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AUTOMATED INTEGRATING SPHERE CALIBRATION STANDARD

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Automated Integrating Sphere Calibration Standard

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ABSTRACT

Calibration of sensitive, imaging type photometers , radiometers, or spectroradiometers for response generally requires a large area, uniformly radiating source that is accurately calibrated for luminance, radiance, or spectral radiance over relatively wide dynamic ranges [1/]. In many cases, automatic or computer control of the calibration source is desirable. This paper describes a series of automated integrating sphere calibration sources whose output can be precisely varied by either the accompanying electronic controller or an external computer. The calibration standard, which consists of a source module and an electronic controller, is designed such that it can be configured with integrating spheres having different diameters and various sized radiating ports. The luminance of the automated sphere sources can be varied from a maximum of 35,000 footlamberts to a minimum of 0.0001 footlamberts. The corresponding spectral radiance at 550 nm can be varied from 10^4 to 10^{-4} W/cm² sr nm.

Key Words: Automatic, Calibration Sources, Color Temperature, Luminance, Photometers, Radiometers, Spectral Radiance, Spectroradiometers, Sphere Sources.

1.0 INTRODUCTION

A series of completely microprocessor controlled integrating sphere calibration standards has been developed for automatic calibration of various imaging types of photometers, radiometers, and spectroradiometers. These calibration standards, designated as the OL Series 462, are available with integrating spheres having diameters ranging from a minimum of 4 inches to a maximum of 80 inches with corresponding radiating (exit) ports ranging from 1 inch to 20 inches. Each OL 462 Standard consists of a motorized source module (Optics Head) and a separate electronic display console/programmable power supply (Controller). Figure 1 illustrates the OL Series 462 Automated Integrating Sphere Calibration Standard.

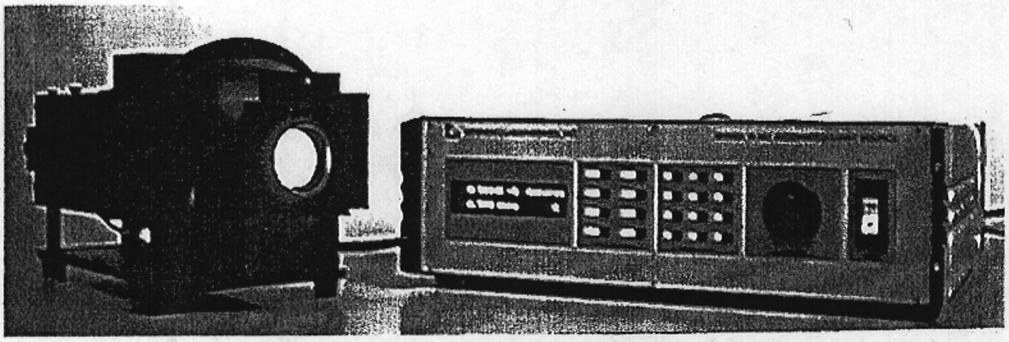

Figure 1 - OL 462 Automated Integrating Sphere Calibration Standard

This combination generates a large area, uniform, diffusely radiating source with a luminance than can easily be varied over many decades without changing the color temperature. Figure 2 illustrates the dynamic range of the OL 462 for several sphere diameters.

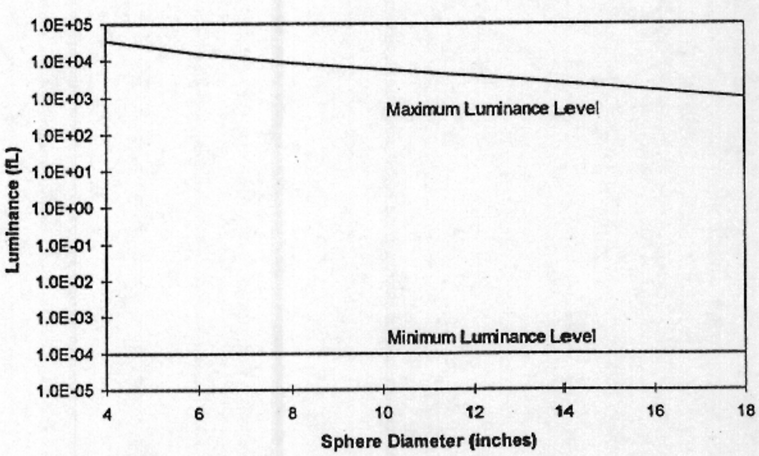

Figure 2 - OL Series 462 Minimum and Maximum Luminance Levels

Luminance, color temperature, and lamp current can easily be set. The user simply enters the desired luminance and color temperature (or lamp current) and the microprocessor controlled OL 462 Controller will automatically adjust the variable aperture and lamp current to attain the desired parameters.

