Lumen Uncertainty Measurements:

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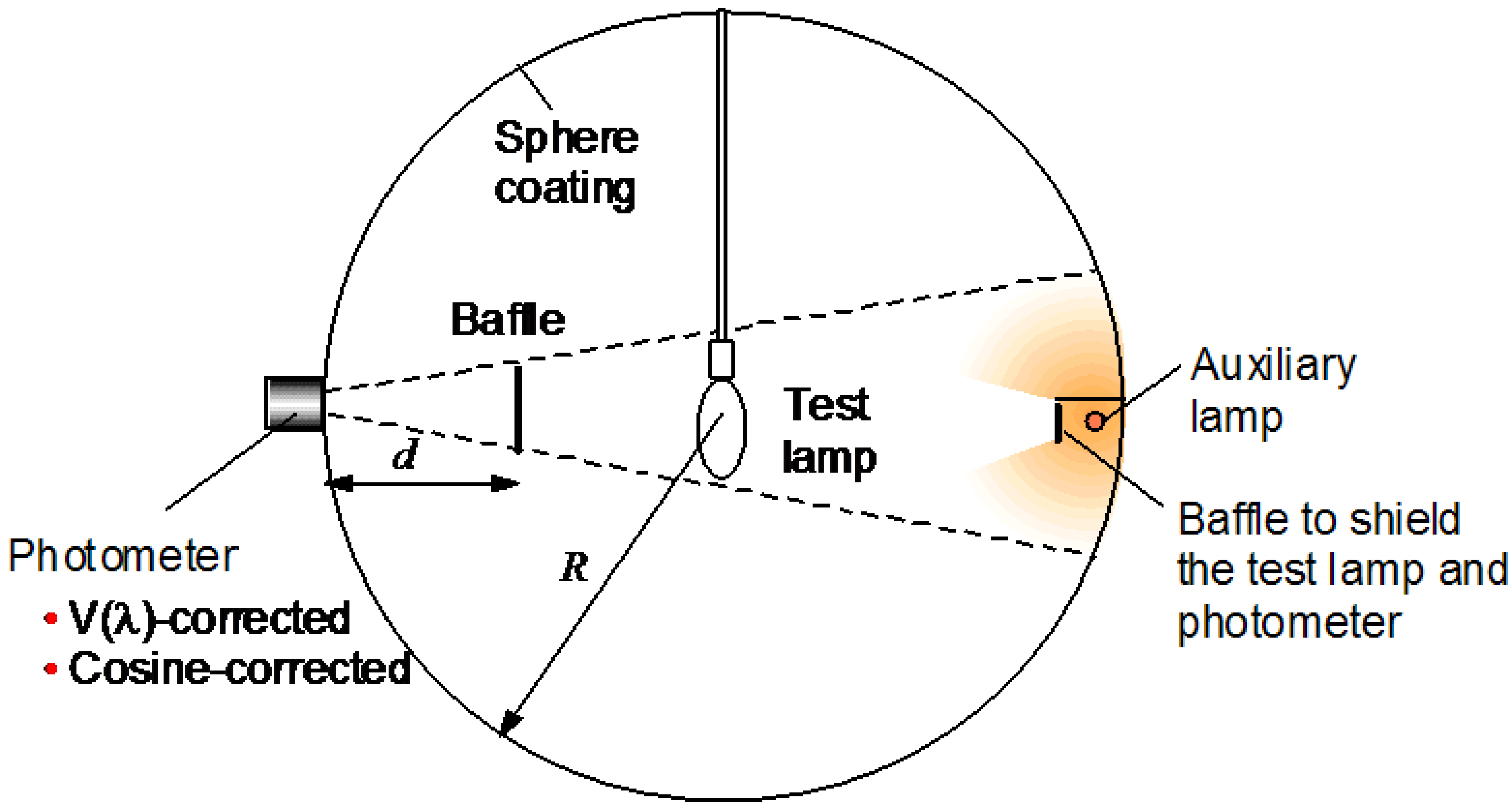
  - Aurora International Test Laboratory (AITL)

Integrating Sphere Photometer



NIST Integrating Sphere

Procedure for determining uncertainty of Lumen Flux

- Follow Guide for Uncertainty Measurements
- Develop spreadsheets for a number of situations
  - Integrating Sphere: Incandescent lumen standard / incandescent lamp with broadband detector using calibrated resistive shunt
  - Integrating Sphere: Incandescent lumen standard / SSL or CFL lamp with spectral detection
  - Mirror Goniometer: Incandescent intensity standard / SSL fixture with broadband detector

8-step GUM Procedure

1. Write an equation for the lumen output in terms of all the input variables $Y = f(X_1, X_2, \ldots X_n)$
2. Determine x_i, the estimated value of input quantity X_i, through statistical analysis of measurements
3. Evaluate the standard uncertainty $u(x_i)$ of each input estimate $x_{i.}$ Type A or Type B evaluations.
4. Evaluate the covariances
5. Calculate the result of the measurement, that is, the estimate y of the measurand Y
6. Determine the *combined standard uncertainty* $u_c(y)$ of the measurement result y from the standard uncertainties

8-step GUM Procedure (cont.)

