UVGI Dose Monitors: Characterization, Calibration and Application

2021 CORM/CIE Joint Conference

Labsphere

Labsphere, Inc.

- Founded in 1979
- 8,000 m^2 facility in North Sutton, NH, with satellite facility in Shanghai
- 100+ employees worldwide
- Subsidiary of Halma plc since 2007
- ISO 9001:2015 Registered
- ISO/IEC 17025-2017 Accredited for various products and services (NVLAP Lab Code 200951-0)

Ocean Insight

HALMA

Avo Photonics

Labsphere Explainer Video: [Labsphere: Advancing the Technology of Light - YouTube]

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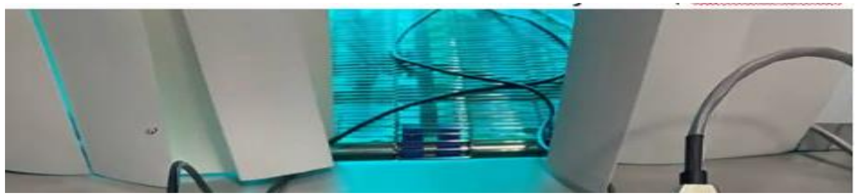
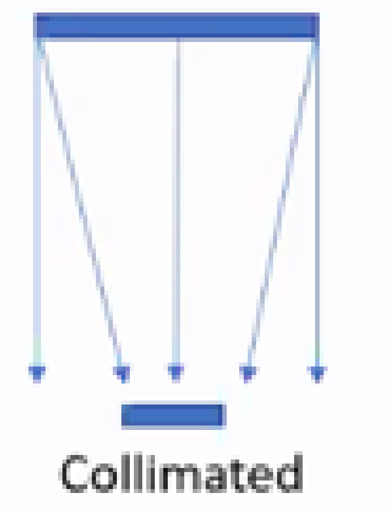
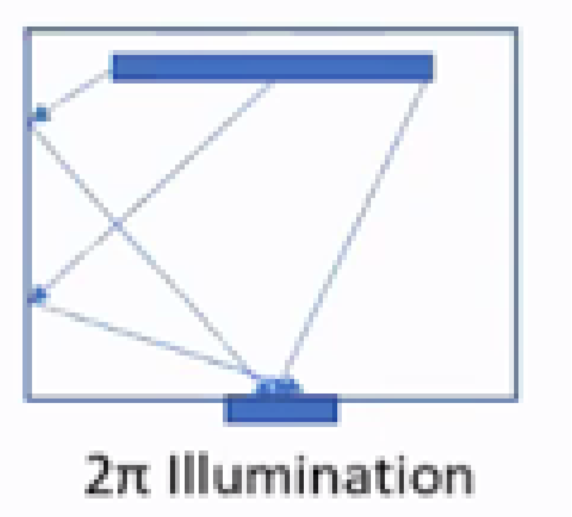
Industry Challenge: Detector Calibration and Characterization

254 nm Low Pressure Mercury Irradiance Measurement in Enclosure



Meter	Meter reading (mW/cm^2)	Deviation from Mean
Meter A	8.53	-42%
Meter B	14.8	1%
Meter C	20.7	41%



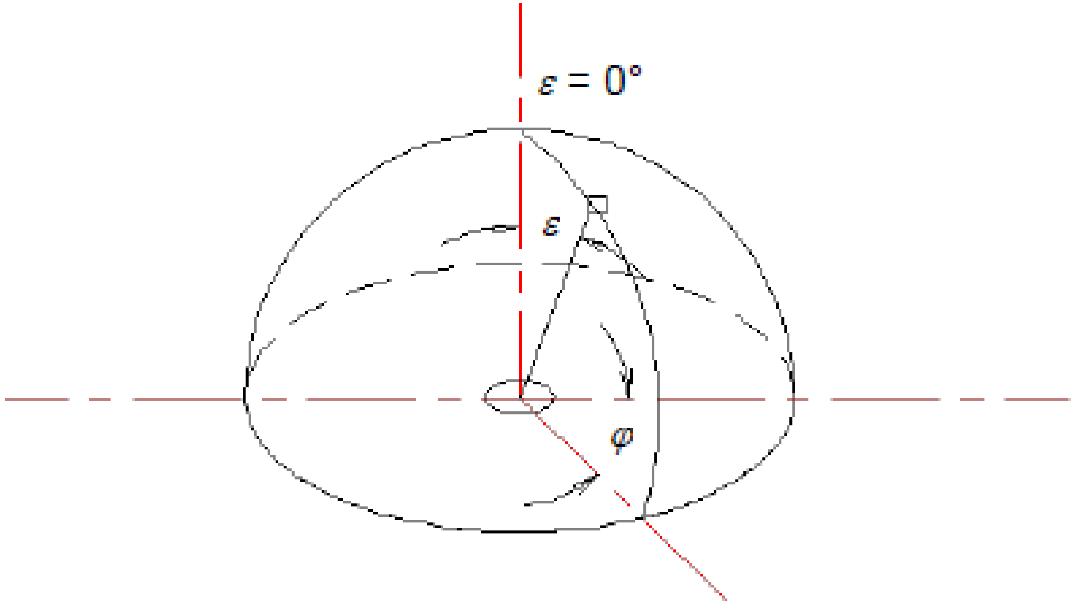


Source: NIST at ICUDAS 2020

Directional Response Index, f_2

f_2 is an index describing the deviation from the ideal cosine law of the responsivity of the radiometer head to radiation incident at angles other than normal to the reference plane of the head

$$f_2(\varepsilon,\varphi) = \frac{Y(\varepsilon,\varphi)}{Y(\varepsilon = 0°,\varphi)\cdot\cos\varepsilon} - 1$$



Source: Technical Report CIE 220:2016

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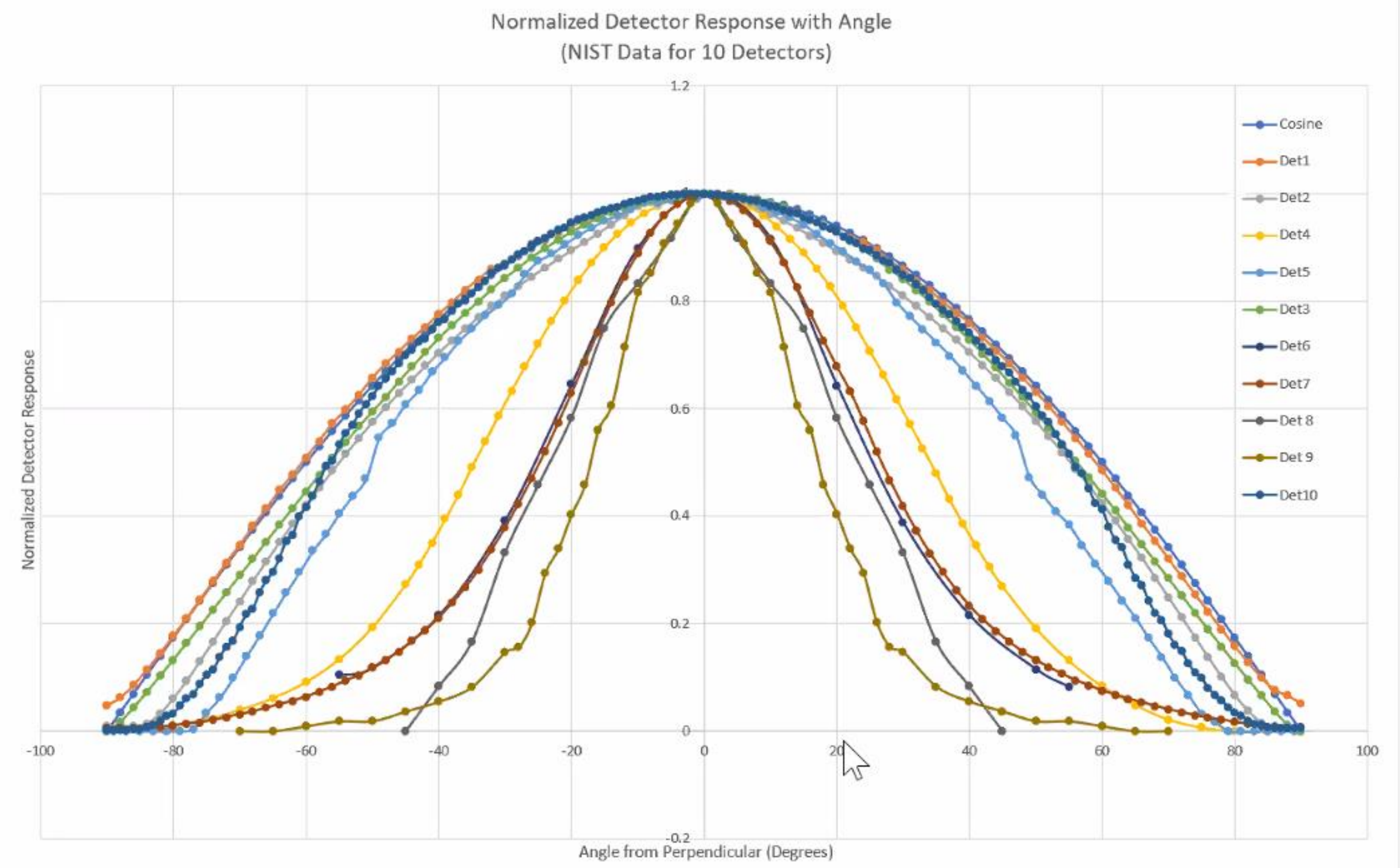
f_2 10 UV sensors with 254 nm source



There are many UV-C sensors with no specs on angular sensitivity (f_2)