2.0 OPTICS HEAD

Figure 3 shows an OL Series 462 Optics Head. The source is a 150-watt tungsten quartz-halogen reflectorized lamp. An automated, micrometer-controlled, variable aperture is positioned directly behind the entrance port of the sphere (between the lamp and the entrance port). Thus, the radiant flux entering the sphere and the resultant flux radiating from the exit port can be continuously varied over eight decades. A silicon detector/photopic filter combination having an accurate photopic response is mounted in the sphere wall and monitors the sphere luminance.

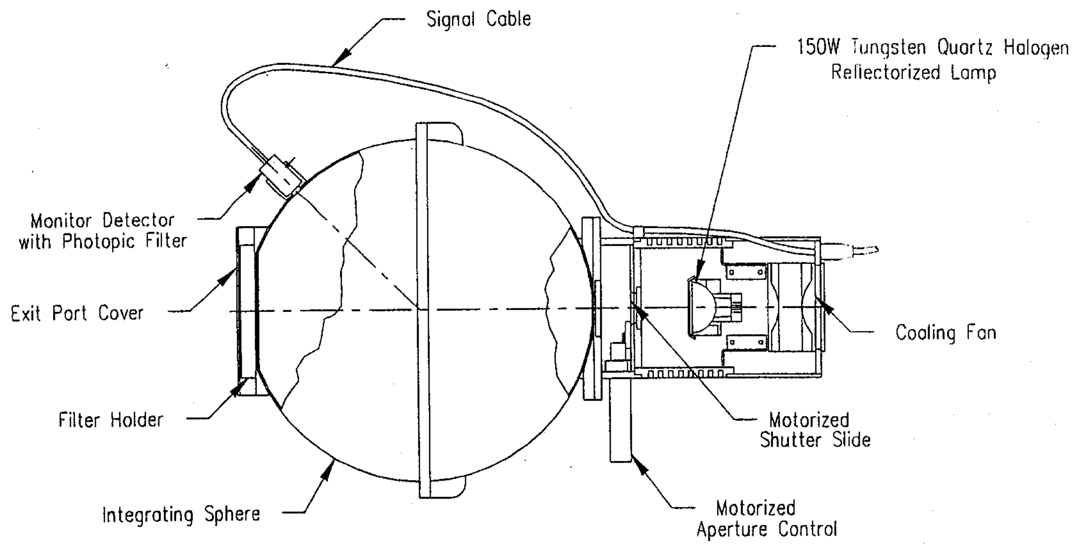

Figure 3 - OL 462 Optics Head

The sphere geometry can be either in-line with an intermediate spider baffle as shown in Figure 3 or 90° (entrance and exit ports are 90° to each other). For most calibration applications, the in-line geometry is preferred as it normally generates higher levels of luminance and provides for exceptional near normal uniformity across the radiating aperture.

In addition to the automated variable aperture, a motorized, computer controlled shutter is located between the lamp and entrance port of the integrating sphere. The location of the shutter at the entrance port, as opposed to shuttering at the monitor detector, permits quantification of any stray light (room light) entering the radiating port of the sphere while zeroing the meter.

