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Instruction manual for Konica Minolta CS-1000 and CS-2000 spectroradiometers

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2. Overview

Konica Minolta CS-1000 and CS-2000A (Figure 1) are array spectroradiometers that can be used in various photometric, colorimetric and radiometric measurements. The wavelength range of both instruments is 380–780 nm, and the output interval of the wavelengths is 1 nm. According to the manufacturer, the full width at half maximum bandwidth of both instrument is 5 nm or less [1]. The sensors of the instruments are Peltier-cooled to improve the signal-to-noise ratio. In the standard configuration, CS-1000 measures spectral radiance and luminance in a fixed measurement angle of 1°, while the measurement angle of CS-2000A is user selectable (0.1°, 0.2°, and 1°). With an additional diffuser adapter, the instruments can be used in spectral irradiance and illuminance modes.

The instruments can be operated using either the controls of the instrument itself, the Konica Minolta measurement software CS-S10w Professional, or Labview drivers. In Section 4, a short instructions on how to perform basic irradiance and radiance measurements with the instrument are given. The calibration procedure of the instrument is explained in Section 5. For full instructions on how to operate the instrument and the measurement software, as well as on how to install the software, refer to instruction manuals [1], [2], and [3].

Note: The instructions below are written and tested for CS-2000A which is more commonly used instrument of the two in calibrations at MRI. However, CS-1000 and CS-2000A are very similar instructions, and thus most of the instructions apply to CS-1000 as well.



Figure 1: Konica Minolta CS-2000A spectroradiometer [image credit: Konica Minolta].

3. Measurement principle and data processing caveats

The instrument performs various automated operations before, during, and after the measurement that the user should be aware of when interpreting the results.

Before the actual measurement, the instrument performs a pre-measurement to determine the optimal integration time for the measurement. The instrument also has an internal neutral density (ND) filter that is used when the light level reaches a certain threshold. *These behaviors can be modified in the measurement settings as will be discussed in Section 4.6.* If the internal ND filter is utilized in the calibration of the instrument but not in the actual measurement (or vice versa), the uncertainty of the measurement may be increased due to the uncertainty of the transmittance calibration of the internal ND filter. Since it is hard to determine whether the internal ND filter is used in the measurement or not, it is recommended to force the instrument to use the same filter setting in both the calibration and the measurement by manually setting the internal ND filter on or off, in measurements where very low uncertainty is required.

After the measurement, the instrument blocks the beam with an internal shutter and carries out a dark signal measurement. The dark signal of the array is then subtracted from the measured spectrum. *This behavior cannot be modified.* An additional dark measurement may be needed if straylight is present in the measurement, as straylight is not subtracted from the spectrum in this automated process. When performing a manual dark signal measurement, it is advisable to use the same integration time as in the actual measurement.

The instrument performs straylight, linearity and possibly other corrections on the measured spectrum. *These correction cannot be turned off, modified, or inspected. The raw counts of the diode array cannot be extracted,* and the output spectrum is always corrected by either the factory or a user calibration. The wavelengths in the output array do not correspond with the exact locations of the pixels in the diode array.

The instrument calculates various photometric, colorimetric, and other parameters from the measured spectrum. It was discovered that the correlated color temperature (CCT) reported by the instrument deviates somewhat from the value obtained by iteratively searching for the chromaticity point in the Planckian locus which minimizes the distance to the chromaticity coordinates of the source. It is possible that the instrument uses one of the approximation formulas that have been developed for efficient determination of CCT. As an example, it was found that for an incandescent lamp with CCT at around 2856 K – the CCT of CIE Standard Illuminant A – the value reported by the instrument was about 1.5 K above the value calculated from the measured spectrum using the iterative method. The difference between the two results depends on the color coordinates, and consequently on the CCT, of the source. Therefore, in measurements requiring very accurate knowledge of the CCT, the CCT value calculated by the instrument should not be utilized directly.

4. Measurement instructions

Below is a step-by-step guide to measuring with the instrument:

1. Turn on the instrument (warm-up time of 20 minutes or more is required).
2. Connect the instrument and the USB copy protection key to the computer.
3. When measuring in irradiance mode, attach the diffuser adapter.
4. Select the measurement angle.
5. Focus and align the instrument.
6. Select the correct calibration file.
7. Select the CIE Photometric Observer (typically: 2° observer).
8. Select the speed mode and internal ND filter options.
9. Initiate the measurement.
10. Save the measurement data.

More detailed information of each step is given in the following subsections. For full description of each step as well as information on other measurement modes, such as object color measurement mode, refer to instruction manuals [1] and [2].

4.1. Powering up the instrument and warm-up

The power plug and the power switch are located on the side of the instrument. Only the dedicated Konica Minolta AC power adapter (model AC-A312, labelled CS-2000A) should be used to power up the instrument.

Note: The minimum warm-up time of the instrument is 20 minutes, as recommended by the manufacturer. This is the minimum warm-up time even if the instrument has been turned off only briefly before turning it on again [1].