Source: Cameron Miller, NIST

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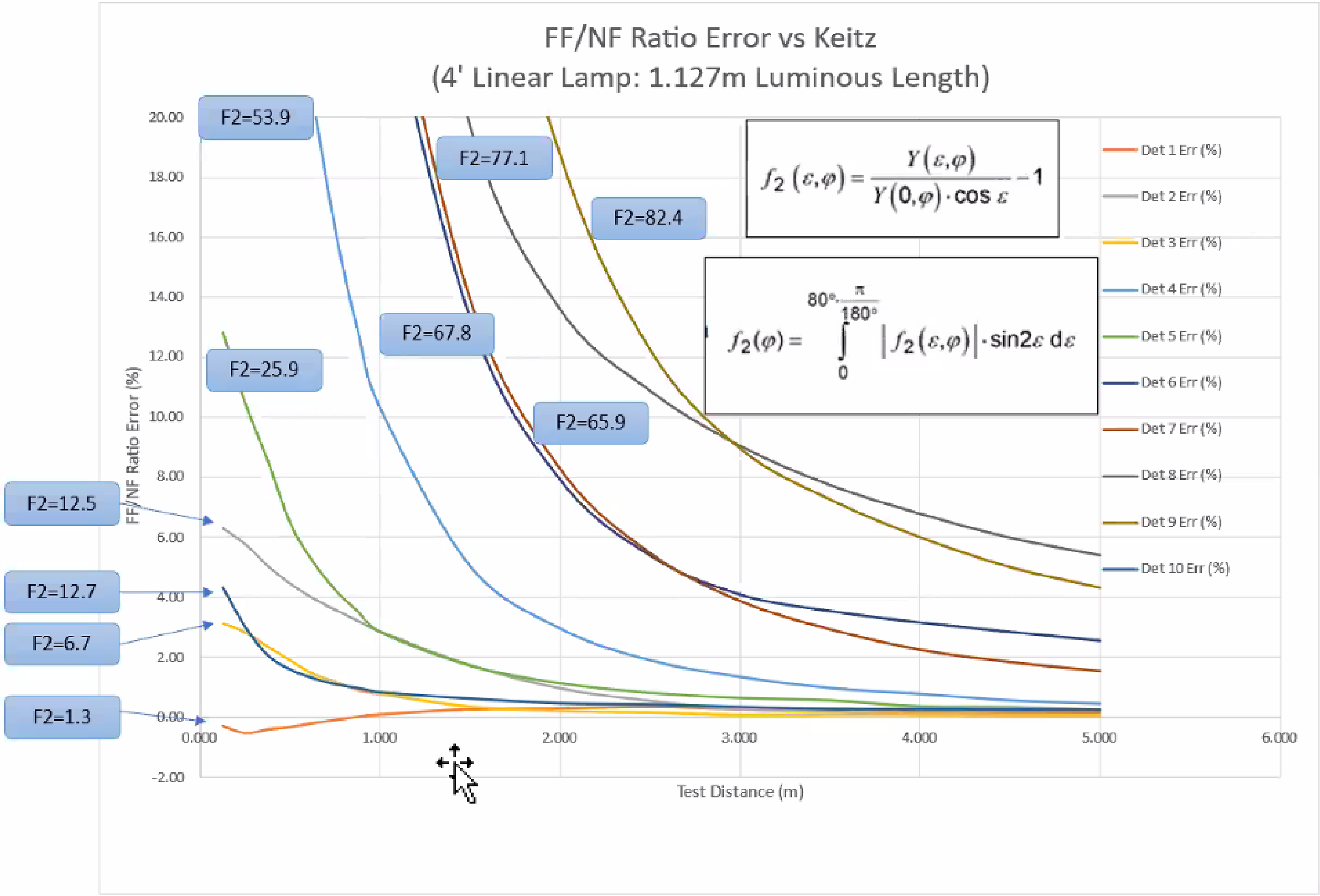
Modeled irradiance measurements of linear UV lamp vs f_2



Modeled and tested impact of the 10 sensors

An f_2 value <3% is desired to minimize errors association with near field measurements

Source: Mike Grather, Lightlab International

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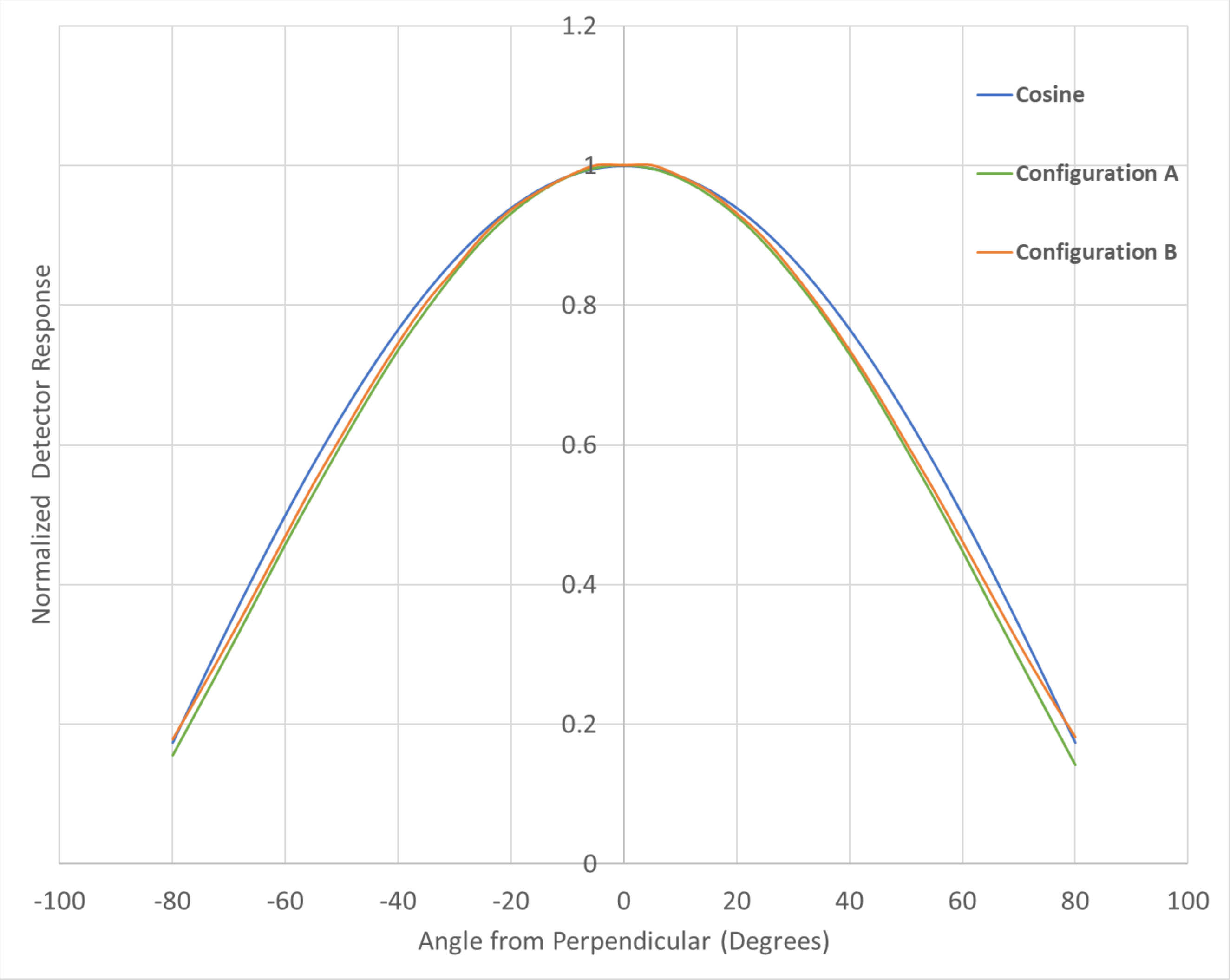
f_2 Sensitivities to Sensor Design

Primary Parameters
Optical Diffuser Material
Diffuser Material Geometry
Sensor/ Diffuser Relations
Shadow Ring
Sensor Signal
Reference Plane

Flat Quartz Bubble Glass

f_2 of 5.8% to 6.0%



At best we were getting Fair performance

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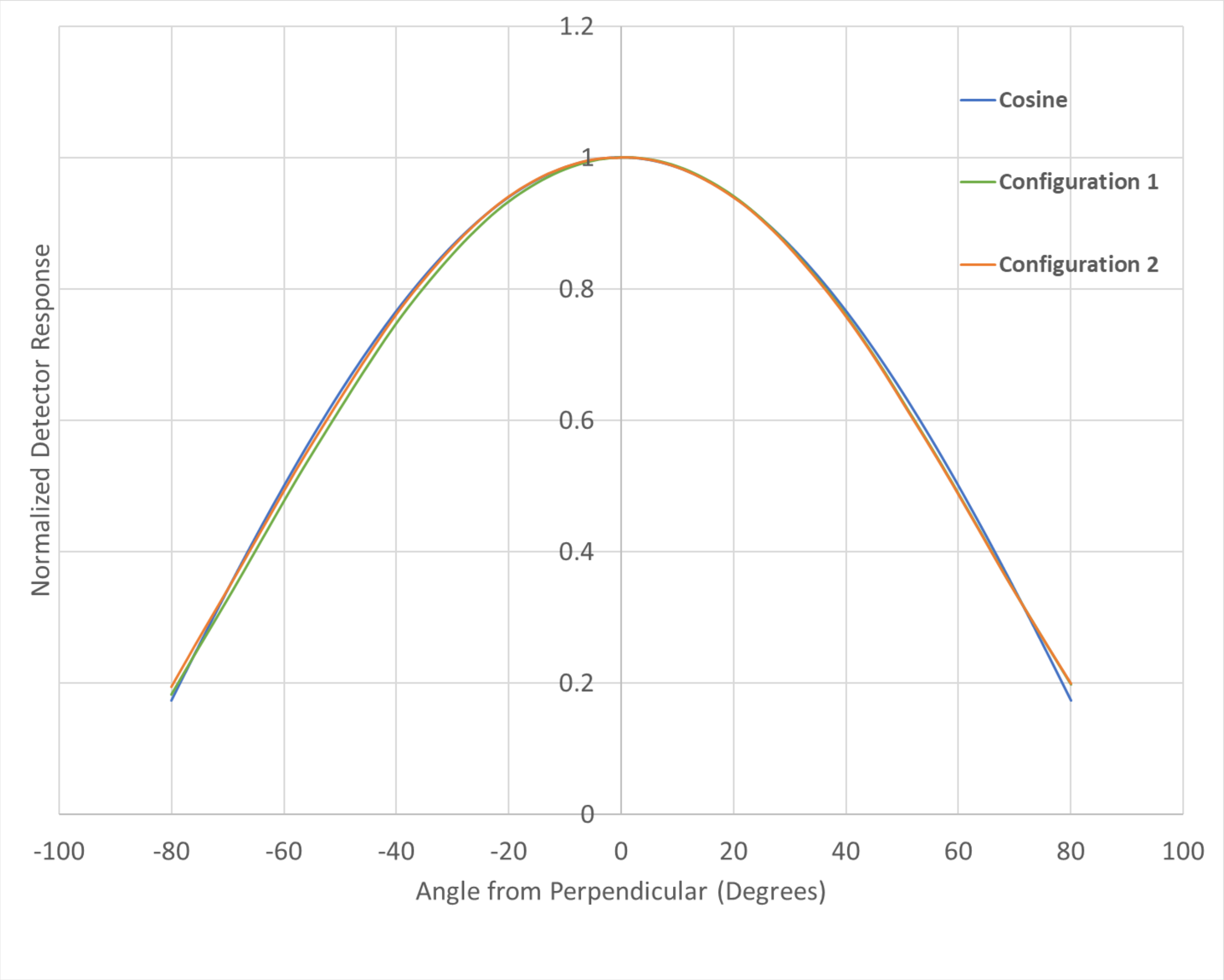
PTFE Dome

