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UVA-Induced Fade of Penetrant and FPI Indications

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Acknowledgments

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Overview

- Contrast between the indication and background affects detectability. Signal-to-noise ratio=contrast
- Convention would say that higher UVA intensity results in brighter indications
- UVA sources with output of 50,000 μWatts/cm^2 (@15”) are commercially available
- Inspection UVA intensity many times higher than that traditionally used may cause indications to be missed due to rapid fade
- All penetrants can be shown to fade when exposed to UVA radiation, only the rate of fading varies

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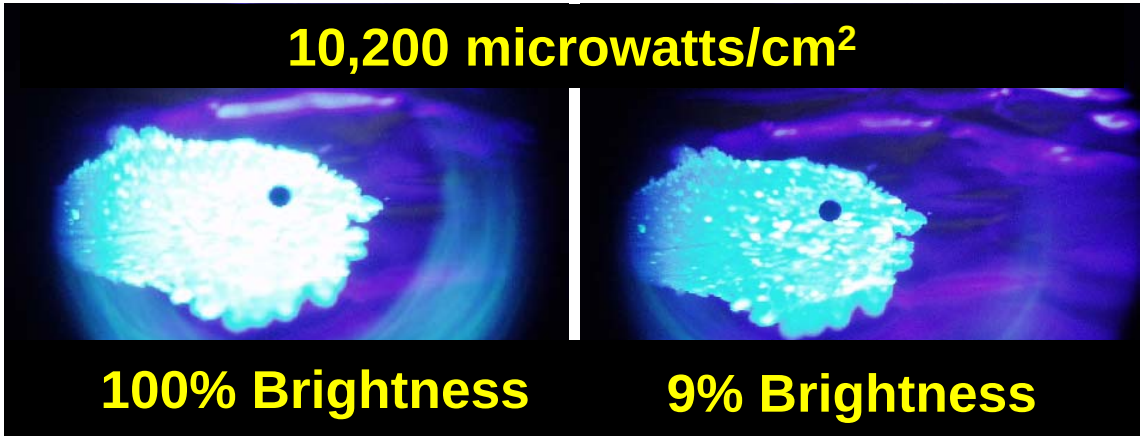
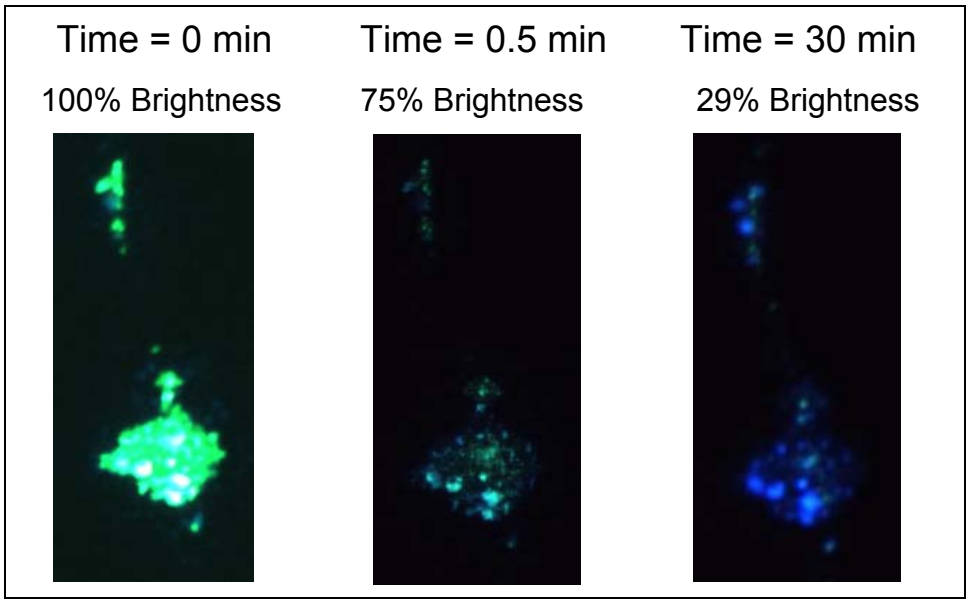
Why it Happens

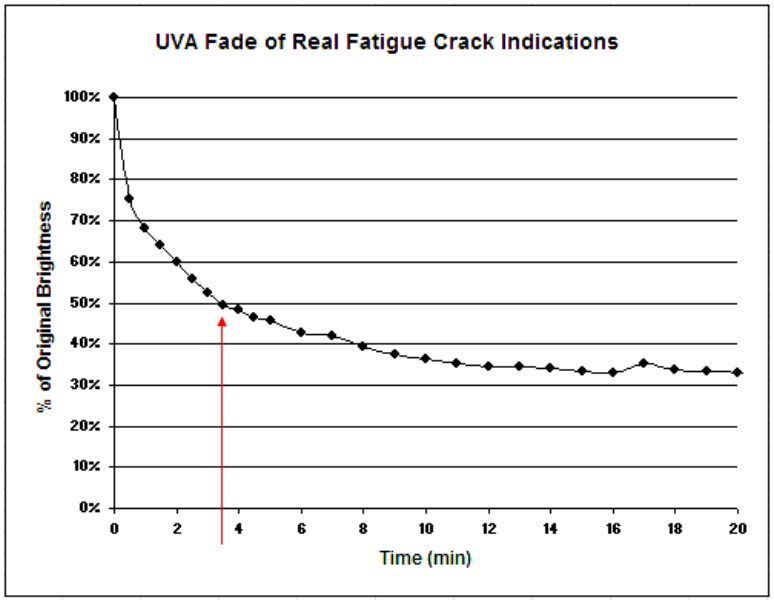
- Dye molecules in penetrant absorb, and are made more reactive by UVA excitation
- Excited molecules undergo oxidation and/or reduction = photobleaching (fade)
- Increased temperature, or increased airflow speeds the fade rate at a given UVA intensity



Who Should Be Aware

- The brightness of a crack indication may be reduced by half in 3.5 minutes at 20,000 µW/cm^2
- Fade rate follows an exponential decay curve, and the initial slope for higher intensities is quite steep
- Inspectors working with critical parts, or time-consuming inspections should be aware of this issue



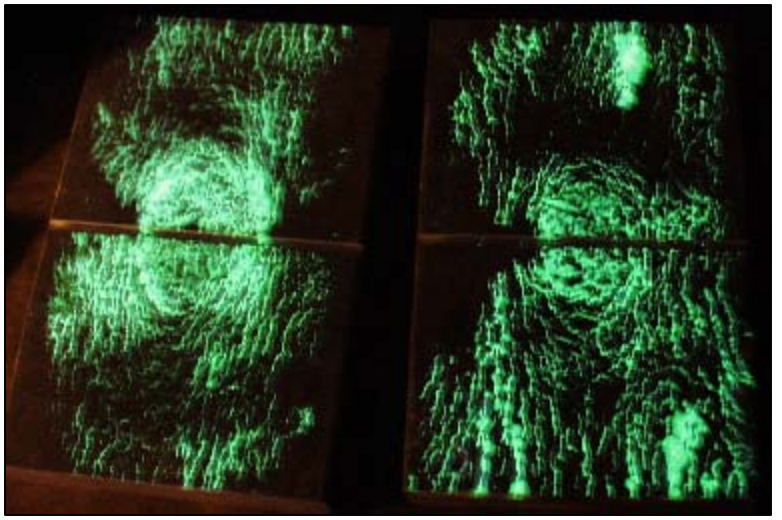


50% brightness reduction in 3.5 minutes

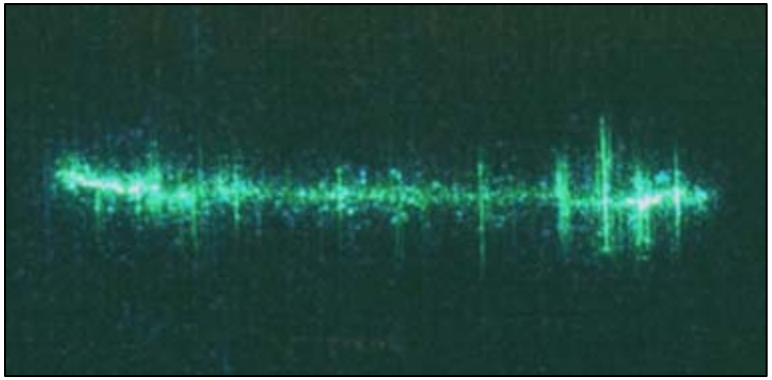
Material: Inconel **Crack Length: 0.060”** **UVA Intensity: 19,200 µW/cm^2**

What Work Was Done

- Real crack indications were faded, as well as small quantities of undiluted penetrant
- A variety of UVA sources were utilized to determine relative effect
- The effects of increased heat and/or airflow were evaluated



Thermally-cracked aluminum blocks processed per AMS 2647



FPI indication from an 0.080” long low-cycle fatigue crack in Inconel-718

How Was It Performed

- Brightness measurements were made with a Photo Research PR-880 photo-spotmeter
- UVA intensity measured with Spectroline DSE-100X and broadband DIX-365 sensor
- UVA illumination provided by:
  - 100W mercury vapor (a)
  - 35W gas discharge (b)
  - Twin 40W fluorescent bulbs (c)
  - 100W short-arc mercury bulb (d)


(a)


(b)


(c)


(d)

How Was It Performed

- UV-grade fused silica discs were used to evaluate environmental conditions
  - Fused silica provides a superior transmission curve for UVA and visible wavelengths
  - Interstitial penetrant between 2 fused silica discs allowed for reduced oxygen fade testing without a vacuum setup
- Digital hotplate and a fan provided controlled heat and airflow
- Fatigue and thermal crack panels were processed according to industry standards