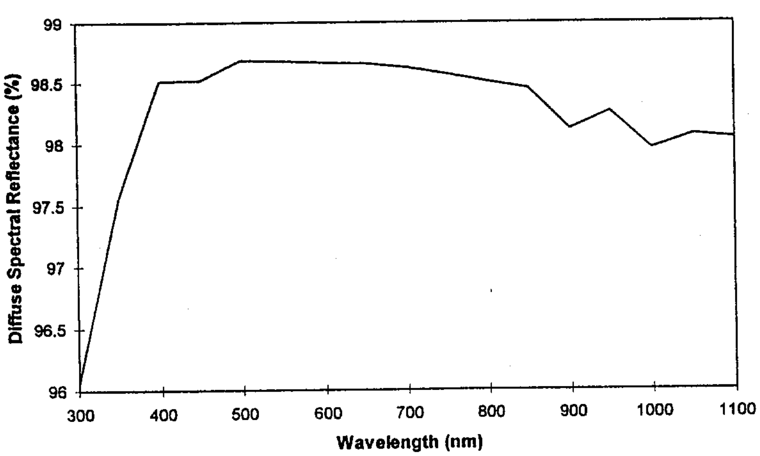

Figure 4 - Diffuse Spectral Reflectance of Optolon 2

The standard coating for the OL Series 462 is Optolon 2[2/] or pressed PTFE. Optolon 2 is a rugged, sprayable coating with a high, diffuse reflectance. It is well suited for calibration applications as it is extremely durable and insensitive to moisture which enhances it's long term stability.

3.0 CONTROLLER - GENERAL

The microprocessor based Controller performs all the system interface and monitoring functions. An automatic ramp/up down function eliminates potentially dangerous current surges and thermal shock to the lamp. Luminance, color temperature, lamp current and operational prompts are displayed on a 2 line by 20 character alphanumeric vacuum-fluorescent display. A 20 key keypad, rotary encoder knob and main system power switch are located on the front panel for easy access to all system functions. Figure 5 shows the front panel of the OL 462 Controller.

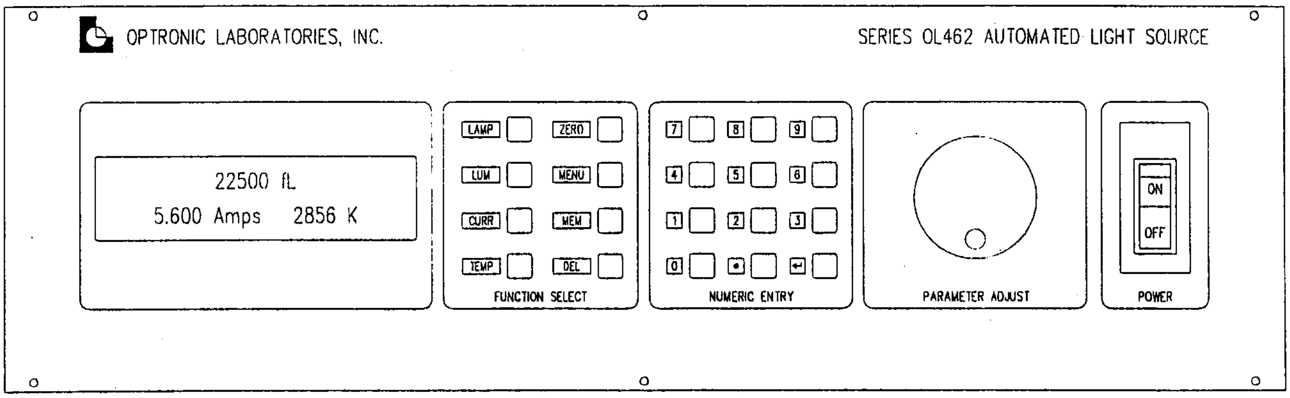

Figure 5 - OL 462 Controller Front Panel

The optical quantity can be displayed with 4½ digit resolution in units specified by the user. In addition, the Controller can be programmed to read out in virtually any pertinent units the user desires. The lamp current supplied to the 150-watt lamp in the Optics Head has a 0.001 ampere resolution with an uncertainty of less than ± 0.05%. The Controller computes the color temperature of the source and displays lamp current or color temperature over the range of 2000 to 3000K. The luminance, color temperature and lamp current can also be set by an external computer via the standard RS-232C interface. RS-422 and GPIB (IEEE-4888) interfaces are also available.

3.1 Parameter selection

The automated integrating sphere source controller has a means of viewing menu selections and adjusting menu parameters such as optical units, current, zeroing, baud rate, etc. It also employs means to adjust an operating target value and display menu options when selected.

3.2 Functions

The controller for the automated integrating sphere source has the following functions:

- A function to set the lamp current. This function includes a current ramp up/ramp down feature which increases the life and stability of the lamp.
- A function to generate the desired optical quantity (typically either luminance or radiance) by adjustment of the variable aperture.
- A function to set the color temperature.
- A function to automatically close the shutter, take dark current readings, zero the photometer, and then reopen the shutter.
- A recall function to restore any user-stored aperture/current targets.