With proper design and testing excellent f_2 can be performance achieved

- Optical diffuser materials and geometry
- Shadow ring location and depth
- Interreflections
- Sensor/diffuser relations
- Form factor
- Sensor Signal

End Results: f_2 range of 1.5% to 2.2%



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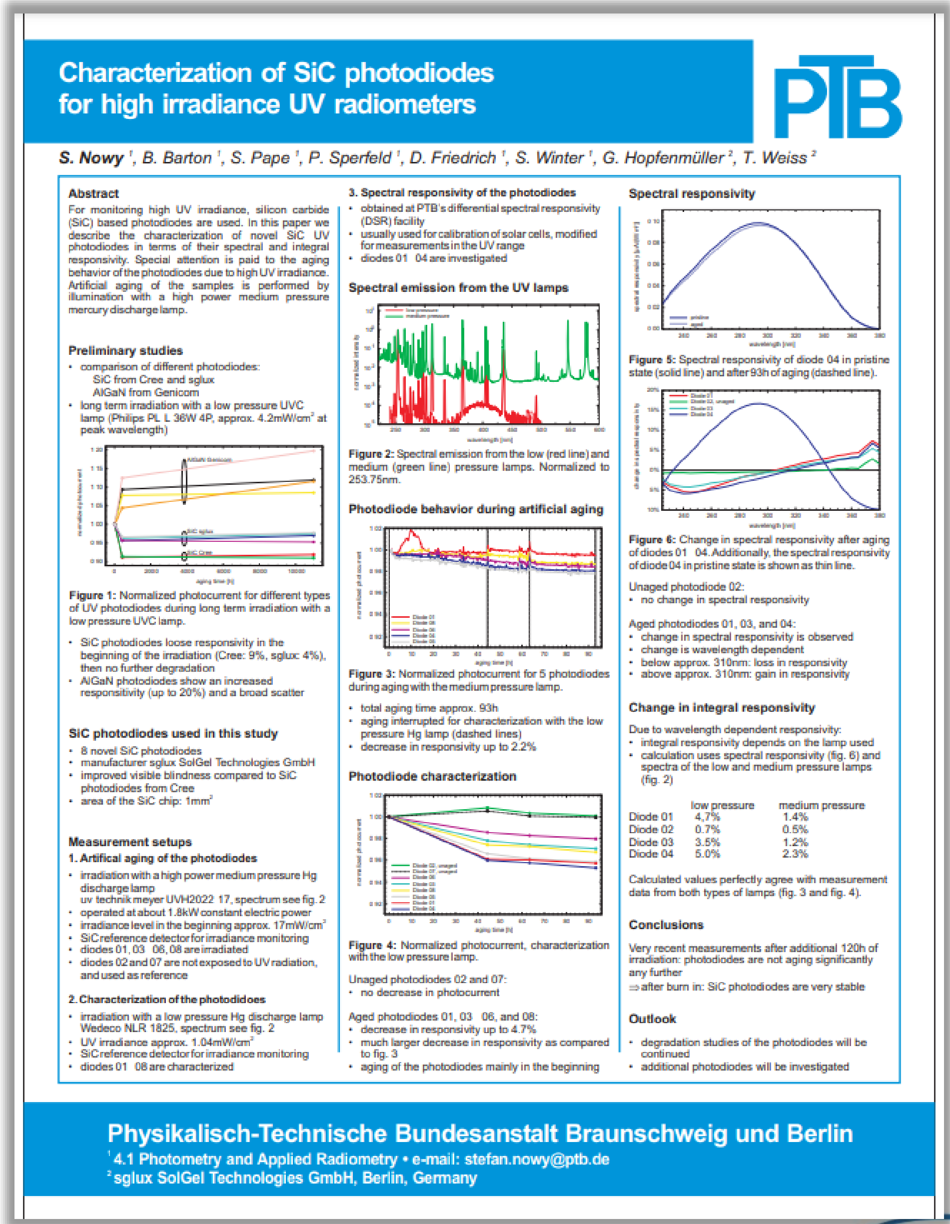
Sensor Stability

- UV photodiodes experience a decay in responsivity with exposure to UVC irradiation.
- This phenomenon has been studied in depth by PTB

For this reason, we evaluated UV sensors currently that are available for the intended applications.



Characterization of SiC photodiodes for high irradiance UV radiometers

PTB

S. Nowy [1], B. Barton [1], S. Pape [1], P. Sperfeld [1], D. Friedrich [1], S. Winter [1], G. Hopfenmüller [2], T. Weiss [2]

Abstract

For monitoring high UV irradiance, silicon carbide (SiC) based photodiodes are used. In this paper we describe the characterization of novel SiC UV photodiodes in terms of their spectral and integral responsivity. Special attention is paid to the aging behavior of the photodiodes due to high UV irradiance. Artificial aging of the samples is performed by illumination with a high power medium pressure mercury discharge lamp.

Preliminary studies

- comparison of different photodiodes:
  SiC from Cree and sglux
  AlGaN from Genicom
- long term irradiation with a low pressure UVC lamp (Philips PL L 36W 4P, approx. 4.2mW/cm² at peak wavelength)

Figure 1: Normalized photocurrent for different types of UV photodiodes during long term irradiation with a low pressure UVC lamp.

- SiC photodiodes loose responsivity in the beginning of the irradiation (Cree: 9%, sglux: 4%), then no further degradation
- AlGaN photodiodes show an increased responsitivity (up to 20%) and a broad scatter

SiC photodiodes used in this study

- 8 novel SiC photodiodes
- manufacturer sglux SolGel Technologies GmbH
- improved visible blindness compared to SiC photodiodes from Cree
- area of the SiC chip: 1mm²

Measurement setups

1. Artifical aging of the photodiodes

- irradiation with a high power medium pressure Hg discharge lamp
  uv technik meyer UVH2022 17, spectrum see fig. 2
- operated at about 1.8kW constant electric power
- irradiance level in the beginning approx. 17mW/cm²
- SiC reference detector for irradiance monitoring
- diodes 01, 03 06, 08 are irradiated
- diodes 02 and 07 are not exposed to UV radiation, and used as reference

2. Characterization of the photodidoes

- irradiation with a low pressure Hg discharge lamp Wedeco NLR 1825, spectrum see fig. 2
- UV irradiance approx. 1.04mW/cm²
- SiC reference detector for irradiance monitoring
- diodes 01 08 are characterized

3. Spectral responsivity of the photodiodes

- obtained at PTB's differential spectral responsivity (DSR) facility
- usually used for calibration of solar cells, modified for measurements in the UV range
- diodes 01 04 are investigated

Spectral emission from the UV lamps

Figure 2: Spectral emission from the low (red line) and medium (green line) pressure lamps. Normalized to 253.75nm.

Photodiode behavior during artificial aging

Figure 3: Normalized photocurrent for 5 photodiodes during aging with the medium pressure lamp.

- total aging time approx. 93h
- aging interrupted for characterization with the low pressure Hg lamp (dashed lines)
- decrease in responsivity up to 2.2%

Photodiode characterization

Figure 4: Normalized photocurrent, characterization with the low pressure lamp.

Unaged photodiodes 02 and 07:
- no decrease in photocurrent

Aged photodiodes 01, 03 06, and 08:
- decrease in responsivity up to 4.7%
- much larger decrease in responsivity as compared to fig. 3
- aging of the photodiodes mainly in the beginning

Spectral responsivity

Figure 5: Spectral responsivity of diode 04 in pristine state (solid line) and after 93h of aging (dashed line).

Figure 6: Change in spectral responsivity after aging of diodes 01 04. Additionally, the spectral responsivity of diode 04 in pristine state is shown as thin line.

Unaged photodiode 02:
- no change in spectral responsivity

Aged photodiodes 01, 03, and 04:
- change in spectral responsivity is observed
- change is wavelength dependent
- below approx. 310nm: loss in responsivity
- above approx. 310nm: gain in responsivity

Change in integral responsivity

Due to wavelength dependent responsivity:
- integral responsivity depends on the lamp used
- calculation uses spectral responsivity (fig. 6) and spectra of the low and medium pressure lamps (fig. 2)

	low pressure	medium pressure
Diode 01	4,7%	1.4%
Diode 02	0.7%	0.5%
Diode 03	3.5%	1.2%
Diode 04	5.0%	2.3%

Calculated values perfectly agree with measurement data from both types of lamps (fig. 3 and fig. 4).

