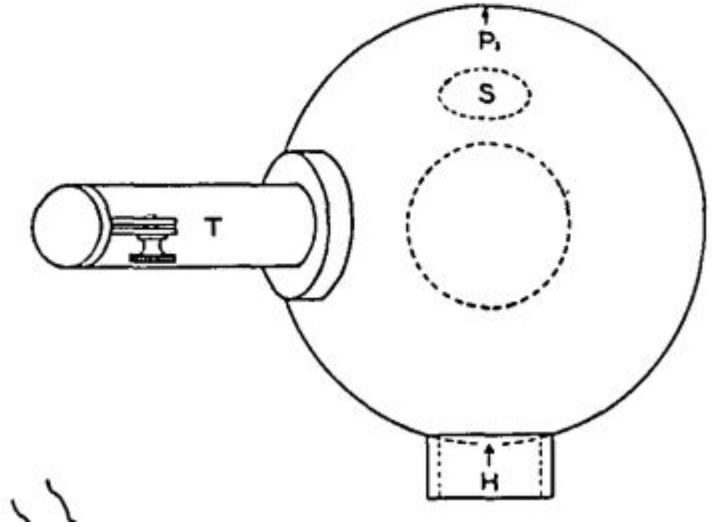
Parabolic Reflectometry: A new method to rapidly evaluate reflectivity

Christopher Bowers

XCMR™

Introduction

- Measurement of material reflectance has been of interest for nearly 100 years.



From Taylor, 1935

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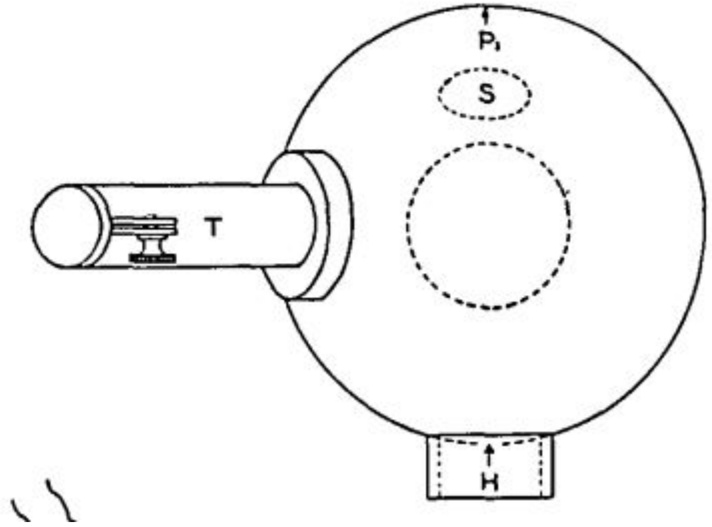

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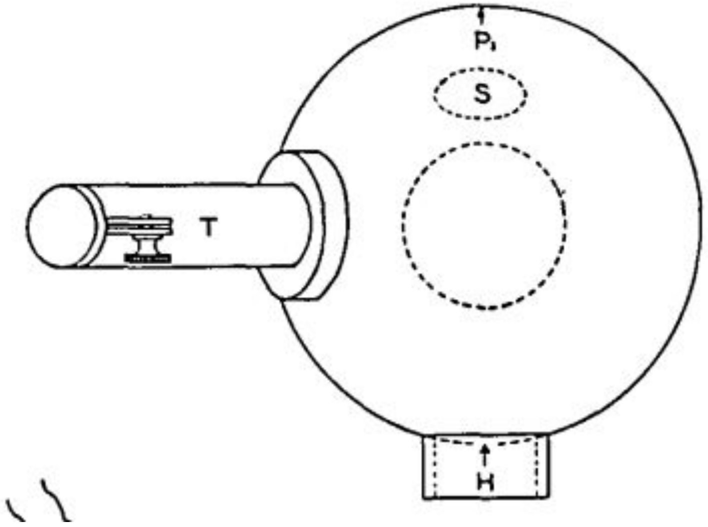

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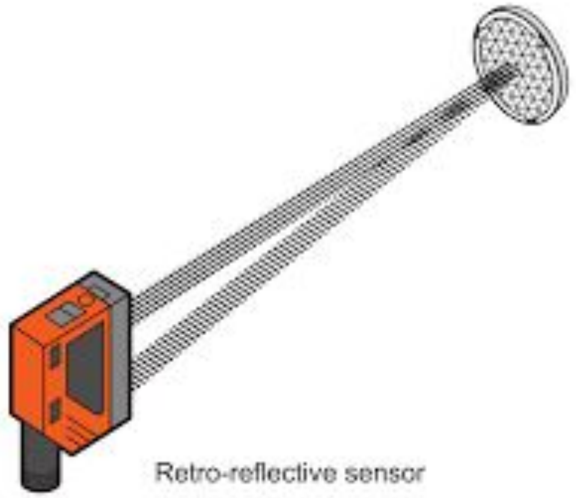

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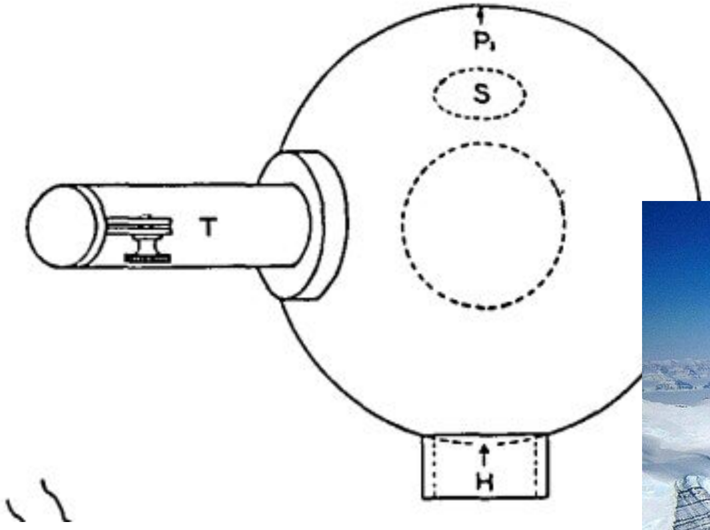

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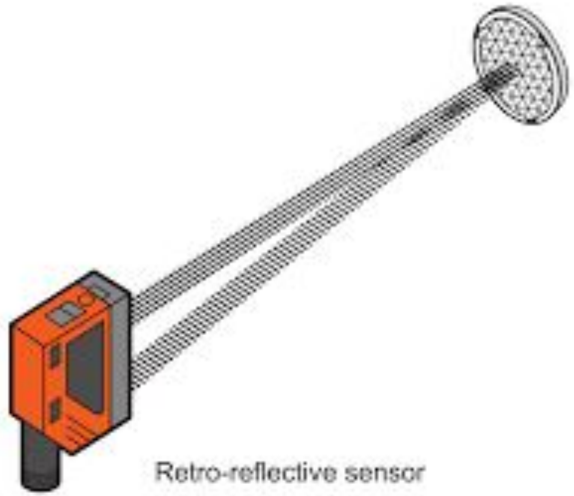

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    - Climate change
    - **Disinfection technology**

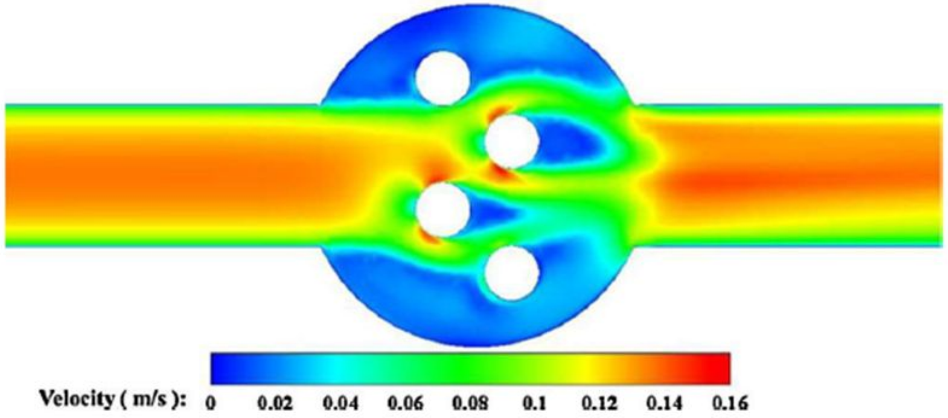


Fig. 6. The velocity field along the middle plane of the reactor using the SST k-ω model.

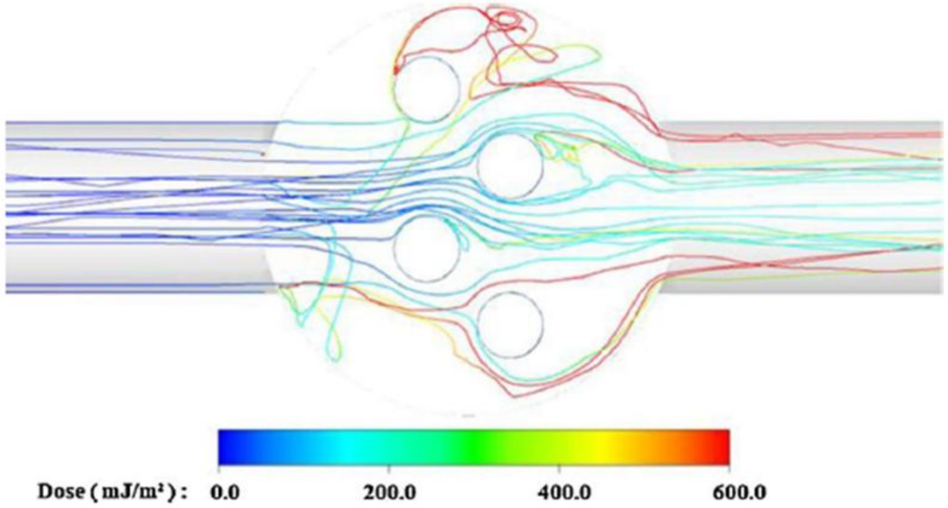
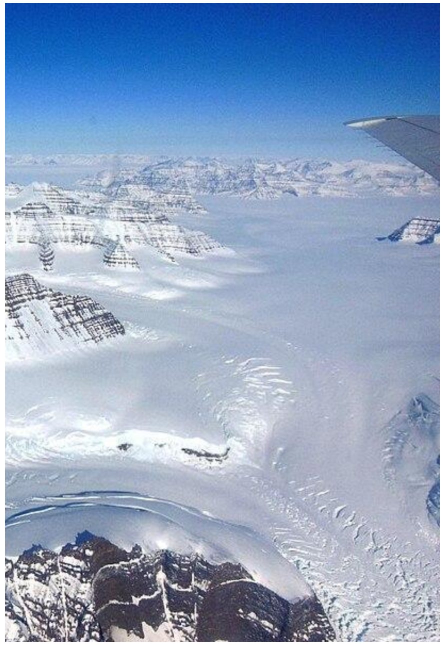


Fig. 7. The received dose of 25 random microorganisms along the motion path.



From Heidarinejad et al., Journal of Water Process Engineering (2020)

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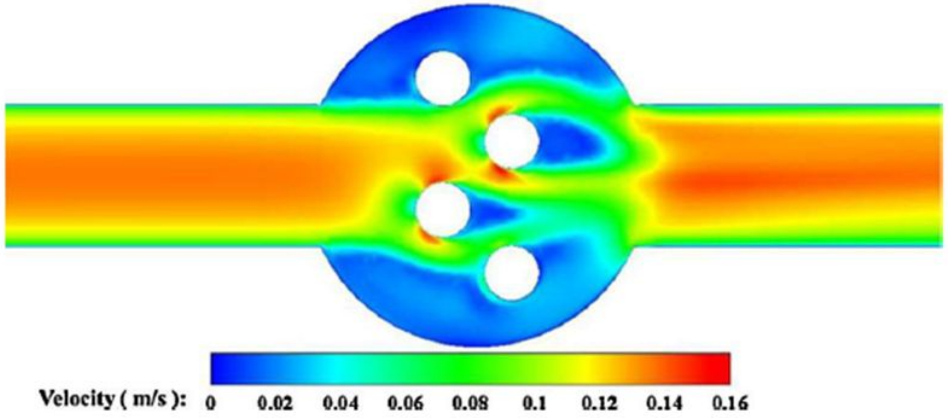
Using high reflectance material, it is possible to significantly increase UV dose within an enclosed reactor



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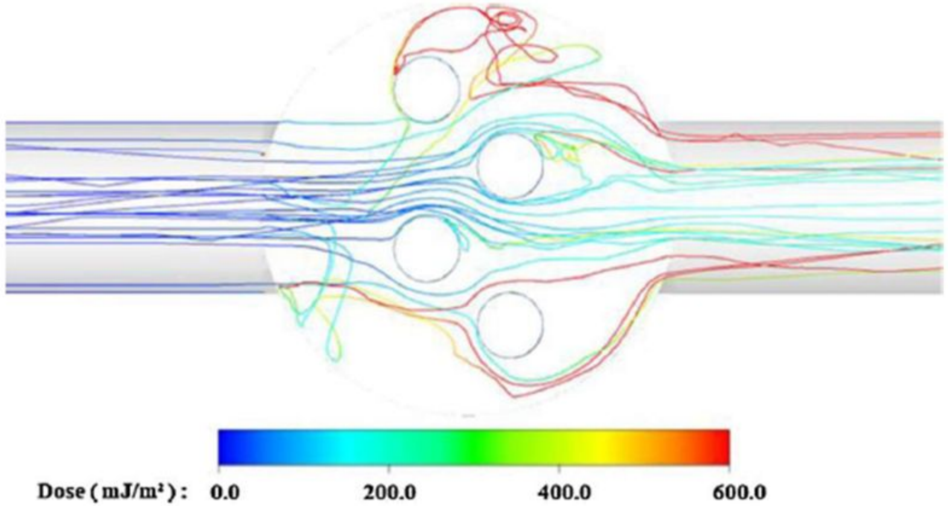

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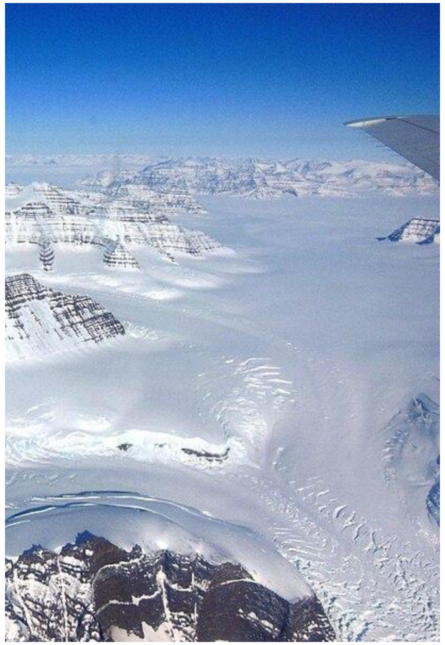

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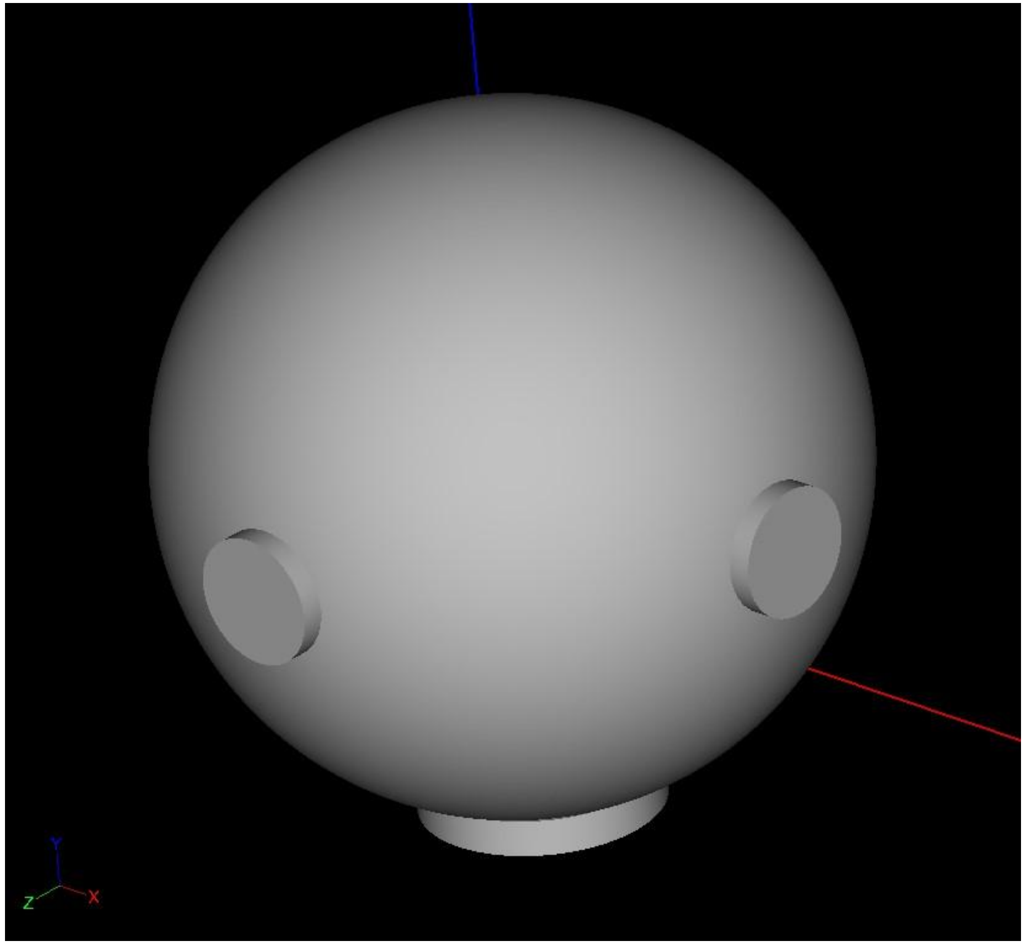
Photon Recycling Principles

- Integrating spheres have been in use since before Taylor (1935), and can be used to determine the optical outputs of a lamp.
- These spheres are based on photon recycling, and provide an analytical solution for the optical energy, given by Sumpner's principle.

$$E = \frac{\Phi}{\pi D^2} \frac{r_\Phi}{1 - r_\Phi}$$



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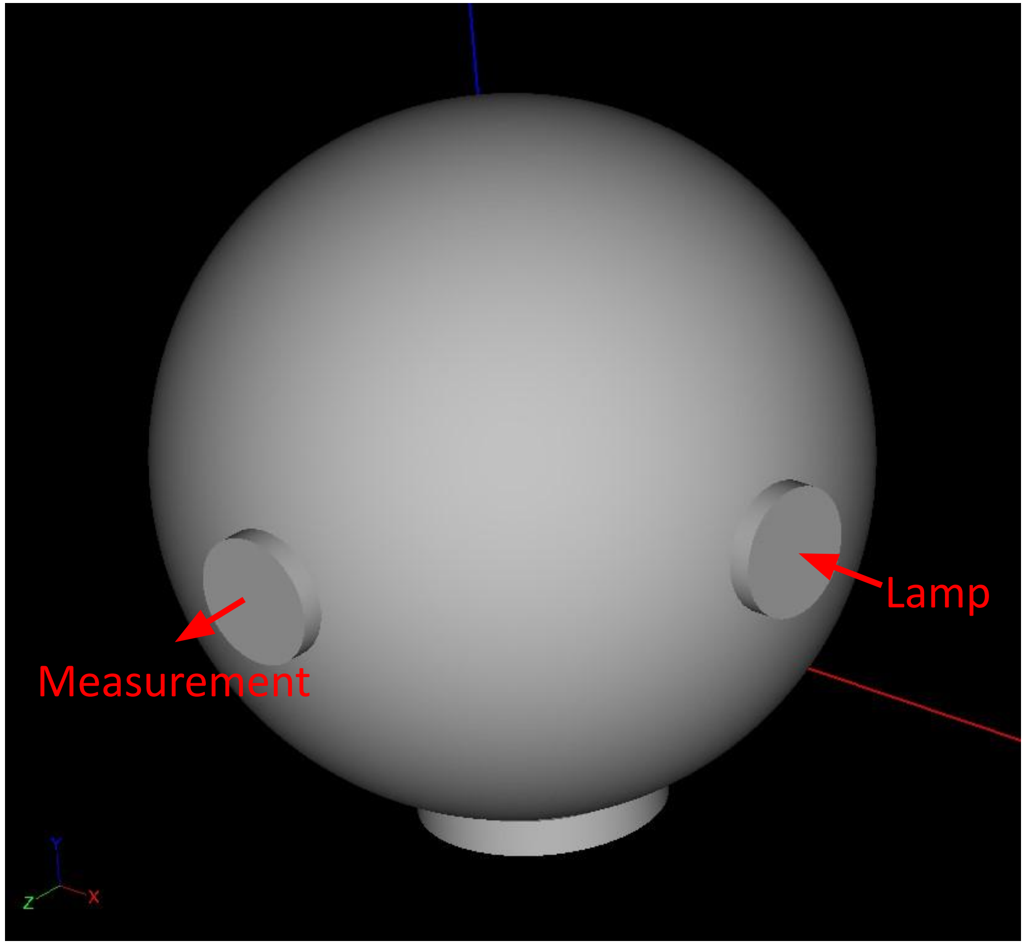
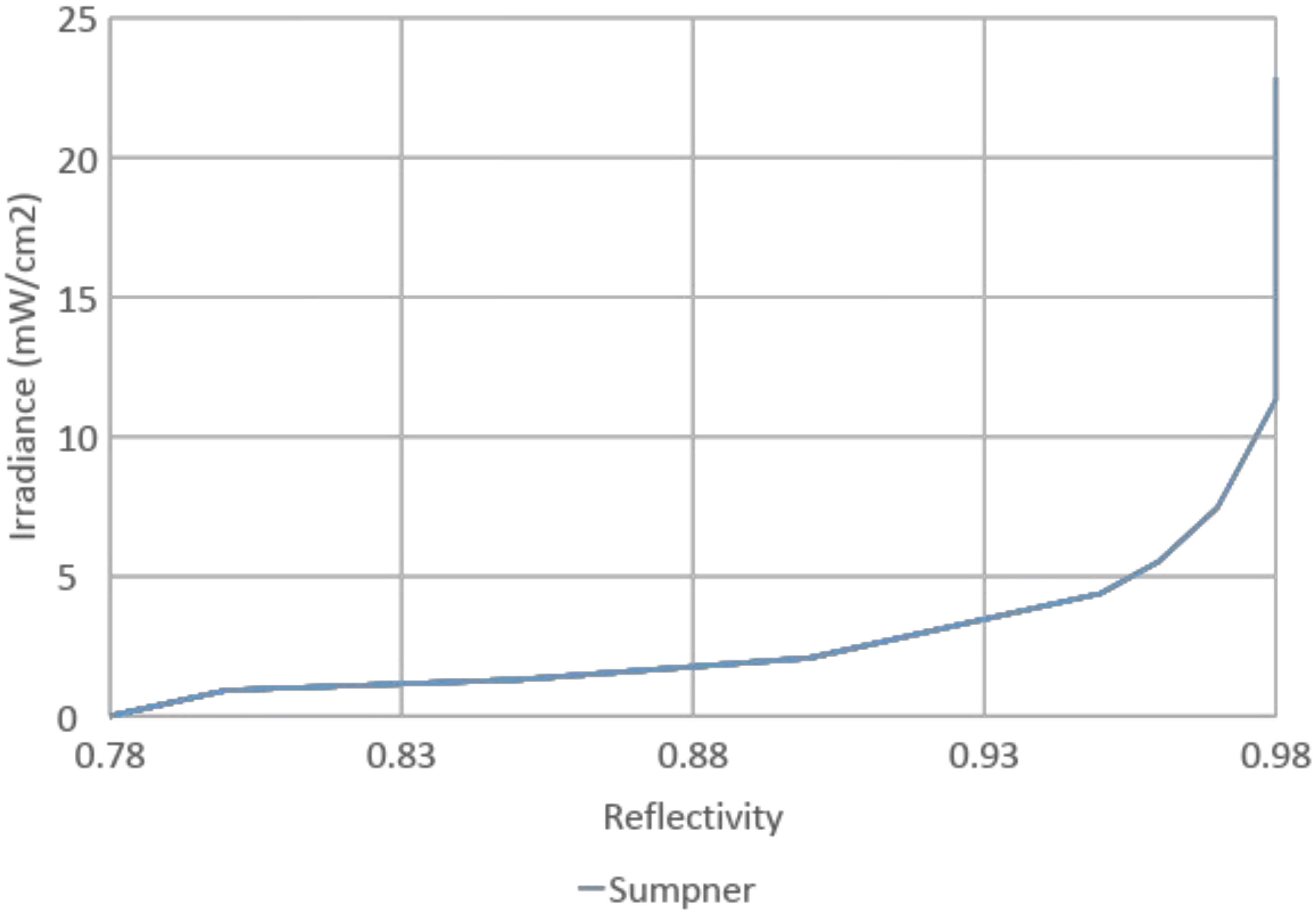