6. Determine the *combined standard uncertainty* $u_c(y)$ of the measurement result y from the standard uncertainties
7. If it is necessary to give an *expanded uncertainty* U. multiply the combined standard uncertainty $u_c(y)$ by a coverage factor k, typically in the range 2 to 3, to obtain $U = ku_c(y)$.
8. Report the result of the measurement y together with its combined standard uncertainty $u_c(y)$ or expanded uncertainty U.

Step 1: Equation of Input Variables

- List Input variables that contribute to uncertainty. Assume spectral detection
  - Raw lumen value: reference and test lamp
  - Burning time: reference standard
  - Stray light: reference and test lamp
  - Spatial distribution of light: reference and test lamp
  - Angular response of detector: reference and test lamp
  - Self-absorption: reference and test lamp
  - Electrical measurements: reference and test lamp
  - Ambient temperature variation: test lamp

Integrating Sphere Errors

- Self-absorption of test lamps.
- Spectral mismatch of the sphere photometer.
- Spatial non-uniformity of sphere response.
- Near-field absorption.
- Detector angular response

Corrections

- Use auxiliary lamp
- Use diode array or CCD detector
- Map sphere response using small-beam source
- Not correctable
- Use auxiliary sphere

Step 1: Equation of Input Variables

- Model Equations
  - $corS = (1 + \alpha\Delta T_{\alpha} - \Delta_s f - S(\theta) - \gamma\Delta t)$
  - $corS_R = (1 + \alpha_R \Delta T_{\alpha R} - \Delta_s f_R - S_R(\theta) - \gamma_R \Delta t_R)$
  - $\Phi = \Phi_R \cdot \frac{y}{y_R} \cdot \frac{y_{AR}}{y_A} \cdot \left(\frac{U \cdot c_U}{U_0}\right)^{m_U} \cdot \left(\frac{U_R \cdot c_R}{R \cdot J_R}\right)^{m_{JR}} \cdot \frac{corS_R}{corS}$

Step 2: Find Values of all inputs

- Use a spreadsheet
  - List all the variables used in the model equations one per row
  - Provide columns for variable name, symbol, units and values
  - Determine values from statistical analysis of repeat measurements (Type A) or from calibration sheets or by an educated guess.
  - List output variable (lumens) as last row

Step 3: Determine the uncertainty

- Record values for standard uncertainty, $u(x_i)$ in spreadsheet column following the mean value
  - Standard uncertainty for a normal distribution is the standard deviation
  - Standard uncertainty for a tolerance interval is the interval divided by square root of 12.
- Record statistical type, A or B, in next column

Step 5: Calculate lumen output

- Step 4 is not needed as covariances are all zero for lumen evaluations
- Using model equation calculate lumen output on spreadsheet

Step 6: Determine combined uncertainty

- This involves obtaining sensitivity coefficients (partial derivative of output variable with respect to given input variable as defined by model equation)
- Multiply standard uncertainty by the sensitivity coefficient to obtain relative uncertainty
- Sum the squares of the relative uncertainty values and take square root of sum