Photometer, UVA source, and digital hotplate used for some runs

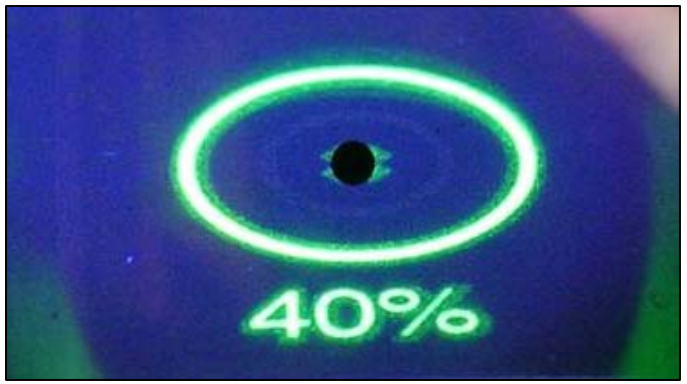
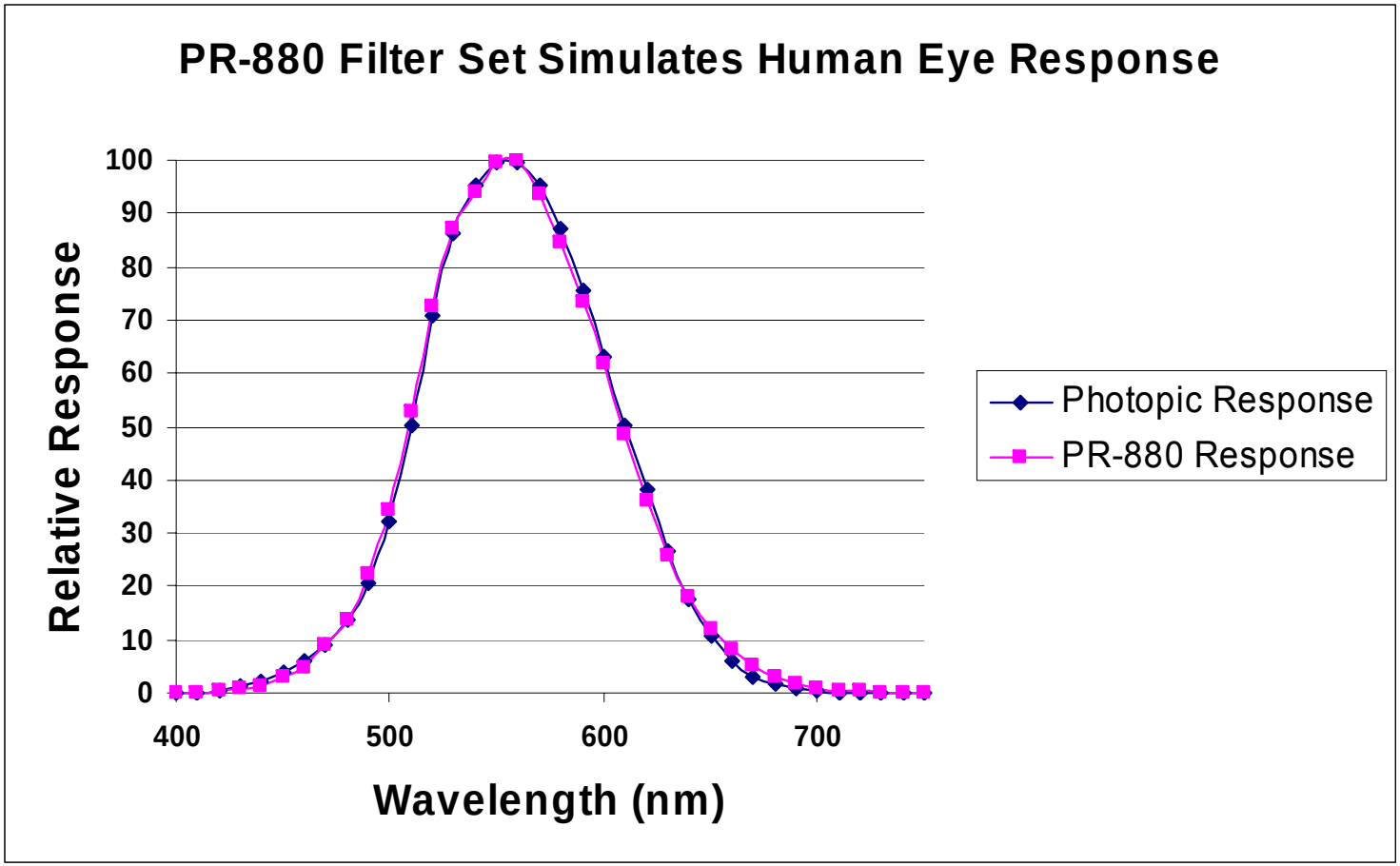


Image taken through photometer eyepiece while measuring the 40% area of a Universal Technical Equipment card

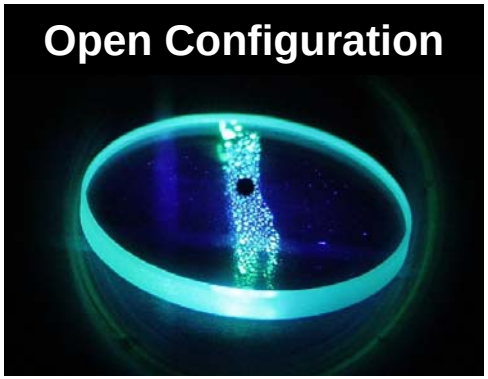
How Was It Performed

Photometer's color response matches human vision, although the unit's overall sensitivity has not yet been correlated with an inspector's detection sensitivity



Bulk Penetrant Fade

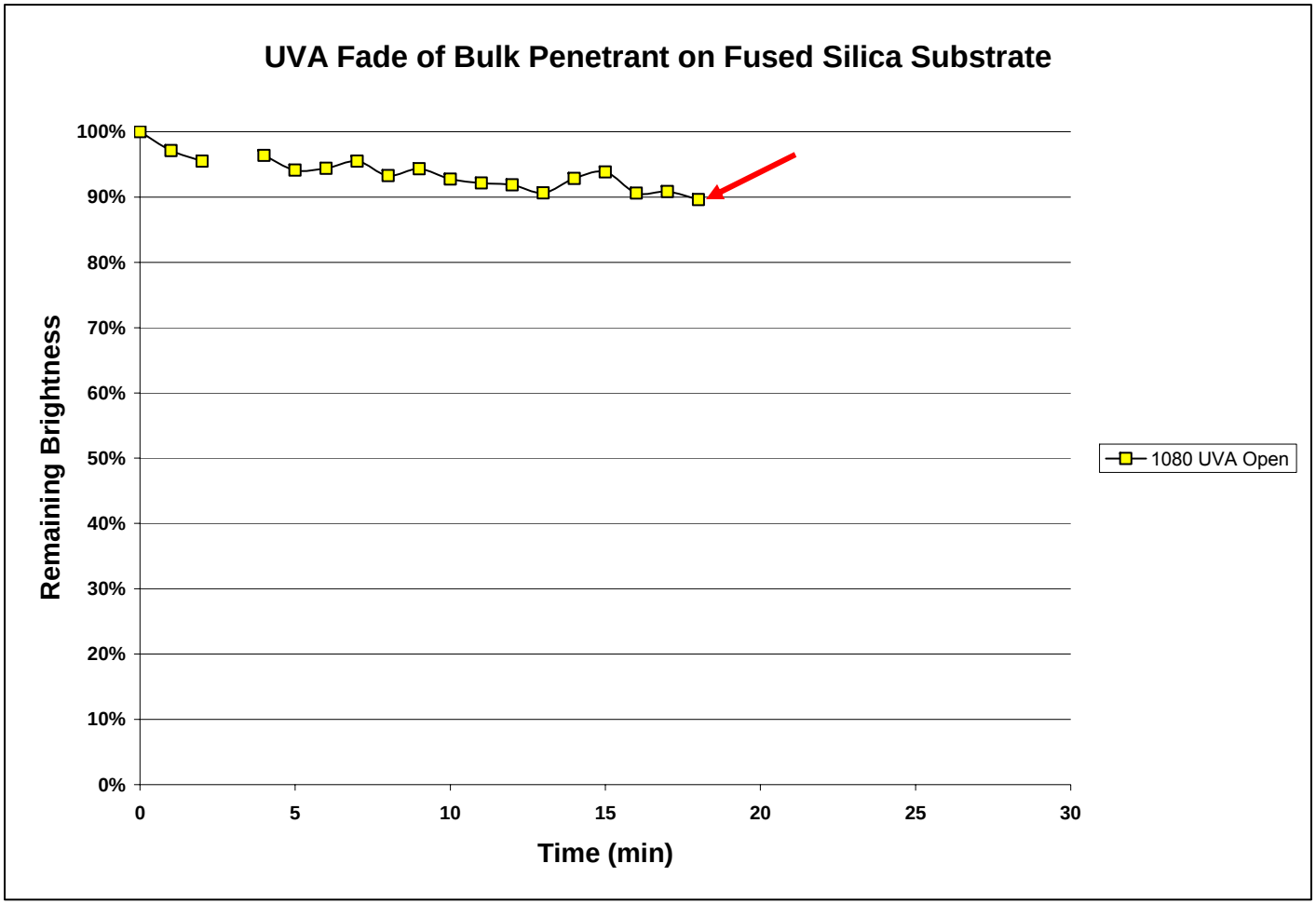
- Either 1 (open configuration) or 2 (closed configuration) fused silica discs were used to control and individually measure the effect of UVA, heat, and airflow on photobleaching
- UVA intensity ranged from 1,000 to 74,000 $\mu W/cm^2$ (estimated using inverse square law)
- Heat was provided by a hot plate set to 150°F
- Approximately 800 ft^3/min airflow was provided by a fan
- Closed configuration had penetrant filling interstice between two discs to approximate testing in a vacuum environment



Single disc with a swabbed and paper towel-blotted penetrant line

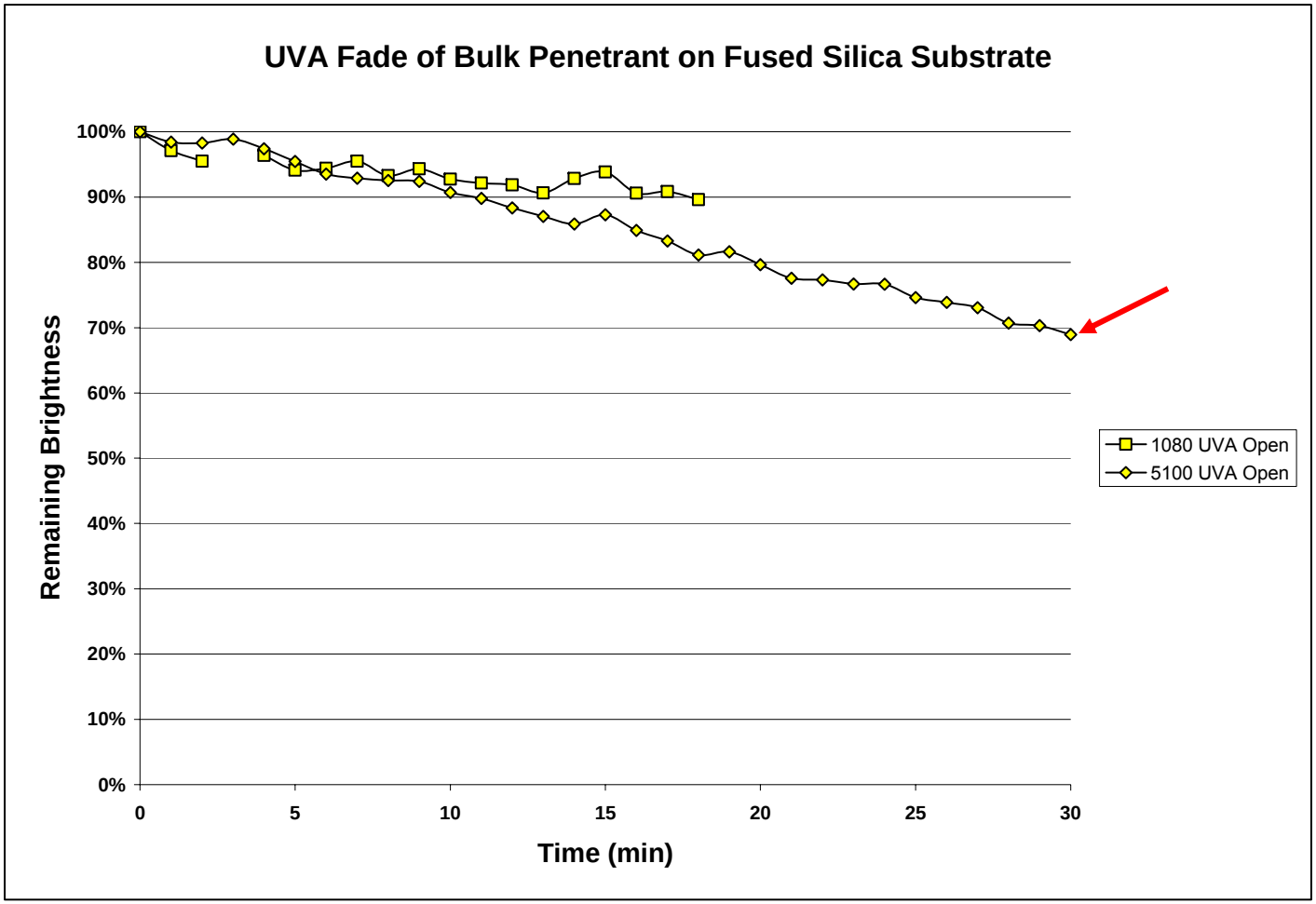
Two-disc penetrant sandwich effectively removing air interaction