Conclusions

Very recent measurements after additional 120h of irradiation: photodiodes are not aging significantly any further
⇒ after burn in: SiC photodiodes are very stable

Outlook

- degradation studies of the photodiodes will be continued
- additional photodiodes will be investigated

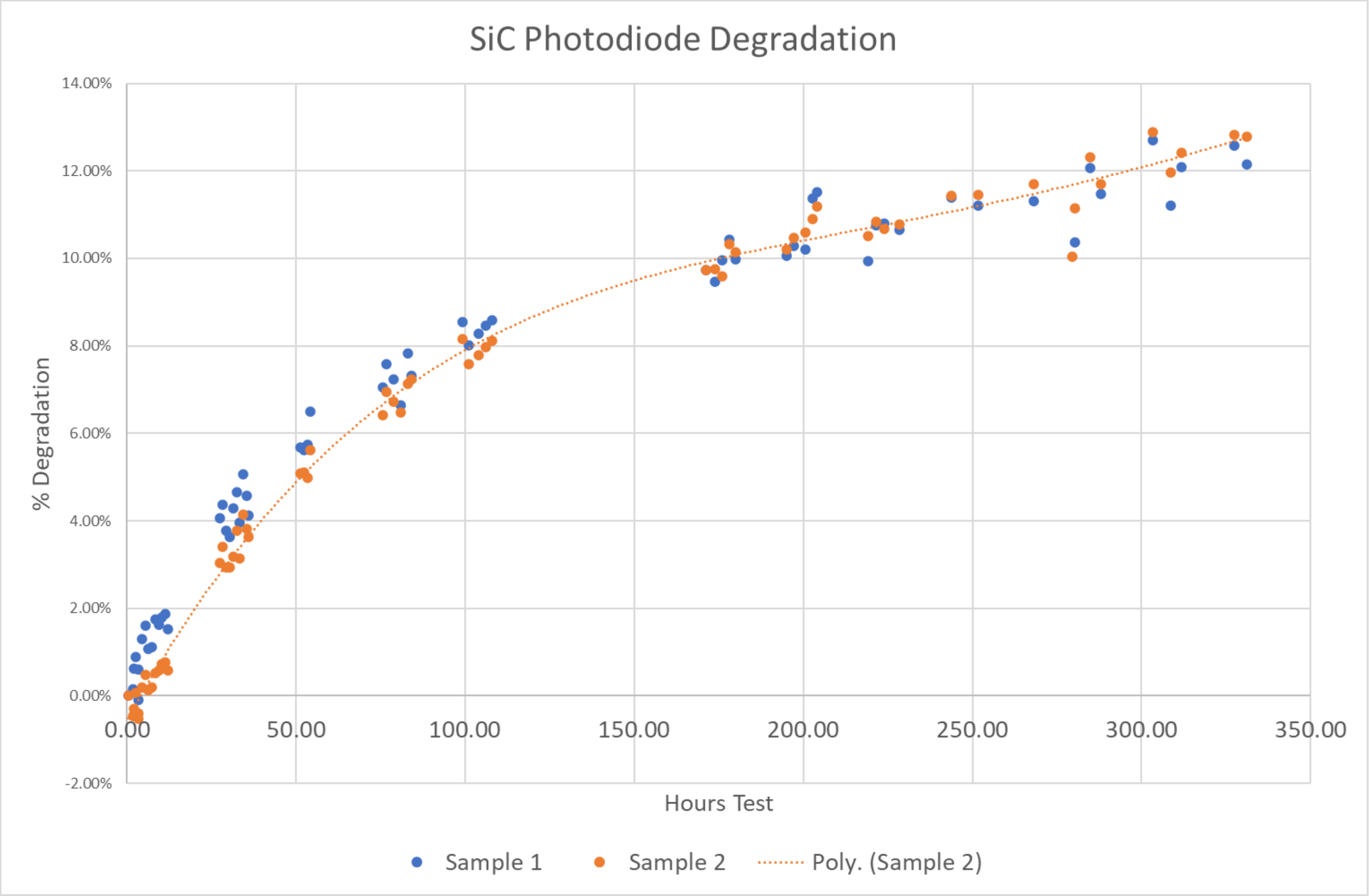
Physikalisch-Technische Bundesanstalt Braunschweig und Berlin
[1] 4.1 Photometry and Applied Radiometry • e-mail: stefan.nowy@ptb.de
[2] sglux SolGel Technologies GmbH, Berlin, Germany

Source: PTB Publication

Sensor Stability

Labsphere has studied the degradation of UVC photodiodes to determine a pre-production exposure process.

Degradation becomes linear after 150 hrs. of exposure at a know irradiance level



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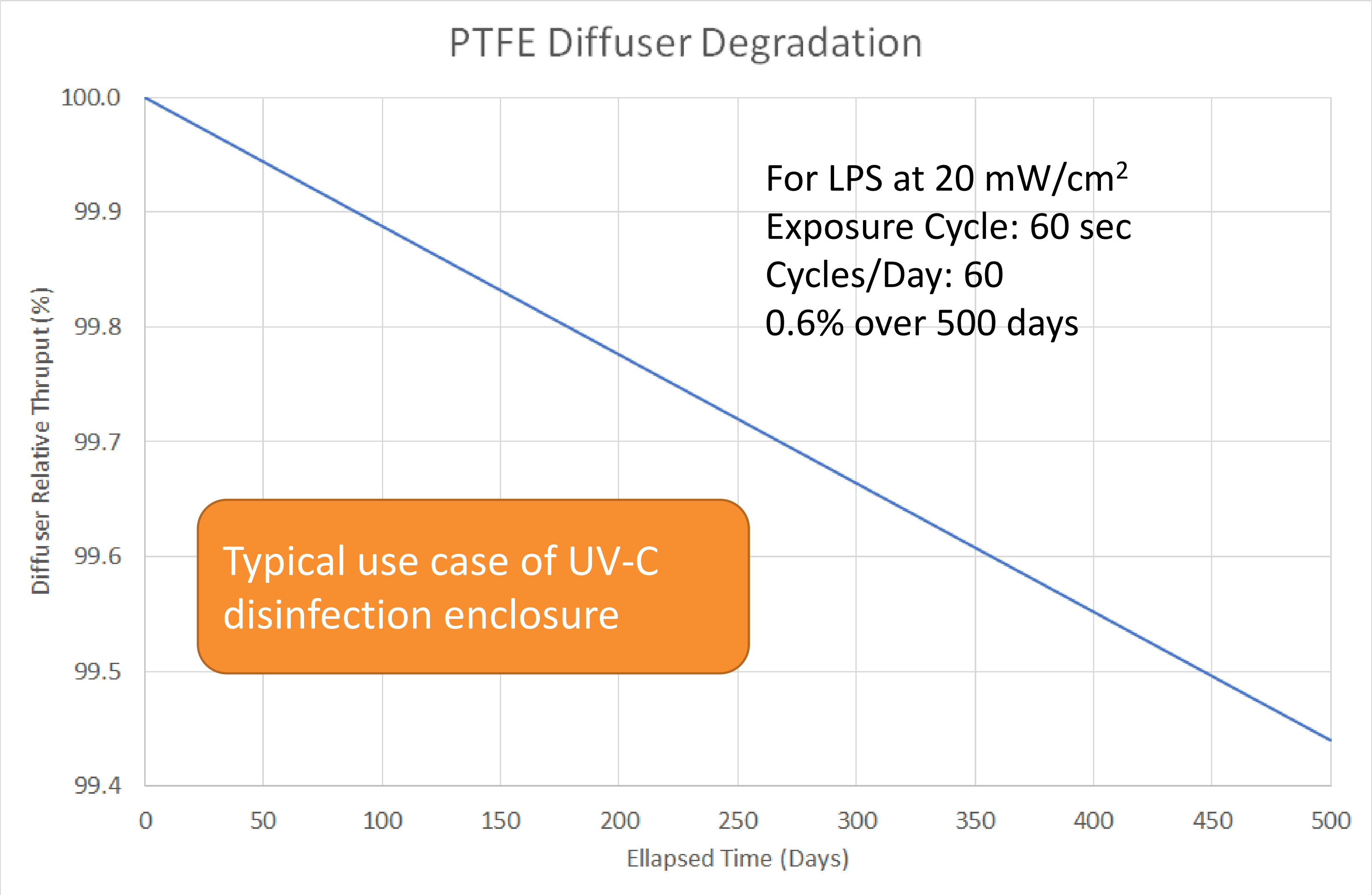
Diffuser Stability

- Anecdotal information claims degradation of Teflon diffusers with exposure to UV-C.
- Labsphere has studied this phenomenon for specific use case.
- Our results show predicted diffuser degradation for specific use case. Accounts for exposure and duty cycle.



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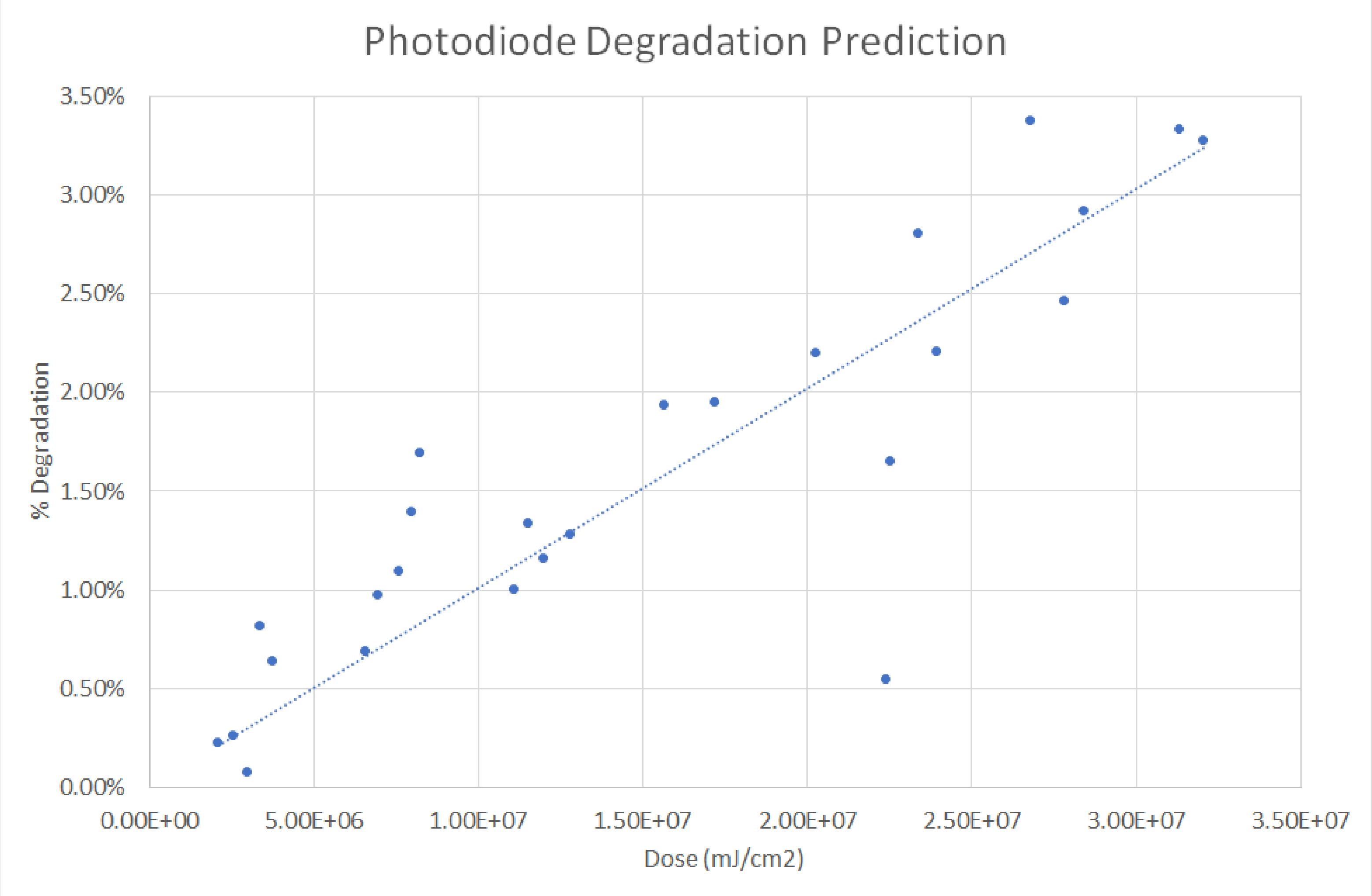
Sensor System Life Projections