3.3 Parameters

Typical parameters available in the automated integrating sphere sources include the following:

- Optical Units - For selection of the optical units to be displayed. Either amperes or user-defined units (i.e. footlamberts, cd/m², W/(sr cm² nm), etc.) can be selected.
- Aperture Shutter - For opening and closing of the shutter.
- Disable Aperture - For disabling or enabling the motorized aperture.
- Aperture Tolerance - Allows the user to adjust the tolerance window of an aperture target.
- Edit Optical Units - Allows the user to define the optical units.
- Set Real Time Clock - Allows the user to set the hours, minutes, day and date.
- Select Communication Interface - Enables the user to select the standard RS-232C interface or GPIB (IEEE-488) interface.
- Zero All Ranges - Command the automated integrating sphere source to scan through all the gain ranges and take readings to be used as the zero offsets for each gain range. This provides the utmost in range-to-range offset accuracy.
- Calibrate Current - Displays the date of the last current calibration.
- Calibrate Preamp - Displays the date of the last preamp calibration.
- Calibrate Color Temperature - Displays the date of the last color temperature calibration.

4.0 AUTOMATED INTEGRTING SPHERE SOURCE SPECIFICATIONS

4.1 Source module/optics head

Sphere Diameter	4 to 80 inches
Radiation Port Diameter	1 to 20 inches
Luminance Uncertainty (FS)	±2% relative to NIST
Color Temperature Range	2000 to 3000 K
Color Temperature Uncertainty	±25 K
Source Stability @ 2856 K	
Short Term	±0.5%
Long Term	±2% 100 hours/1 year
Spectral Radiance Uncertainty @ 550 nm	±2% relative to NIST
Sphere Coating (reflectance)	>99% (350 to 1100 nm)
Luminance Aperture	Motorized
Shutter	Motorized

4.2 Controller

Luminance Unit Display	user selectable
Luminance Display Range	0.001 to 50,000 fL
Luminance Display Resolution	4½ digits
Current Range	0.001 to 6.700 amperes
Lamp Power Cycle	60 second ramp function
Current Uncertainty	±0.05% @ 6.500 amperes
Current Regulation	±0.01% for 10% line variation
Operating Temperature Range	15° to 35° C
Current Temperature Regulation	±0.025%/10° C
Operating Humidity Range	10% to 85% (noncondensing)
Power (user selectable)	115 or 230 VAC (60/50 Hz) ±10%
Size	18" x 18" x 5¼"
Weight	39 lbs.

5.0 CALIBRATION OF INTEGRATING SPHERE SOURCE FOR SPECTRAL RADIANCE

The standard calibration of integrating sphere sources includes luminance and color temperature. Calibration for spectral radiance is available over the wavelength ranges of 350 nm to 1100 nm and from 250 nm to 2500 nm. Color temperature and spectral radiance calibration data for a typical integrating sphere source is shown below. Since both luminance and color temperature can be derived from spectral radiance, a more detailed description of the methods used to determine the spectral radiance of the automated sphere source follows.

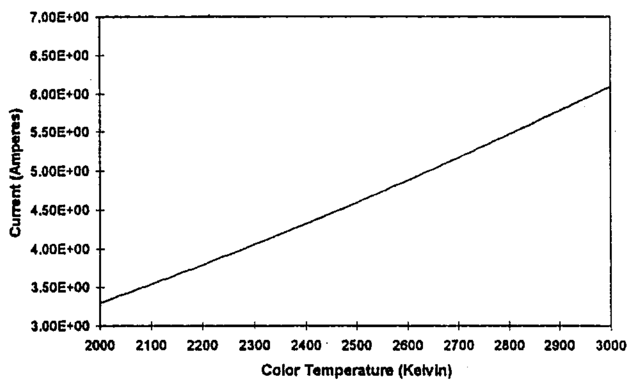

Figure 6 - Color Temperature vs. Current for 6-Inch Diameter Integrating Sphere Source

