UHP Lamp Performance and Characterisation Systems

Integrating Sphere Systems for Lamp Measurement

Automated Lamp Measurement Systems

Phosphor QE Systems

LED Measurement Systems

UV Spectroradiometer Systems

Combined Spectroradio/photometer Systems

Hybrid Systems for Lamp Research

Goniometer Systems

High Intensity UV Systems

Linear Tube Colour Uniformity Systems

www.bentham.co.uk
Bentham manufactures an extensive range of integrating spheres from 2cm to 2m diameter, for measuring the total flux, spectral power distribution and chromaticity of almost any light source. All our spheres can be coupled to our high performance spectroradiometer systems for UV-visible-IR spectral power distribution measurements yielding full colour information including colour rendering indices, chromaticity co-ordinates, colour temperature, etc. Alternatively precision photometric detectors can be fitted for direct total lumen output measurements.

The LAS5000 series of modular lamp analysis systems has been configured to perform thorough testing of UHP lamps. It can provide extensive lamp performance data as well as previously unavailable device operating characteristics determined using IR spectroscopic diagnostic techniques developed at the High Temperature Science Laboratories of the Chemistry Department at Sheffield University.

- lamp operating pressure
- spectral power distribution (0.5nm resolution)
- colour temperature
- full chromaticity data
- total lumen maintenance
- arc length
- lamp voltage, etc.

The IS1000 1m sphere shown is particularly suited to measuring energy efficiency related parameters of compact fluorescent lamps and associated control gear (eg. EN60969). It is also routinely employed testing small filament lamps including GLS as well as LED arrays.
Larger spheres, such as the IS1800 1.8m diameter sphere are typically used for spectral measurements of tubular fluorescent lamps (EN60081) and high power lamps such as SOX and SUN. They are also suitable for use with some reflector based lamps and small luminaires. They are available with many options and accessories including:

- spectroradiometer/photometer/colorimeter
- wide range of standard lamp holders
- adjustable lamp holders
- rotating lamp holder (0-360° rotation)
- temperature monitors
- safety interlocks
- wiring options (internal/external control gear, HF operation, etc.)
- calibrated standard lamps and power supply
Fully Automated Spectroradiometer
(Ceramic Metal Halide 15W-1kW)

The picture illustrates a fully integrated and automated lamp measurement facility for testing and characterising ceramic metal halide lamps ranging in power from 15W to 1kW. An integrating sphere based spectroradiometer is combined with software selected control gear (power supply, ballasts and ignitors) and electrical measurement instrumentation to allow complete lamp characterisation. The lamps are mounted on a turntable allowing lamp orientation to be rotated in 5 degree intervals, 0-360 degrees. A simple Windows form instigates a full measurement procedure under complete software control including:

- Reference ballast selection (15W to 1000W)
- Ignitor selection (or electronic)
- Applied voltage and frequency selection
- Lamp stabilisation time and monitoring
- Spectral power distribution (spectral flux, 250-1700nm)
- Colour temperature
- Colour rendering indices
- Chromaticity co-ordinates
- Emission peak wavelengths
- Total lumens
- Lamp flicker (%)
- Lamp extinction voltage
- Sphere/ambient temperature
- Electrical parameters: V_{min}, V_{pk}, V_{rms}, A, W and PF etc
The above picture shows a system for determining the quantum efficiency of phosphor powder samples used in the lighting industry. Up to 6 samples can be loaded into the motorised carousel. A calibrated Hg source, with closed loop controller for necessary stability, is used to excite the phosphors. Significantly, the temperature of each sample can be heated to 200°C ±1°C all under software control. A carefully designed integrating sphere is used to collect all of the emitted light which is measured by a spectroradiometer system. Besides quantum efficiency of the phosphors as a function of operating temperature the system also provides full spectral emission and chromaticity data.