- After pre-production exposure photodiode degradation can be predicted.
- Degradation is correlated to dose.

Dose can be tracked for specific applications.



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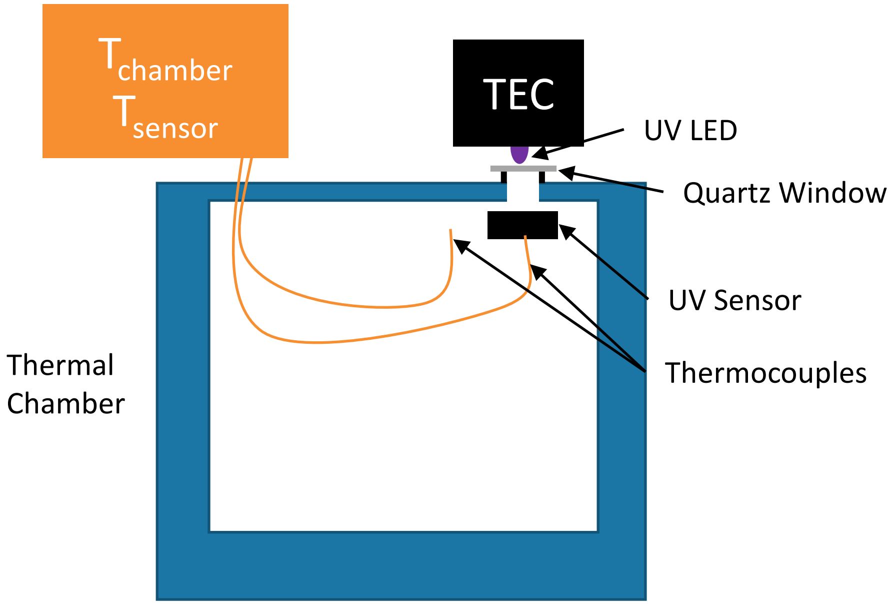
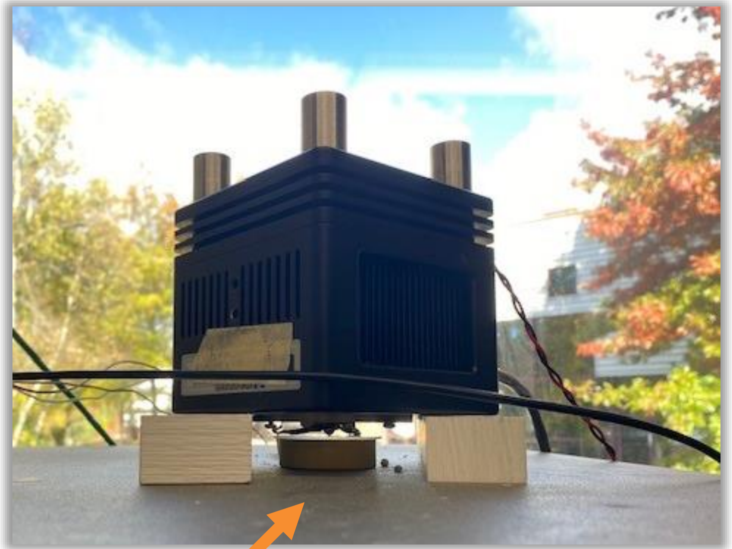
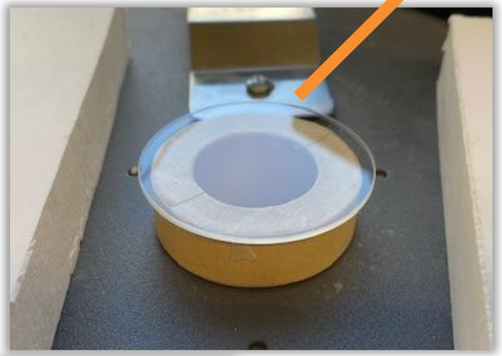
Thermal Sensitivity – Test Setup

- Thermal chamber with UV sensor inside
- UV Source outside
  - TEC Controlled
  - Must be stable over testing period
- Quartz window to shield source from heat
- Thermocouple to monitor Chamber & Sensor







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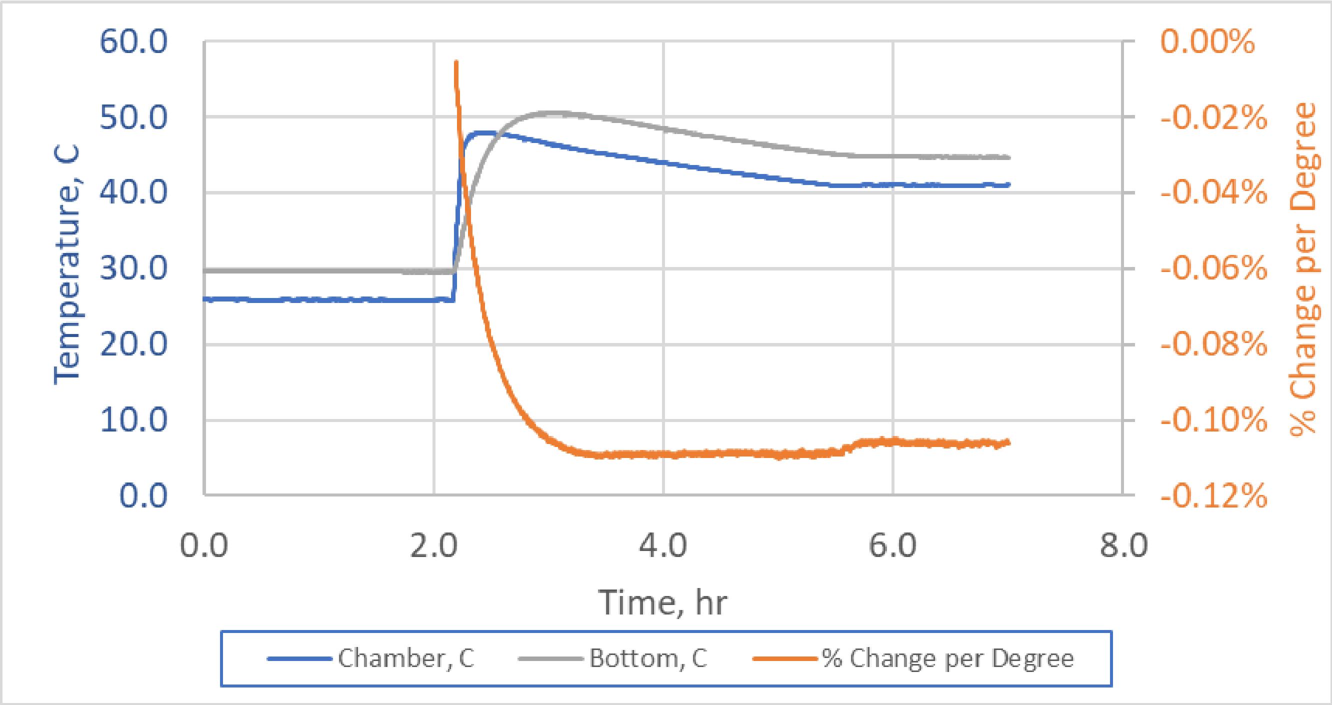
Sensor Thermal Sensitivity

- Expose Sensor to UV Source
- Soak sensor in thermal chamber at 25C for 2 hr.
- Ramp ambient to 40C and soak at 40C for 1 hr.
- Record irradiance
- Calculate change v. Temperature
- Thermal sensitivity = 0.11% per °C

Data allows for determining uncertainty from the differentiation for calibration temperature.