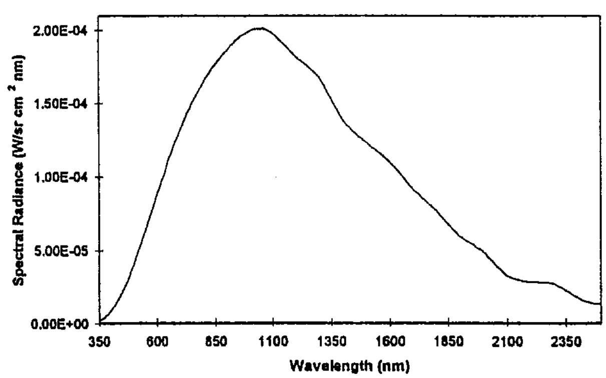

Figure 7 - Spectral Radiance vs. Wavelength for 6-Inch Diameter Integrating Sphere Source

Calibration of the integrating sphere source for spectral radiance is based on both the NIST traceable standards of spectral [3,4] radiance and standards of spectral irradiance [5]. The spectral radiance values are then used to compute the luminance and color temperature of the sphere source. The uniformity of the near normal luminance of the radiating port is tested as well. The typical uniformity of a 12 inch diameter sphere with a 3 inch diameter radiating port is shown in Figure 8.

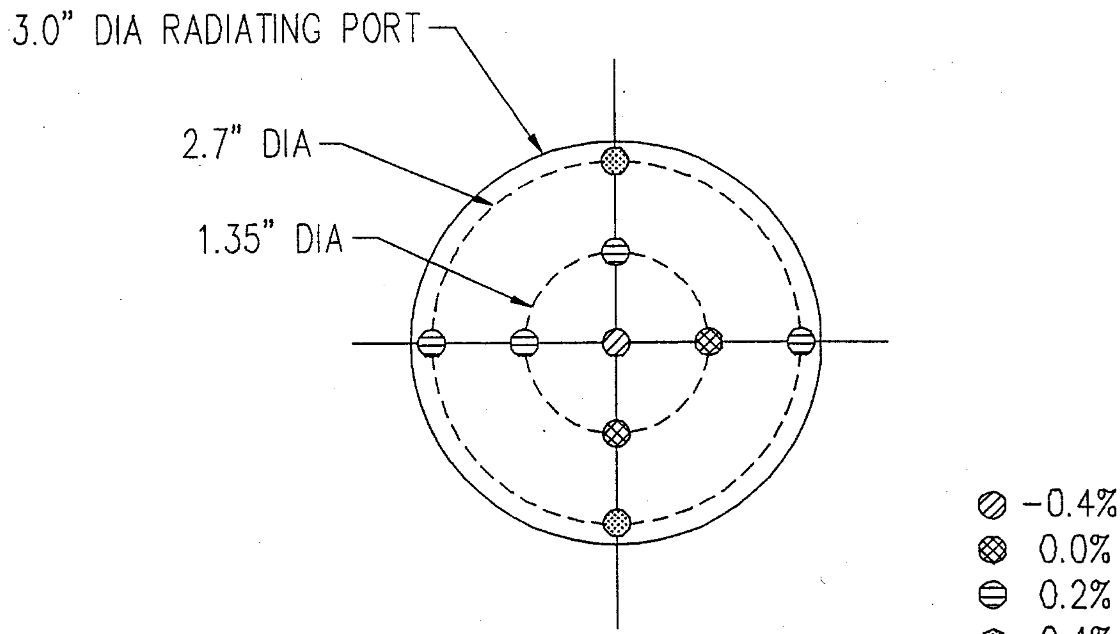

Figure 8 - OL 462-12 Uniformity Test

5.1 Calibration based on NIST standard of spectral irradiance

Three methods using a NIST standard of spectral irradiance were used to determine the spectral irradiance of an integrating sphere source. The spectral radiance was then computed from a knowledge of the spectral irradiance using the relationship:

$$L_\lambda = \frac{E_\lambda \bullet d^2}{A}$$

where, L_λ = Spectral radiance (W/sr cm² nm)
E_λ = Spectral irradiance (W/cm² nm)
A = Area of radiating source (cm²)
d = Distance (cm)

Method 1 utilized an OL Series 750 Double Monochromator Automated Spectroradiometric System configured for comparing the spectral irradiance of the NIST irradiance standard to that of the integrating sphere source. The measurement setup is shown in Figure 9.

