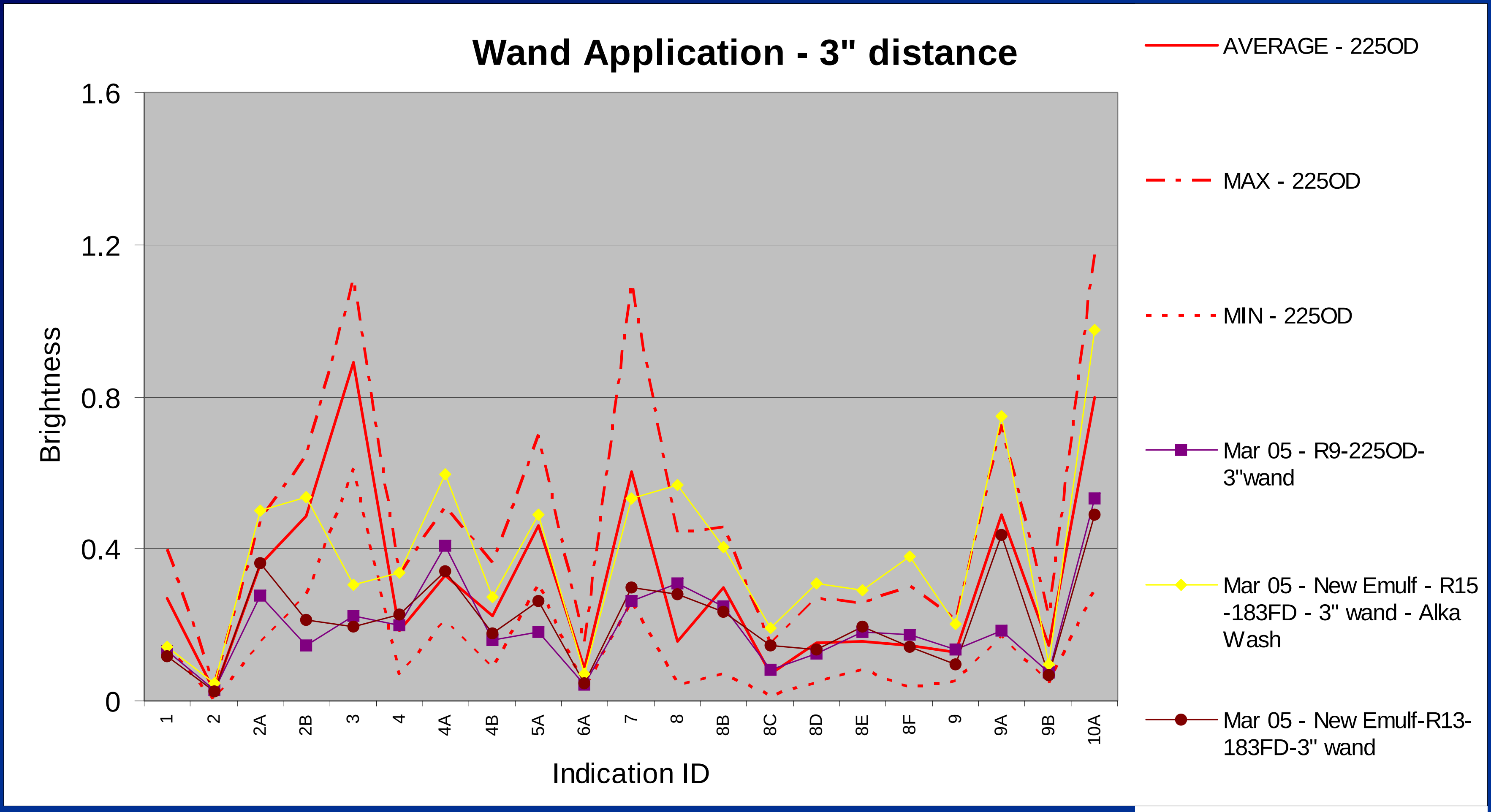


New Emulsifier



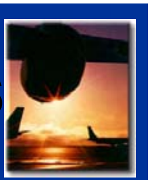
- Brightness increased with new emulsifier compared to original emulsifier
- Use of wand in general led to a reduction in brightness but less variability than with hand processing

Flash Dry Comparison



- No difference between OD and FD with new emulsifier and 3" wand
- Brightness increased after heavy duty alkaline clean and FD back to "hand processing conditions"

CASR Thermal Mass Drying Study Conclusions



- Average brightness similar for both oven dry temperatures, i.e., 225F and 250F
- FD data requires additional statistical analysis
  - More variation found with FD when compared to 225OD, original emulsifier
  - With new emulsifier, FD and OD performed similarly
- Background brightness relatively consistent in Mar05, i.e., not related to changes in emulsifier
- Use of wand showed less variability than hand processing but at a lower average brightness
- Emulsifier change led to improvements in brightness
- Dust chamber application shows similar brightness debits to those found using lcf samples
- Use of heavy duty alkaline clean led to improvements in brightness
- Recommend final study to establish minimum acceptable drying temperature for parts, i.e., energy savings benefits