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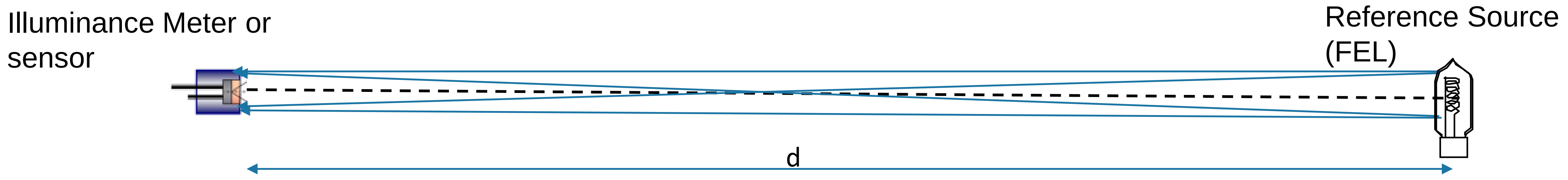
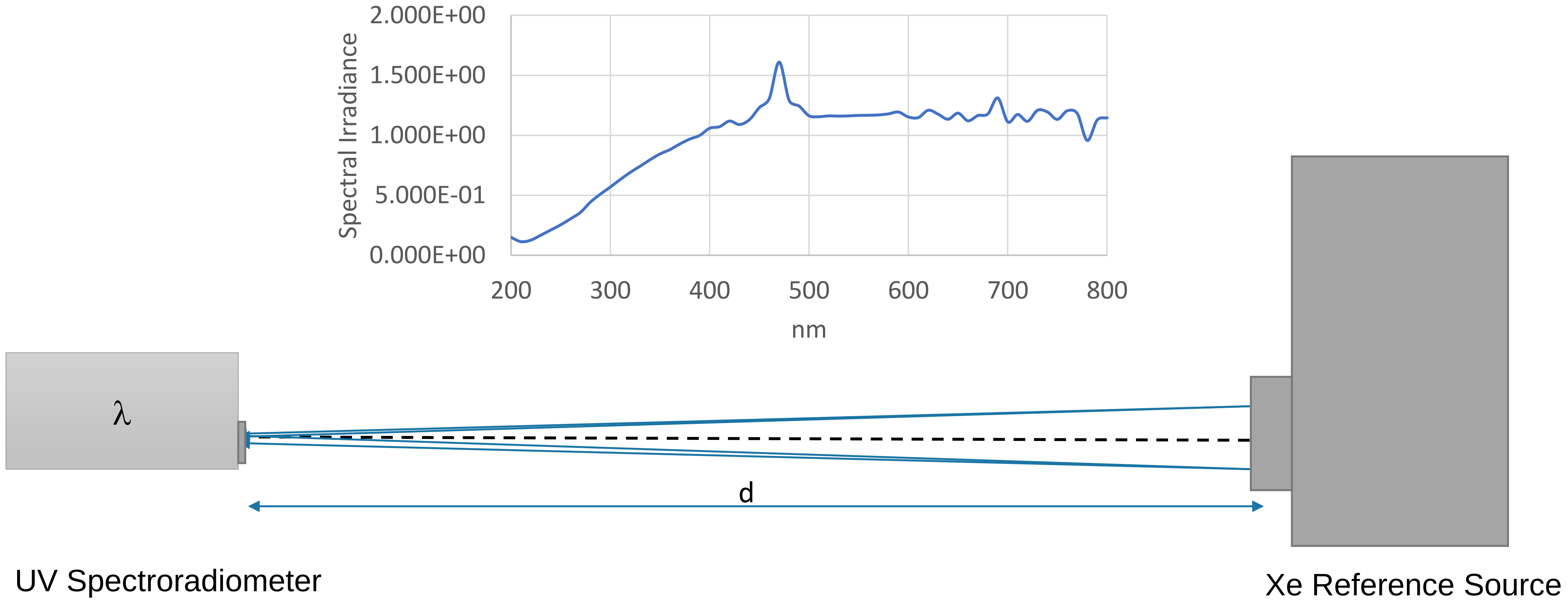
Typical Sensor Illuminance Responsivity Calibration Method

Illuminance Responses of Optical Sensors
At normal incidence



Step1: Irradiance Transfer with UV Spectroradiometer



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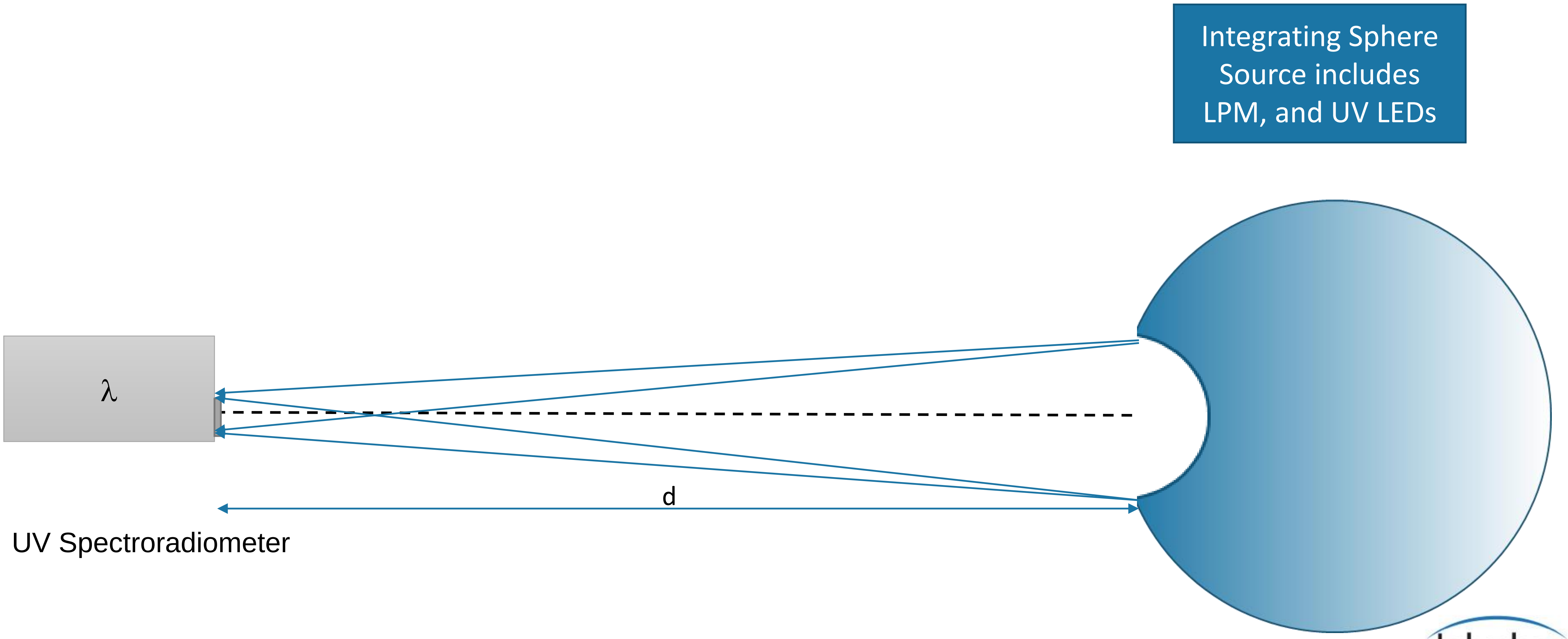
Step 2: Irradiance Transfer with UV Spectroradiometer

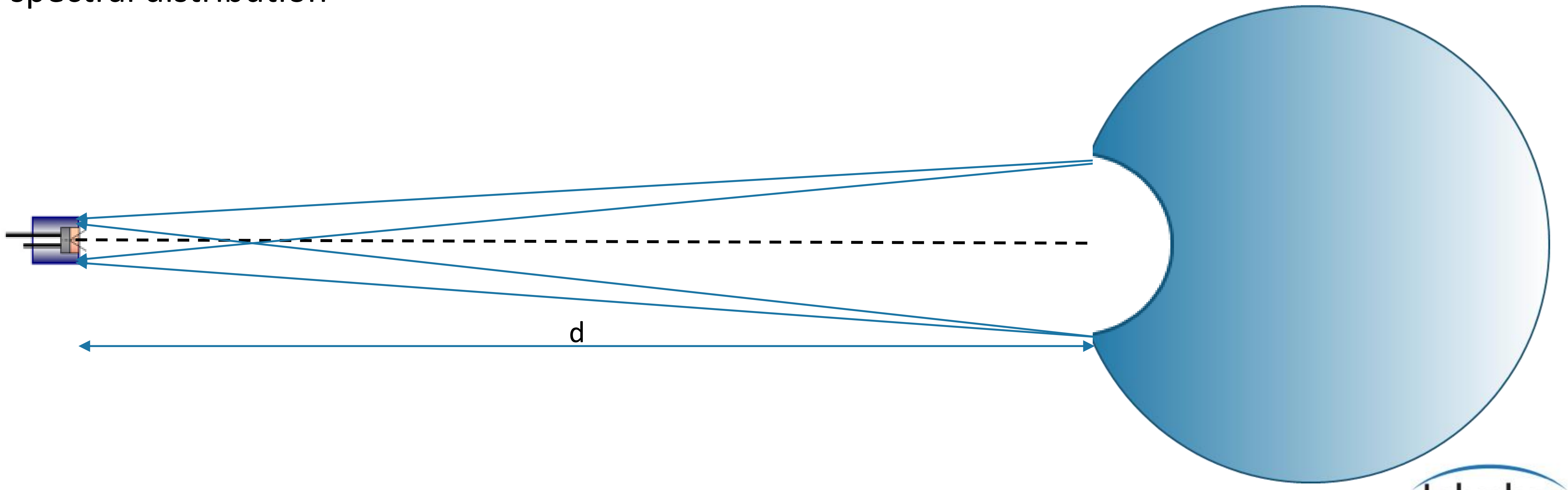


Step 3: Modified Sensor Irradiance Responsivity Calibration Method

Irradiance Response of Sensor

Reference source spectral distribution is the similar as test source spectral distribution