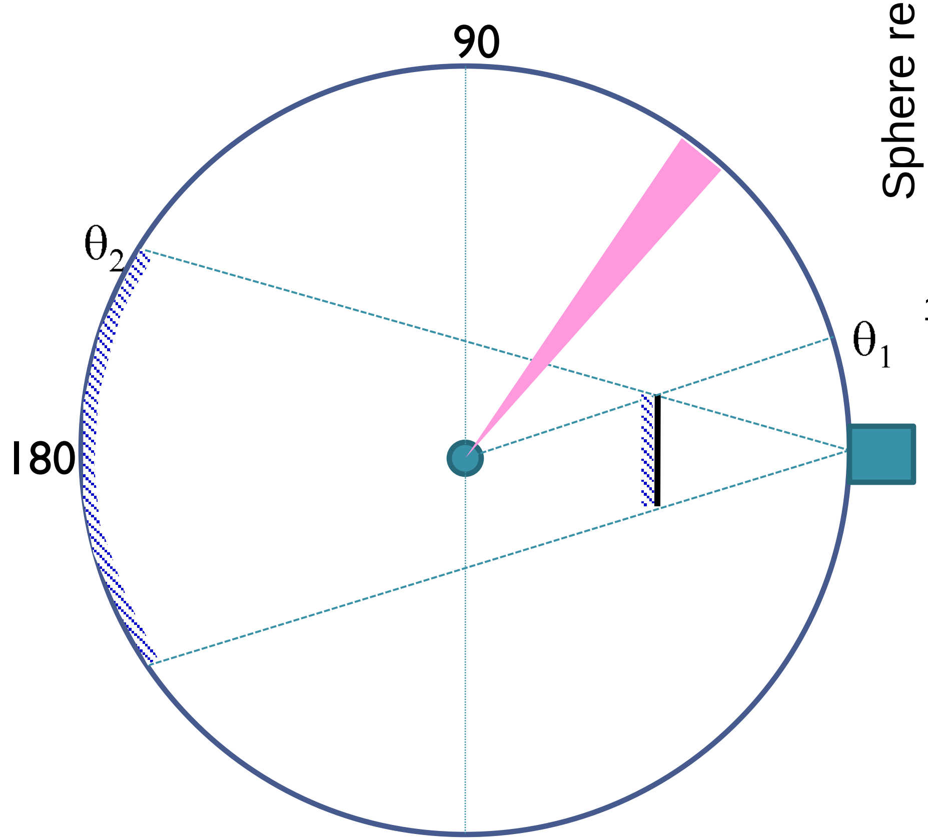
Determine expanded uncertainty

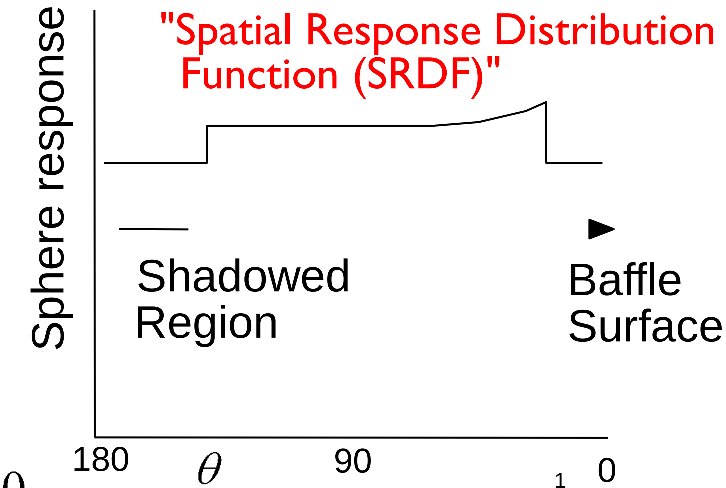
- Multiply combined uncertainty by a coverage coefficient, k, to obtain expanded uncertainty
  - k about equal to 2 implies 95 % confidence
  - k about equal to 3 implies 99 % confidence
- The number of degrees of freedom of a given variable value and uncertainty influence the relationship between k and the confidence level.

CLOSER LOOK AT HOW TO DETERMINE SOME OF THE ERRORS

NIST rotating collimated source for mapping sphere spatial distribution

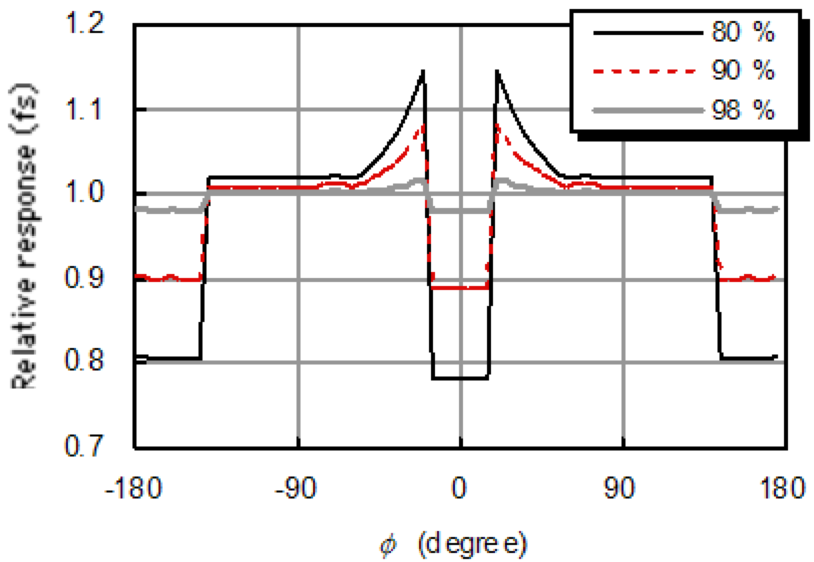
NIST Spatial Map of an Integrating Sphere