Bulk Penetrant Fade



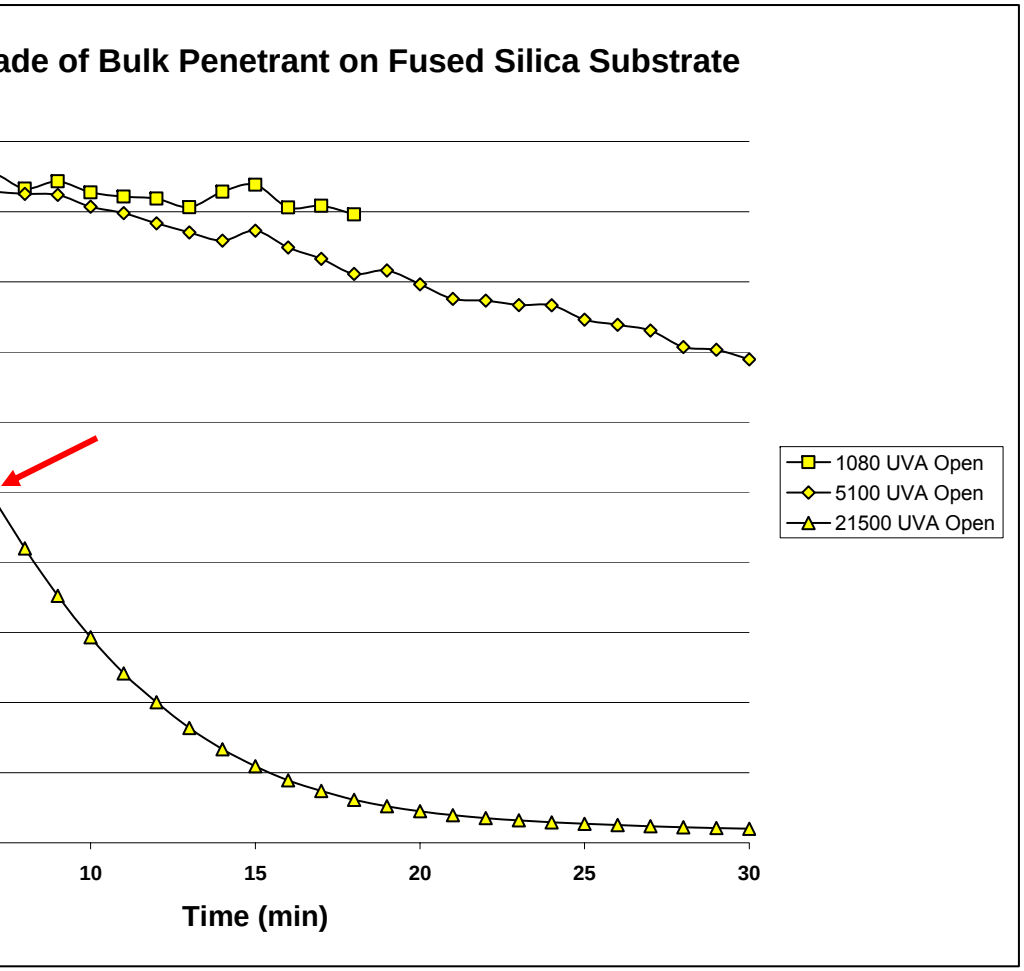
UVA Intensity: 1,000 µW/cm2 – Open Configuration

Bulk Penetrant Fade



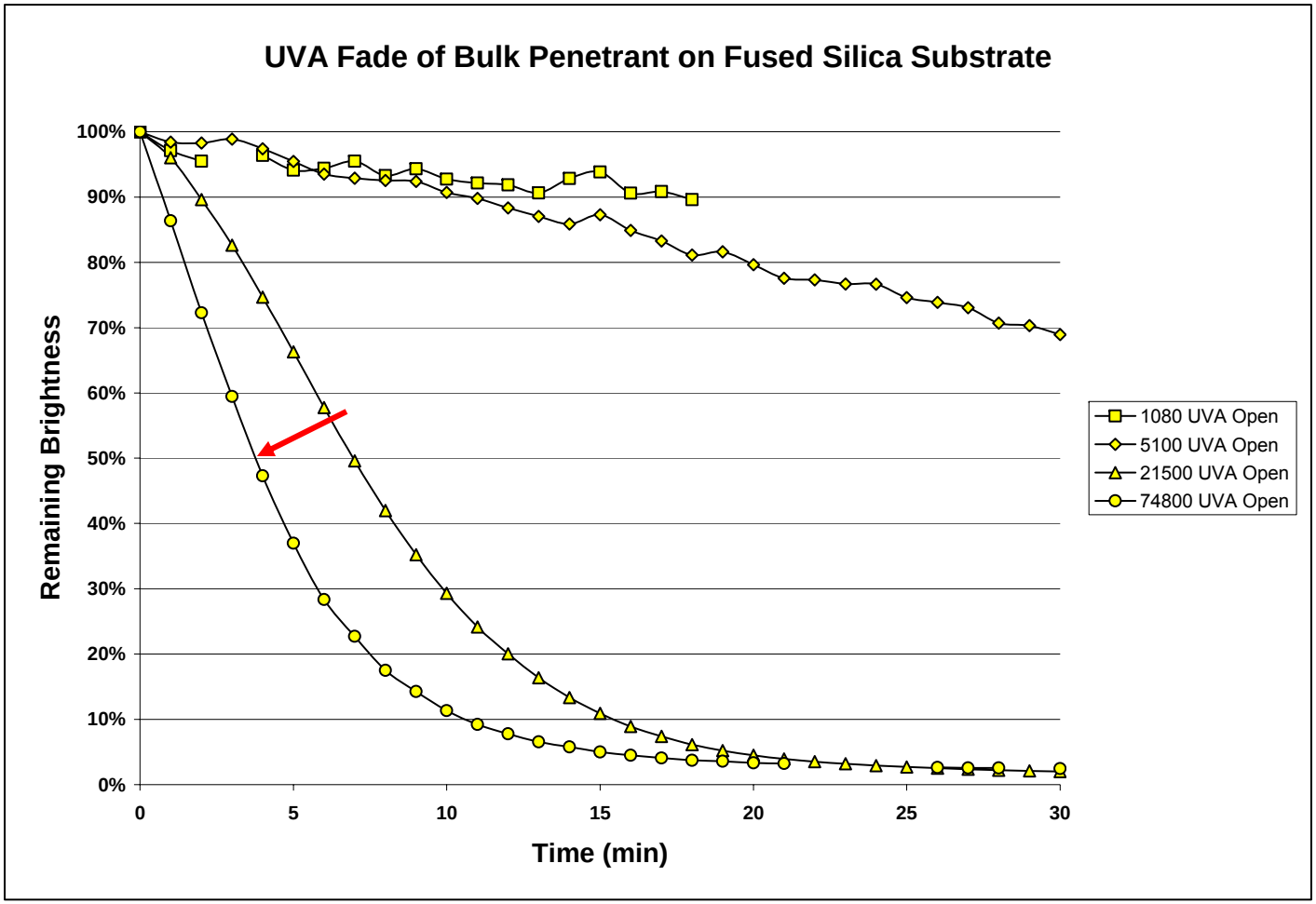
UVA Intensity: 5,000 µW/cm2 – Open Configuration

Bulk Penetrant Fade



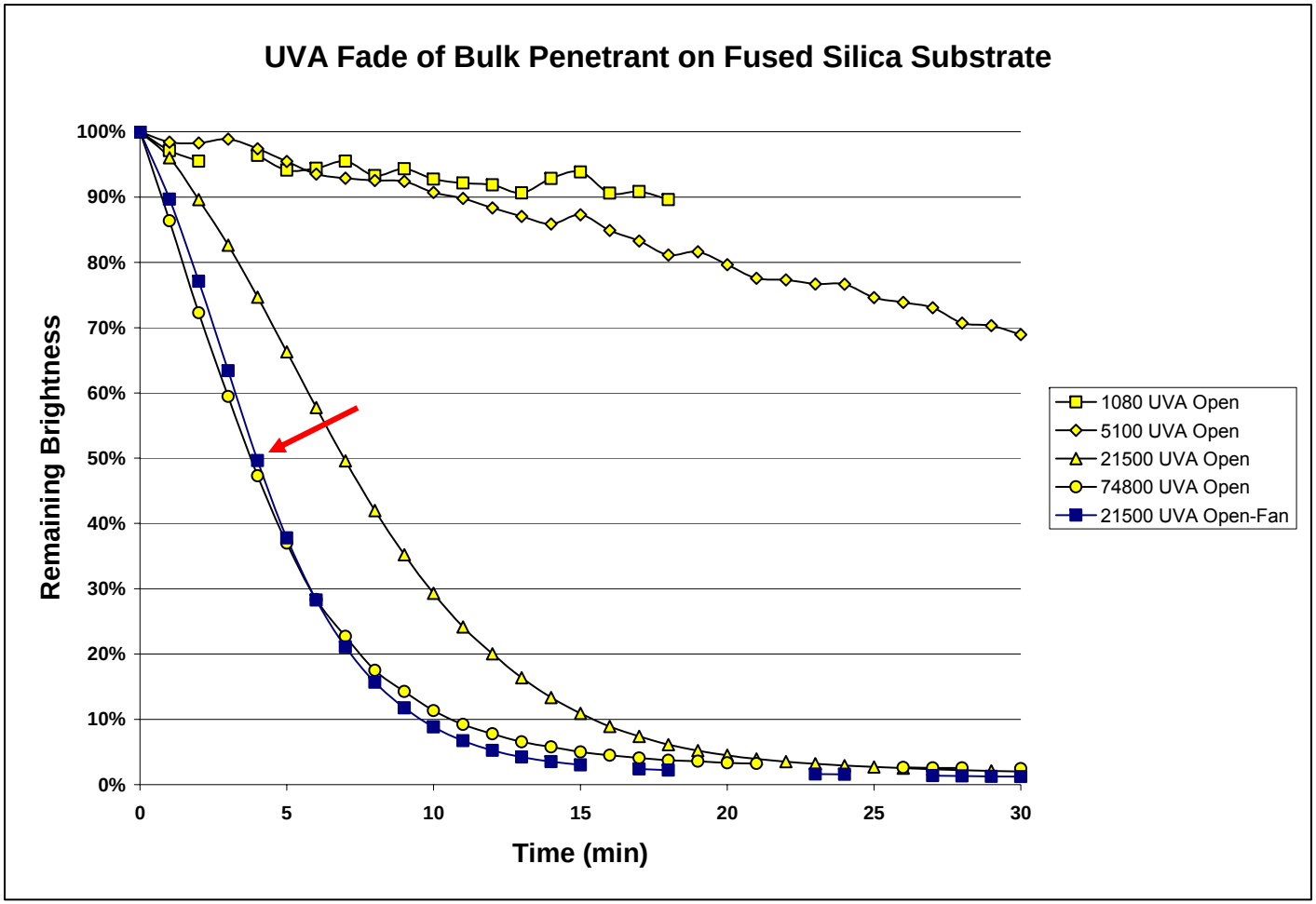
UVA Intensity: 20,000 µW/cm2 – Open Configuration