Integrating Sphere Model

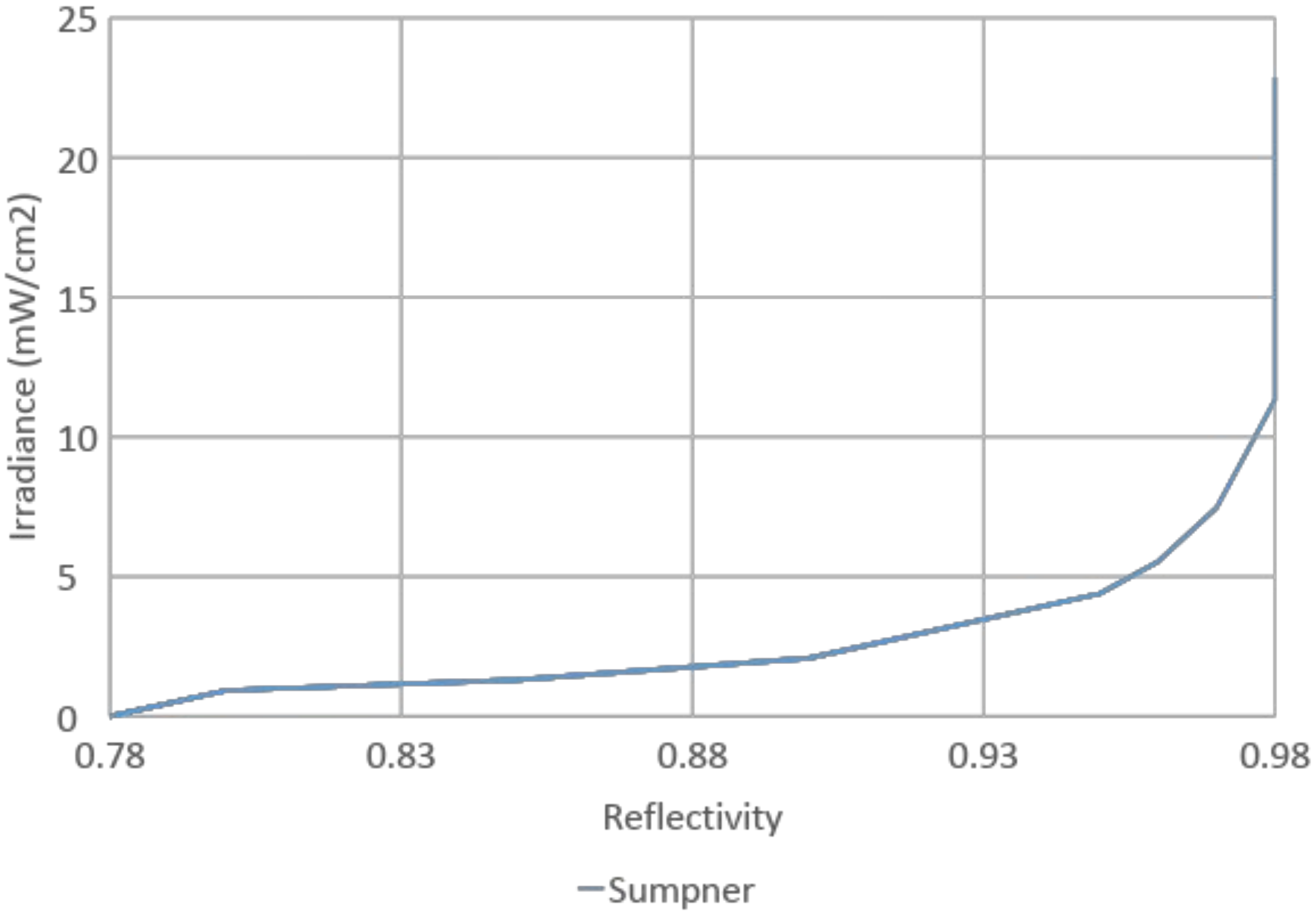
Photon Recycling Principles – Cont'd

- Irradiance grows exponentially.



Photon Recycling Principles – Cont'd

- Irradiance grows exponentially.
- Compared to 80% reflectivity, we see a 4x increase at 90%, 7x at 97%, and 21x at 99%



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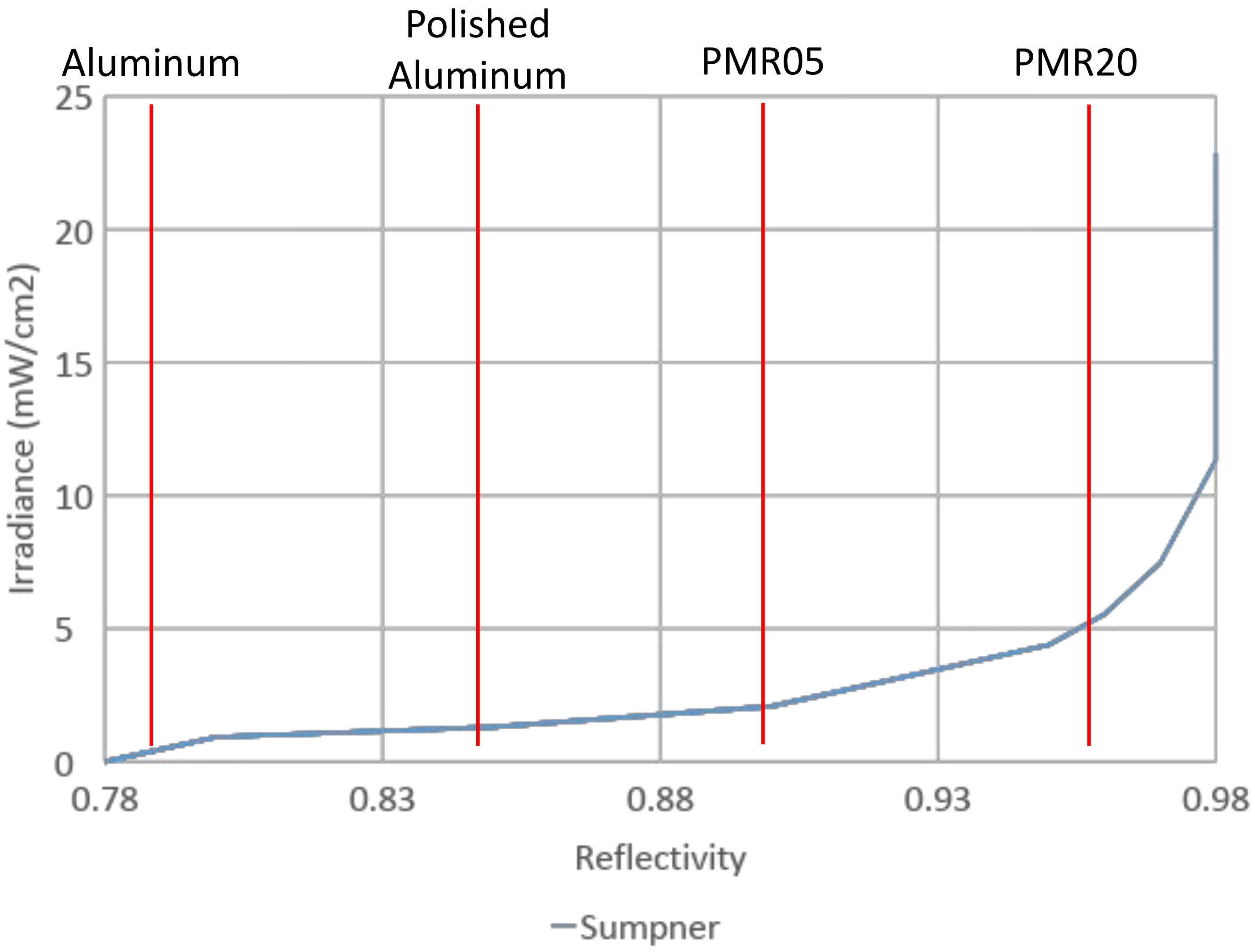

Photon Recycling Principles – Cont'd

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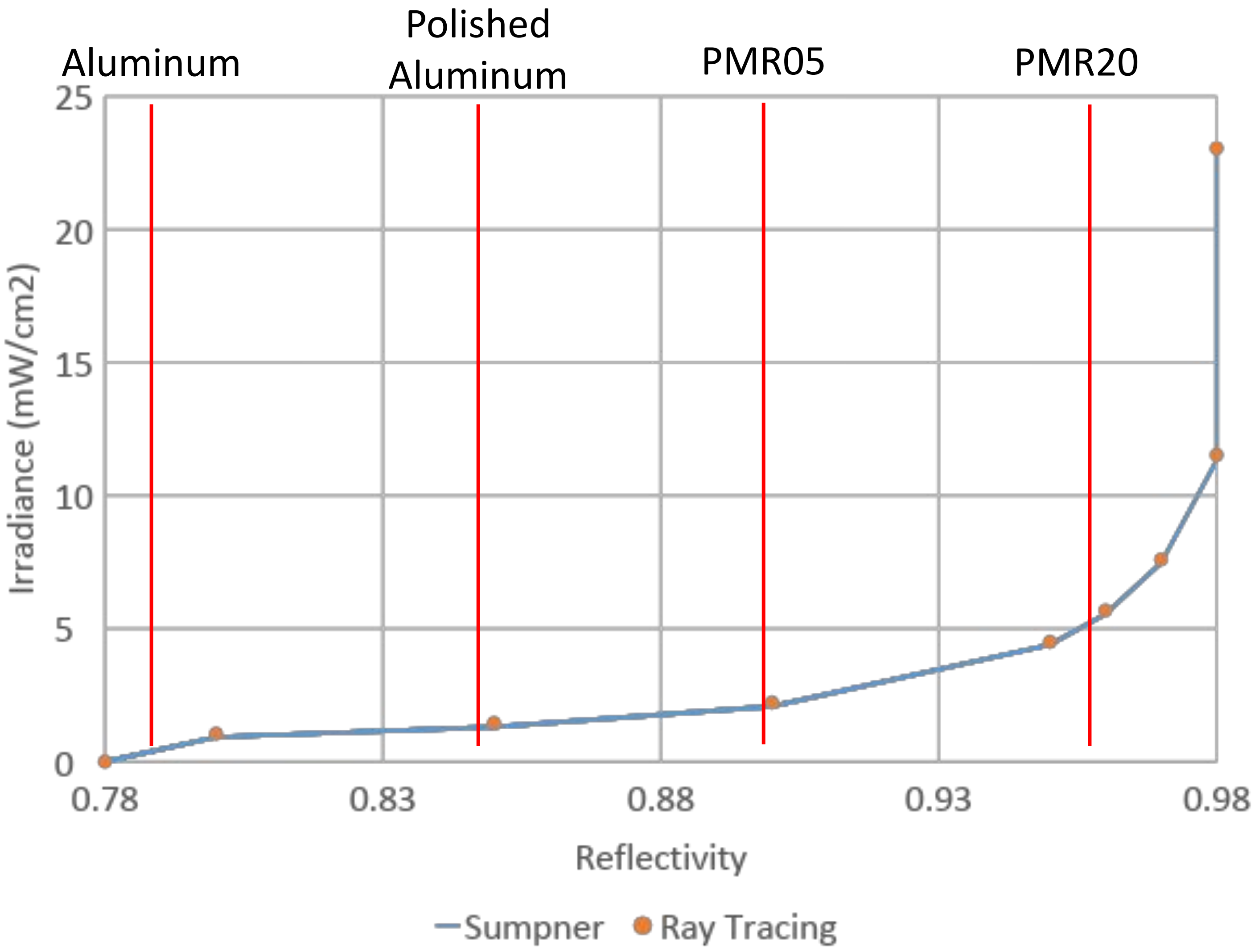
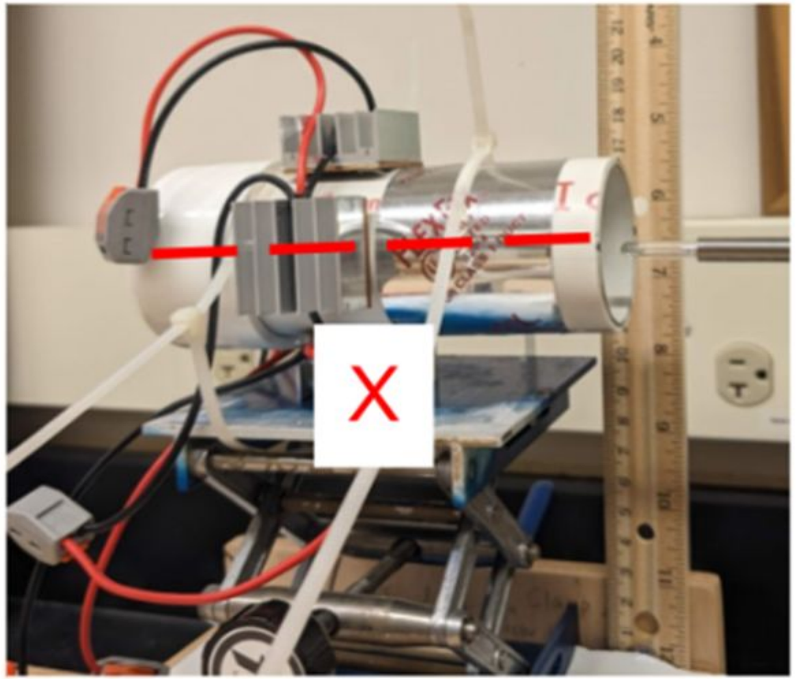
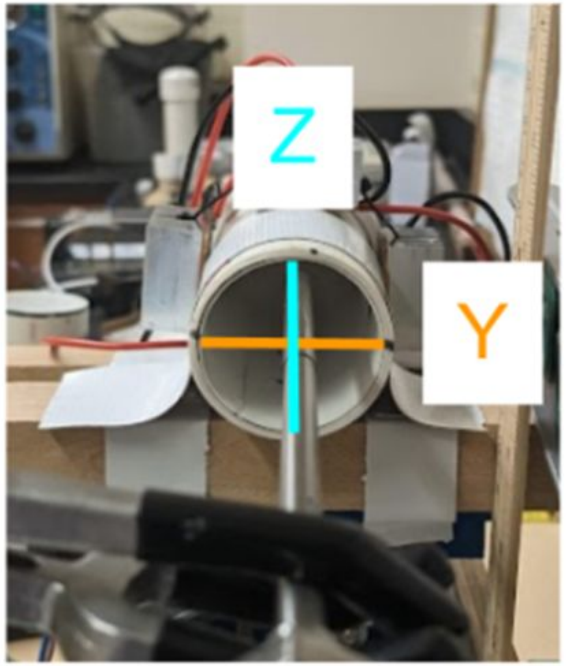
- Compared to 80% reflectivity, we see a 4x increase at 90%, 7x at 97%, and 21x at 99%
- Optical simulations carried out using Photopia match the analytical solution well.



Real World Scenario

- We have observed improvements in real enclosed reactors with reflectivity.





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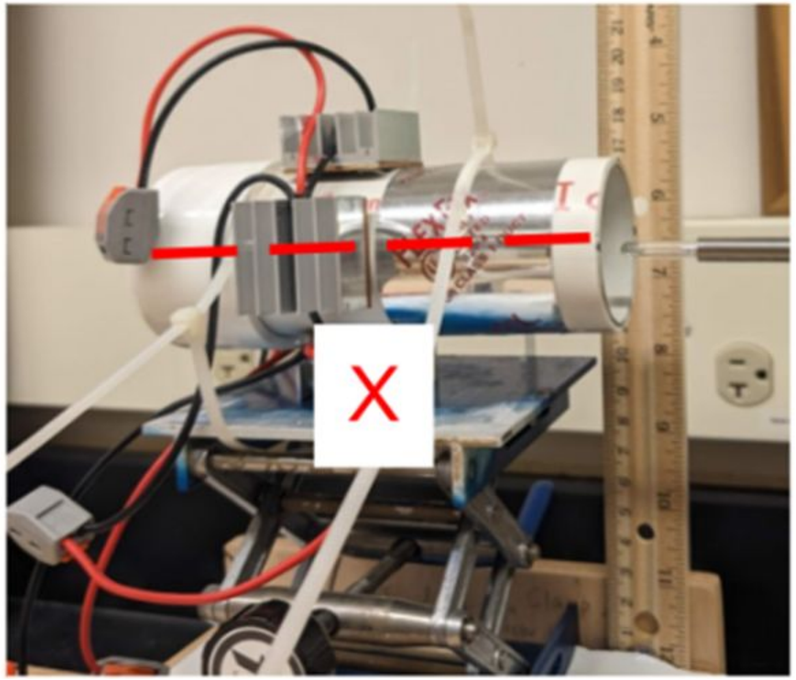

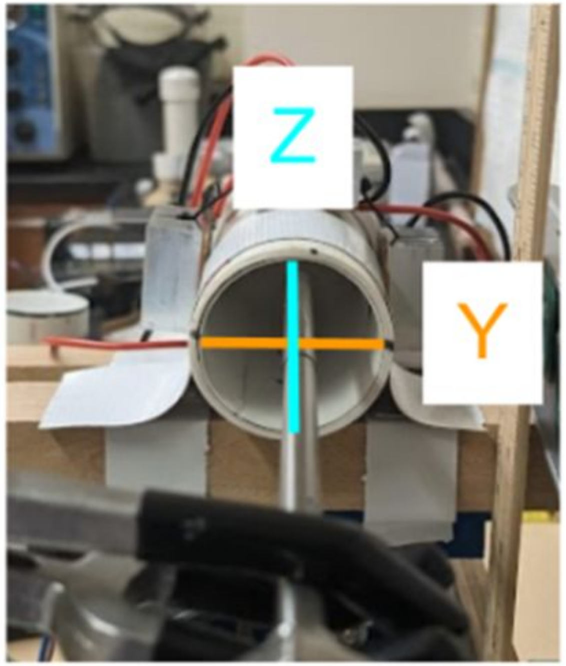

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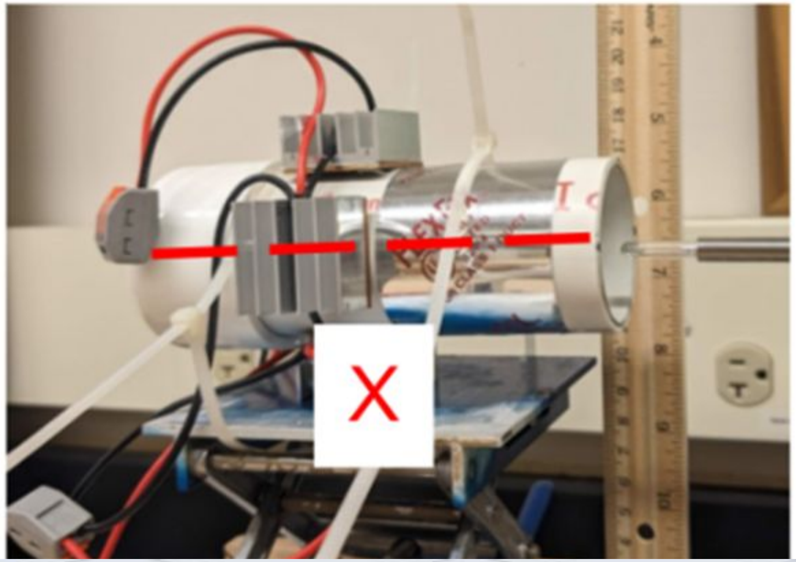

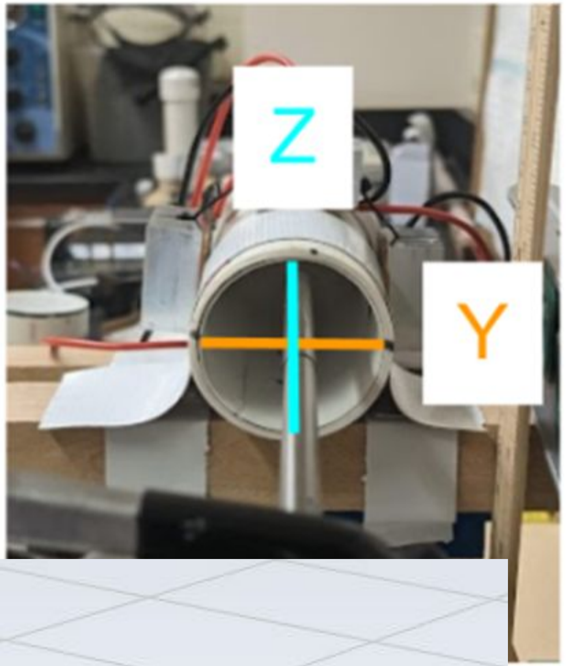

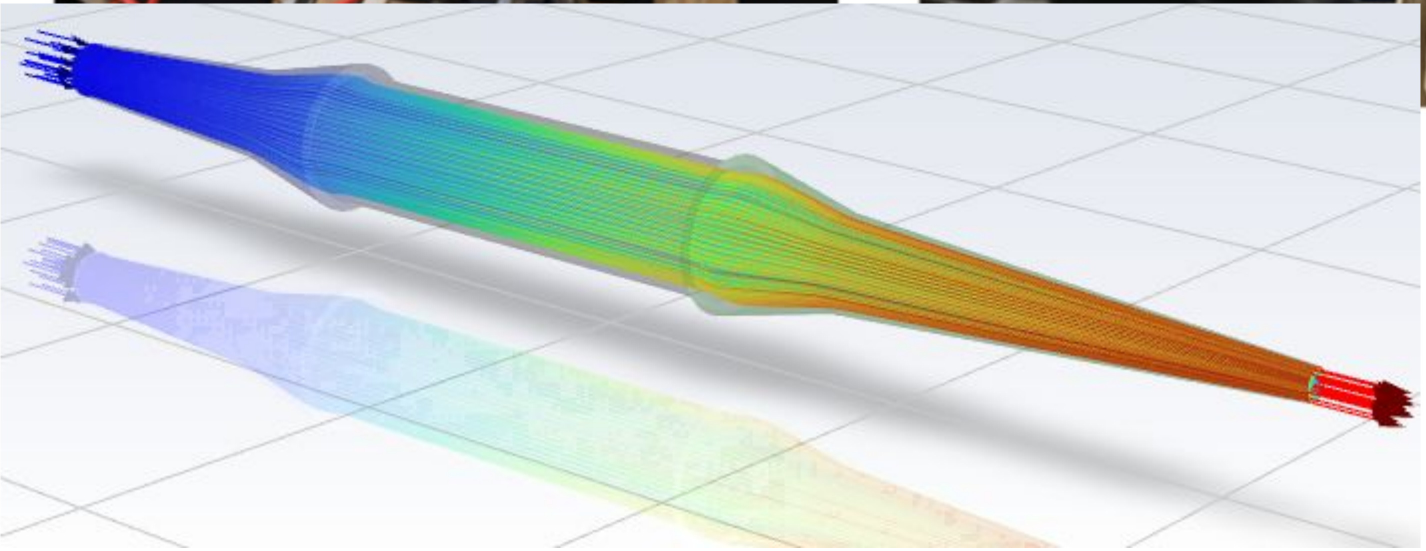

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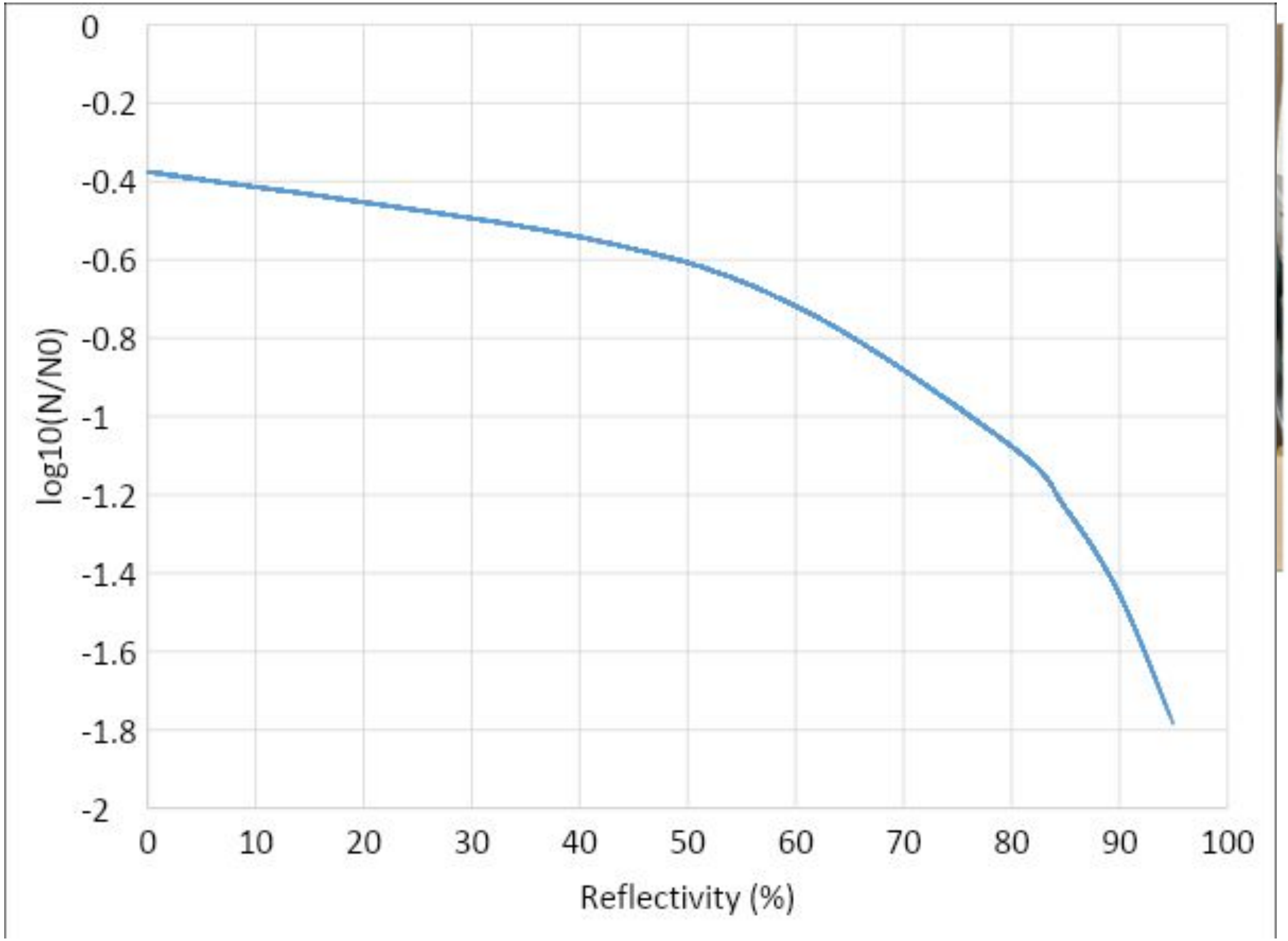
- Based on these particle tracks, we can determine log-inactivation. Here we are flowing at 32.3 L/min