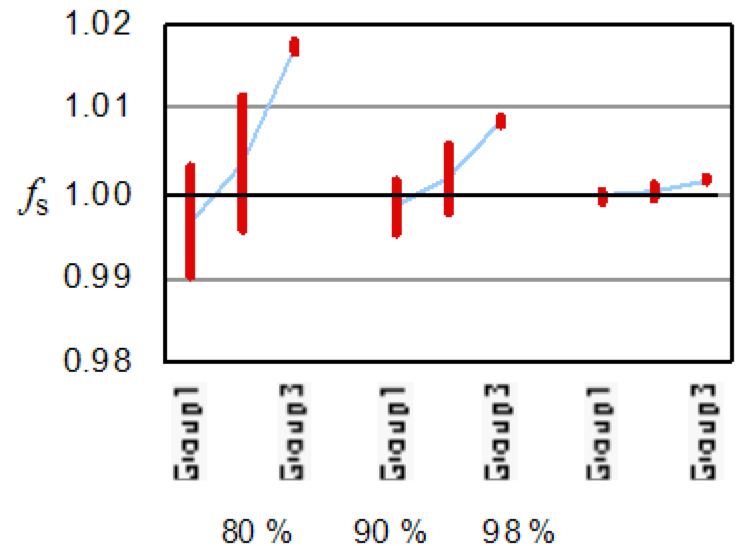


Effect of Sphere Reflectance on Spatial Distribution

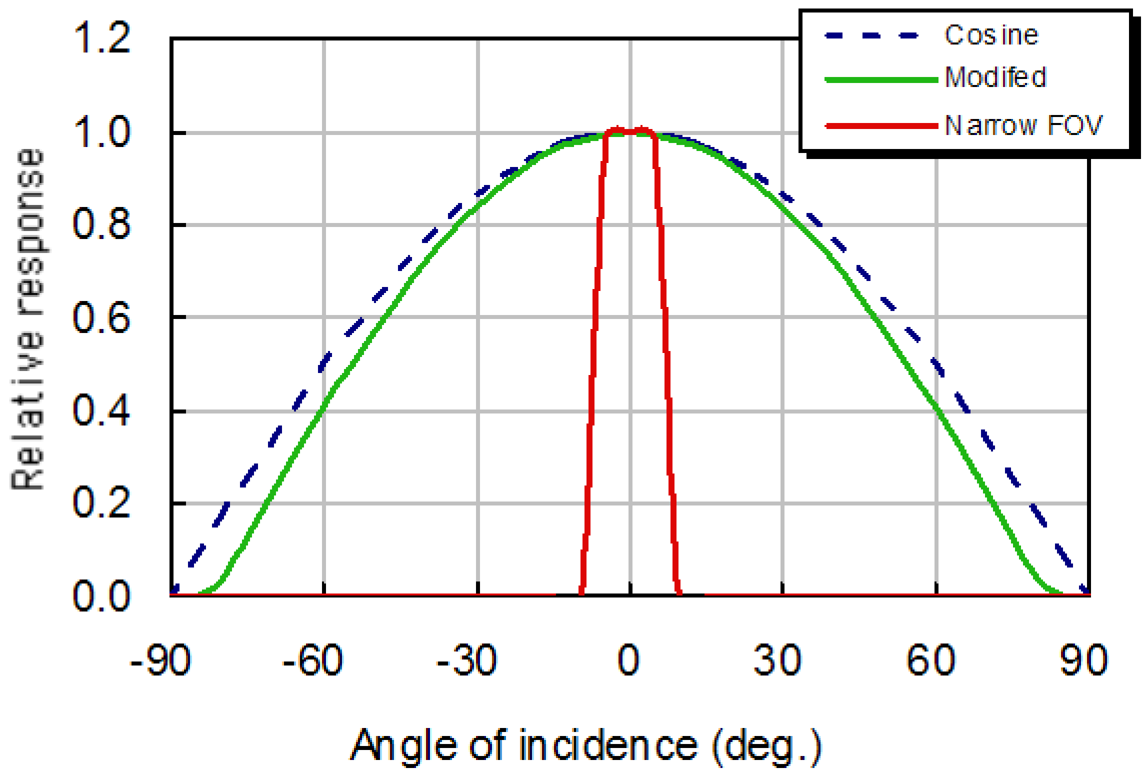
SRDF curves (equator)