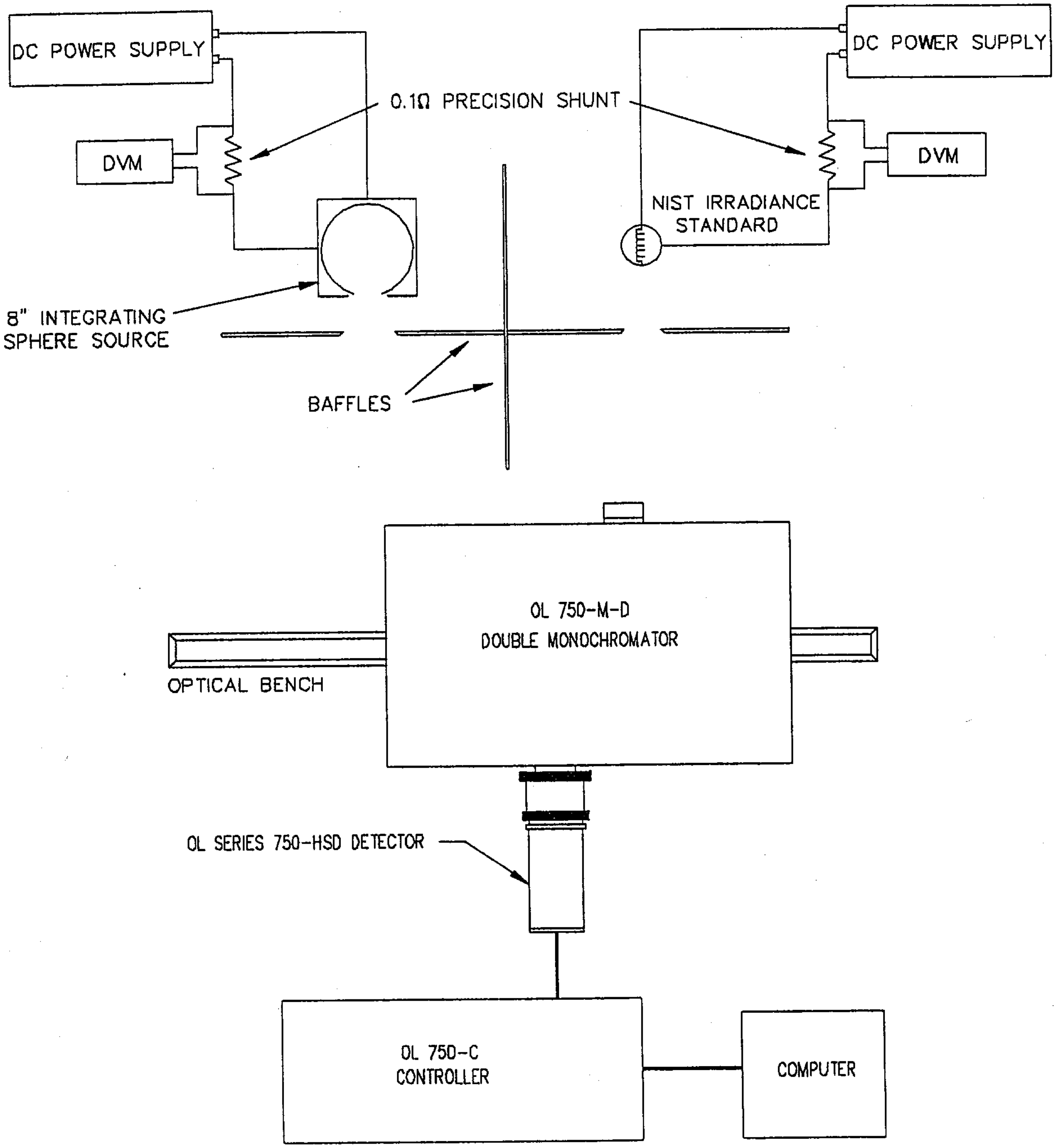

Figure 9 - Spectroradiometric Setup for Calibration of Spectral Irradiance

Method 2 utilized a series of detector/narrow bandpass interference filter combinations. The measurement setup is identical to the spectroradiometer setup shown in Figure 9 except the spectroradiometer is replaced by the filter radiometer. Table 1 gives the estimated uncertainties in the spectral radiance of the integrating sphere source using both methods.