Real World Scenario

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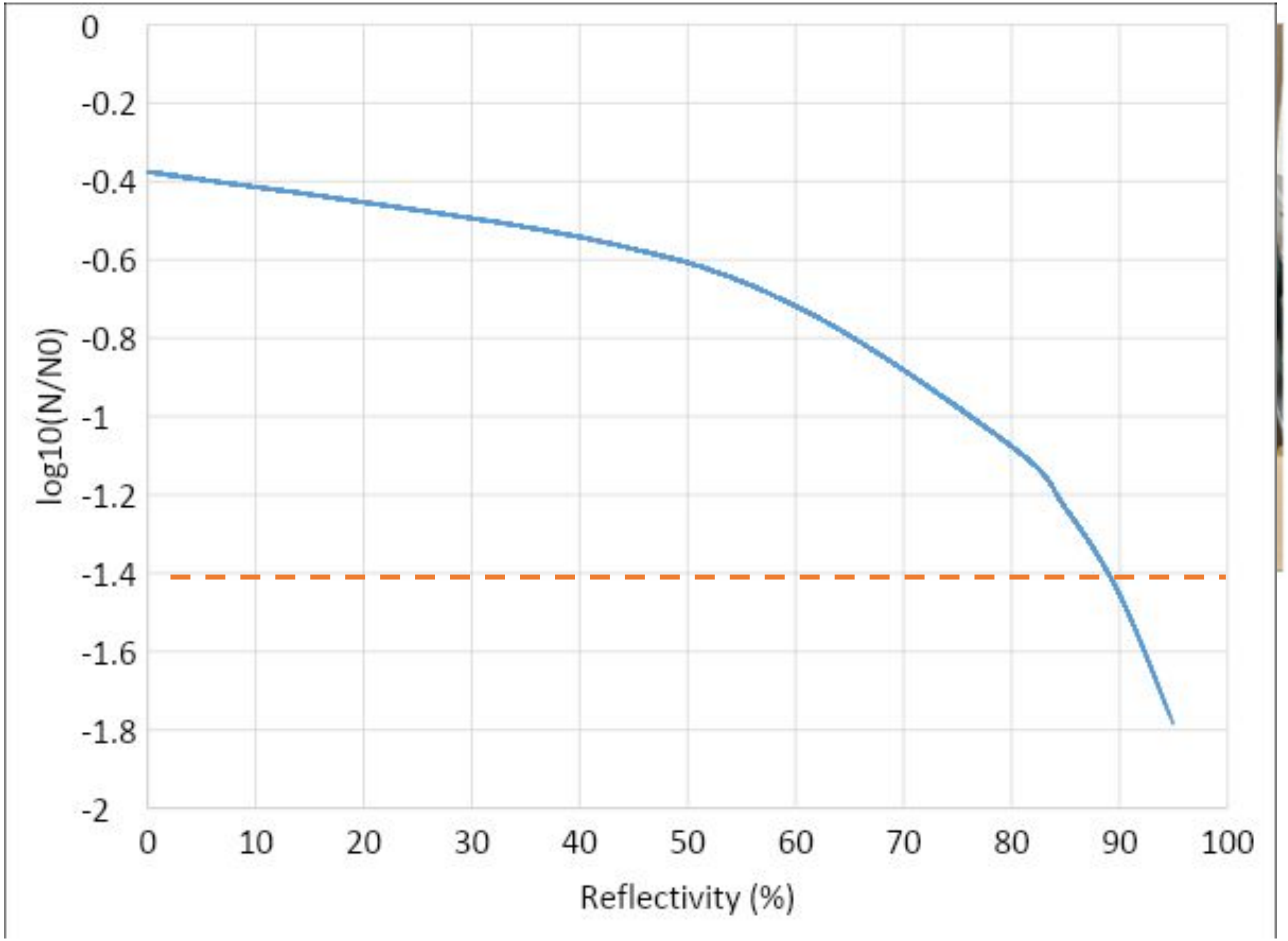
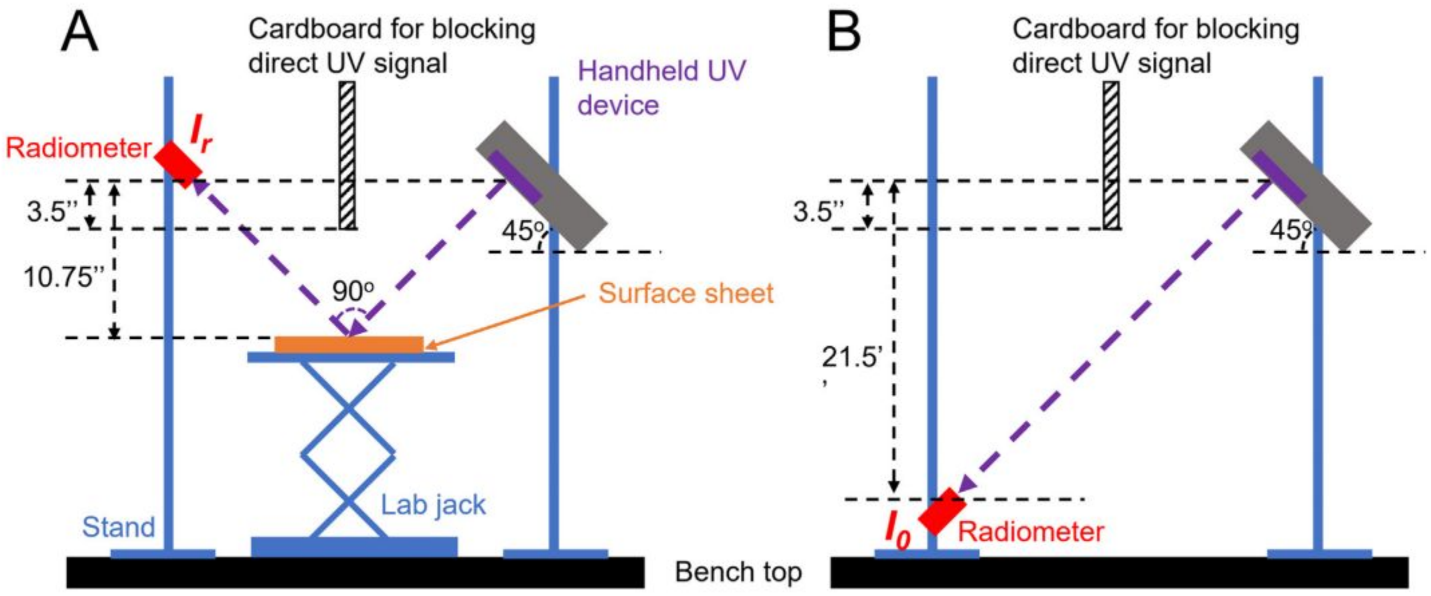
- Based on these particle tracks, we can determine log-inactivation. Here we are flowing at 32.3 L/min
- Note the huge difference between 0%, 80%, and 95% reflectivity!



Other Reflectometric Methods

- There are several different methods used currently to measure reflectance, including:
  - Angular offset



From *Reflection of UVC wavelengths from common materials during surface UV disinfection: Assessment of human UV exposure and ozone generation*, Ma et al., 2023

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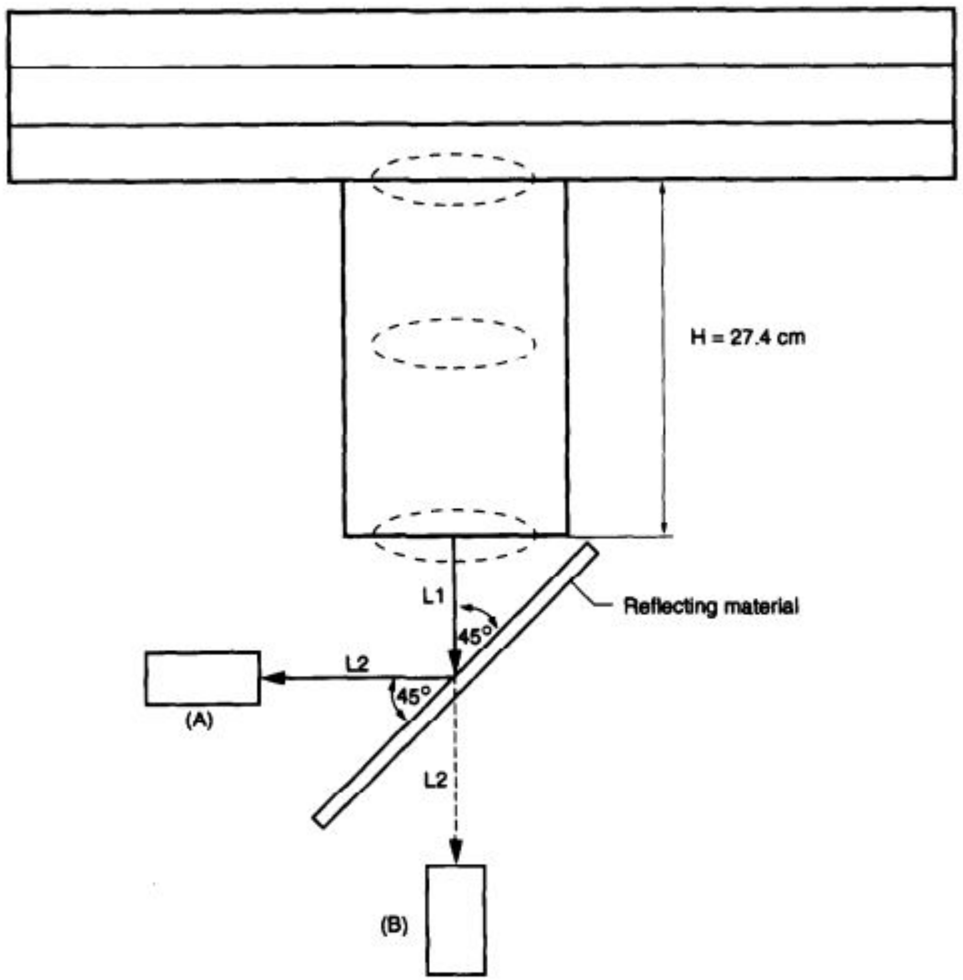

From *Numerical modelling of UV intensity: Application to collimated-beam reactors and continuous-flow systems*, Blatchley, 1997

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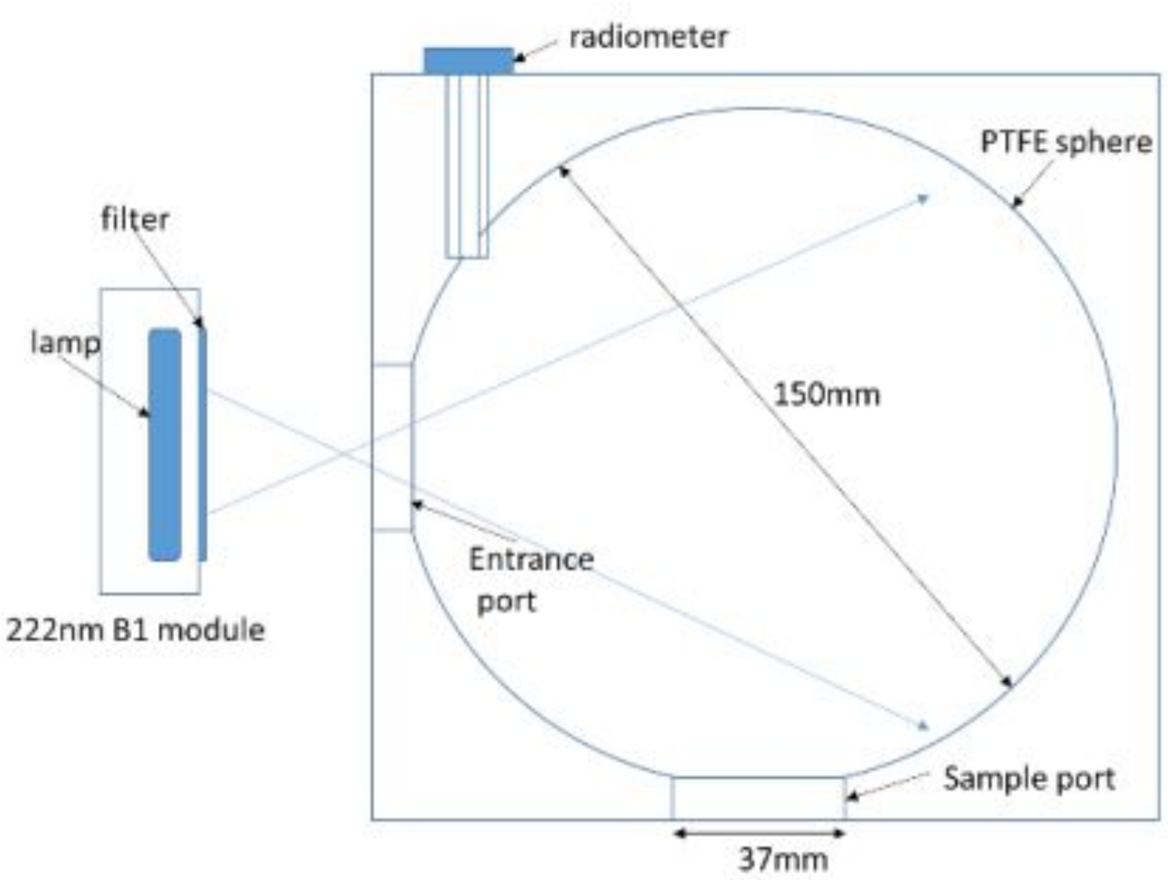

From Reflectance measurements of building materials in the Far UVC (222 nm) wavelength range, Claus and Cooksey, 2022

Other Reflectometric Methods

- There are several different methods used currently to measure reflectance, including:
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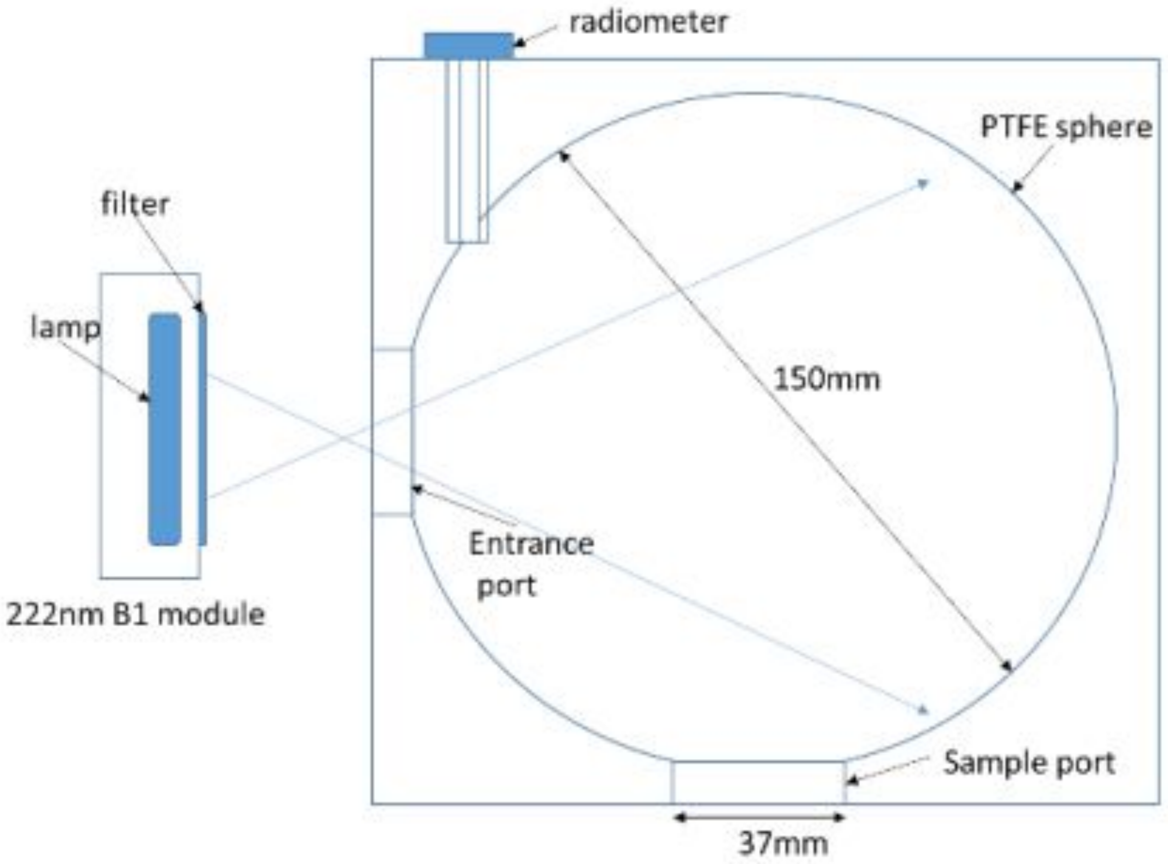
  - 1st Taylor
- As a test case, two current methods were compared to the new method.



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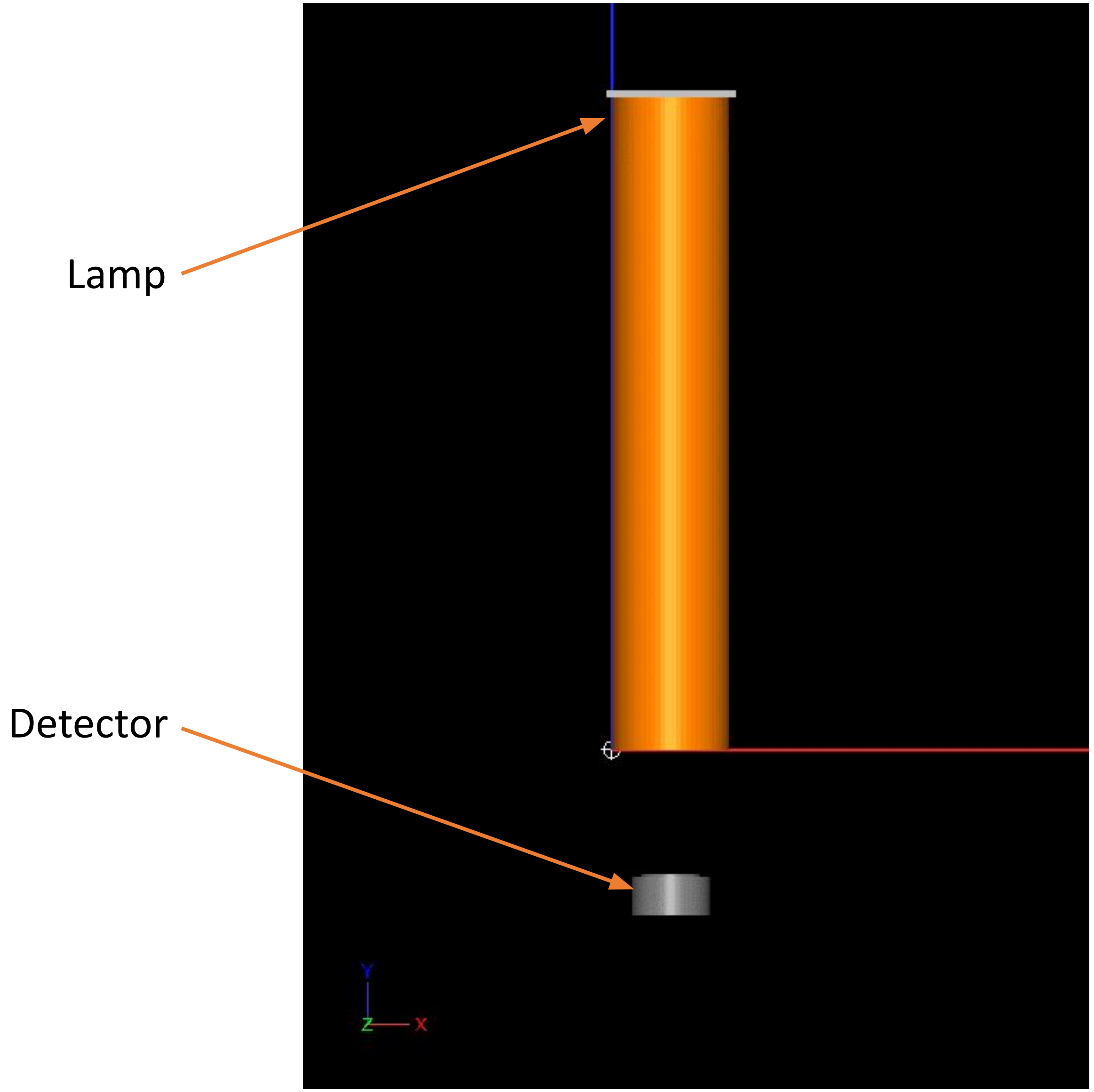