Bulk Penetrant Fade



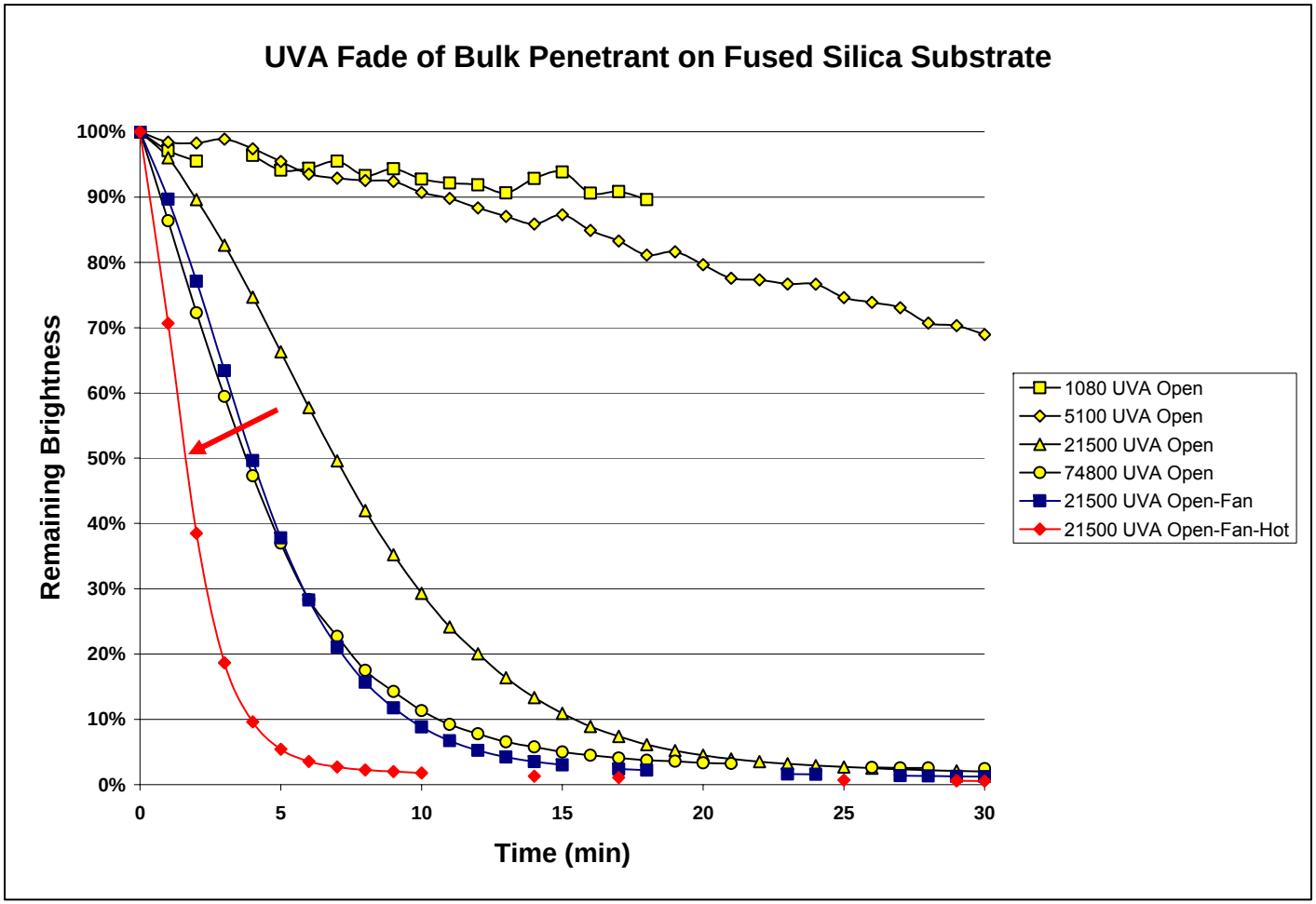
UVA Intensity: 75,000 µW/cm2 – Open Configuration

Bulk Penetrant Fade



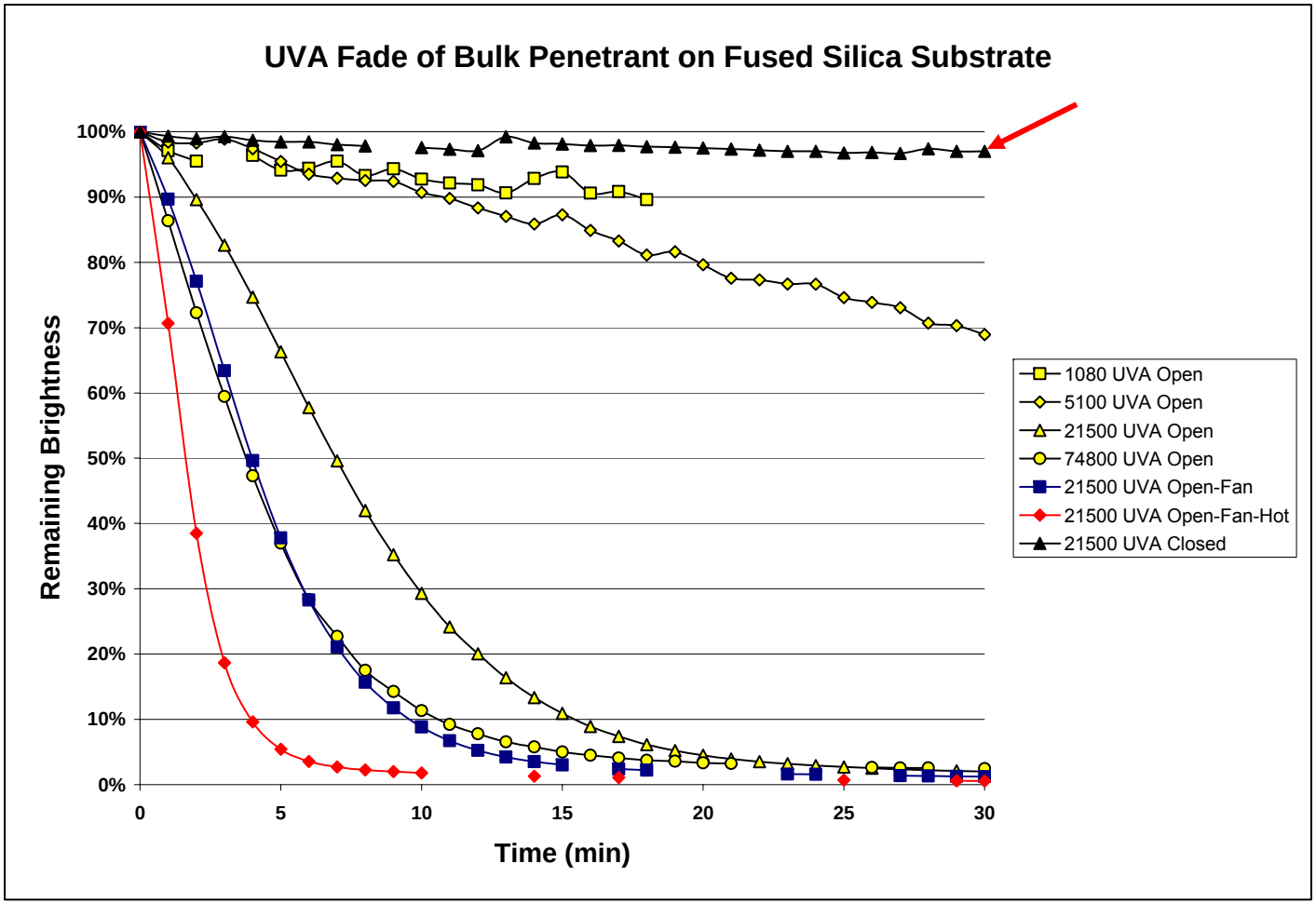
UVA Intensity: 20,000 µW/cm2 – Open + Fan