Table 1

Spectral Radiance Uncertainties for Calibration Based on NIST Standard of Spectral Irradiance (Estimated)		
Factor	Spectroradiometric	Radiometric
Distance	±0.2%	±0.2%
Alignment	±0.2%	±0.1%
Current: Sphere Source	±0.04%	±0.04%
FEL 1000-W Standard	±0.04%	±0.04%
Geometry	±0.3%	not applicable
Measurement Repeatability	±0.3%	±0.2%
Radiance Conversion	±0.2%	±0.2%
Transfer Uncertainty (RMS)	±0.55%	±0.36%
NIST Uncertainty	±1.3%	±1.3%
Note: Errors such as alignment repeatability, lamp stability, and signal readout are included in the measurement repeatability uncertainty		

The third method using the NIST standard of spectral irradiance consisted of placing a PTFE reflectance plaque 50 cm from the NIST standard. The spectral radiance of the plaque was computed from the relationship:

$$L_\lambda = \frac{E_\lambda \bullet \rho_\lambda}{\pi}$$

where, L_λ = Spectral radiance (W/sr cm² nm)
E_λ = Spectral irradiance (W/cm² nm)
ρ_λ = Spectral reflectance of Plaque
π = 3.1416

The spectral radiance of the NIST standard/reflectance plaque combination was then compared to the radiance of the integrating sphere source using a filter/teleradiometer. The measurement setup is shown in Figure 10. Table 2 gives the estimated uncertainties in the spectral radiance of the integrating sphere source using the reflecting diffuser method of calibration.

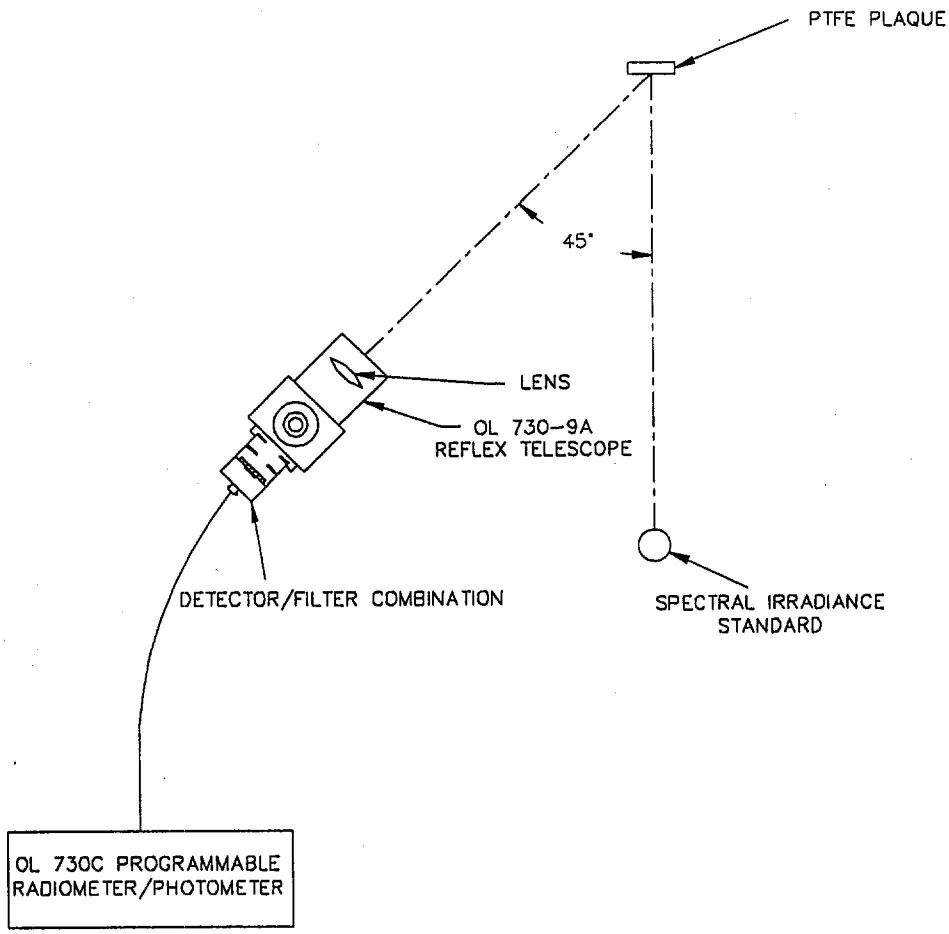

Figure 10 - Reflecting Diffuser - Irradiance Standard Setup for Calibrating Filter Teleradiometer