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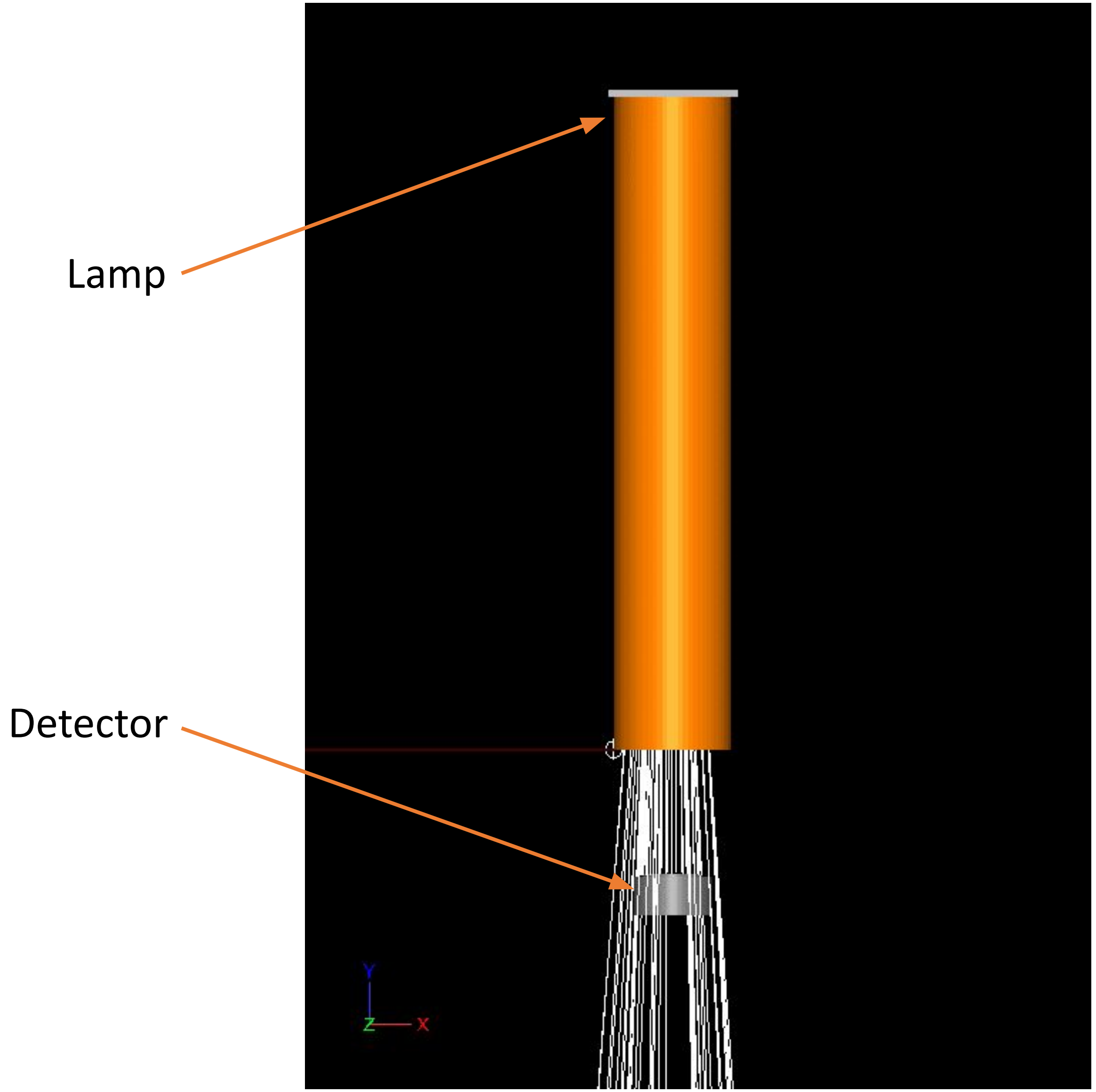

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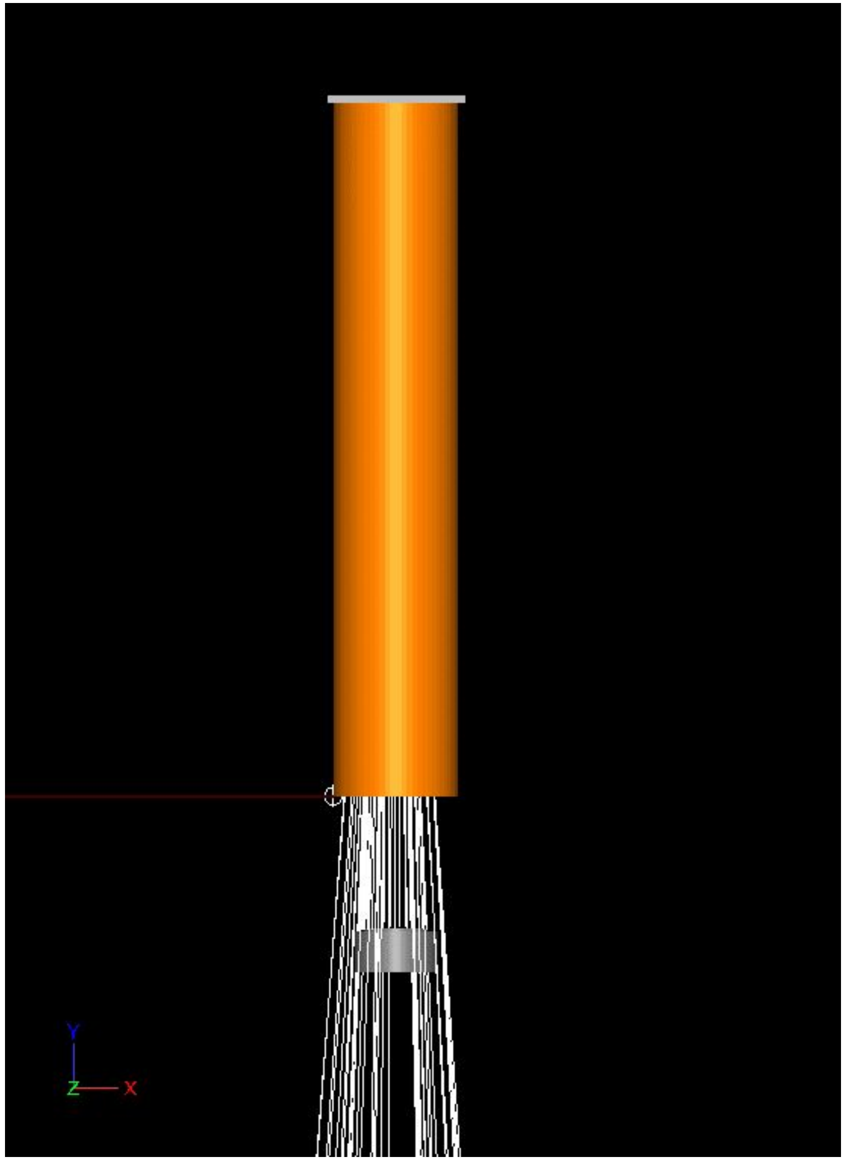

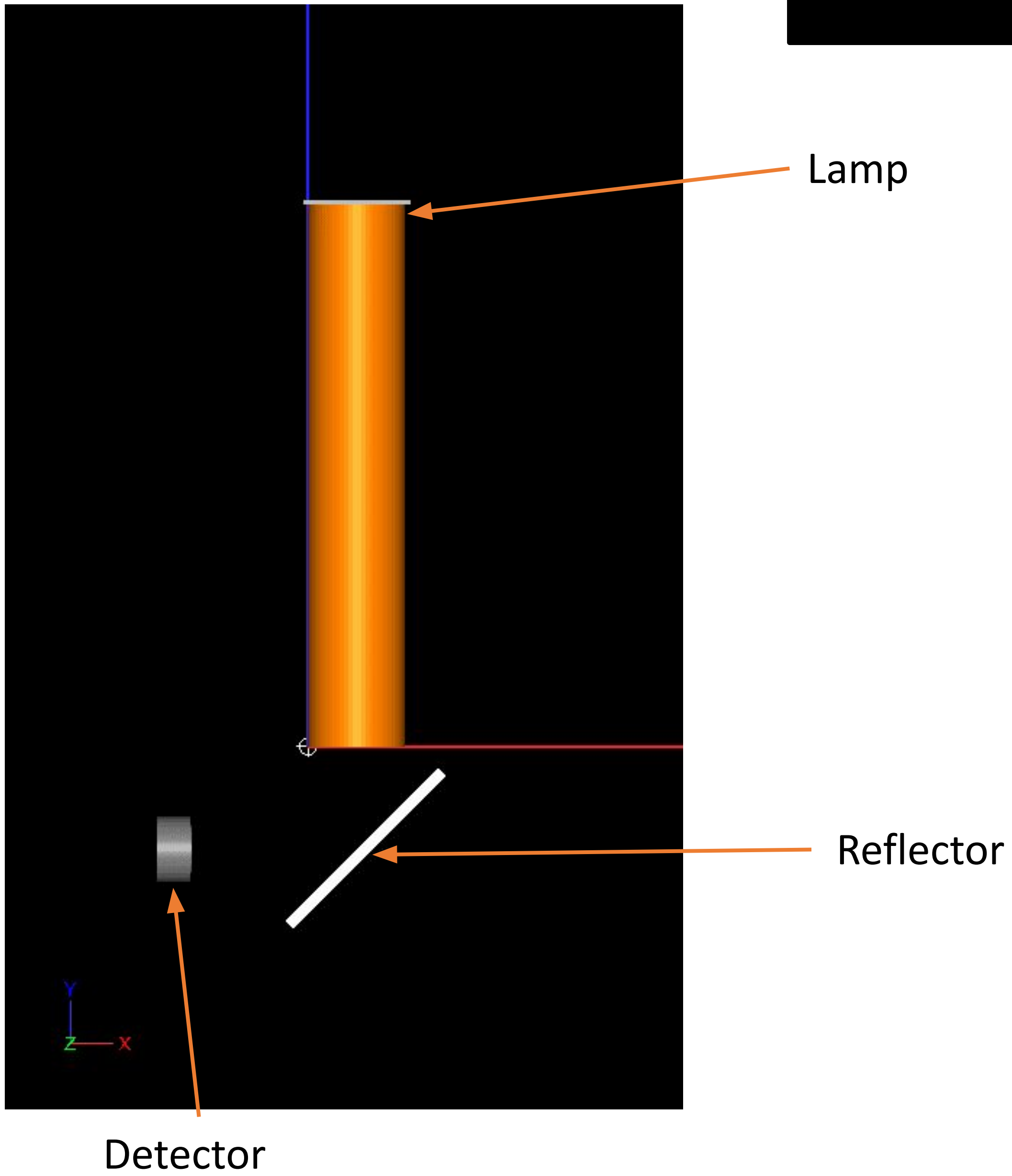

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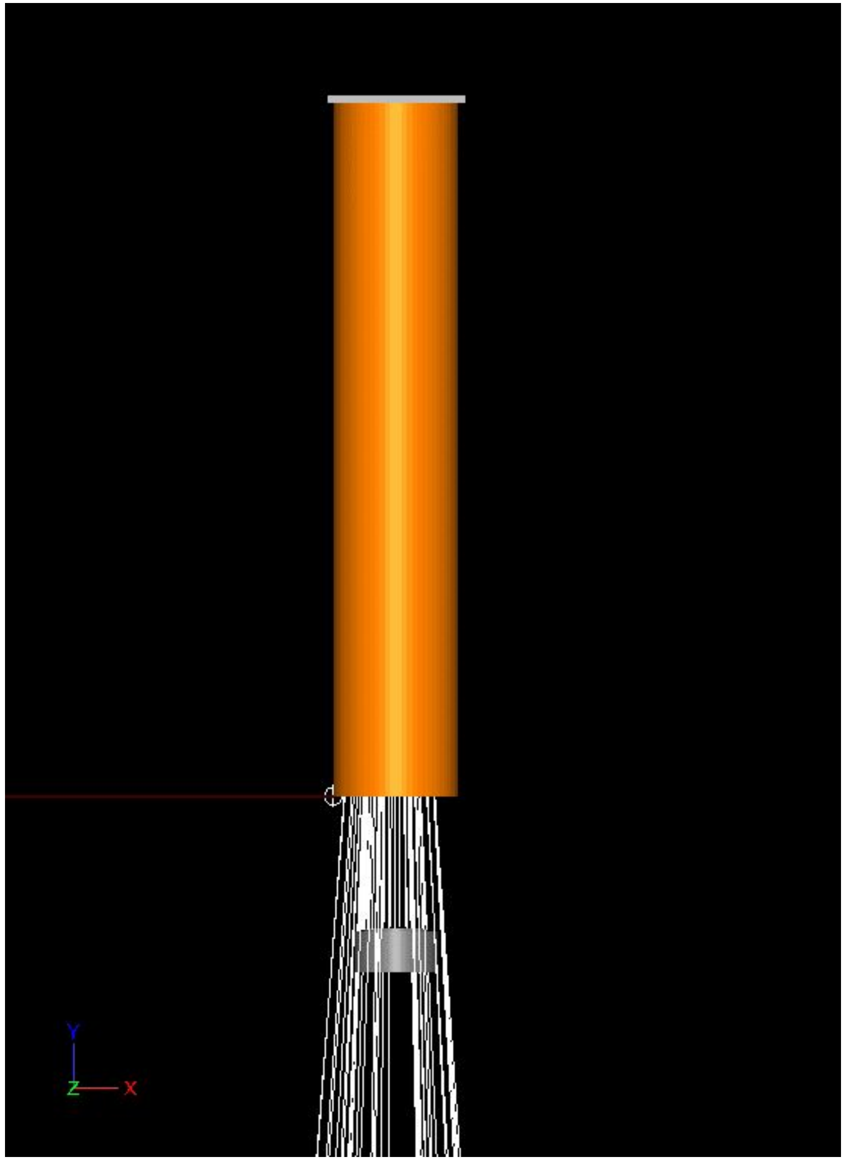

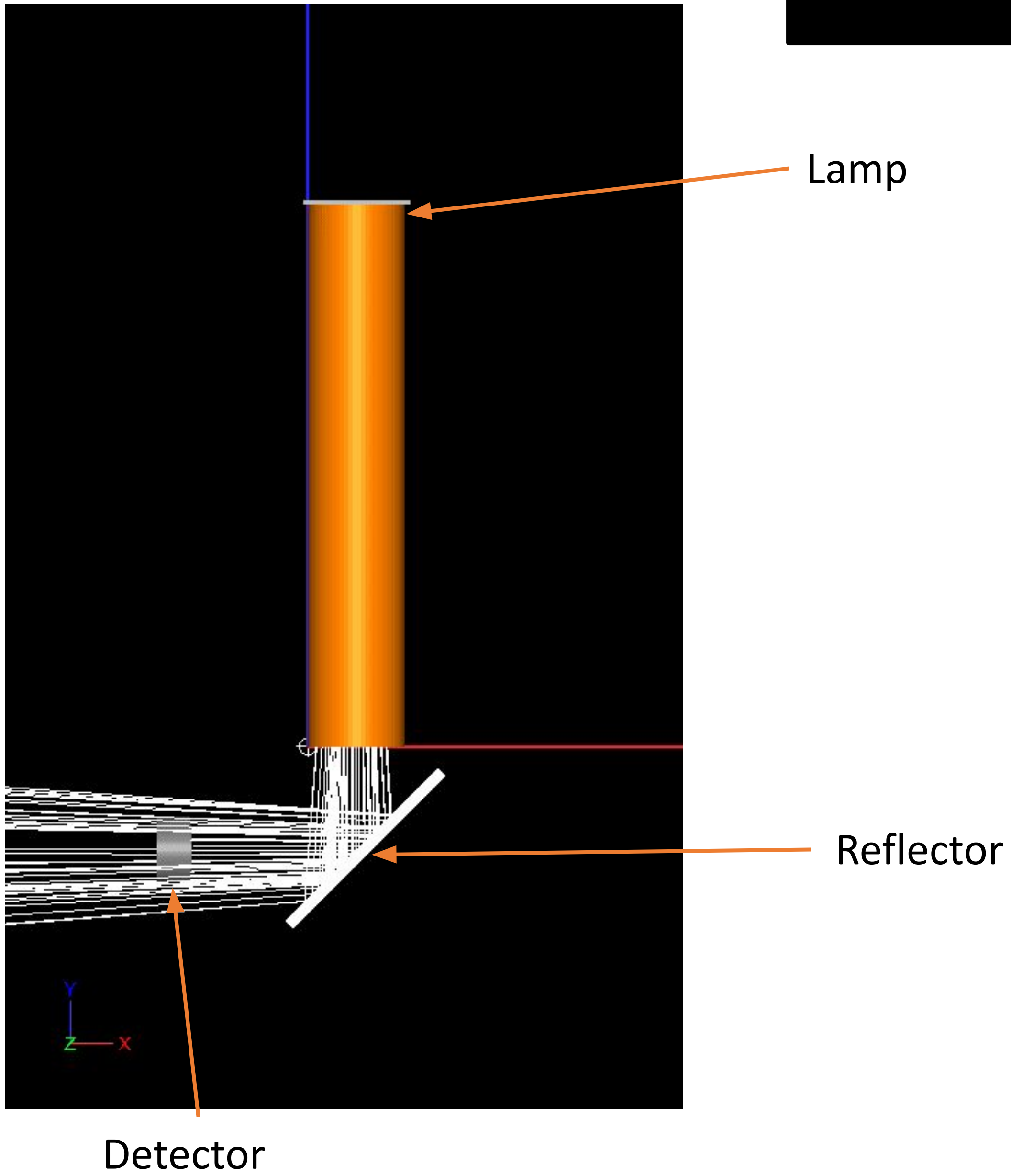

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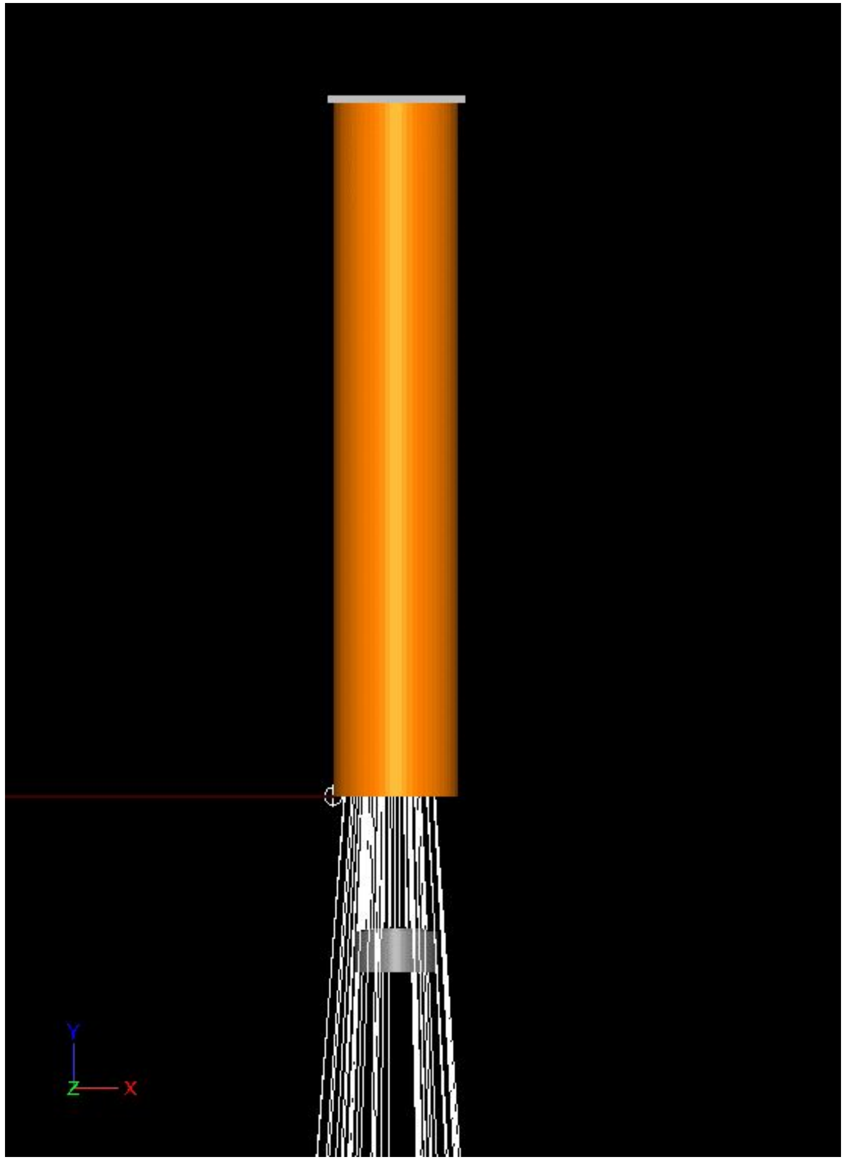
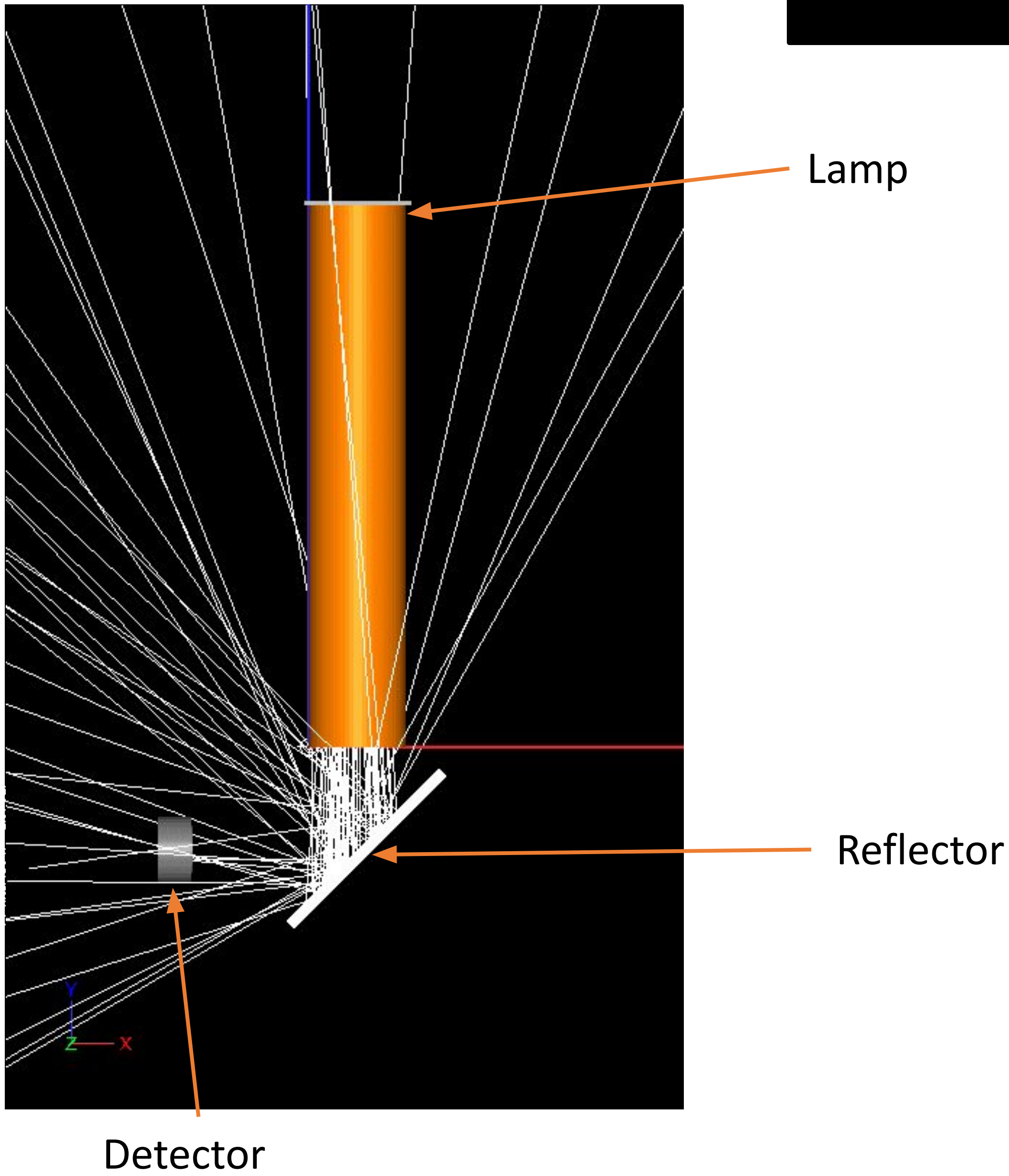
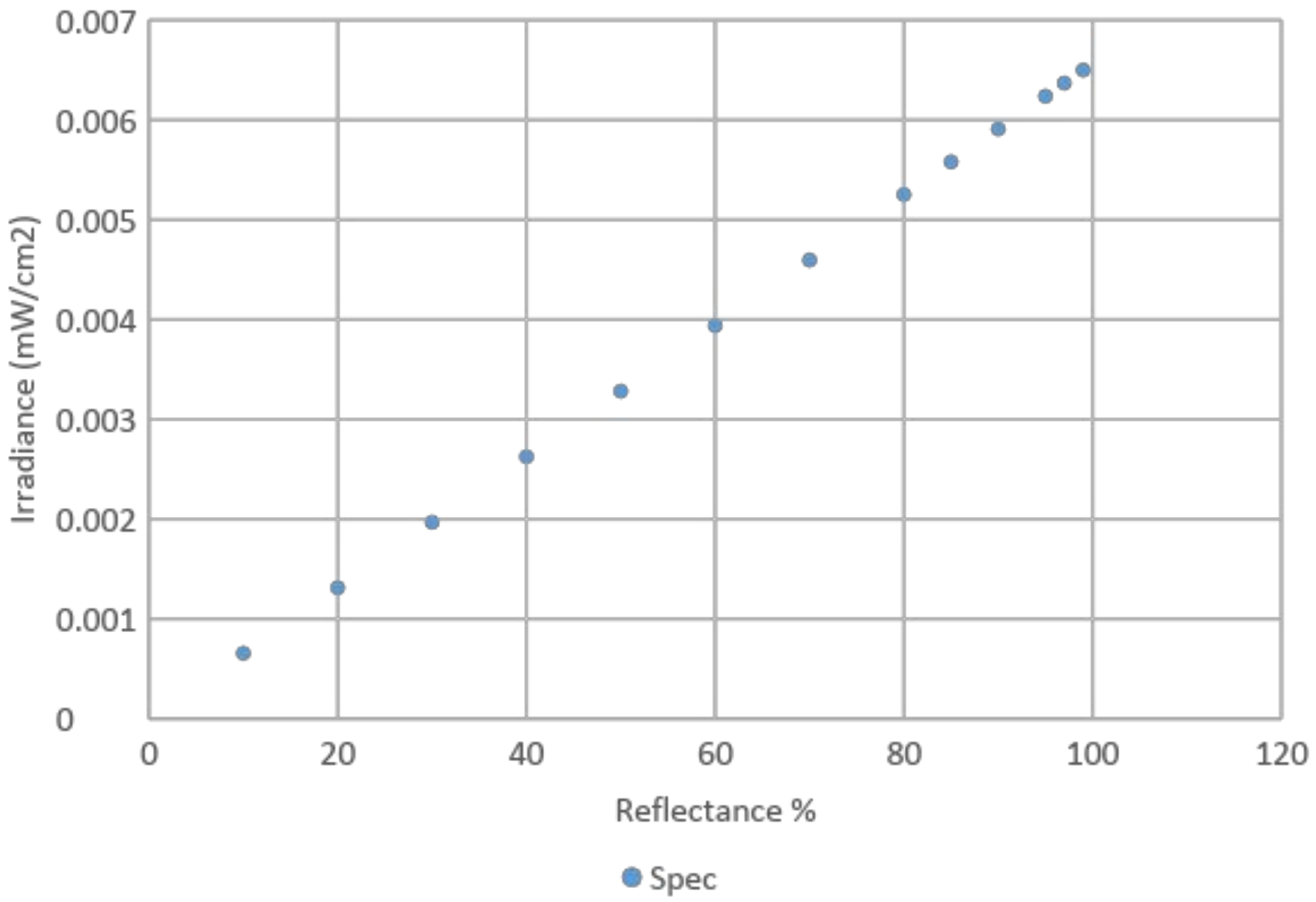