Integrating Sphere Source includes LPM, and UV LEDs



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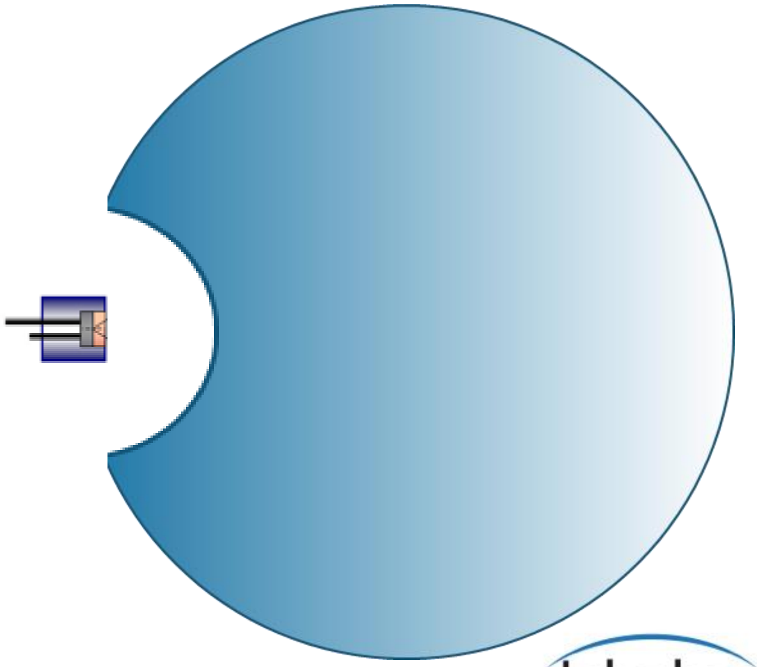
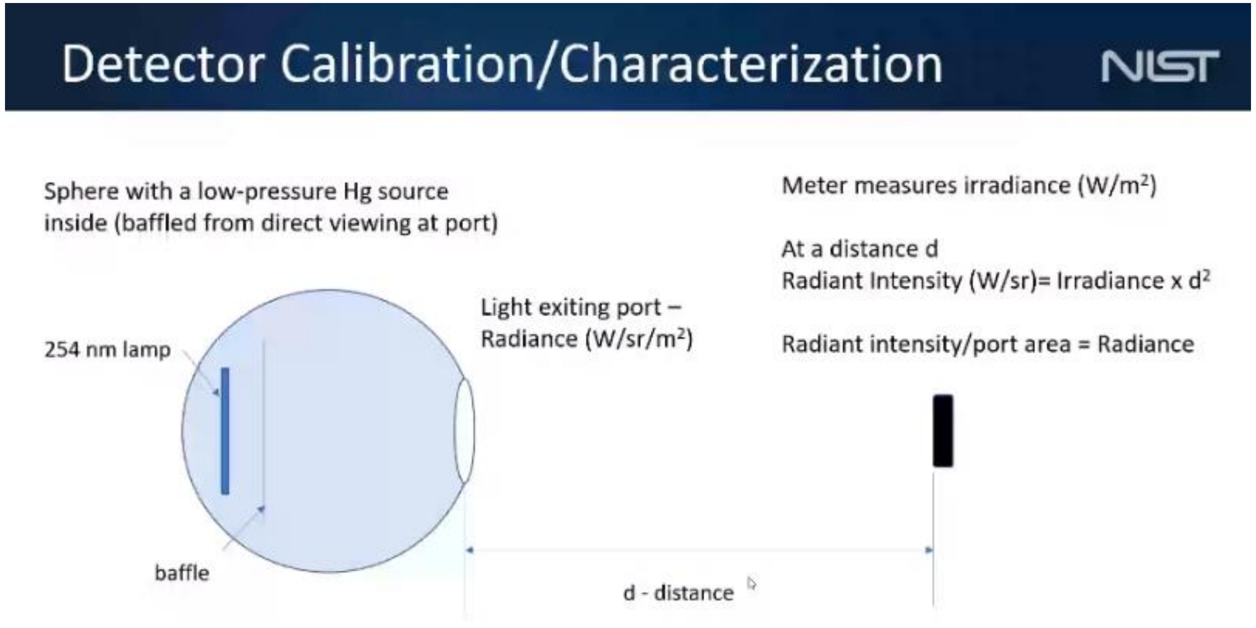
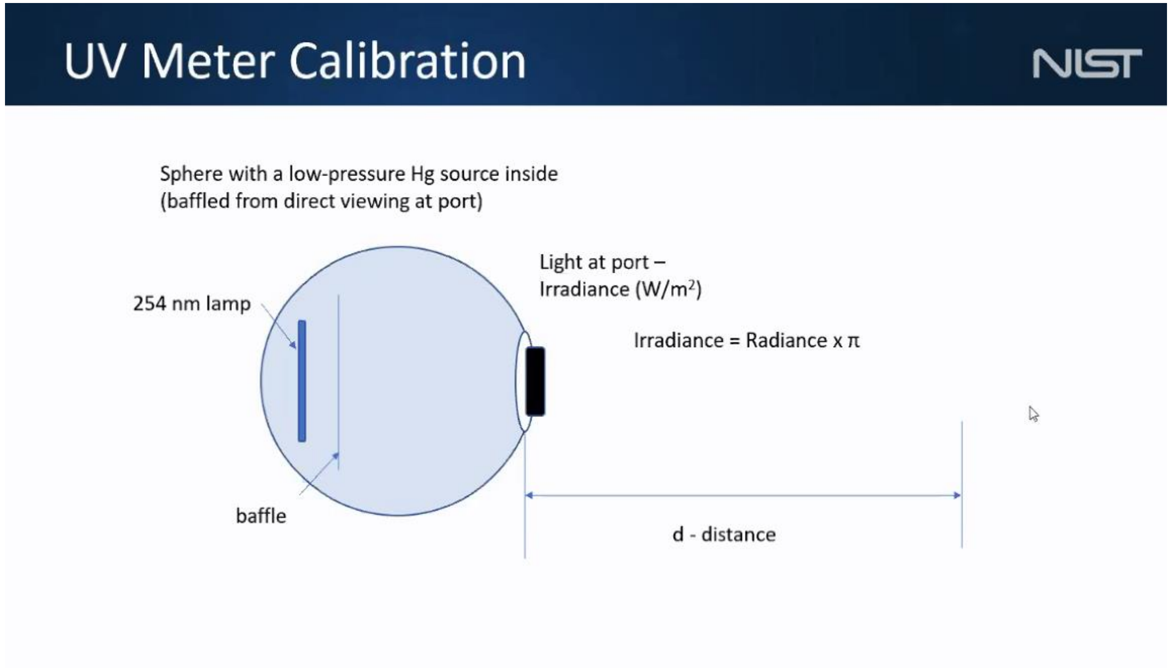


Proposed method for correcting f2 errors of UV sensors





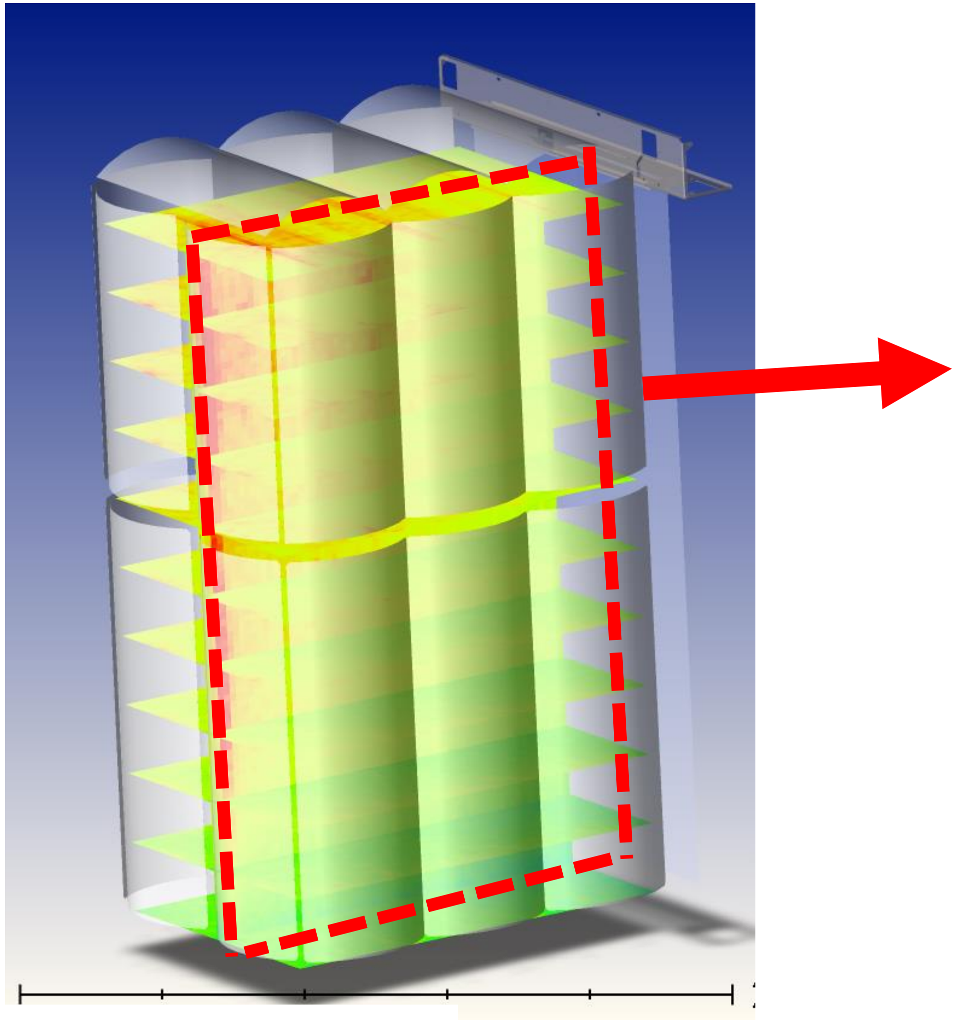
New ANSI IES Reference being developed to address UV-C detector Characterization and Calibration

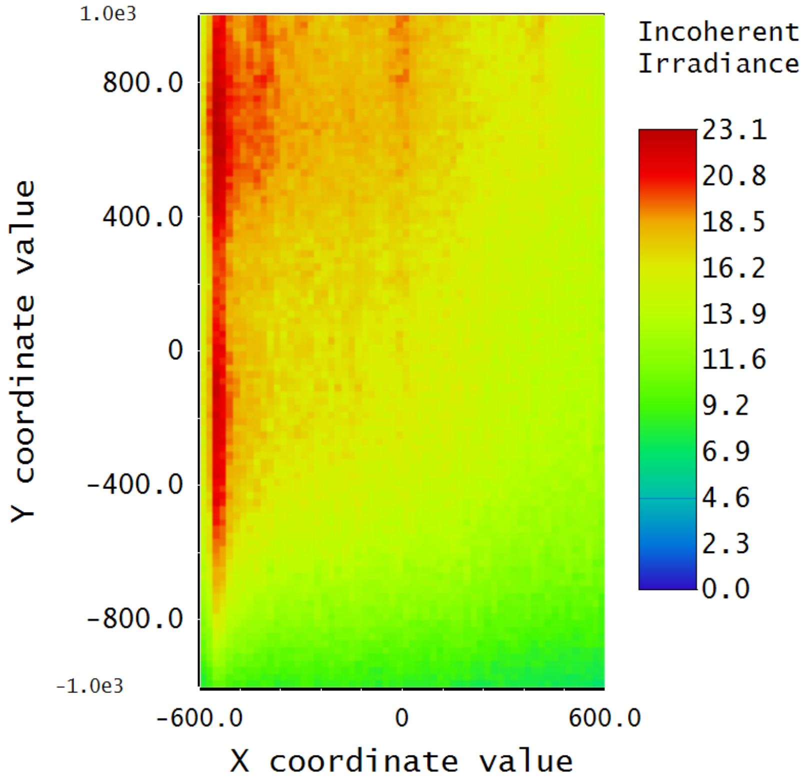
Case Study: Modeling for Optimization of Sensor Locations in an Enclosure