Table 2

Spectral Radiance Uncertainties for Reflecting Diffuser Method Based on NIST Standard of Spectral Irradiance (Estimated)	
Factor	Uncertainty
Distance	±0.3%
Alignment	±0.2%
Current: Sphere Source	±0.04%
FEL 1000-W Standard	±0.04%
Geometry	±0.2%
Measurement Repeatability	±0.1%
Diffuser Reflectance	±0.3%
Transfer Uncertainty (RMS)	±0.52%
NIST Uncertainty	±1.3%
Note: Errors such as alignment repeatability, lamp stability, and signal readout are included in the measurement repeatability uncertainty	

5.2 Calibration based on NIST standard of spectral radiance

The NIST standards of spectral radiance consist of tungsten, ribbon-filament lamps operated at currents as high as 35 amperes dc. The radiating filaments are approximately 3 x 15 mm. The central portion of the filament, which is fairly uniform in temperature, is calibrated for spectral radiance. Since the NIST standards of spectral irradiance are derived from a comparison to the NIST standards of spectral radiance, the spectral radiance standards have slightly lower uncertainties (on the order of 0.75%). The advantages of direct spectroradiometric comparison of the integrating sphere source to the standard of spectral radiance are:

1. Distance measurements errors are eliminated.
2. Geometric differences are eliminated.
3. The errors associated with converting from spectral irradiance to spectral radiance are eliminated.

The disadvantages of the direct radiance measurement are:

1. The radiance difference between the integrating sphere source and the NIST standard of spectral radiance is on the order of 2 to 3 decades. Thus, the detection system must be linear.
2. Proper imaging of both sources on the entrance slit of the monochromator is critical.

The estimated uncertainties associated with the direct spectral radiance calibration are listed in Table 3.

Table 3

Spectral Radiance Uncertainties for Calibration Based on NIST Standard of Spectral Radiance

Factor		Uncertainty
Focusing/Alignment		±0.3%
Current:	NIST Standard	±0.04%
	Integrating Sphere	±0.04%
Measurement Repeatability		±0.3%
Transfer Uncertainty (RMS)		±0.43%
NIST Uncertainty		±0.60%

Note: Errors such as alignment repeatability, lamp stability, and signal readout are included in the measurement repeatability uncertainty

The estimated uncertainties in the spectral radiance values obtained using the three methods based on the NIST traceable standard of spectral irradiance and the method based on the NIST traceable standard of spectral radiance differ by less than 1.0%. Table 4 lists the measured spectral radiance values for a sphere source at wavelengths where measurements were made using the spectroradiometer, filter radiometer, and reflecting diffuser methods based on the NIST traceable standard of spectral irradiance and the spectroradiometer method based on the NIST traceable standard of spectral radiance. The agreement in the spectral radiance values between the various methods is within the corresponding estimated uncertainties.

Table 4

Comparison of Spectral Radiance Values of a Sphere Source as Determined with NIST Standards of Spectral Irradiance and Radiance

Wavelength (nm)	Spectral Radiance (μW/sr cm^2 nm) A	B	C	D
600	1.461	1.466	1.456	1.470
800	2.797	2.833	2.793	2.833
1000	3.421	3.364	3.330	3.391
1300	2.918	2.891	2.879	not applicable

A: Spectroradiometer Measurements/NIST Standard of Spectral Irradiance
B: Filter Measurements/ NIST Standard of Spectral Irradiance
C: Reflecting Diffuse/ NIST Standard of Spectral Irradiance
D: Spectroradiometer Measurements/NIST Standard of Spectral Radiance

6.0 SUMMARY

This series of automated, integrating sphere calibration standards provides a convenient means to quickly and accurately calibrate various imaging type instruments for photometric, radiometric, or spectroradiometric response. In addition, the automated sphere sources are quite useful in determining the linearity of these imaging instruments over many decades. The selection of sphere sizes and corresponding radiating ports, enables the user to choose an automated sphere source with a uniformly radiating port that will fill the field of view of the device to be calibrated. The agreement between the various methods of calibration along with the stability of the photopic sensor, mounted in the side wall of the sphere, gives the user added confidence in the accuracy of the automated sphere source.

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