Bulk Penetrant Fade



UVA Intensity: 20,000 µW/cm2 – Open + Fan + Heat

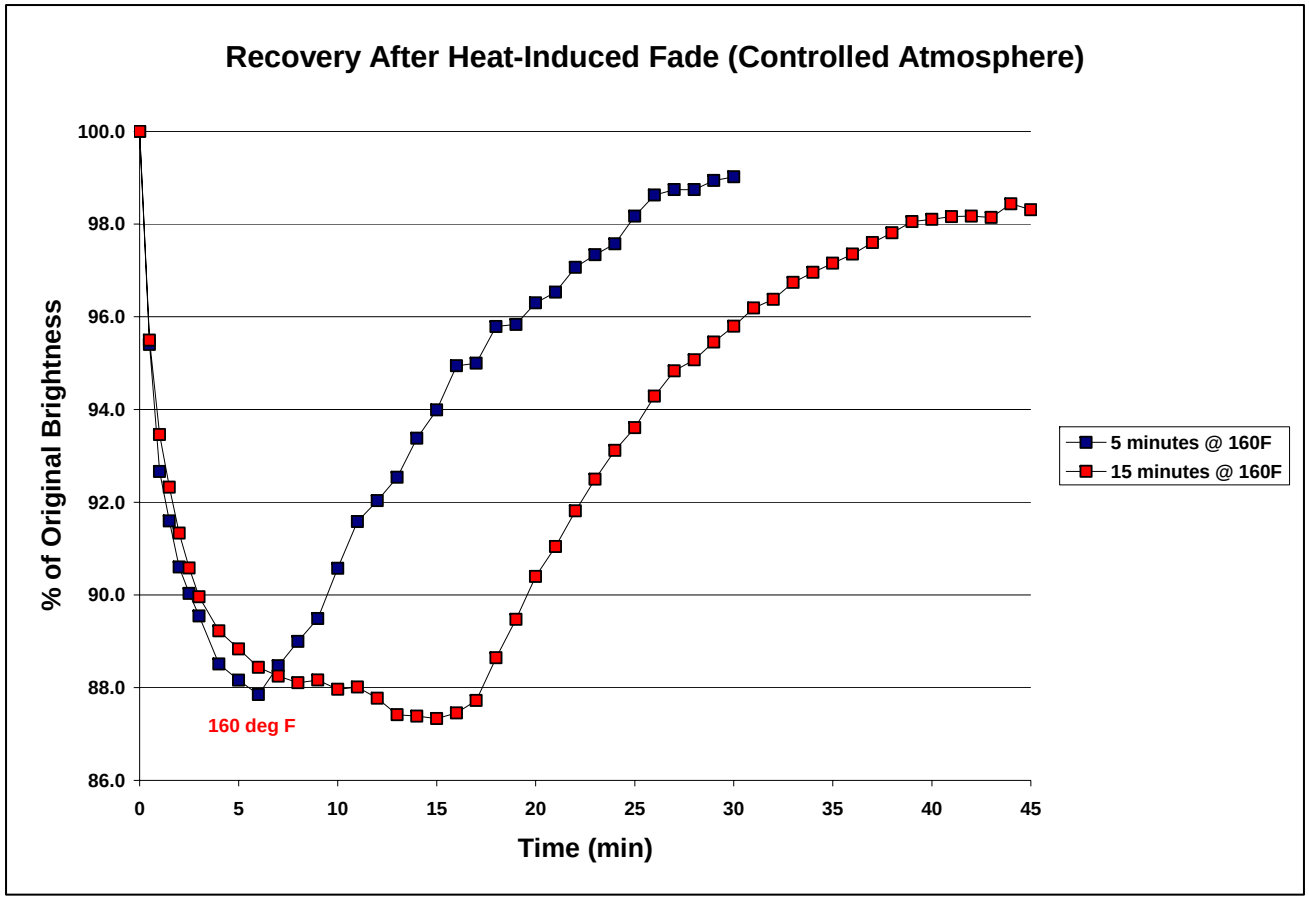
Bulk Penetrant Fade



UVA Intensity: 20,000 µW/cm2 – Closed Configuration

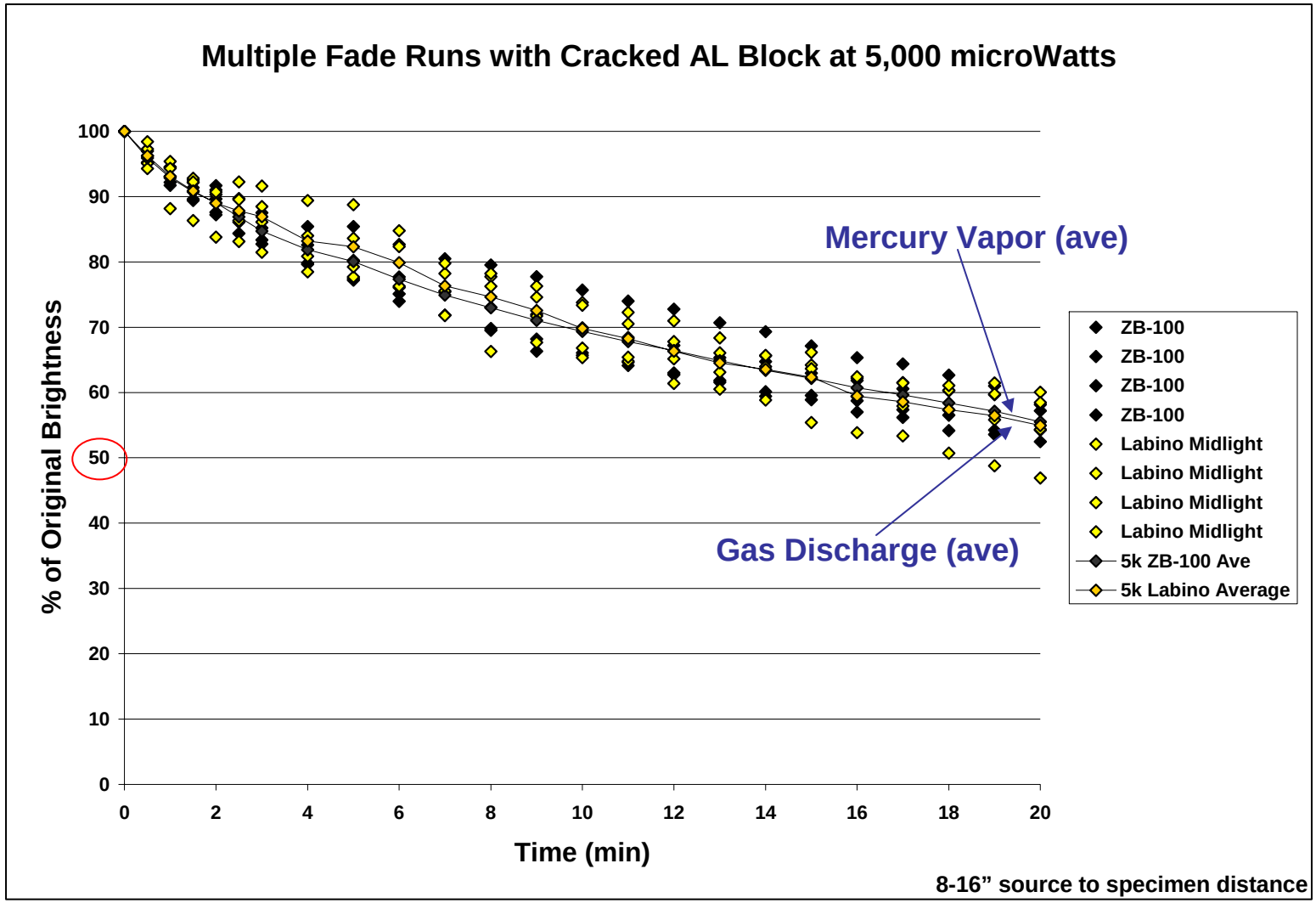
Bulk Penetrant Heat Fade

- ZL-37 penetrant heated to 160°F in a closed configuration and then cooled nearly regained nearly all of original brightness (1,500 µW/cm2)
- Recovery from the 13% brightness loss was similar when held at 160°F for 5 or 15 minutes



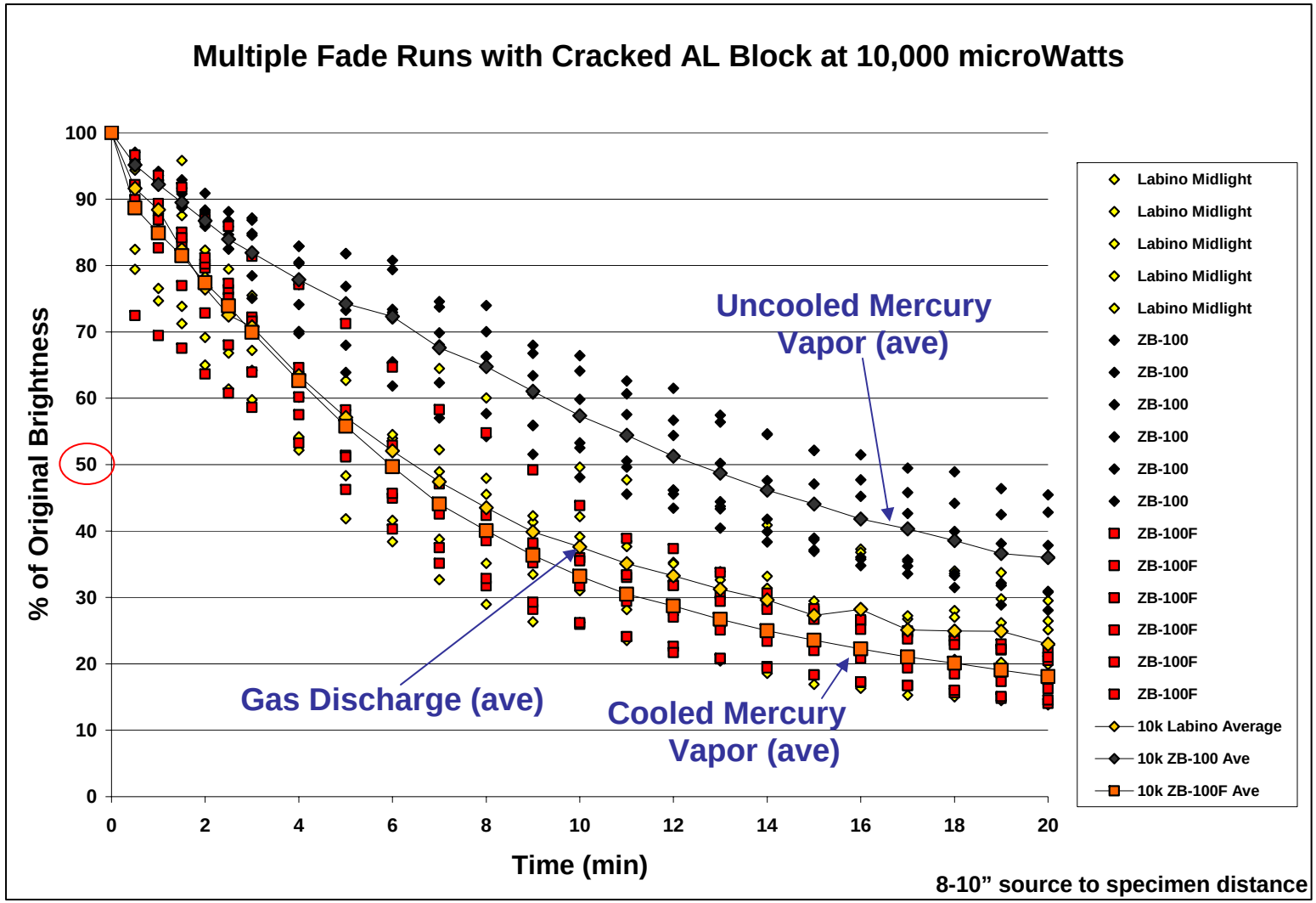
Real Indications: AL Blocks

With a UVA meter reading of 5,000 µW/cm^2 the gas discharge and mercury vapor (fanless) sources reduced indication brightness by 45% in 20 minutes.