Blatchley 1997 Results

- As expected, specular reflection is represented linearly



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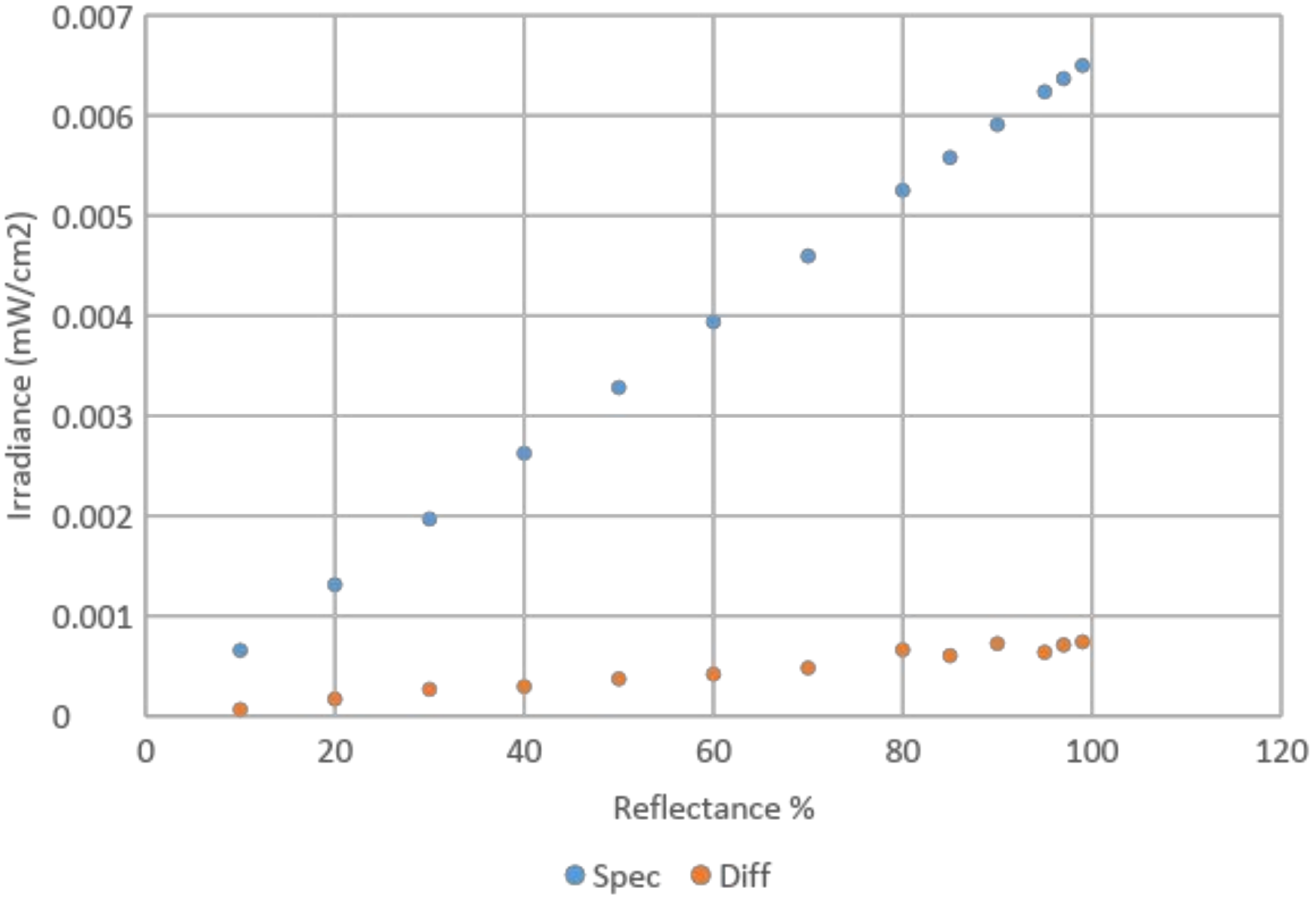

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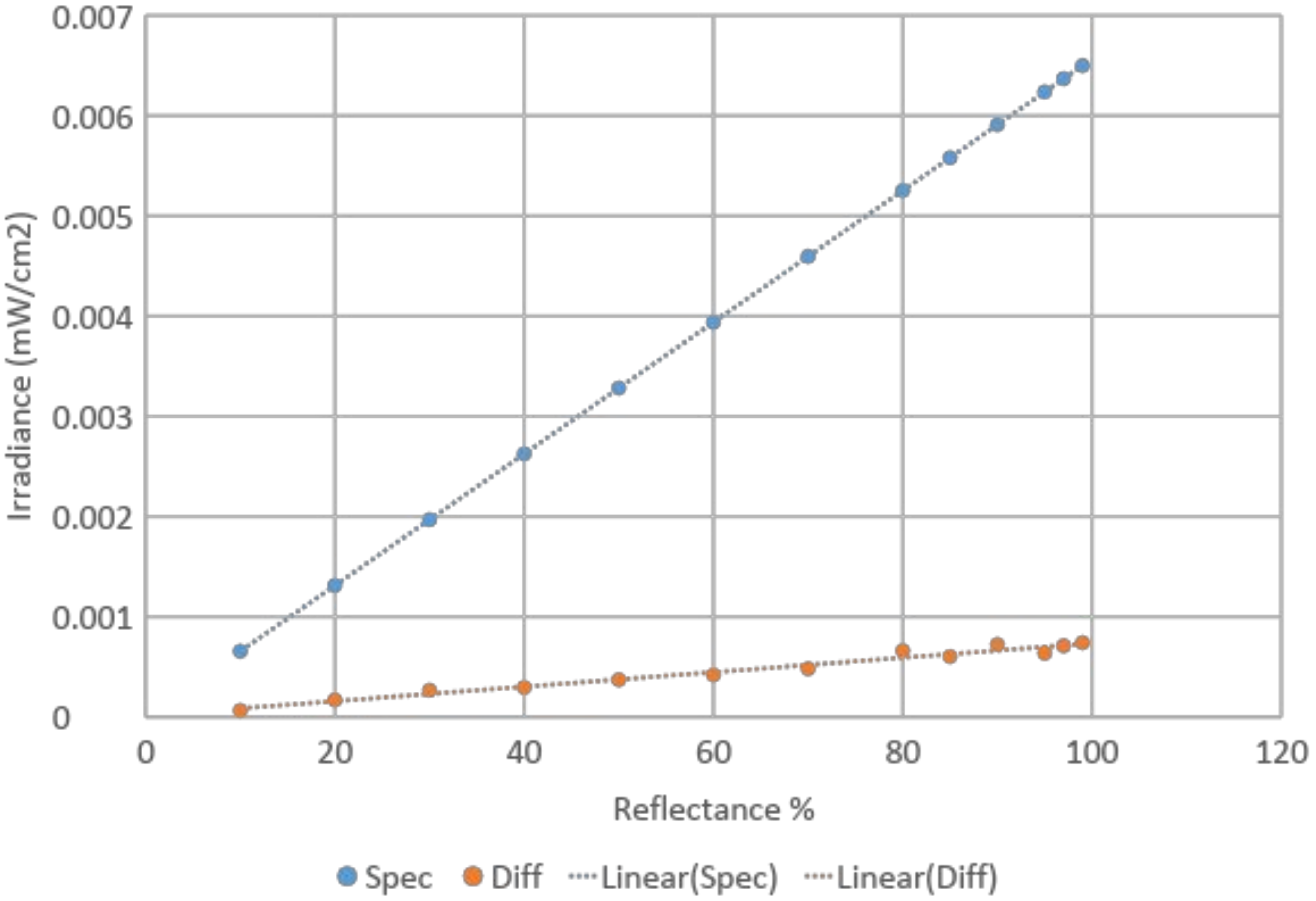

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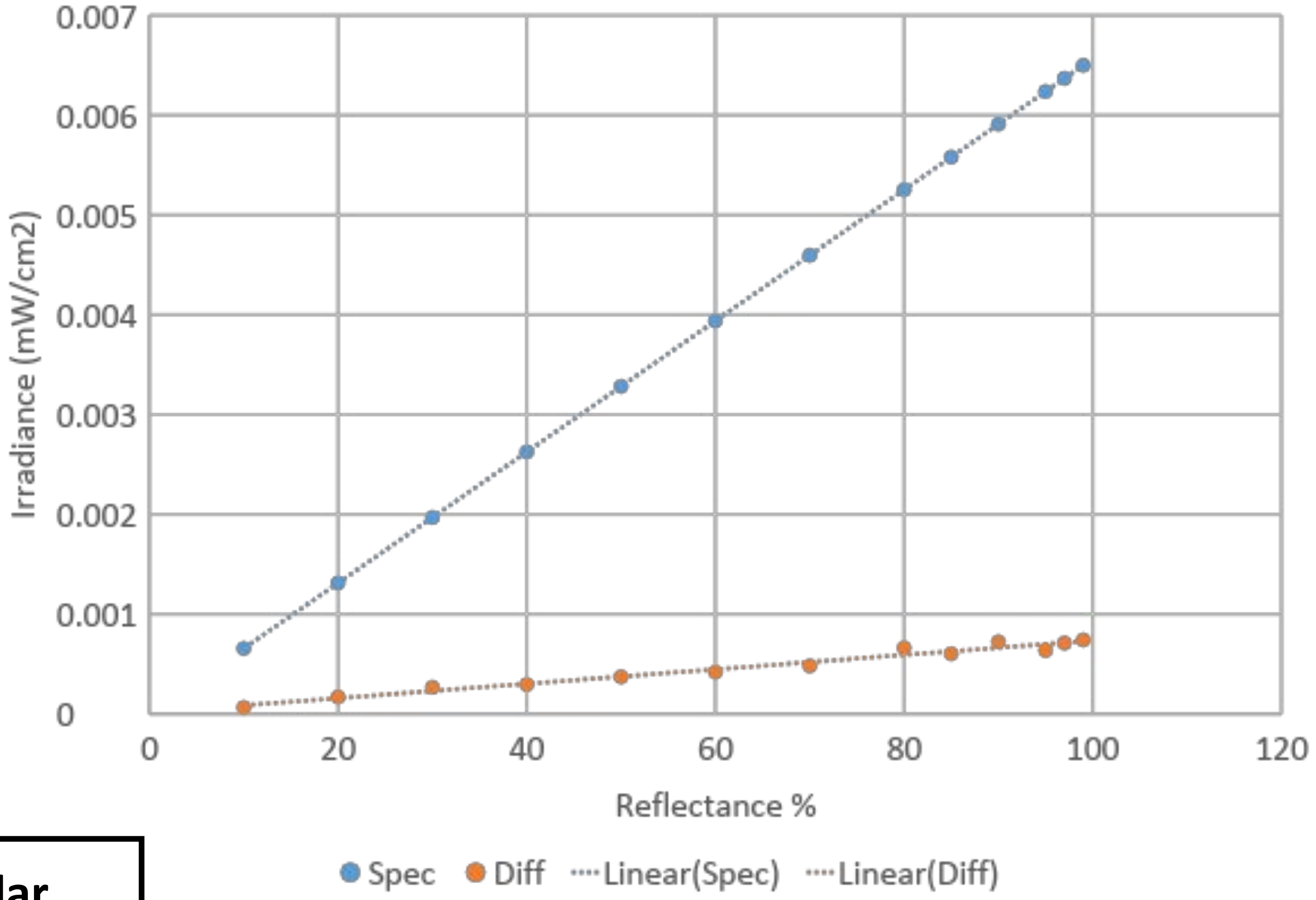
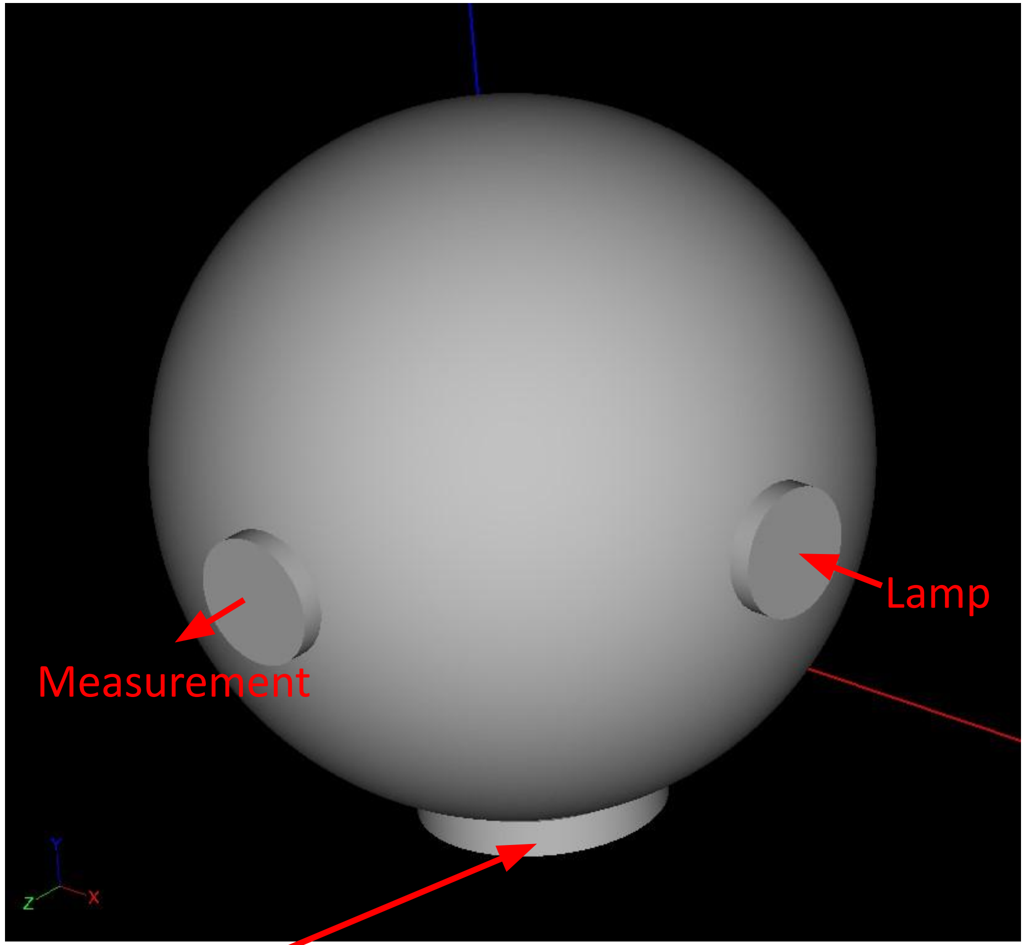


This method is well suited for specular reflection, but may be difficult to use for diffuse reflection

1st Taylor Method

- Back to the integrating sphere!



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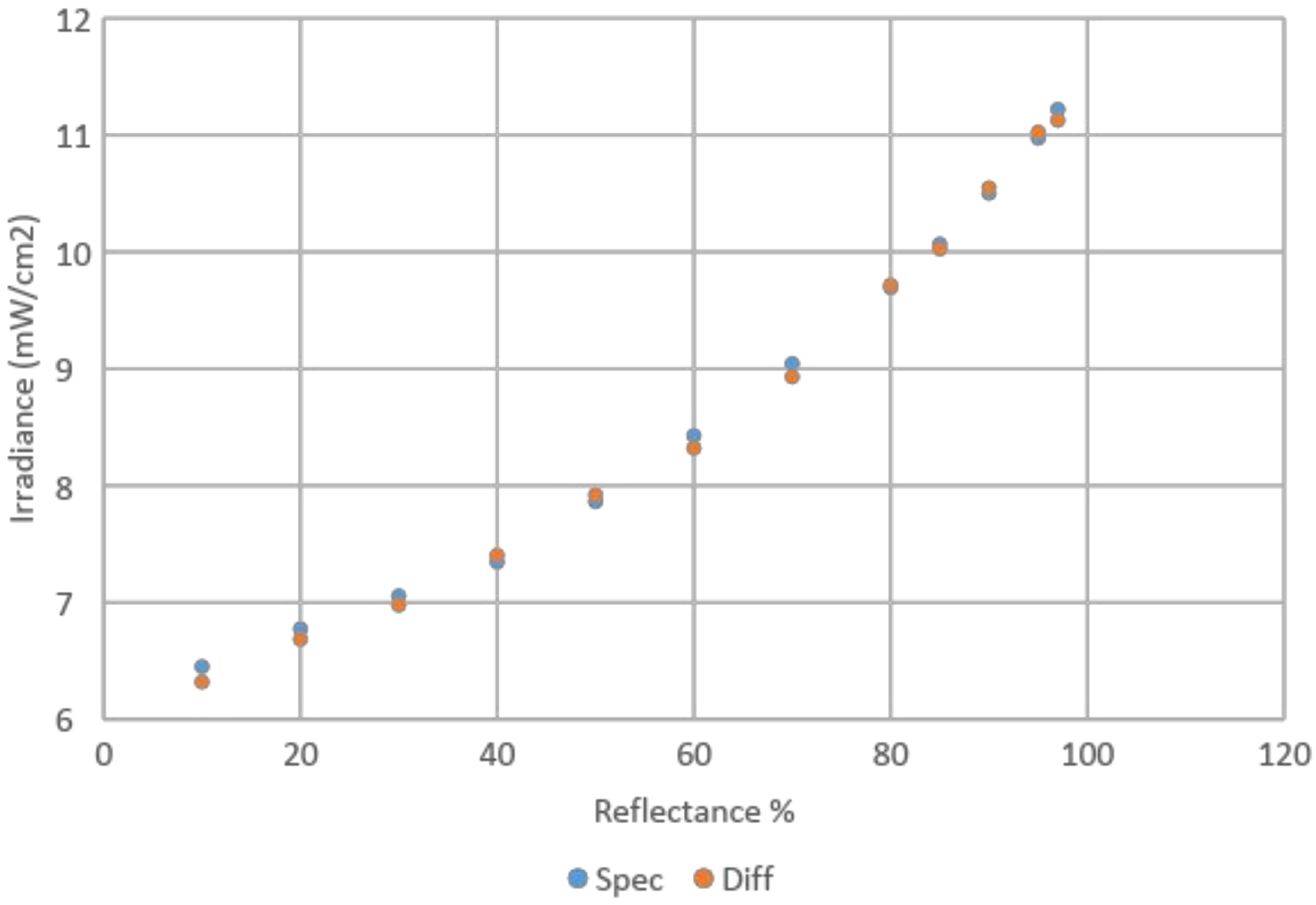
- Back to the integrating sphere!
- Exhibited non-linear response to reflectance.
- Specular and diffuse reflectance are roughly equivalent