In order to fully characterise both excitation and emission spectra of phosphors, Bentham supplies a dual monochromator based system. Typically a dual excitation source comprising Xenon and quartz halogen lamps is fitted to the excitation monochromator and PMT, silicon and InGaAs detectors can be fitted to the emission monochromator, therefore both excitation and emission spectra can be measured from 200nm to beyond 1800nm.
Bentham manufactures a system for batch testing LEDs. Each carrier board accommodates up to 50 devices. A universal mounting socket has been developed to suit nearly all LED device packages currently supplied. A single keystroke enables full optical and electrical characterisation of each device with seamless integration with database and analysis software. The modular drive electronics are most commonly supplied with programmable forward current, $I_f$, and reverse voltage, $V_r$ power supply. The system records for each device:

- Full spectral distribution
- Averaged intensity, $I_{LED_B}$
- Peak wavelength and bandwidth
- Dominant wavelength
- Chromaticity co-ordinates
- Colour purity and CRIs
- Forward voltage, $V_f$
- Reverse current, $I_r$

Bentham manufactures a range of equipment to facilitate the measurement of LEDs in accordance with CIE127 recommendations. The CIE defines a new quantity ‘Averaged LED intensity’ and is specified for two geometries, CIE Standard Condition A and Condition B. These requirements specify a detector with circular entrance aperture of 100mm² area and measurement distances of 316mm for Condition A and 100mm for Condition B, which are fulfilled with our LED intensity tube that incorporates a small integrating sphere.

A larger sphere is used for total flux measurements and incorporates the necessary auxiliary and calibration lamps. Both the intensity tube and total flux spheres can be used in conjunction with our spectral measurement systems or filter based photometer/radiometer products.

Bentham also supplies equipment for compliance testing of LED based products.
The ultimate accuracy of most spectroradiometric measurements is limited by the scattered light inside the instrumentation used. This is particularly so for many UV measurements especially health and safety related work. Bentham's family of double monochromator based systems are used in national measurement institutes, industry, hospitals, universities, etc. across the world for accurate UV spectral measurements.

Typical applications include measurement of light sources employed in following:

- Type testing of sunbeds in accordance with EN60335-2-27
- Photostability of pharmaceutical products (ICH guidelines)
- Sun protection factor testing of sun cream (COLIPA SPF test method)
- Phototherapy light sources (PUVA and UV-B)
- Solar simulators
- Germicidal UV lamps
- UV curing and drying systems

The solid line shows accurate double monochromator based measurement of a QH lamp - note logarithmic scale on Y axis. The dotted line shows the typical error if using a single monochromator or polychromator for such a measurement.

A full technical tutorial is available from:
www.bentham.co.uk/pdf/UVGuide.pdf
Bentham produces a fully automated, double monochromator based spectroradiometer system for the hazard classification of lamps in accordance with CIE S 009/E:2002 Photobiological Safety of Lamps and Lamp Systems. Such systems require high spectral resolution over a wide wavelength range (200nm to 3000nm) and must have excellent stray light rejection. Bentham offers a very high precision cosine response diffuser (f2 error <1%) or integrating spheres for spectral irradiance measurements and a variable aperture telescope for radiance measurements. Exposure limits are determined by software.

### Skin or cornea hazard

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Symbol</th>
<th>Wavelength Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actinic UV skin &amp; eye</td>
<td>$E_S$</td>
<td>200-400nm</td>
</tr>
<tr>
<td>Eye UV-A</td>
<td>$E_{UVA}$</td>
<td>315-400nm</td>
</tr>
<tr>
<td>Blue light small source</td>
<td>$E_B$</td>
<td>300-700nm</td>
</tr>
<tr>
<td>Eye IR</td>
<td>$E_{IR}$</td>
<td>780-3000nm</td>
</tr>
<tr>
<td>Skin thermal</td>
<td>$E_H$</td>
<td>380-3000nm</td>
</tr>
</tbody>
</table>

### Retina hazard

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Symbol</th>
<th>Wavelength Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue light</td>
<td>$L_B$</td>
<td>300-700nm</td>
</tr>
<tr>
<td>Retinal thermal</td>
<td>$L_R$</td>
<td>380-1400nm</td>
</tr>
<tr>
<td>Retinal thermal (weak)</td>
<td>$L_{IR}$</td>
<td>780-1400nm</td>
</tr>
</tbody>
</table>
Sometimes it can be beneficial to combine the requirements of a spectroradiometer and a spectrophotometer into a single system. This can be particularly true for specialist requirements such as UV or IR systems.