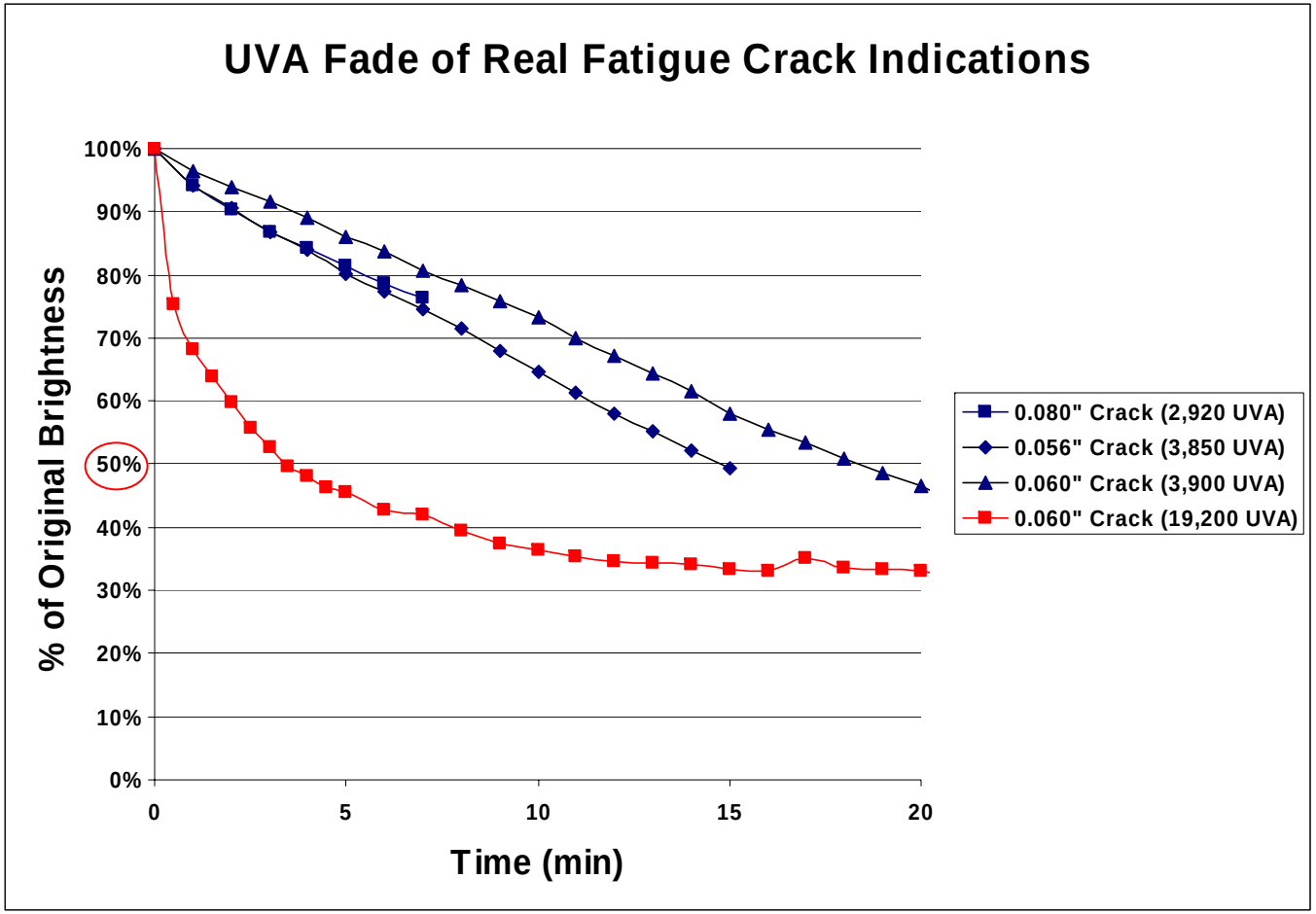
Real Indications: AL Blocks

At 10,000 µW/cm^2 UVA intensity the indications were reduced in brightness by half in 6 to 12 minutes, and the effect of the cooling fan is noticed



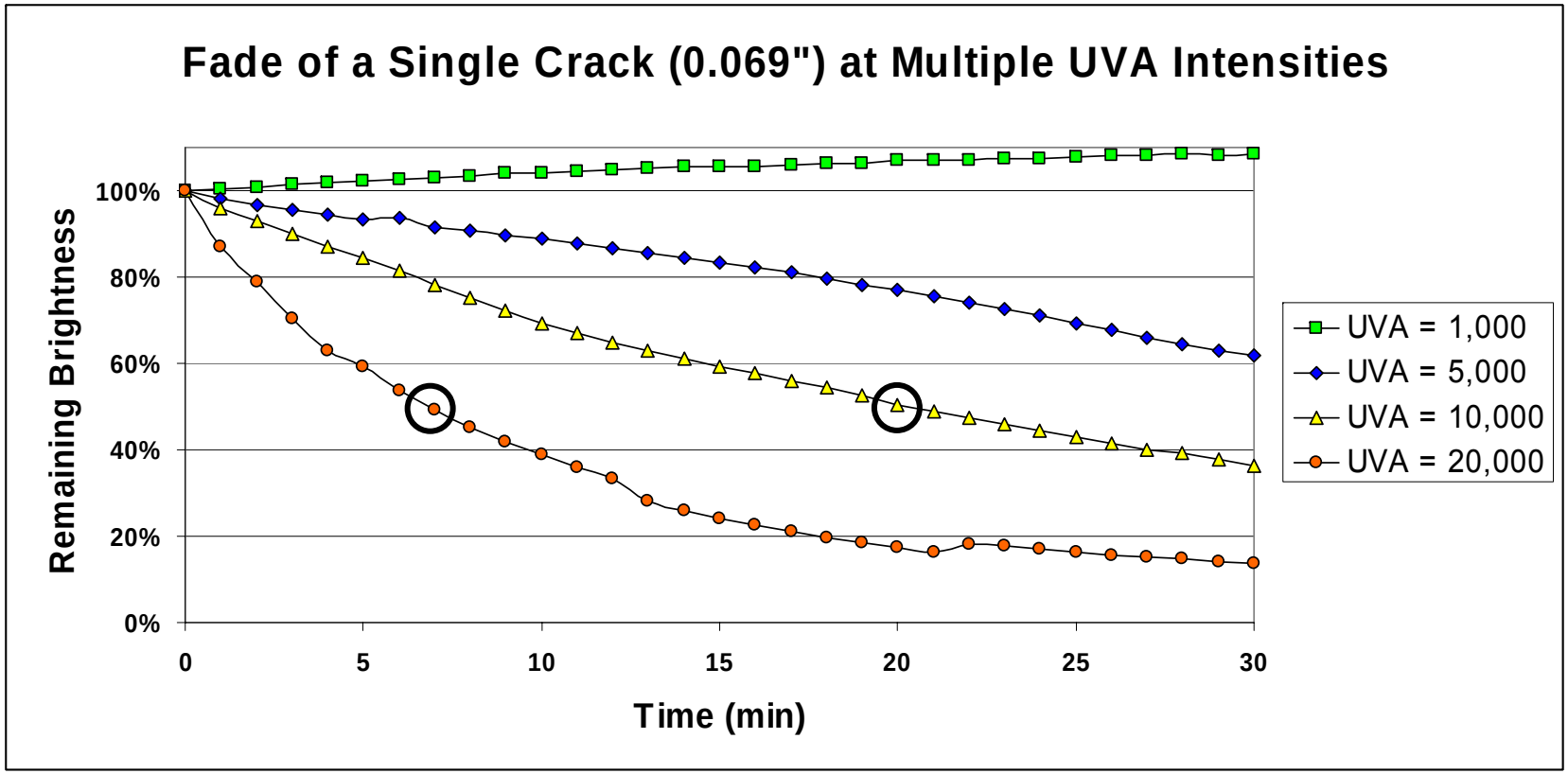
Real Indications: LCF Blocks

- As seen with previous data, higher UVA intensity speeds fade rate
- 50% reduction of a 0.060” indication in 3.5 minutes (19,200 μW/cm^2), and two 0.060” indications in 15 and 19 minutes (3,900 μW/cm^2)



Results on Real Cracks

- The same crack was processed according to AMS 2647, and then exposed to UVA intensities from 1,000 to 20,000 μW/cm^2
- A brightness increase in the 1,000 μW/cm^2 data likely due to bleed-out
- 50% reduction in 7 minutes (20,000 μW/cm^2), and in 20 minutes (10,000 μW/cm^2)



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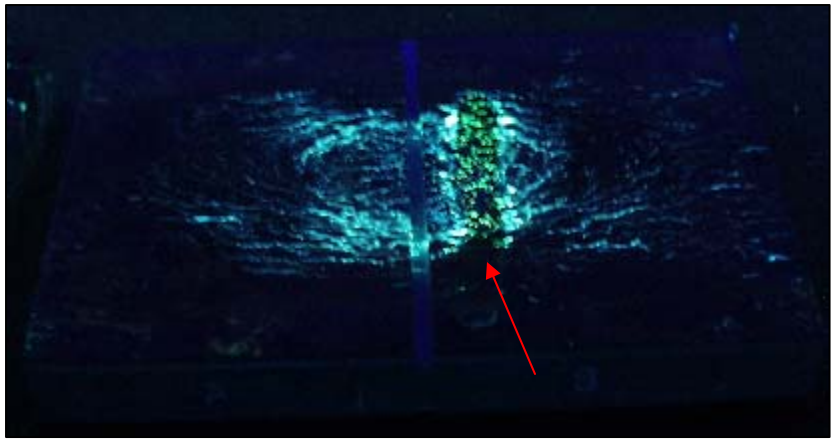
Conclusions

- No penetrant or UVA source evaluated was immune to photobleaching
- Three factors have been shown to affect fade rate: UVA intensity, temperature, and airflow
- S/N ratios of real indications were halved in 3 to 7 minutes (with no heat or airflow) with 20,000 $\mu W/cm^2$ intensity
- Larger, deeper cracks contain more penetrant volume and fade more slowly for a given condition set
- In a controlled environment, brightness reduction due to heating is recoverable

Conclusions

- A maximum UVA intensity of 5,000 µW/cm2 for critical applications may be a prudent limit
- Allow parts to cool prior to UVA inspection, and not blow fans into inspection booth
- Do not allows parts to develop under strong UVA
- Fan cooling of the same UVA source increases the fade rate when intensity, bulb style, and filter remain constant



Thermally-cracked aluminum block crack indications re-bled dimmer, but yellow-green after UVA-induced fade

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Summary of Penetrant and Emulsification Parameter Studies