1^{st} Taylor Method

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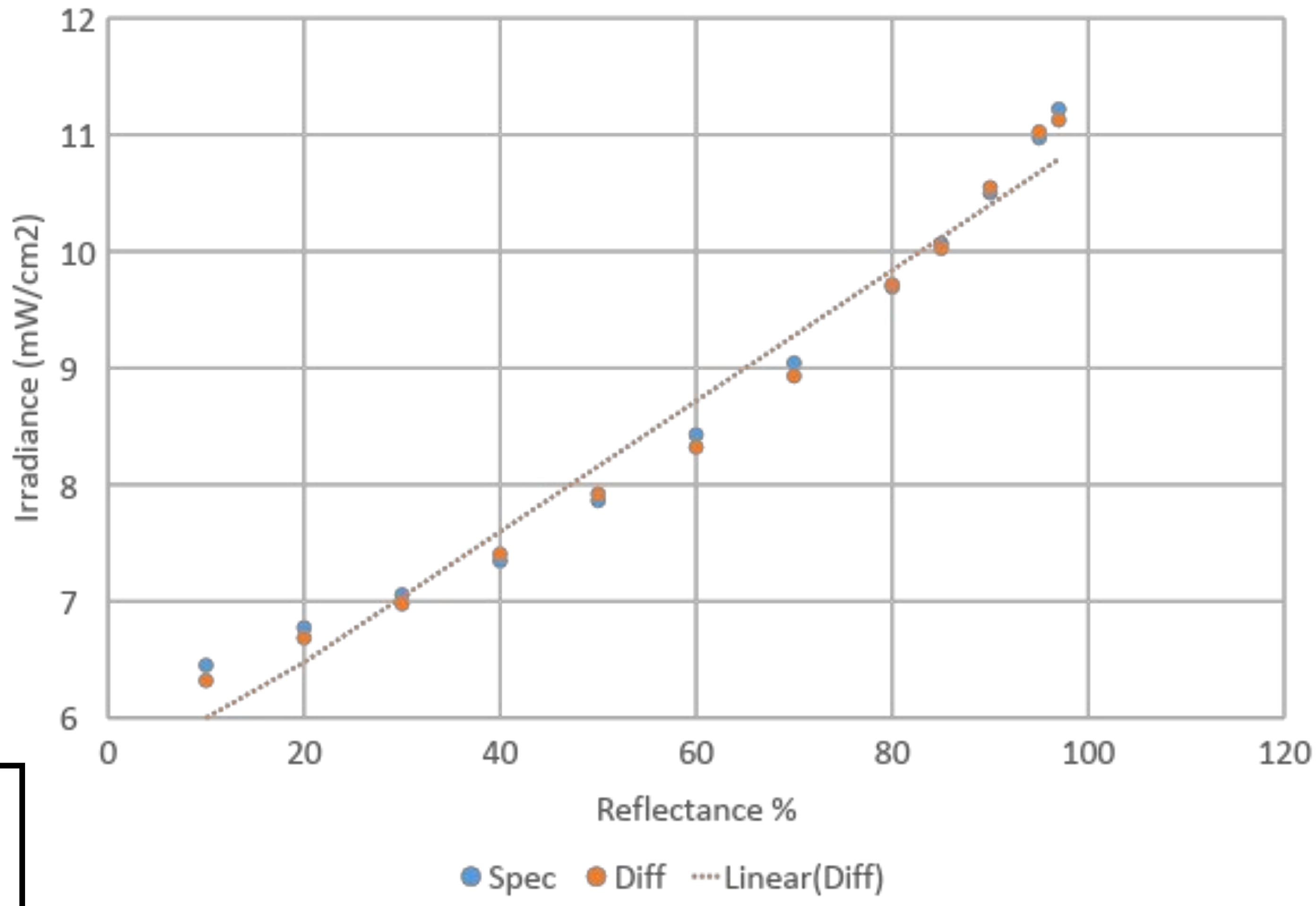
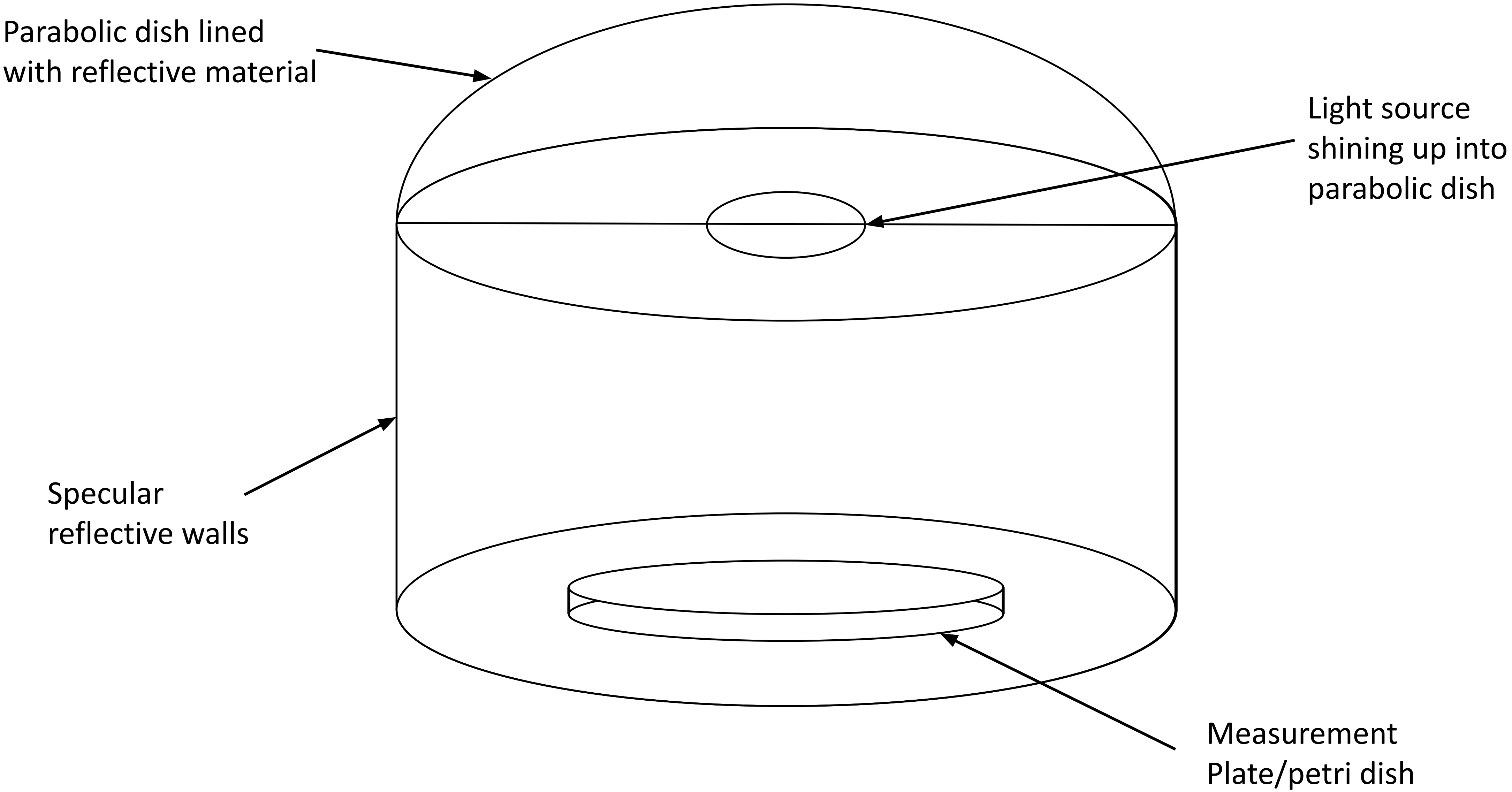
It is possible to use this method at high reflectances, but difficult.

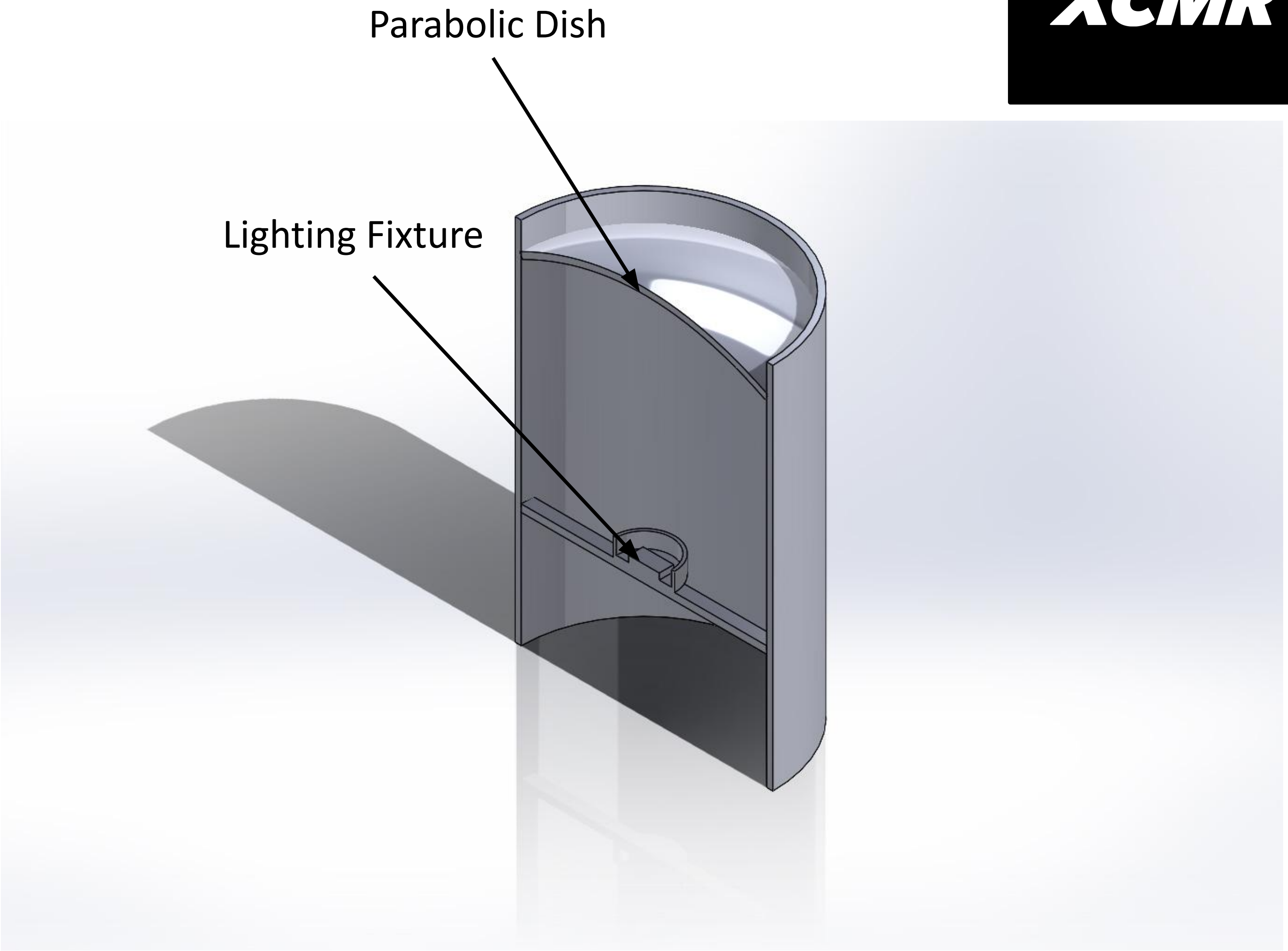


Enter Parabolic Reflectometry



Initial Prototypes

- There are several design questions involved here, including:



Cutaway of CAD model

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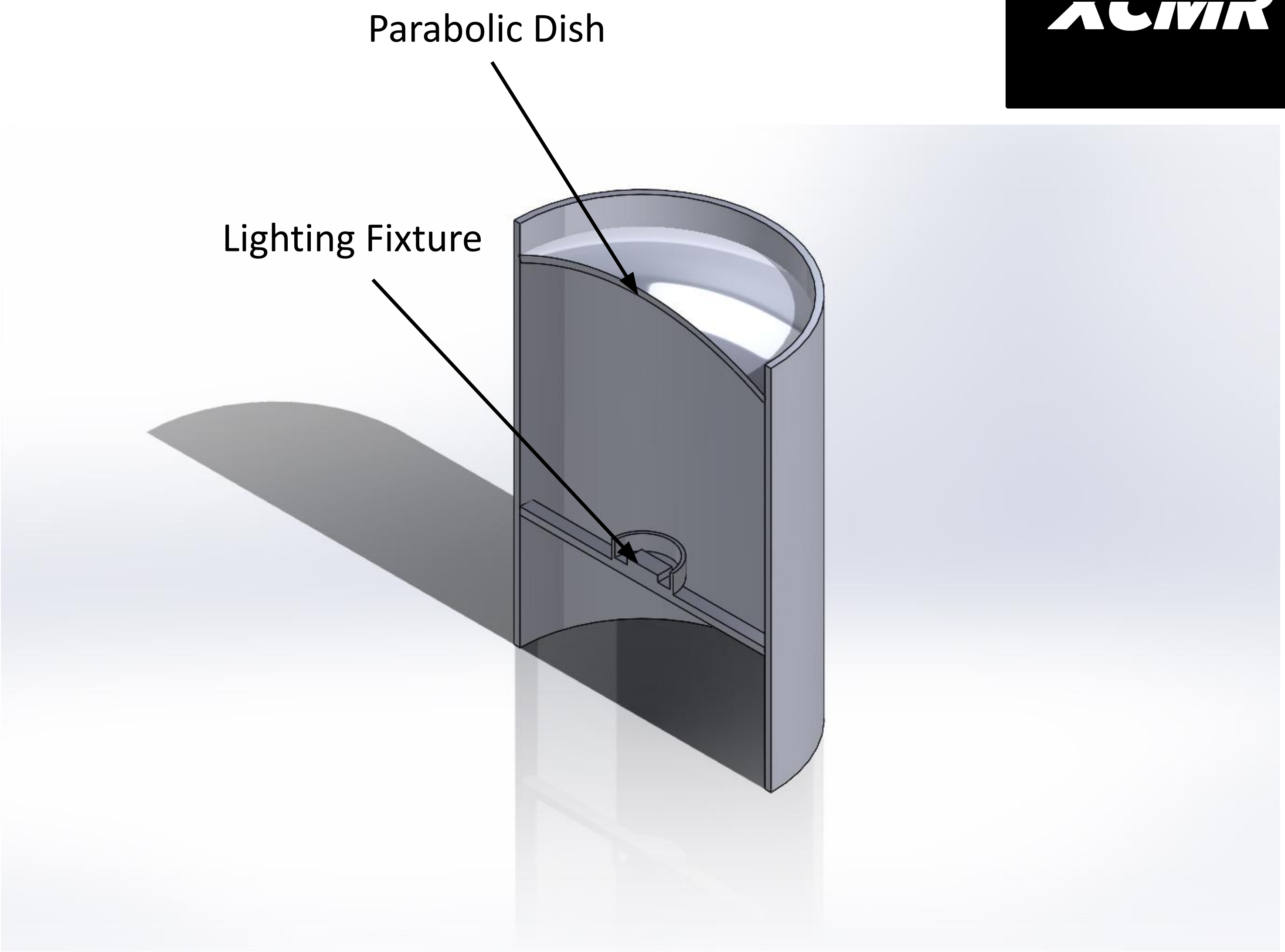
  1. How far should the dish be from the lamp?



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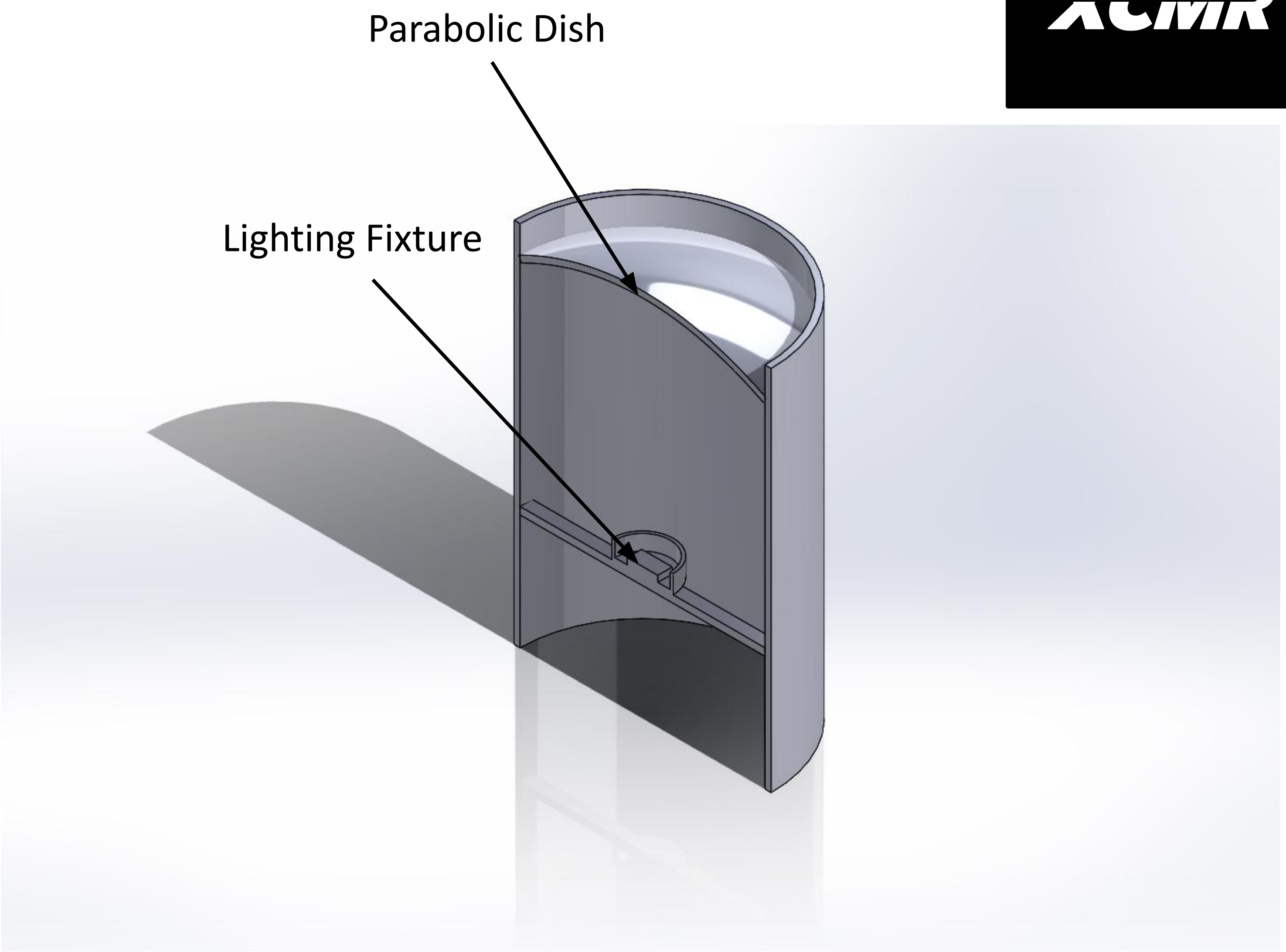

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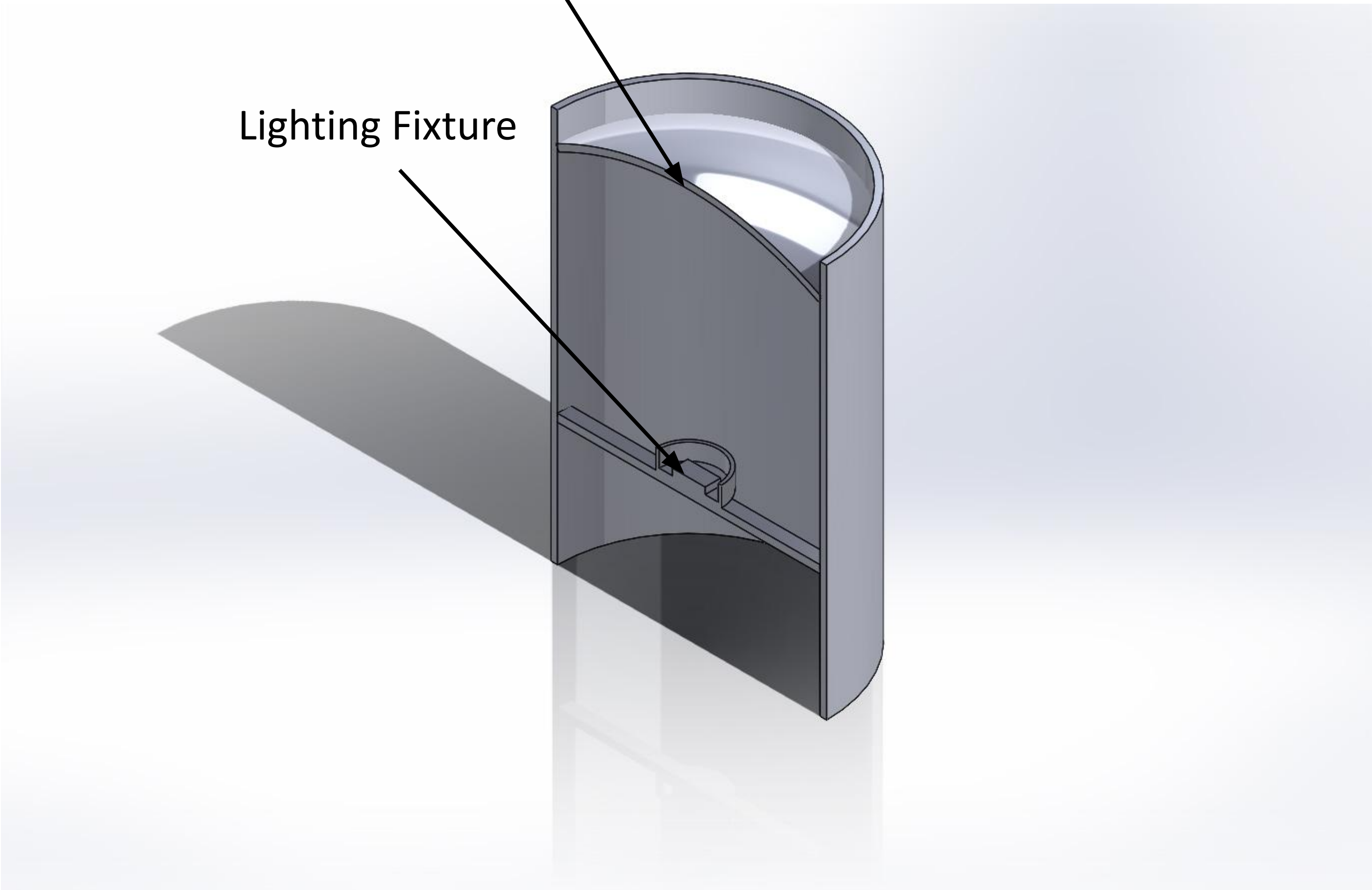

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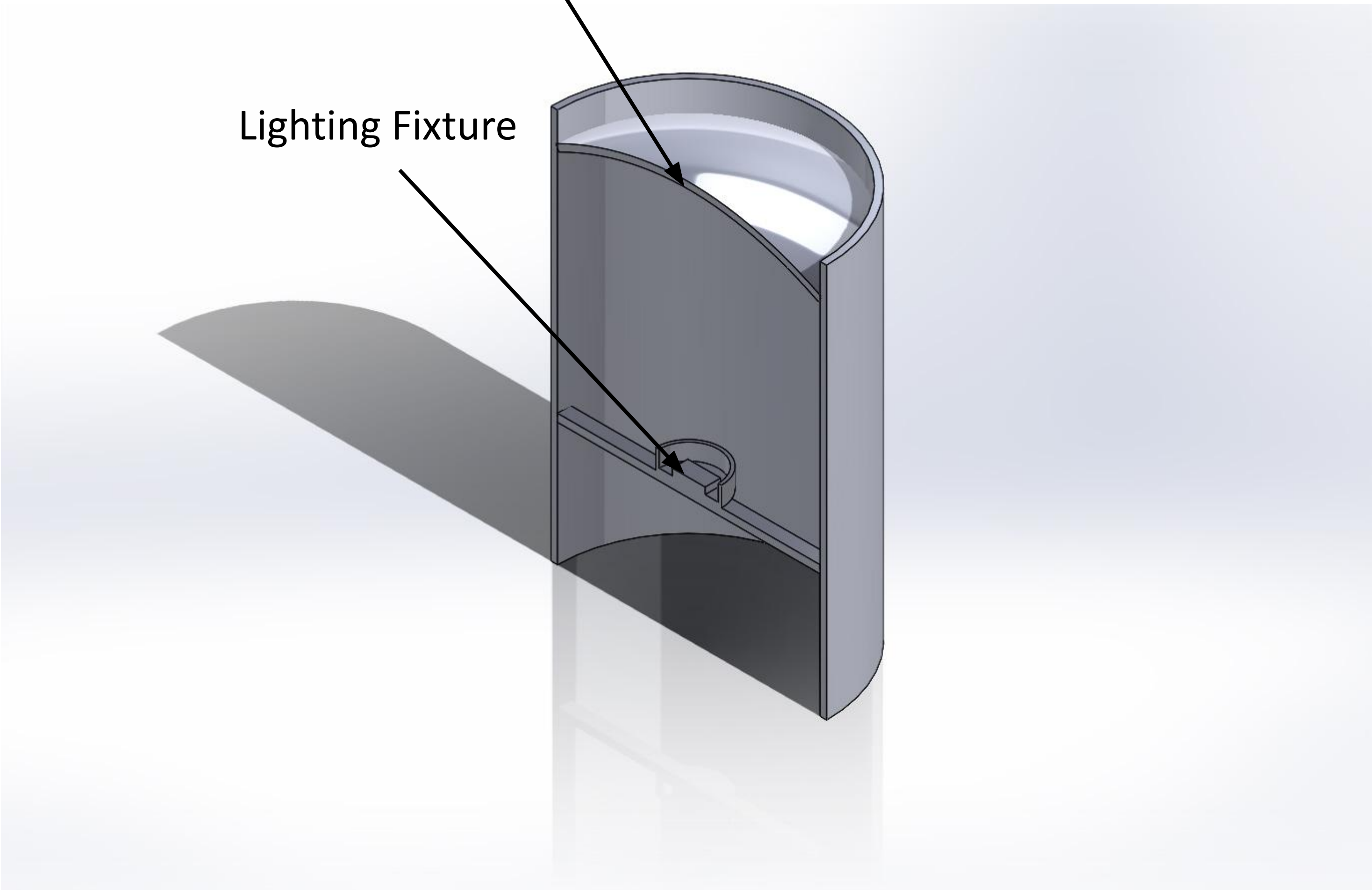
  4. Most important, does it work?!?