Above is shown a DMc150 double monochromator based system suitable for measurements over the wavelength range 180 - 1100nm. A fibre-coupled diffuser is employed for spectral irradiance measurements. Alternatively the UMS (universal measurement system) can be fitted with an integrating sphere for transmission measurements of scattering materials (i.e. lamp diffusers) or reflection of such samples. The UMS can also be fitted with a two axis goniometer for measuring specular reflectance at any angle (i.e. for reflector materials).

The fully automated, multiple grating TMc300 monochromator system shown below performs absolute and radiometric measurements over the wavelength range 1µm to 15µm. A gold-coated integrating sphere is used as the input optic for spectral irradiance measurements as well as inside the UMS for transmission/reflectance measurements. A lock-in amplifier based system is used in conjunction with a pyroelectric detector, peltier cooled PbS/PbSe detectors and liquid nitrogen cooled InSb and MCT offering a wide choice of wavelength range and sensitivities.
Hybrid Systems for Lamp Research

Bentham produces some of the world’s most versatile monochromator systems for fundamental lamp research purposes. For example, the DTMc300V monochromator shown here offers:

- **Double monochromator** (subtractive AND additive dispersion)
- **Can be used as two independent single monochromators** (e.g., excitation and emission phosphor spectra)
- First monochromator used with ICCD or single IR detector
- All slits motorised (software controlled)
- Two internal filter wheels (order sorting and shutter)
- Purge option (for use to 150nm)
- Interchangeable triple grating turret
- Imaging optics (torroidal mirror option)

Simultaneous UV, visible and IR measurement of lamps (200-3000nm) is achieved by this three monochromator system. Note the use of a double monochromator to achieve accuracy in the UV region.
Bentham manufactures manually positioned and motorised goniometer systems for many applications ranging from single LED polar distributions to profiling transmission and reflection of complex shapes such as helmet visors.

The examples shown are both motorised 2 rotary axis systems. Above is a photonic crystal research system and below is a larger system also including motorised linear stages for measuring thin film coatings.
Accurate measurements of high intensity UV sources used in industrial processes such as UV curing/coating, reprographic equipment, water purification and air conditioning systems pose particular difficulties. For example, medium pressure mercury arc lamps used for curing are typically rated from 80 to 400W per cm and may exceed 2m in length. The lamps operating environment is usually very hostile e.g. high temperature, hazardous to operators, etc.

Bentham provides a range of solutions for measuring the functional efficiency of such lamps as well as accurately assessing health and safety issues. The pictures show a double monochromator based system with motorised x-y stage for mapping the UV irradiance of UV curing lamps and a system for measuring total flux of metal halide lamps.

High Intensity UV Systems

Linear Tube Colour Uniformity Systems

The novel integrating sphere shown here determines the colour uniformity along the length of linear fluorescent tubes. Interchangeable 'jaws' accommodate T5 to T12 tube sizes. The measurement is performed with the CT3701 temperature-controlled 4-detector colorimeter.

Bentham also offers coating thickness gauges for fluorescent tubes.
Spectroradiometer Measurement Quantities

The optical quantity measured by a spectroradiometer system is determined by the input optic employed, as described in the table below. An appropriate calibration source is required in each case. Bentham manufactures spectroradiometers covering the spectral range 150nm to 30µm. All photometric, colorimetric, UV radiometric, etc. quantities are most accurately determined by performing spectroradiometric measurements and using software to integrate/weight values as defined by CIE etc. However, Bentham also supplies a range of filter based radiometers/photometers with close match spectral responses for simple integral type measurements.

Typically a light source and UMS, Universal Measurement Station, is added to spectroradiometer type systems in order to perform spectrophotometric measurements such as transmission and reflectance.