Case Study: Modeling for Optimization of Sensors Location in and Enclosure

- **CAD Model** of Enclosure
  - 19 lamps in 7 modules
- **Panel Reflectors Assumptions**
  - 86% per Anomet datasheet
  - 50% diffuse and 50% specular.
  - The floor is non-reflective.
- **16 detector planes**
  - Detector area = 50 mm^2
  - Near Perfect cosine response
- **Reference Sensor**
  - Center of chamber, 1m from floor (predetermined high touch target area)
- **13 Lighting Scenarios**
  - Vary light levels by 5% and 20%
  - Turn off select panels
  - Turn off individual lamps
  - Analyze ratio of irradiance at center sensor and wall sensor

Zemax Model Irradiance Distribution





Allowed Labsphere to determine best locations for embedded dose monitors

Detector Image: Incoherent Irradiance

UV Concepts Enclosure - Irradiance Distribution
4/28/2021
Detector 32, NSCG Surface 1: Vertical Plane
Size 1200.000 W X 2000.000 H Millimeters, Pixels 60 W X 100 H, Total Hits = 142333025
Peak Irradiance : 2.3113E+01 Milliwatts/cm^2
Total Power : 3.6555E+02 Watts

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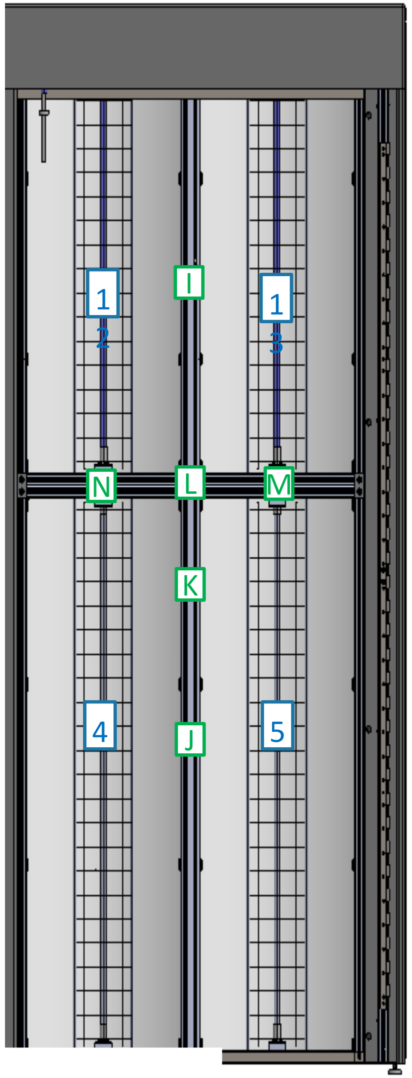
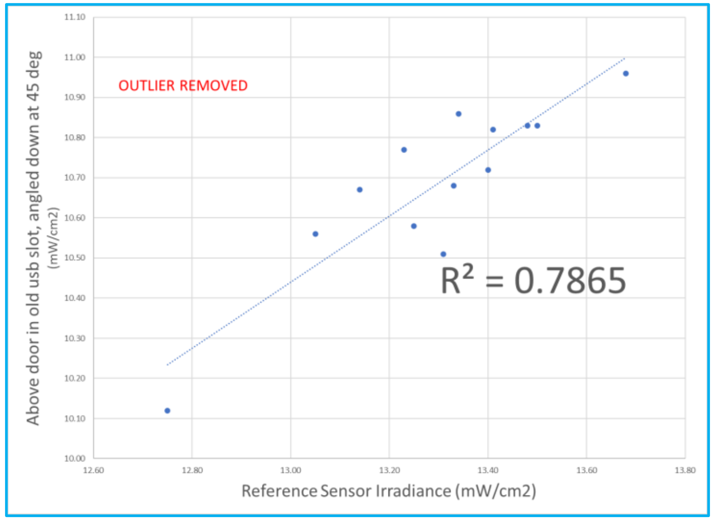
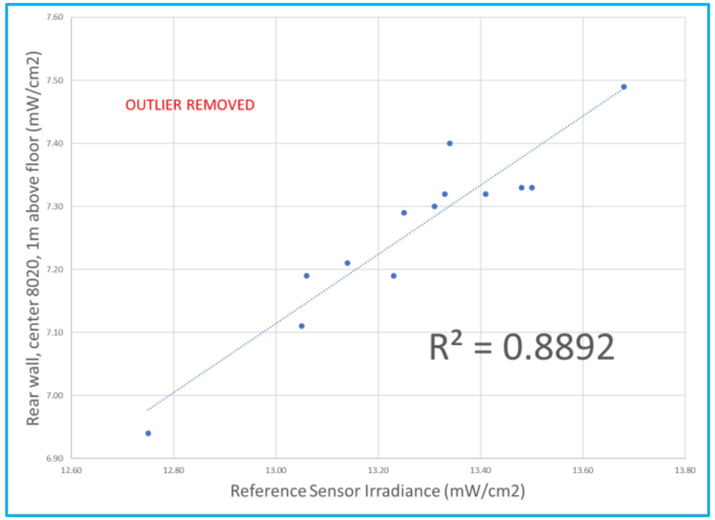
Linear Correlation to Reference Sensor







Summary Modeling and Correlation

- <2% average deviation for all detectors across all scenarios
- Sensor averaging improved correlation
- Results guided us to what dose monitor locations to test
- On site testing validated modeling
- Results of modeling lead to proposal for optimal locations for SMARTSens Dose Monitors

SMARTSens-D Solutions

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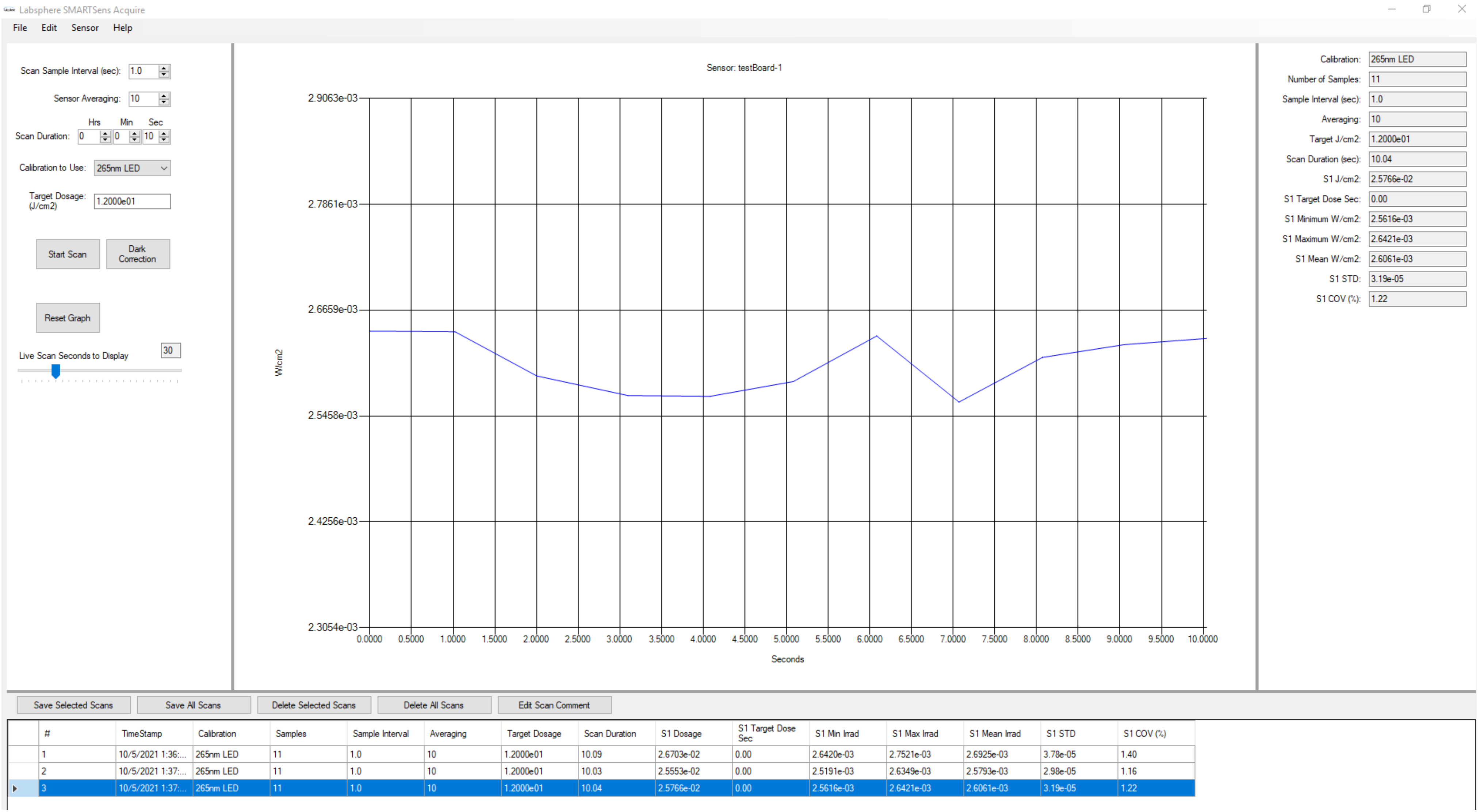
Control and Analytics



API Dashboard Example (Concept)

Main Takeaways

- For existing and new applications of UV-C Sensors f_2 performance is critical, good performance is achievable.
- When critical to system performance, manufacturer’s data should be validated for predictive modeling.
- Use case modeling may be necessary for good irradiance measurements which are key to accurate dose validation
- With the next generation of UV-C Sensors, the User Interface, Configuration, Calibration, and Testing can be optimized to the application.

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