Sphere response factors



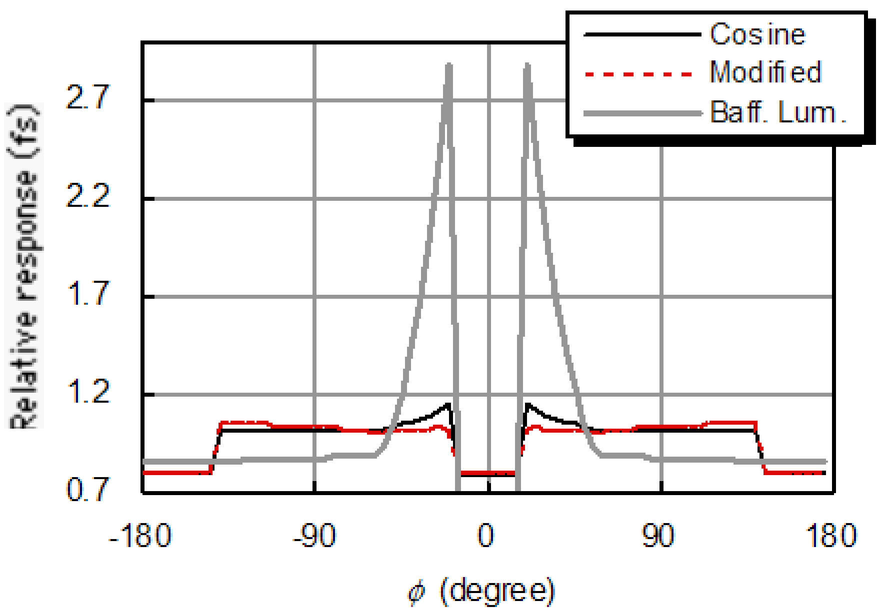
Angular Response of Detector

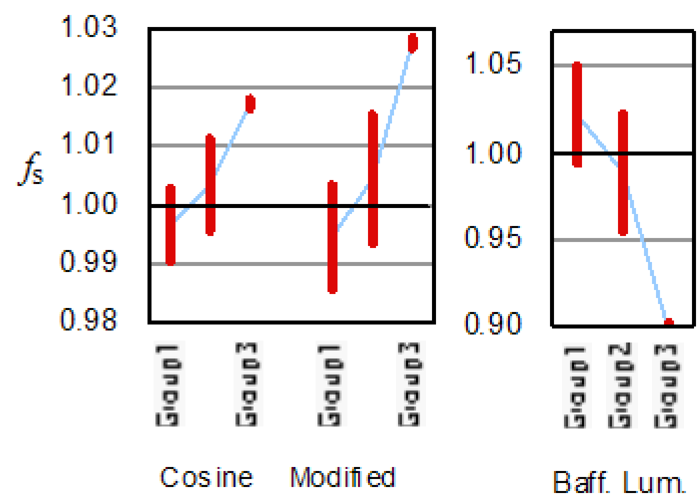


Response of Detectors - Model

2-m sphere, ρ_w =80%, 30 cm baffle

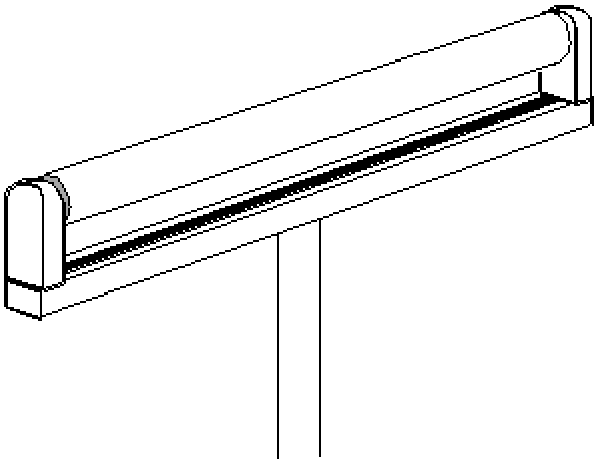
SRDF curves (equator)





Near-field Absorption

- What is it?
  - Objects close to the light source absorb light
- Limitations
  - Cannot be corrected
- How to Fix
  - Place objects as far from lamp as possible
  - Coat object with high reflectance paint
  - Avoid forming cavities



Conclusion

- If time permits we will look at a typical spreadsheet showing an actual lamp measurement