<table>
<thead>
<tr>
<th>Typical Input Optic</th>
<th>Measurement Quantity</th>
<th>Unit</th>
<th>Photometric Parameter</th>
<th>Photometric Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuser</td>
<td>Spectral irradiance</td>
<td>mW/(m² nm)</td>
<td>Illuminance</td>
<td>lux</td>
</tr>
<tr>
<td>Telescope</td>
<td>Spectral radiance</td>
<td>mW/(sr m² nm)</td>
<td>Luminance</td>
<td>cd/m²</td>
</tr>
<tr>
<td>Baffled tube</td>
<td>Spectral radiant intensity</td>
<td>mW/(sr nm)</td>
<td>Luminous intensity</td>
<td>cd</td>
</tr>
<tr>
<td>Integrating Sphere</td>
<td>Spectral total radiant flux</td>
<td>mW/nm</td>
<td>Total luminous flux</td>
<td>lumens</td>
</tr>
</tbody>
</table>

Definitions

**Spectroradiometer**
An instrument for measurement of radiometric quantities in narrow wavelength intervals over a given spectral region (e.g. irradiance, radiance, etc.)  *(CIE)*

**Spectrophotometer**
An instrument for measurement of the ratio of two values of a radiometric quantity at the same wavelength (e.g. transmission, reflection, absorption)  *(CIE)*
The accuracy of any spectroradiometric measurement can only be as good as that of the standard source used to calibrate the system. Bentham offers a range of standard lamps calibrated against an NPL calibrated version of the same product minimising measurement uncertainties. Alternatively, direct NPL, PTB, NIST etc. calibration can be supplied.

### Calibration Standards

The CL6 is a fully enclosed spectral irradiance standard lamp that greatly simplifies the calibration of spectroradiometers, lux meters and radiometers. It removes the need for a dark room, precision optical bench, and alignment tools associated with conventional calibration lamps.

Interchangeable adapters accommodate all Bentham’s diffusers, photometric detectors and integrating spheres as well as many other devices. The system to be calibrated is simply ‘plugged in’ to a very reproducible location alleviating the need for any other positioning or alignment.

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**CL2 Spectral Irradiance, 250-3000nm**

The CL2 is a universal spectral irradiance standard lamp for the calibration of spectroradiometers, lux meters and radiometers. Its mounting bracket is compatible with all optical table and mounting systems. Calibration distance is measured from a simple datum face plate.

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**CL3 UV Spectral Irradiance, 200-400nm**

The CL3 is a universal UV spectral irradiance standard lamp for the calibration of spectroradiometers and radiometers. It is housed in a metal enclosure with optical bench compatible mounting holes in the base. Calibration distance is set using a spacer bar supplied with the lamp. The calibration is performed with respect to National Physical Laboratory (NPL Teddington, UK) calibrated lamps held by Bentham. Alternatively, direct NPL calibration can be offered.

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**SRS8 Spectral Radiance/ Luminance Standard, 380-800nm (ext. 300-2500nm)**

The SRS8 is a uniform source calibrated in spectral irradiance designed for routine calibration of spectroradiometers, telephotometers, luminance meters etc. It comprises a 200mm diameter integrating sphere with a 50mm diameter window (diffuser) and is easily mountable on all optical bench systems or flat surfaces.

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**TSRFx series** of total spectral radiant flux standards are designed for use with integrating spheres with diameters ranging from 100mm to 2m. Standard calibration range is 380-800nm, but this can be extended to cover 300-2500nm range.

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**TSRF1800**

- **Model No.:** TSRF1800
- **Power:** 250W
- **Lamp Rating:** 250W
- **Supply:** 10.400A
- **Lumens:** 9000 lm
- **Spectral range:** 380-800nm (ext. 300-2500nm)
- **Certificate units:** mW/nm
- **Typical sphere diameter:** 2000 mm

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**CL6 Enclosed Spectral Irradiance, 200-3000nm**

Interchangeable adapters accommodate all Bentham’s diffusers, photometric detectors and integrating spheres as well as many other devices. The system to be calibrated is simply ‘plugged in’ to a very reproducible location alleviating the need for any other positioning or alignment.