Lisa Brasche, Rick Lopez,
Dave Eisenmann, and Bill Meeker

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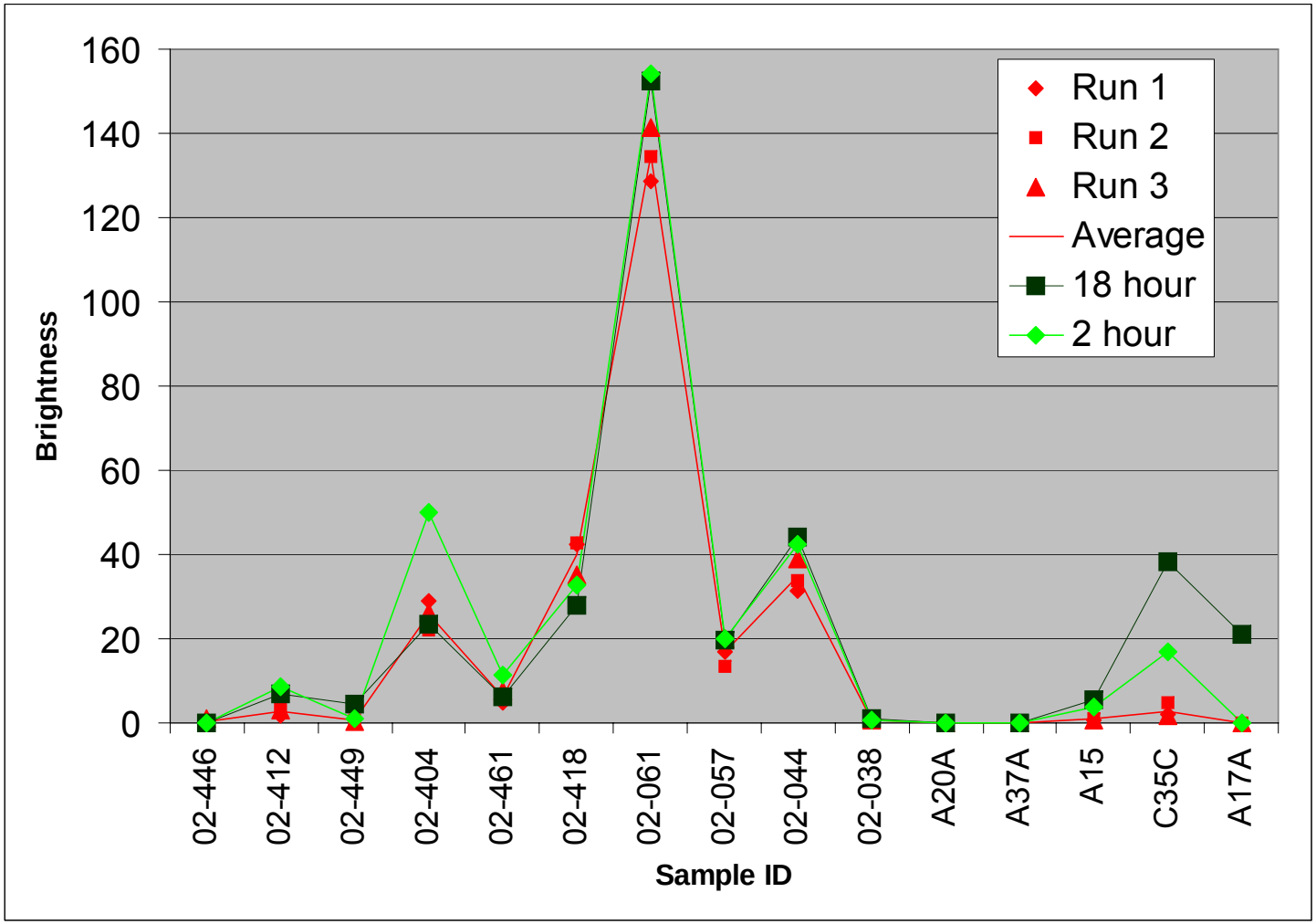
Iowa State University

ES 11 - Penetrant Dwell Time

- Evaluate effect of penetrant dwell time on crack brightness
- All samples hand processed with Level 4 PE penetrant (ZL-37)
- Ten ISU and five RR samples selected
  - RR samples tighter, intermittent cracks in as-machined or shot peened surfaces
- Three baseline runs – penetrant dwell time of 20 minutes
- 18 hour dwell time – penetrant applied followed by 18 hour dwell prior to further processing
- 2 hour dwell time – penetrant applied followed by 2 hour dwell prior to further processing

ES 11 - Penetrant Dwell Time



- Brightness plotted versus average of three baseline runs
- Improvement found in most samples
- Similar results for 2 hour and 18 hour dwell time
- 18 hour better for tightly closed cracks in shot peened surfaces

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Motivation

- When working with hydrophilic emulsifiers, current industry specifications provide allowable concentration ranges for immersion and spray application of each approved chemical, and limit the total contact time for the process.

- However, with complex parts, particularly those with cavities, ensuring that all surfaces are adequately covered, and that the emulsification process is stopped within the time limit can be quite challenging.

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Approach

Four maximum emulsifier concentration ranges are listed in AMS 2647B

- 5% = 5% max
- 10% = 7-10% concentration
- 20% = 17-20% concentration
- 30% = 27-30% concentration

Three representative Level IV sensitivity hydrophilic PE penetrant families were chosen based on their manufacturer's recommended concentrations. They will be referred to as:

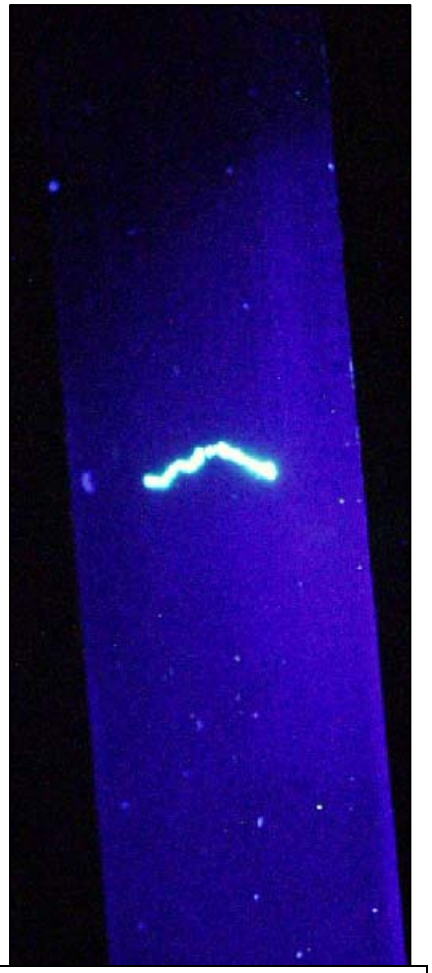
- PL-10 = 10% max
- PM-20 = 20% max (BASELINE MATERIAL)
- PH-30 = 30% max

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.

Approach

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

1. Concentration
    - Lower than recommended
    - Within the recommended range
    - Above the specified range
2. Application Method
    - Immersion
    - Spray
3. Agitation
    - No agitation
    - Periodic agitation
    - Constant agitation
4. Duration
    - Short emulsifier time
    - Maximum emulsification time allowable
    - Twice the maximum emulsification time



Example Indication

How Was It Performed

Spray emulsification using a Hudson Bak-Pak® Sprayer *(model 63184)*

- 5% maximum concentration
- 60, 120, or 240 second spray
- flat fan spray nozzle
- ~80° spray angle
- regulated to 20 psi
- Approximately 1,200 mL/minute
- 12” stand-off distance
- 1 spray pass every 2 seconds

Backpack sprayer for emulsification

Spray emulsification

How Was It Performed

Immersion using a 5-gallon tub

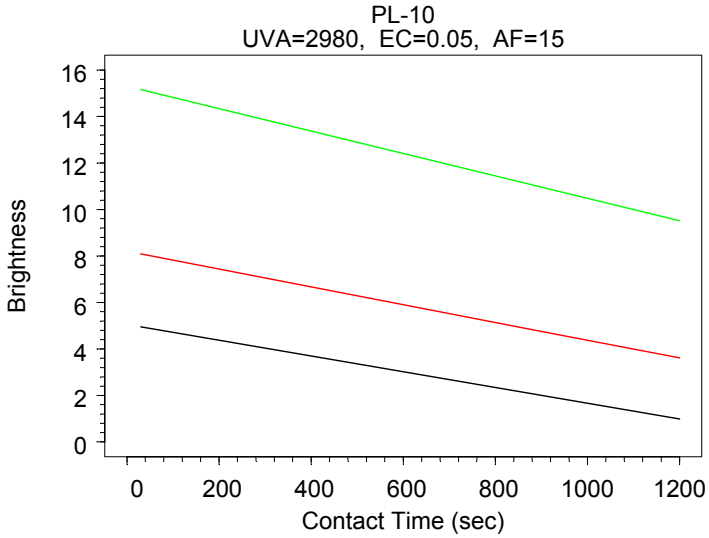
- Concentration
  - PL-10 material
    - 5%, 10%, 15%, 20%
  - PM-20 material
    - 15%, **20%**, 25%
  - PH-30 material
    - 20%, 25%, 30%, 35%
- Time
  - 60, **120**, and 240 seconds
- Agitation
  - none, **15 second intervals**, and constant

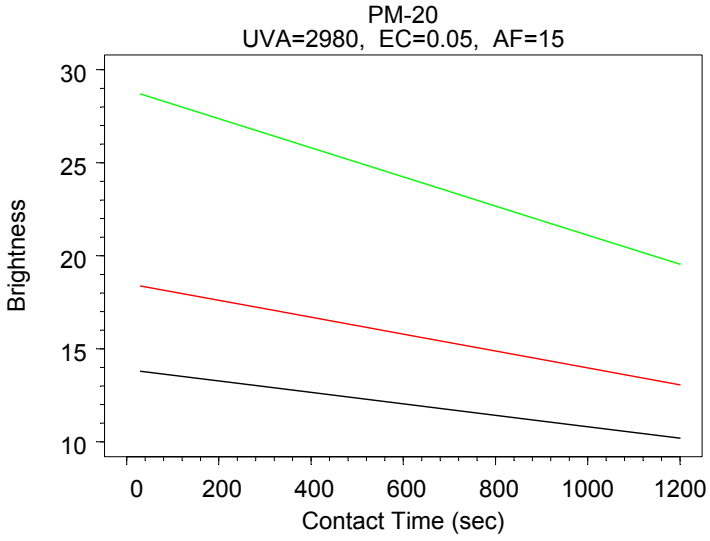
Emulsifier immersion

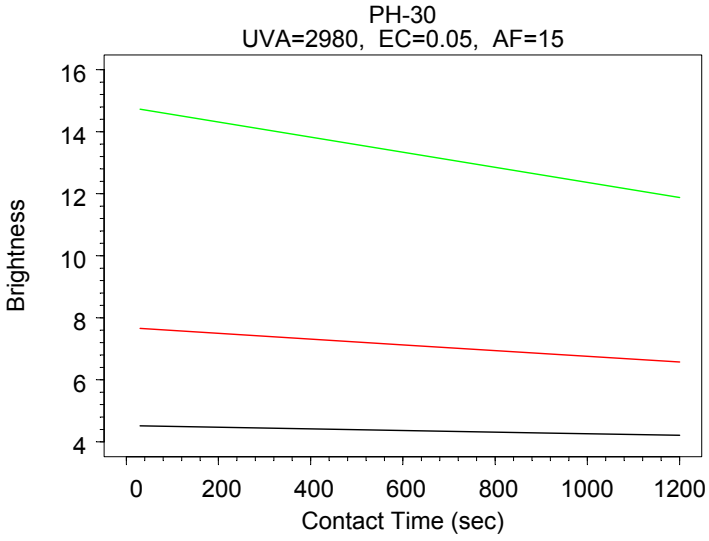
=Baseline Procedure

Contact Time Reduces Brightness

- Regression model used to predict effect of emulsifier contact time on brightness as a function of original brightness
- Brightness decreases with increasing contact time (note predictions beyond 480 minutes are extrapolations of the data)
- Evaluation underway to determine practical significance