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Initial Prototypes

- There are several design questions involved here, including:
  1. How far should the dish be from the lamp?
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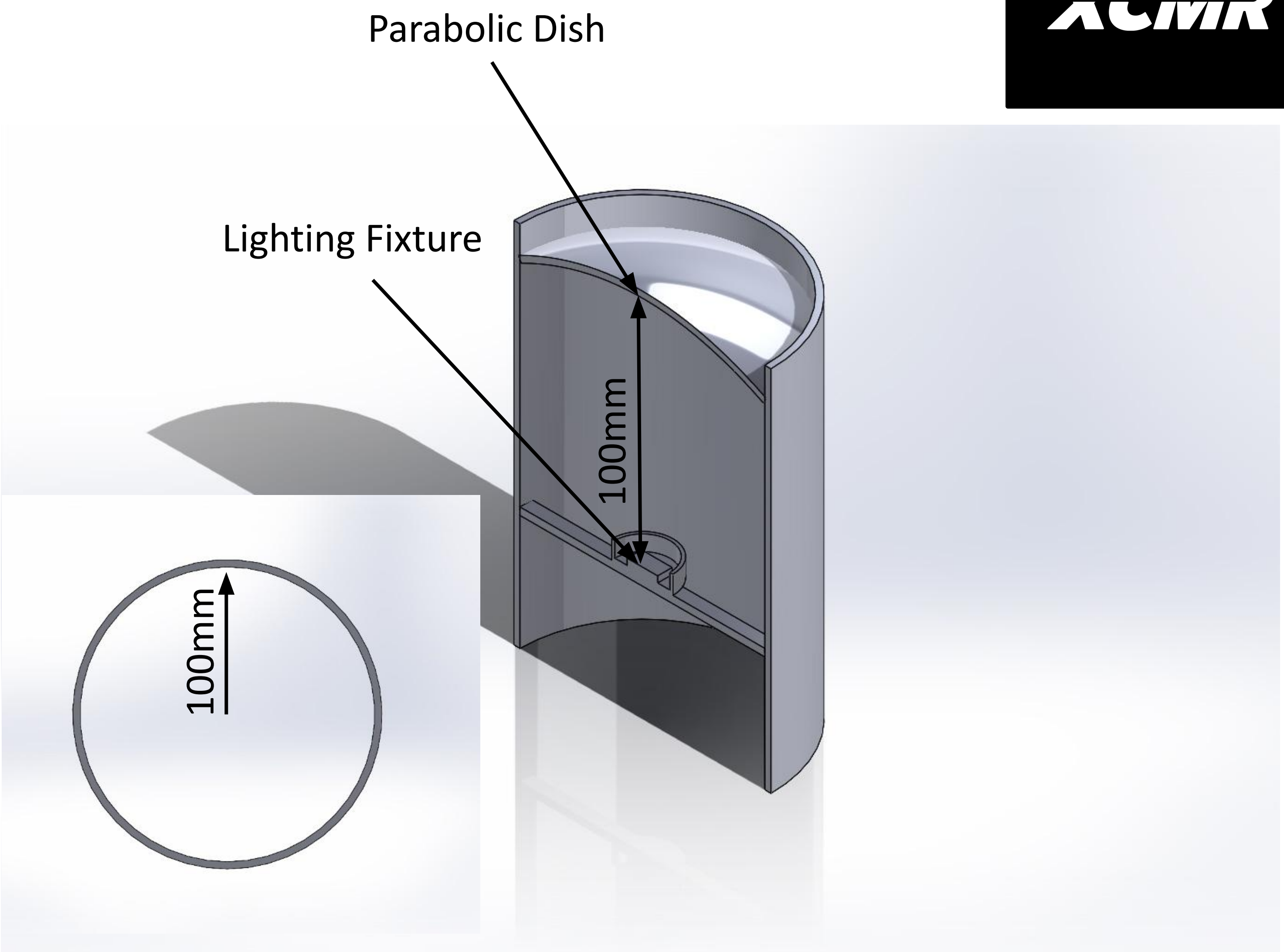
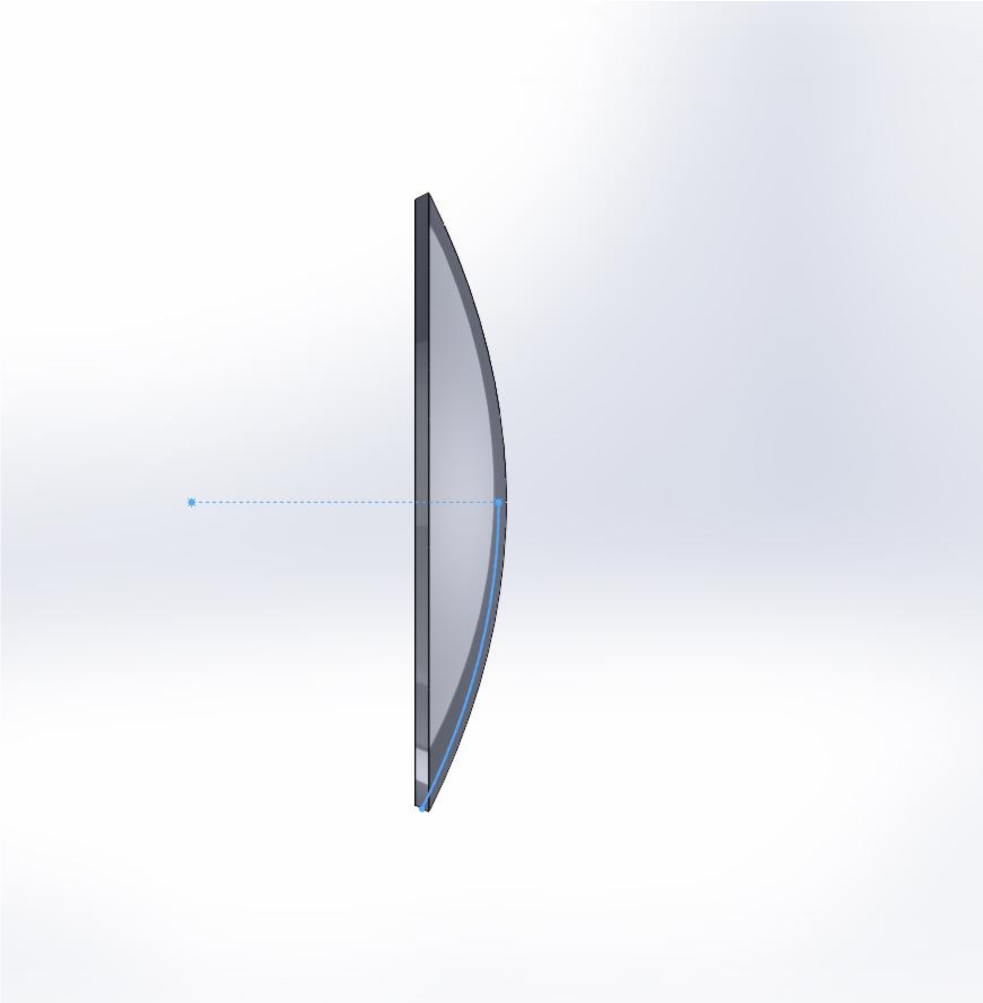
  4. Most important, does it work?!?
- To start with, tested two designs.

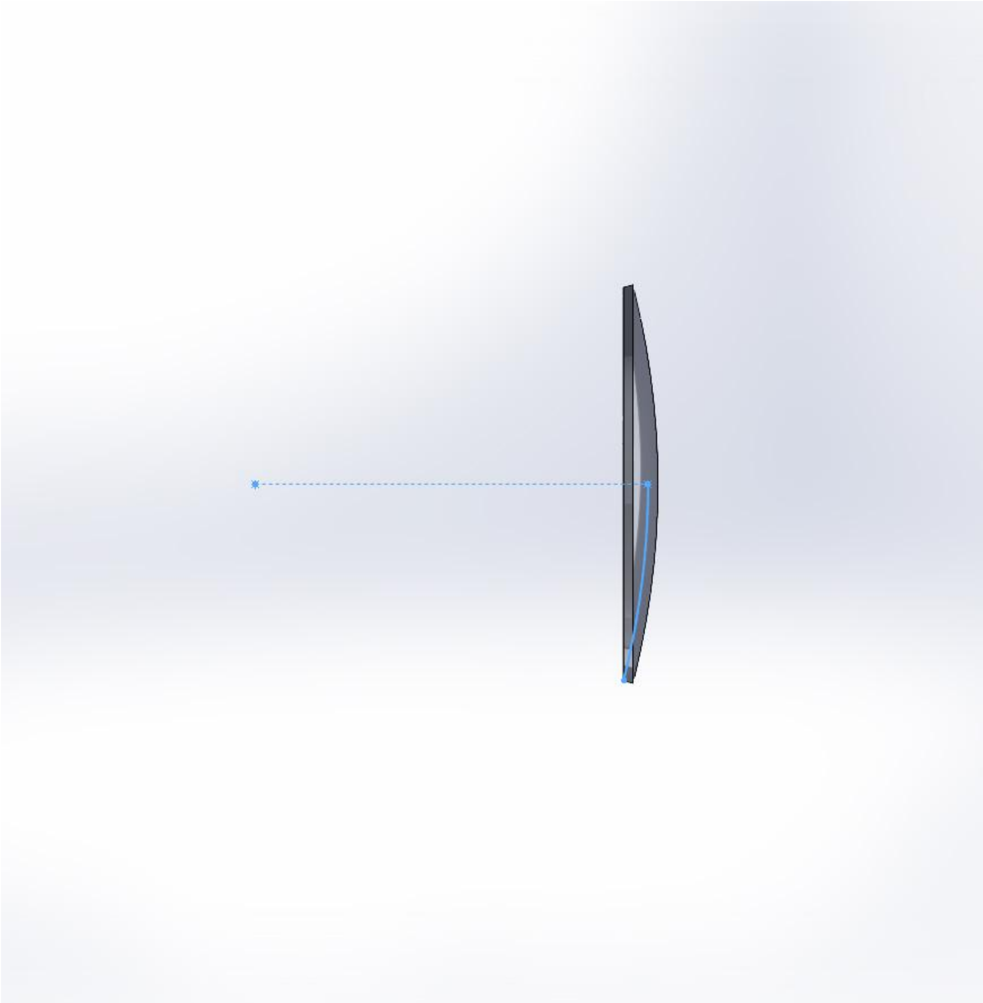


Cutaway of CAD model for 100mm foci distance device. Other prototype has greater foci distance. (image not to scale)

Parabolic Dish Prototypes

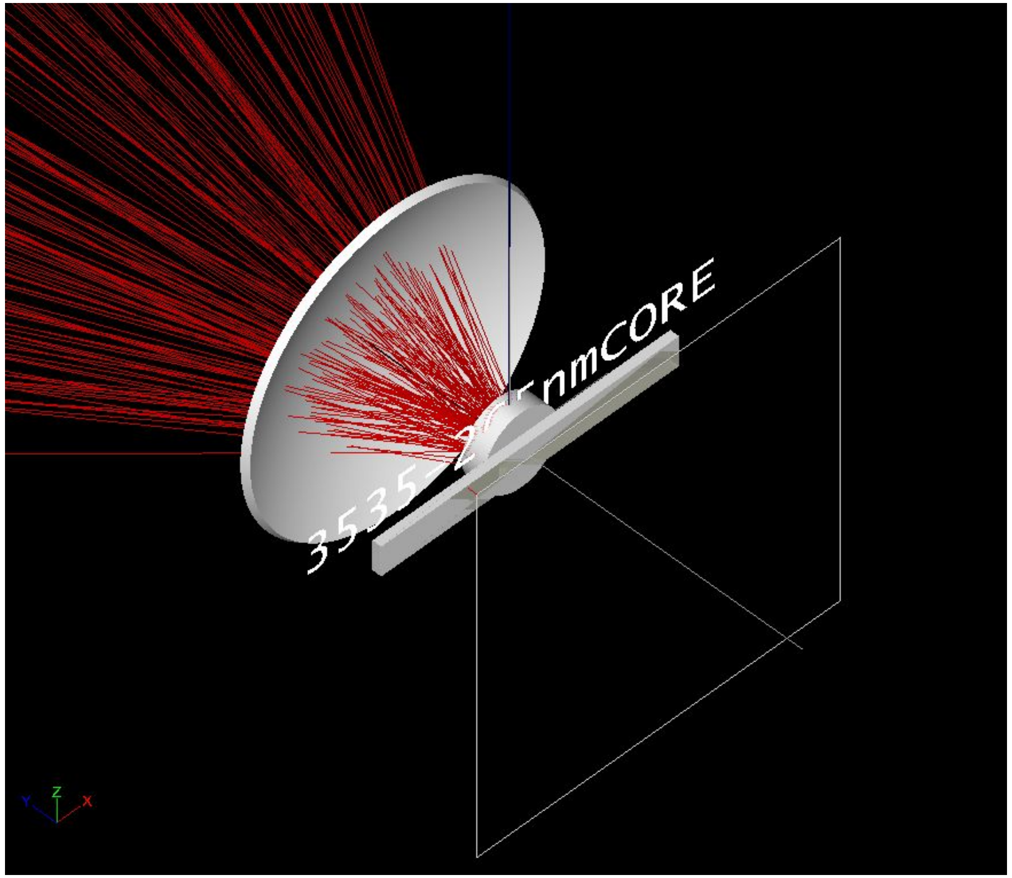


100mm foci length dish



200mm foci length dish

Parabolic Dish Prototypes - Raytracing



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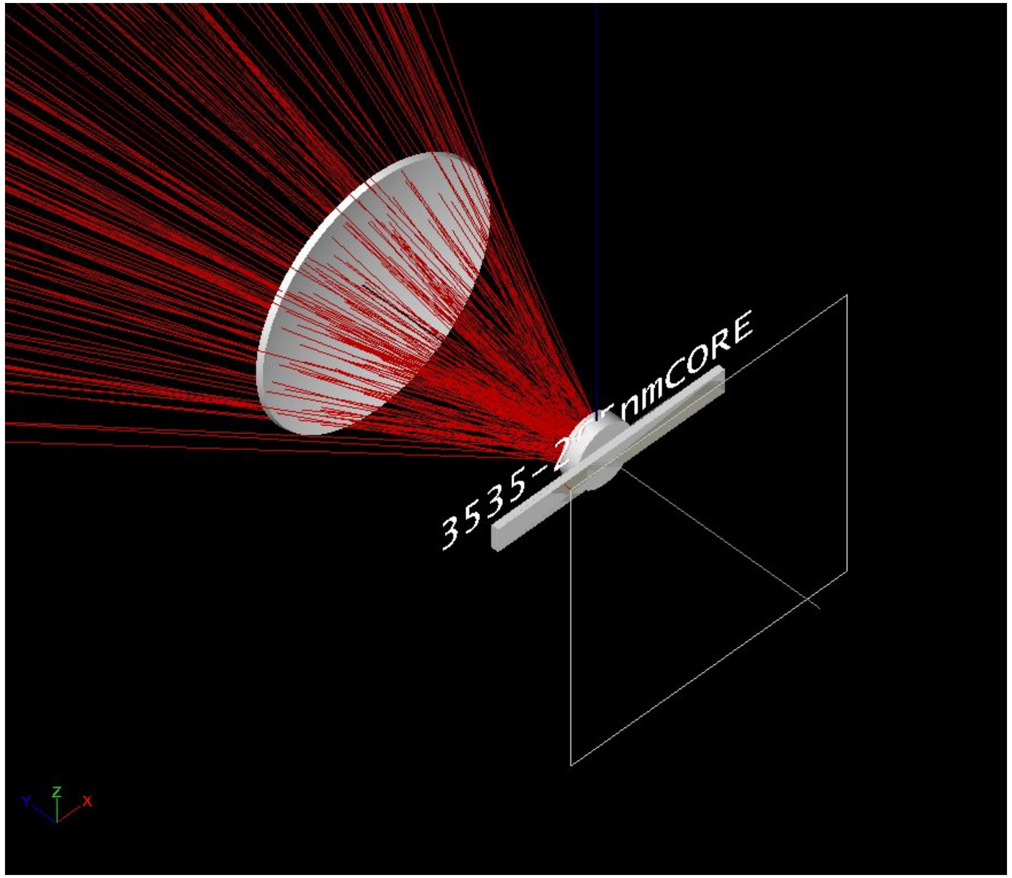

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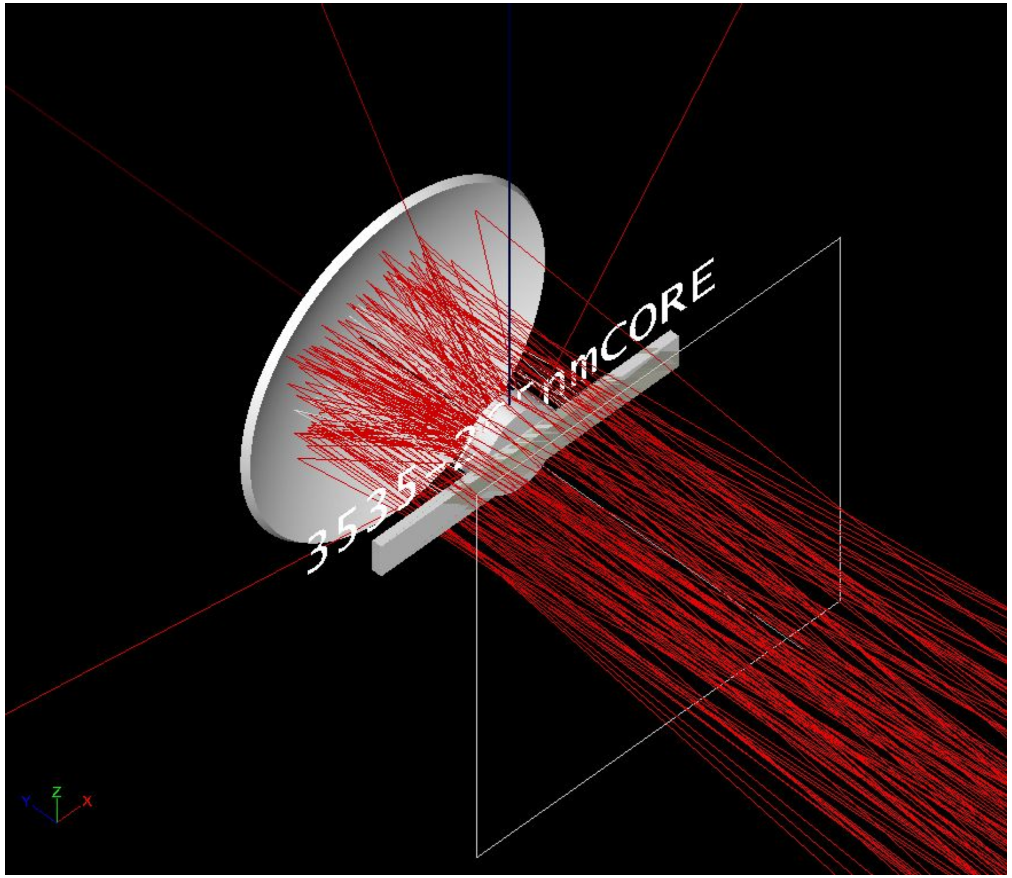
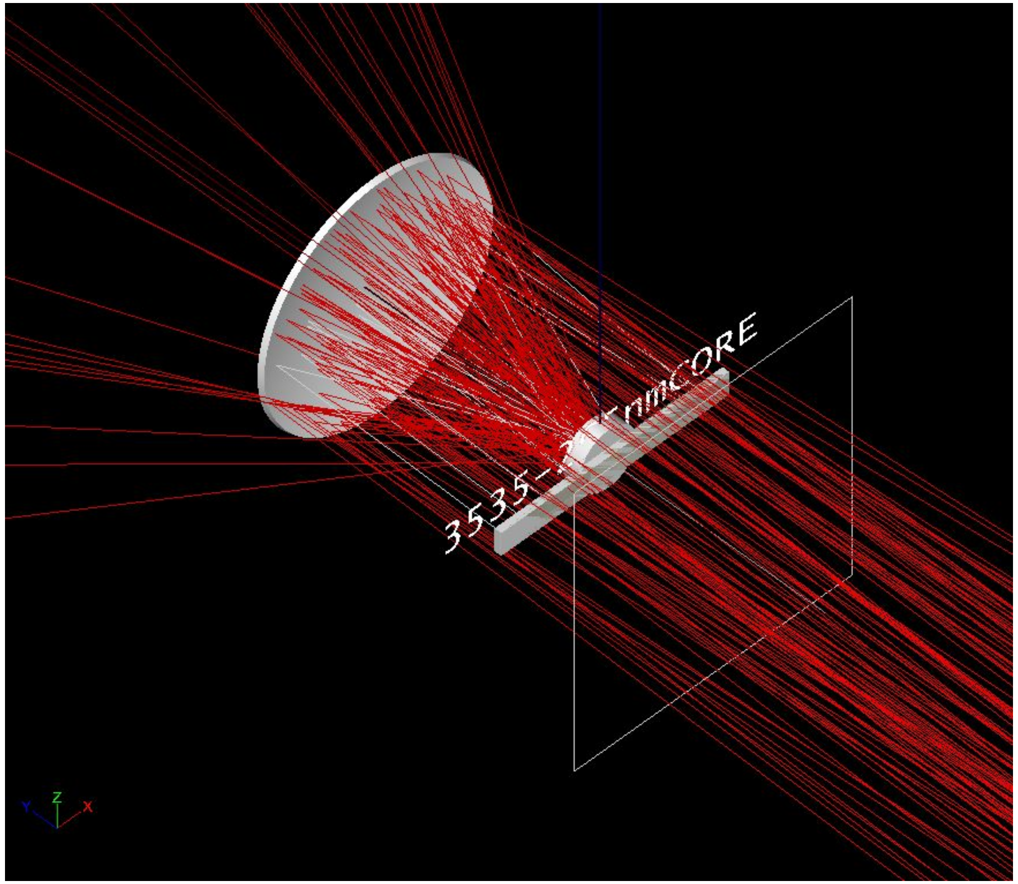
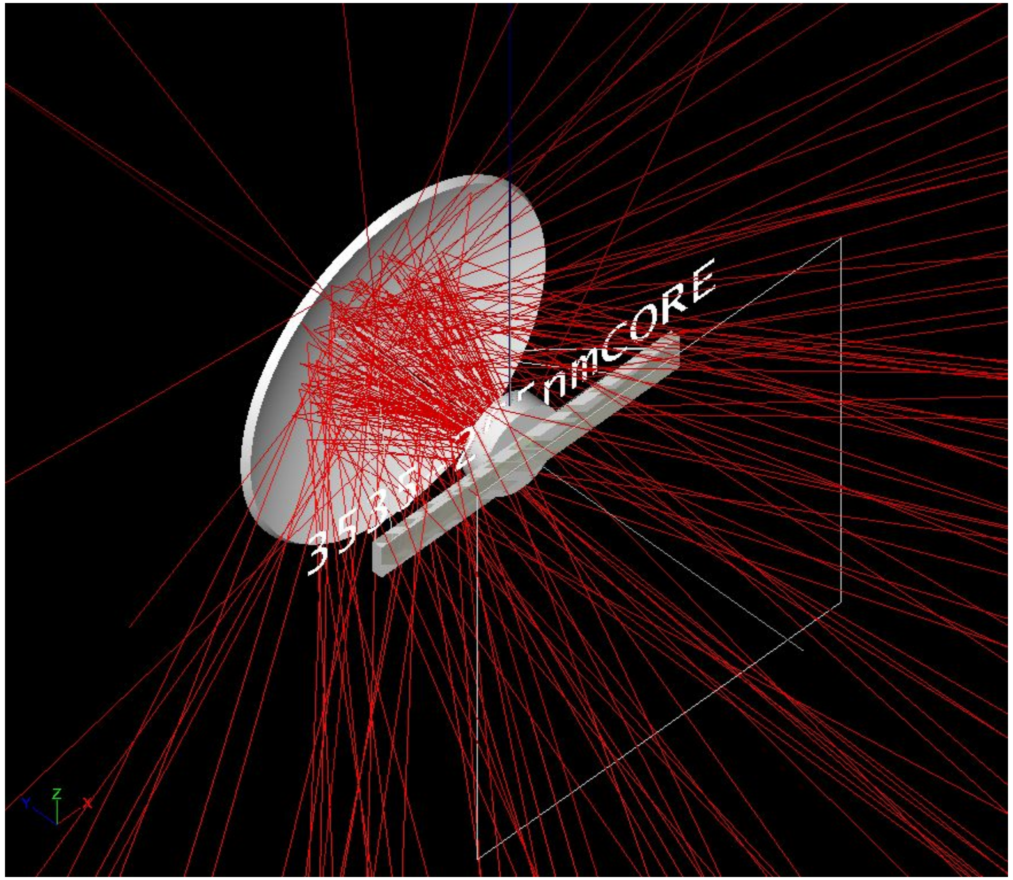