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### Table

<table>
<thead>
<tr>
<th>Units</th>
<th>Model No.</th>
<th>Lamp rating</th>
<th>Power supply current</th>
<th>Typical Lumens</th>
<th>Spectral range</th>
<th>Certificate units</th>
<th>Typical sphere diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>mW/m²/nm</td>
<td>TSRF4</td>
<td>20W</td>
<td>1.666A</td>
<td>480</td>
<td>380-800nm (ext. 300-2500nm)</td>
<td>mW/m²/nm</td>
<td>100 mm</td>
</tr>
<tr>
<td>lm</td>
<td>TLF4</td>
<td>20W</td>
<td>1.666A</td>
<td>480</td>
<td>V(l)</td>
<td>lm</td>
<td>100 mm</td>
</tr>
<tr>
<td>mW/m²/nm</td>
<td>TSRF8</td>
<td>50W</td>
<td>4.000A</td>
<td>1350</td>
<td>380-800nm (ext. 300-2500nm)</td>
<td>mW/m²/nm</td>
<td>200 mm</td>
</tr>
<tr>
<td>lm</td>
<td>TLF8</td>
<td>50W</td>
<td>4.000A</td>
<td>1350</td>
<td>V(l)</td>
<td>lm</td>
<td>200 mm</td>
</tr>
<tr>
<td>mW/m²/nm</td>
<td>TSRF20</td>
<td>100W</td>
<td>8.500A</td>
<td>2800</td>
<td>380-800nm (ext. 300-2500nm)</td>
<td>mW/m²/nm</td>
<td>500 mm</td>
</tr>
<tr>
<td>lm</td>
<td>TLF20</td>
<td>100W</td>
<td>8.500A</td>
<td>2800</td>
<td>V(l)</td>
<td>lm</td>
<td>500 mm</td>
</tr>
<tr>
<td>mW/m²/nm</td>
<td>TSRF1000</td>
<td>100W</td>
<td>8.500A</td>
<td>2800</td>
<td>380-800nm (ext. 300-2500nm)</td>
<td>mW/m²/nm</td>
<td>1000 mm</td>
</tr>
<tr>
<td>lm</td>
<td>TLF1000</td>
<td>100W</td>
<td>8.500A</td>
<td>2800</td>
<td>V(l)</td>
<td>lm</td>
<td>1000 mm</td>
</tr>
<tr>
<td>mW/m²/nm</td>
<td>TSRF1800</td>
<td>250W</td>
<td>10.400A</td>
<td>9000</td>
<td>380-800nm (ext. 300-2500nm)</td>
<td>mW/m²/nm</td>
<td>2000 mm</td>
</tr>
<tr>
<td>lm</td>
<td>TLF1800</td>
<td>250W</td>
<td>10.400A</td>
<td>9000</td>
<td>V(l)</td>
<td>lm</td>
<td>2000 mm</td>
</tr>
</tbody>
</table>
In addition to our extensive family of monochromator and polychromator based spectral measurement systems, we also integrate the Gigahertz-Optik GmbH range of precision filter based radiometer products into our line of light measurement solutions.

The detector range includes:

- Precision photometric, $f_1 < 3\%$
- General photometric, $f_1 < 5\%$
- Scotopic, $f_1 < 5\%$
- UV-A (320-400nm) radiometric
- UV-B (280-320nm) radiometric
- UV-C (254nm) radiometric
- UV-Erythema (250-400nm)
- Blue light hazard (400-520nm)

The CT-3701 and CT-4501 luminous colour detectors are designed with precise $x,y,z$ tristimulus matching functions to measure the illuminance, $x$, $y$, chromaticity values and colour temperature of broadband emitting light sources. Four detectors mounted in one compact housing are used to form the $x_{short}$, $x_{long}$, $y$ and $z$ spectral tristimulus values for the 2 degree viewer.

Both probes feature two separate $x_{short}$ and $x_{long}$ functions to provide more accurate reading in the blue region over detectors with only the $x_{long}$ function and a simulated $x_{short}$ using the $Z$ values.