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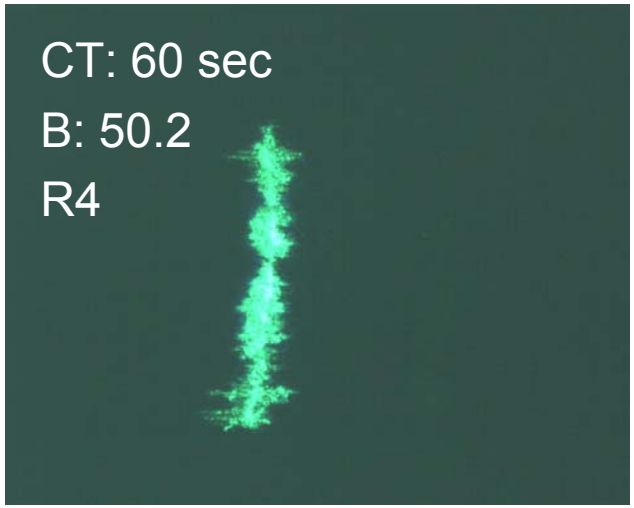
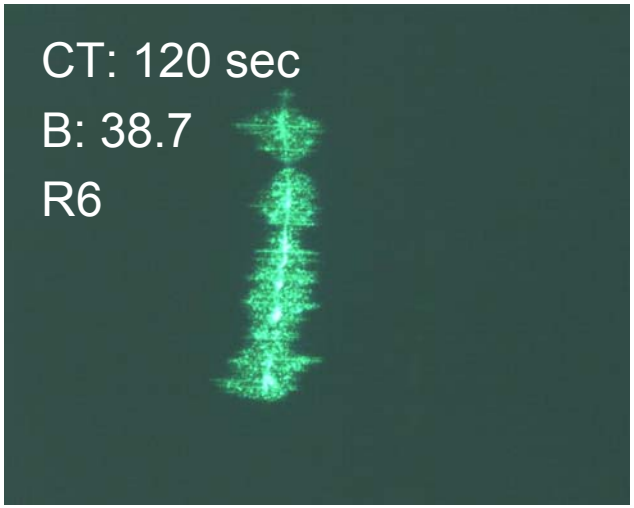
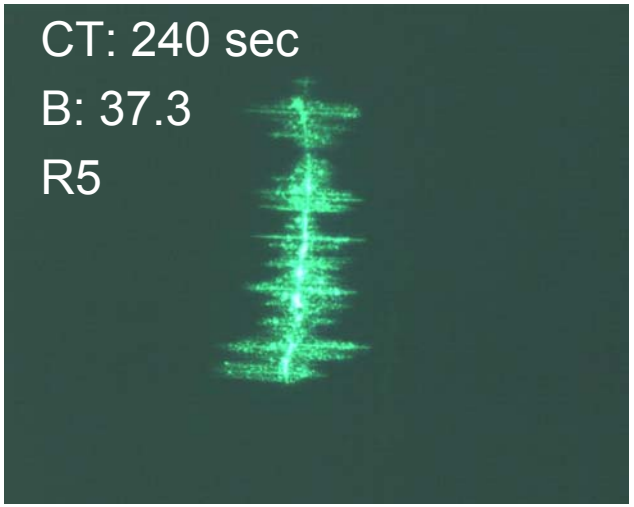
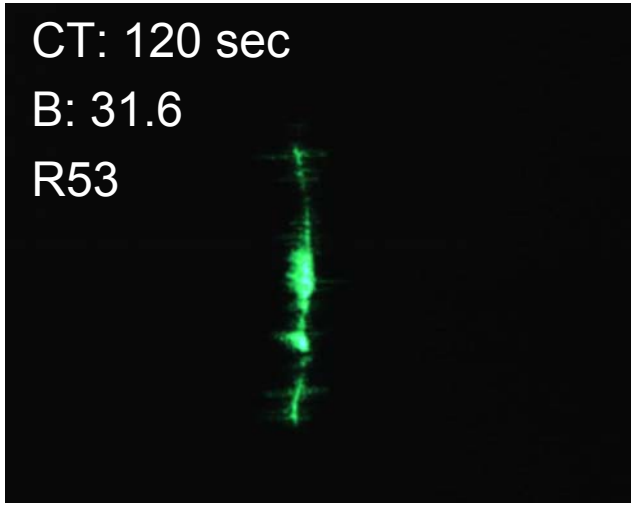
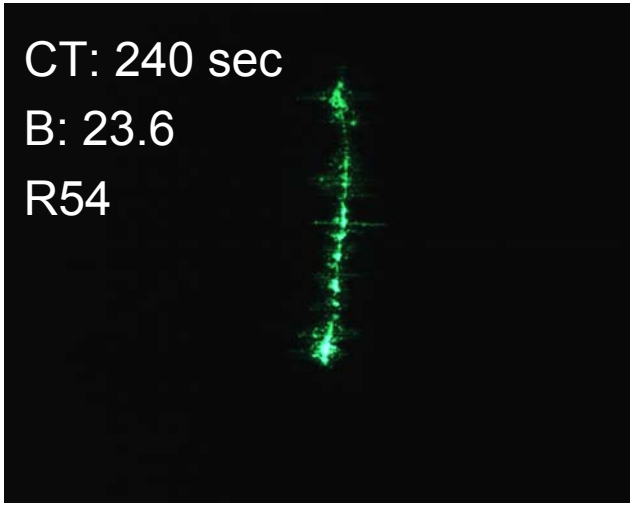
Sample 044 – PM20

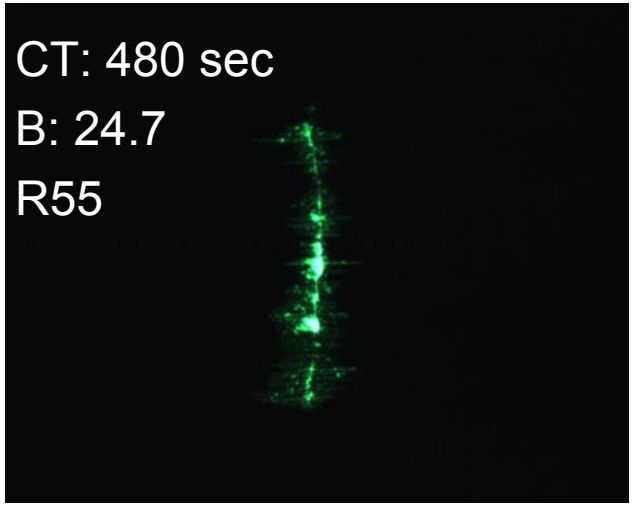












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Conclusions

- Emulsifier concentration has minimal impact on brightness when maintained at reasonable levels (+/- 5% of recommended concentration)
- Contact time has largest impact on brightness with brightness decreasing with increasing contact time
  - Practical significance of decreases under evaluation
- Brightness decreases slightly when no agitation occurs
  - Statistical and practical significance under evaluation

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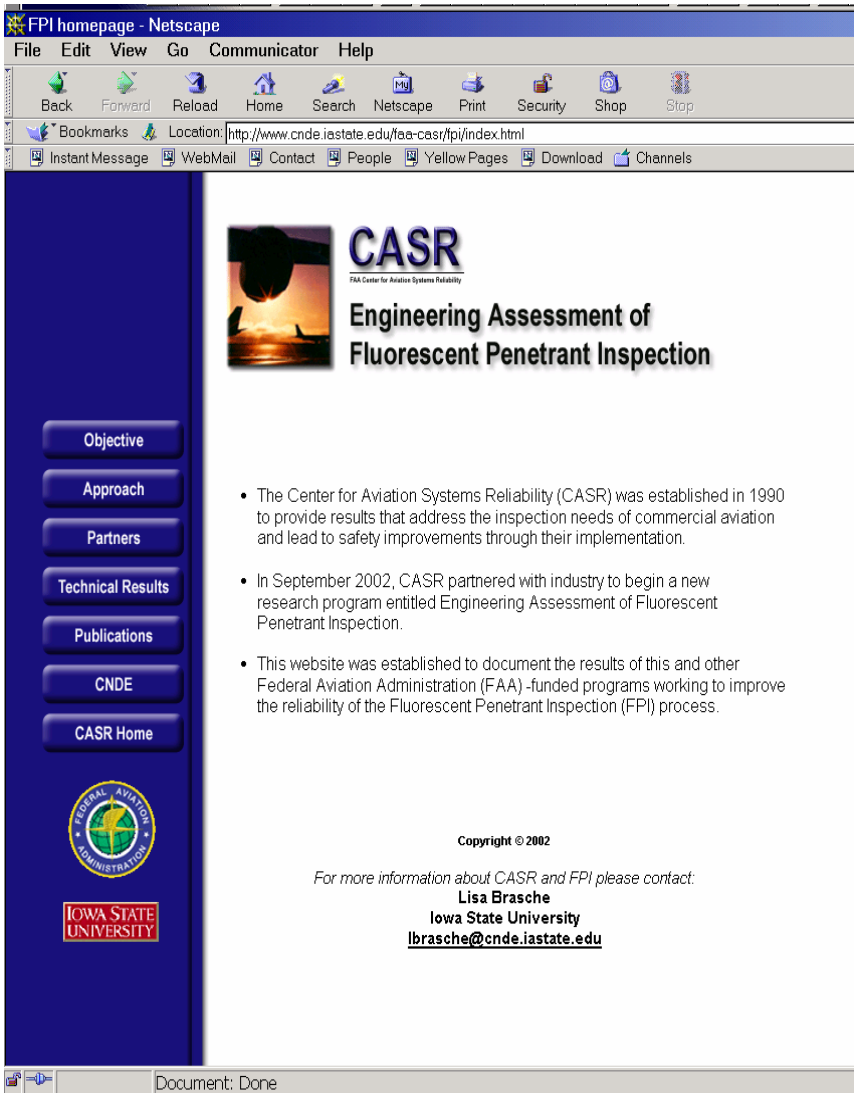
Upcoming Plans

- Complete final runs for emulsifier study and fully document work
- Complete studies of water soluble and water suspendible developers for comparison to earlier dry powder developer work
  - Meeting planned with penetrant vendors and CASR team to fully review the data and arrive at recommendations for improved performance
- Initiate Ti cleaning study with new sample set
- Complete remaining studies in the engineering study plan

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