100mm foci length dish

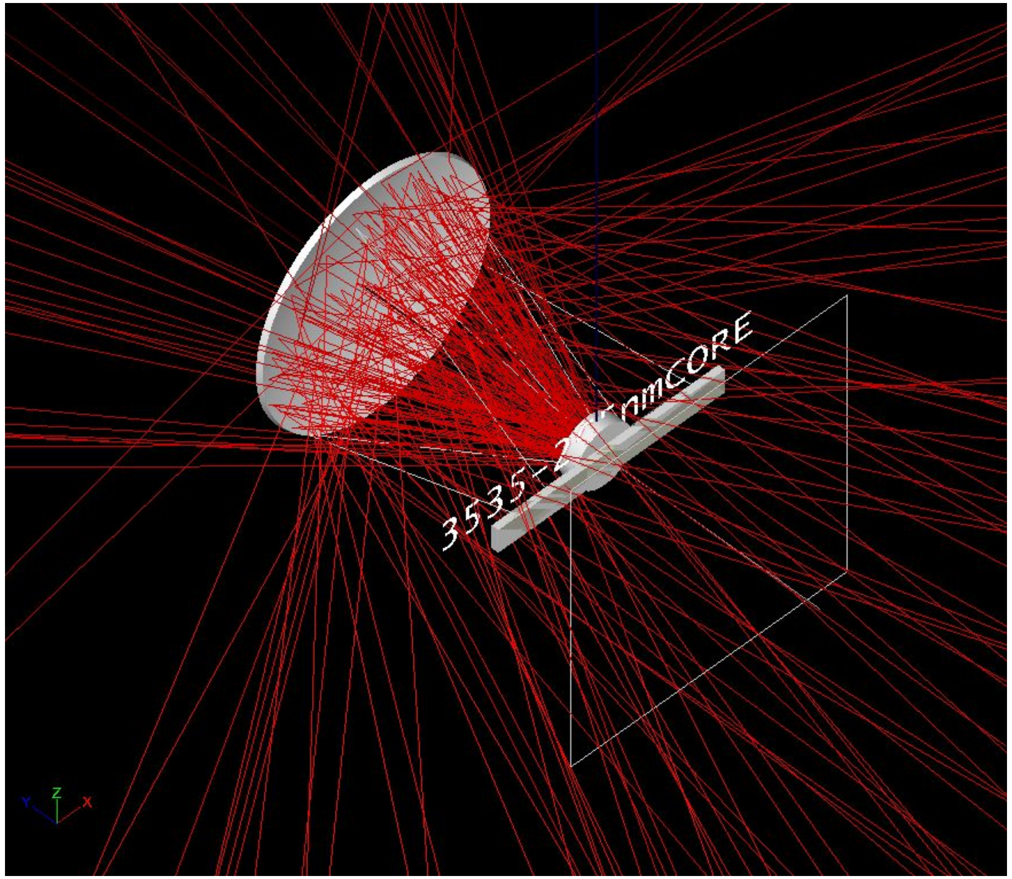


200mm foci length dish

Parabolic Dish Prototypes - Raytracing



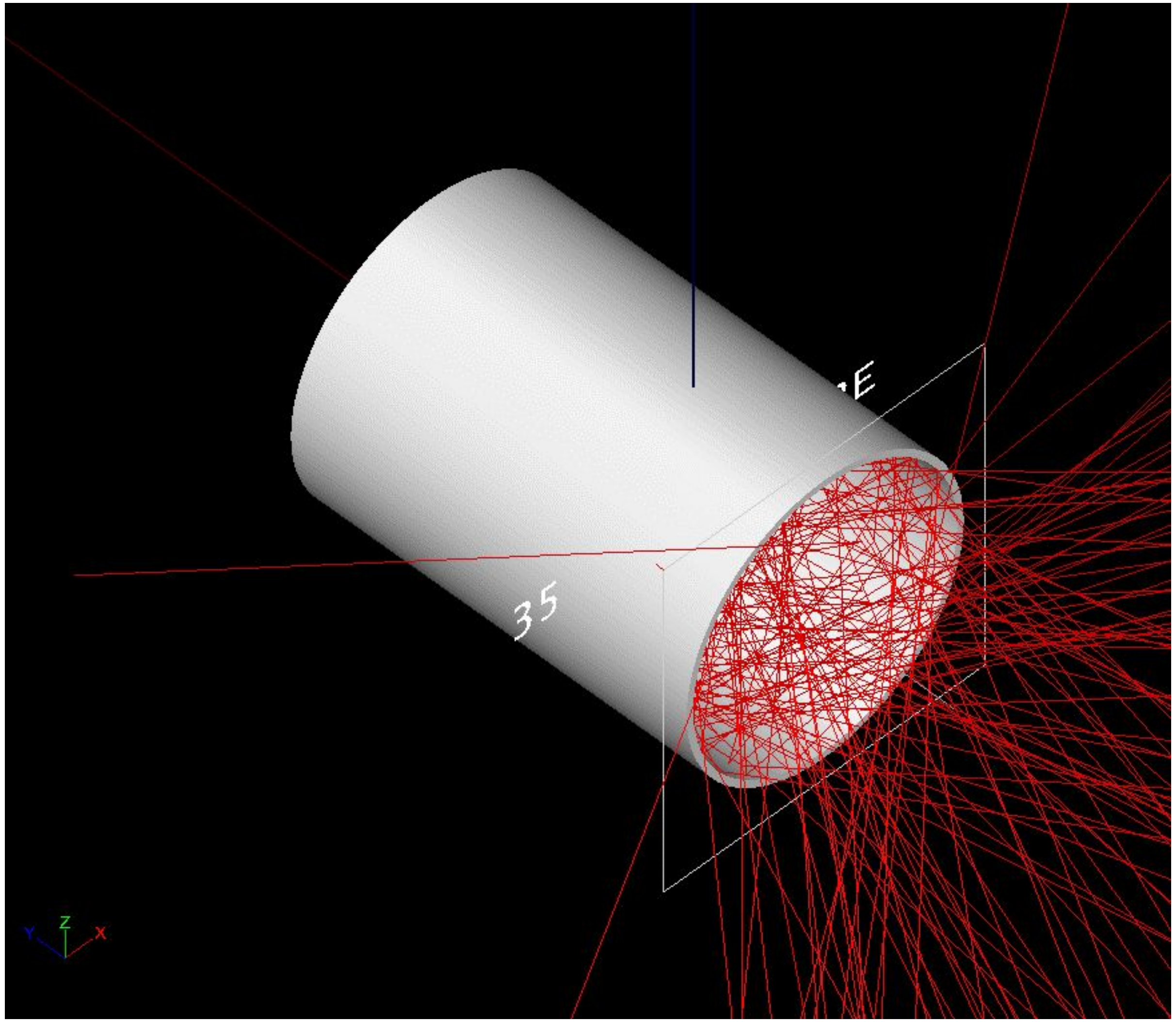
100mm foci length dish



200mm foci length dish

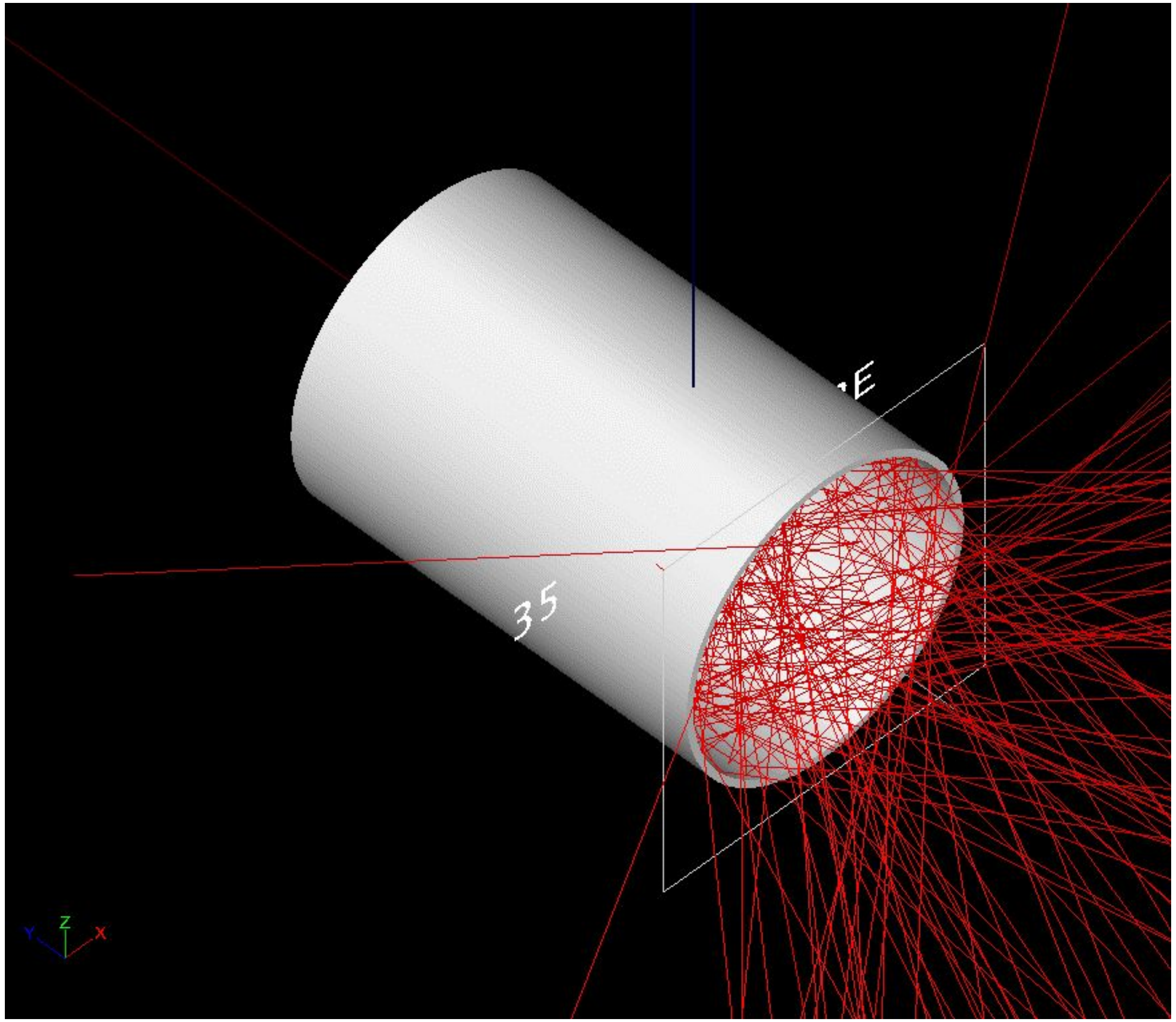
Prototype Results

- The prototype was simulated in Photopia



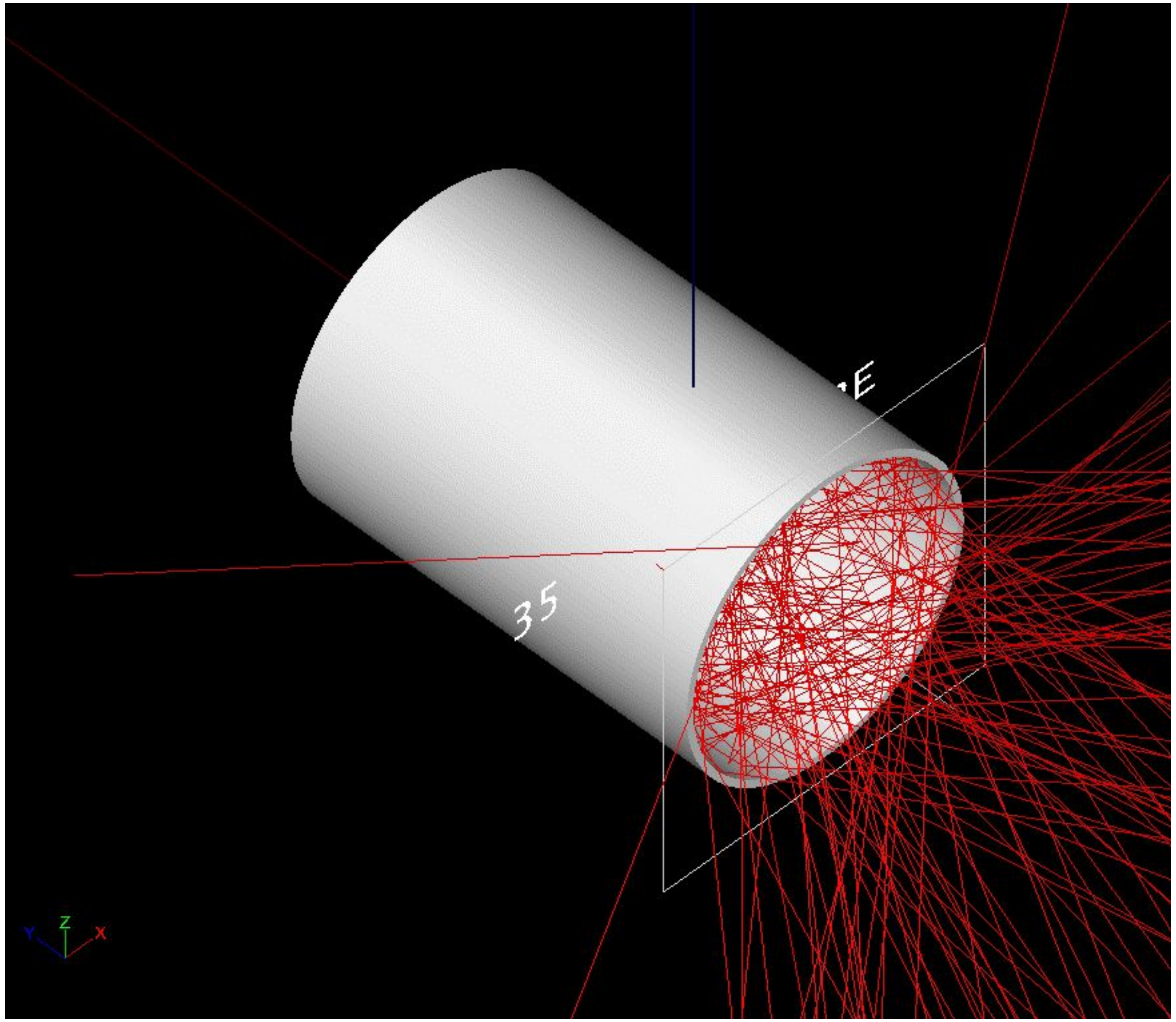
Prototype Results

- The prototype was simulated in Photopia
- Initially, measurements were taken across the whole "outlet"



Prototype Results

- The prototype was simulated in Photopia
- Initially, measurements were taken across the whole "outlet"
- It was determined that most locations could be used, except directly behind the lamp.



Prototype Results – 100 mm Foci

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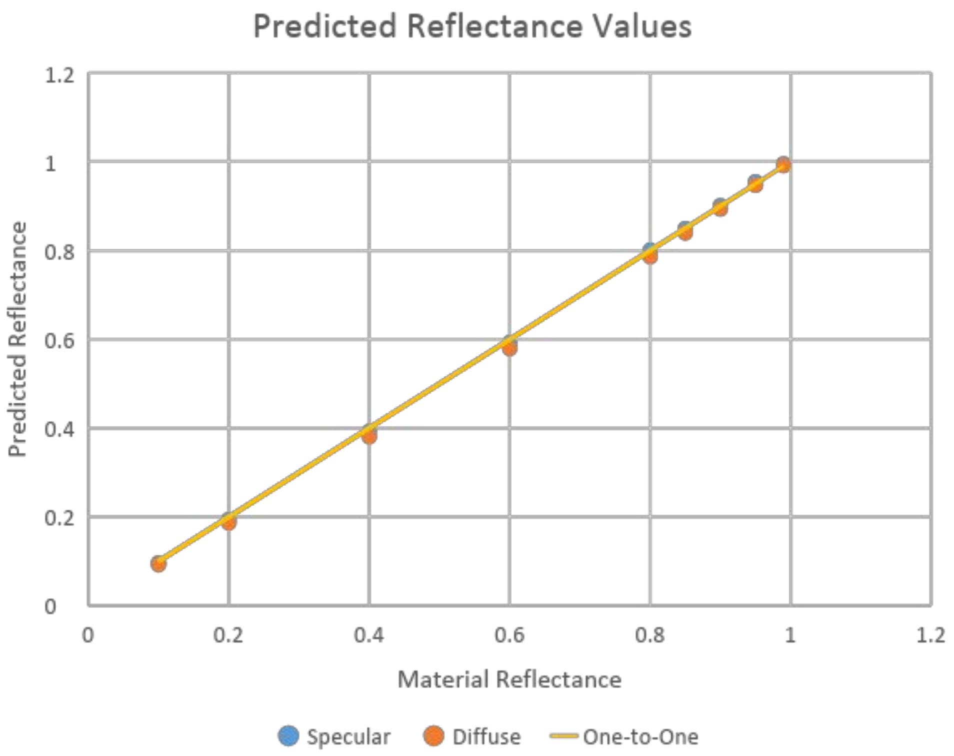
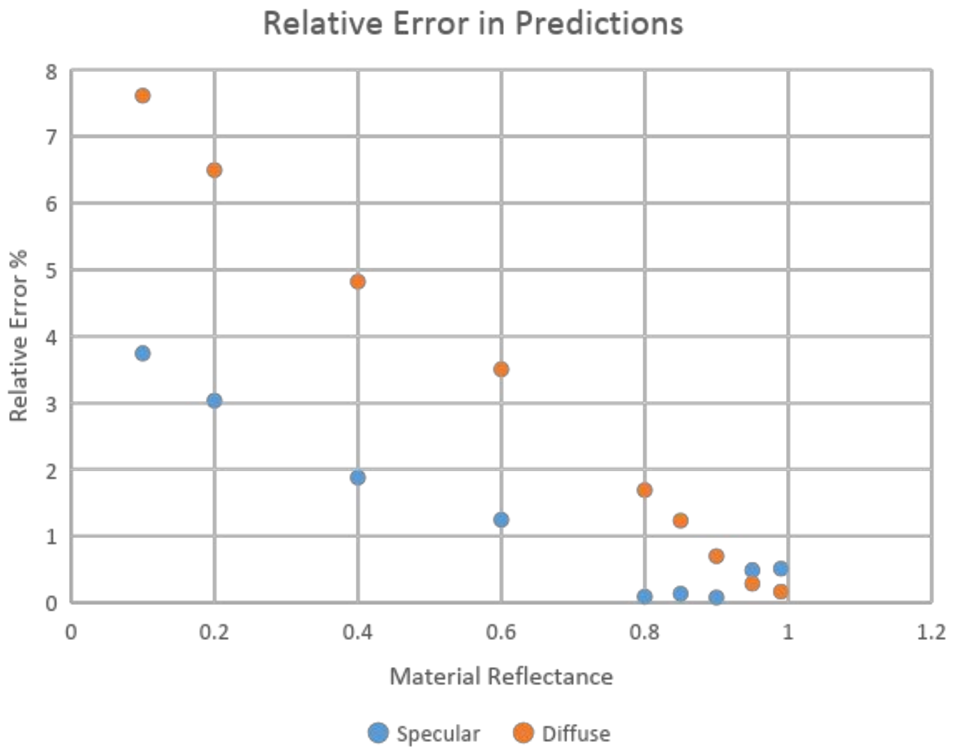
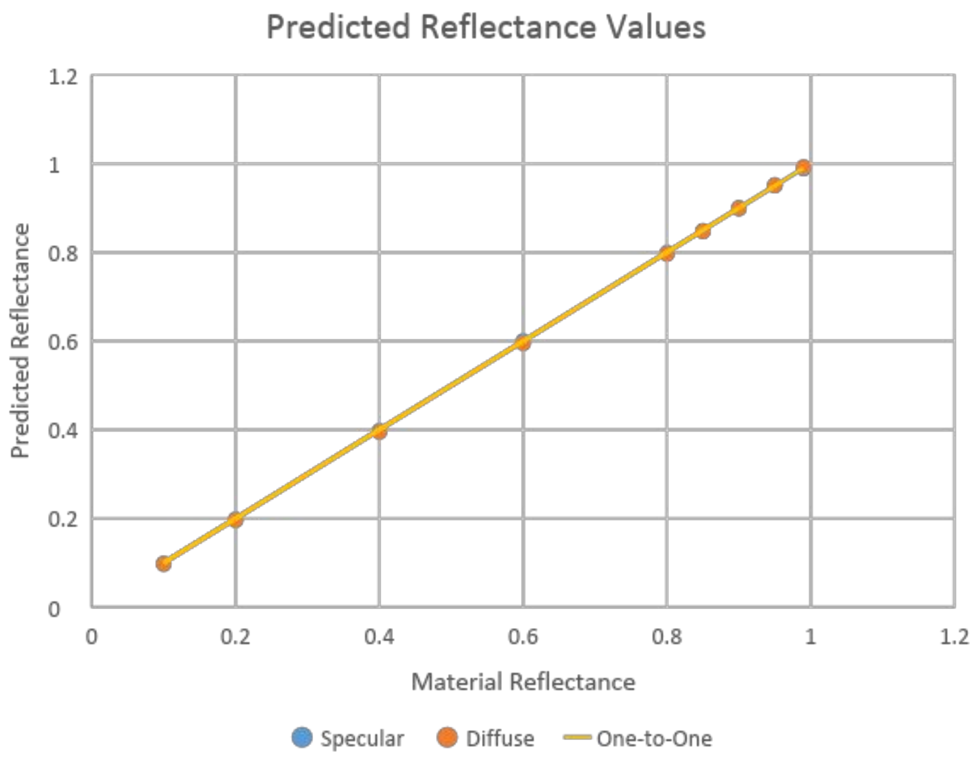
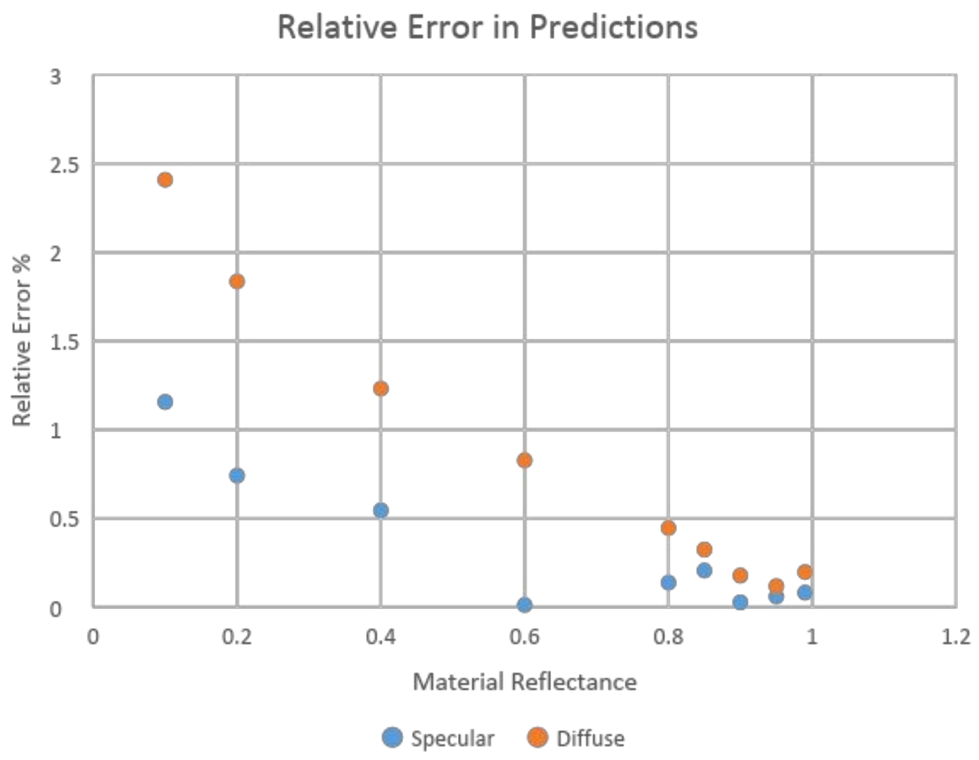




Prototype Results – 200 mm Foci





Summary

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XCMR™

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- When using highly reflective materials in sensitive applications, we need highly accurate methods.
- It is difficult to measure reflectance, even in simulation space!
- While past methods are workable, they are not perfect.
- **The parabolic reflectometer is accurate, relatively insensitive to user error, and easier to use than some methods.**

Questions?