4.2. Starting up CS-S10w Professional Software

If the instrument is to be used with a computer, make sure the measurement software CS-S10w Professional and the USB copy protection key driver are installed on the computer [3]. Connect CS-2000A to the computer with a USB cable and insert the USB copy protection key (Figure 2) in the USB port of the computer. In case of CS-1000, a serial-to-USB adapter is required.

Upon opening, the software asks the user to choose the document type. In typical measurements, *Light-source Color – Normal Mode* should be selected. Before connecting to the instrument, open *Instrument > Communication Setup...*, select CS-2000 in the instrument dropdown menu, press *Comm...*, and select the correct COM port. Establish a connection by selecting *Instrument > Connect* or by pressing the *Connect* button in the user interface. When the connection is established, select *File > New* to open a new measurement sheet.

Note: After use, return the USB key to the USB strap that is tied to the handle of the instrument (see Figure 2)! The measurement software can only be operated if the USB key is plugged in, and replacement keys are expensive.



Figure 2: USB copy protection key in its correct place in between measurements.

4.3. Measurement geometry, focusing and aligning

Before the measurement, remove the lens cap of the instrument. Select the measurement angle (0.1° , 0.2° , or 1°) using the rotary switch at the back of the instrument. The measurement angle corresponds to the black circle that can be seen through the viewfinder of the instrument (see Figure 3). Adjust the diopter if the edge of the black circle in the viewfinder is not sharp by rotating the black ring around the viewfinder. Do this before aligning and focusing the instrument.



Figure 3: View of the viewfinder. Black circle in the middle corresponds to the 1° measurement spot.

When measuring in the irradiance/illuminance mode, attach the diffuser adapter (Figure 4) to the objective lens and set the focus of the instrument to infinity (∞). In irradiance/illuminance mode, the instrument can be aligned with help of a two-beam alignment laser.

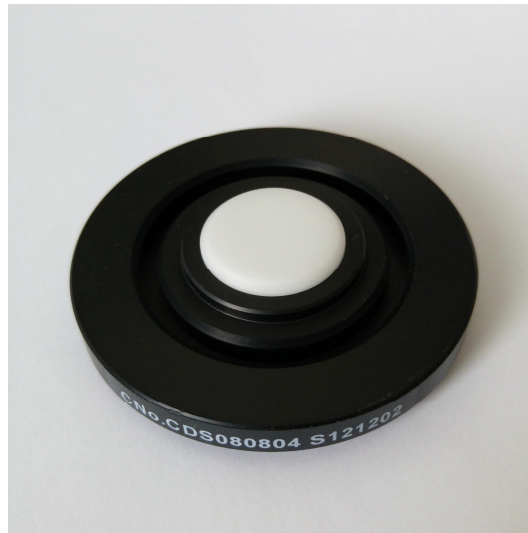


Figure 4: Diffuser adapter for irradiance and illuminance measurements.

When measuring in the radiance/luminance mode, use the adjustment ring of the objective lens to focus the instrument to the correct plane along the optical axis, e.g. the front surface of a panel or the aperture plane of an integrating sphere. If necessary, use an alignment/focusing target to aid in the focusing. *Note: Do not use an alignment laser and the viewfinder to align the instrument in radiance mode, i.e. when the diffuser adapter is not attached. Permanent eye-damage may occur.*

4.4. Calibration data

Before the measurement, make sure that correct calibration data is selected. Different calibration data is required for radiance and irradiance modes. The format of the name of the calibration data is TYPMM-YYYY, where TYP is the type of calibration (RAD for radiance/luminance calibration and DIF for irradiance/illuminance calibration), and MM and YYYY are the month and year of the calibration. In addition to the calibration data, the instrument response is affected by the objective lens (standard or close-up), and external neutral density (ND) filter (none, ND 10, ND 100).

Instrument controls: Calibration data can be set by pressing MENU on the instrument back panel and navigating to *OPTIONS > USER. CAL.* The objective lens and the external ND filter settings can also be found in the *OPTIONS* menu.

Measurement software: Calibration data can be set in *Instrument > Instrument Settings...* menu of the software.

4.5. CIE photometric observer

The instrument has an option to use either CIE 1931 2° Standard Observer and CIE 1964 10° Standard Observer. Note that this setting does not affect the measurement angle of the instrument but only the CIE color matching functions used by the instrument in calculating the colorimetric and photometric values, such as color coordinates, correlated color temperature (CCT) and luminance/illuminance. The radiometric quan-

tities are not affected by this option. *Note: CIE 1931 2° Standard Observer should be used in typical measurements.*

Instrument controls: The CIE photometric observer can be set by pressing MENU and navigating to *SETUP > OBSERVER*.

Measurement software: The CIE photometric observer can be set in *Instrument > Standalone Configuration...* menu of the software.

4.6. Measurement speed and internal ND filter

When a measurement is initiated, the instrument first carries out a short measurement to determine the optimal integration time, and then carries out the actual measurement using that integration time. This behavior can be constrained or overridden by the measurement speed settings. The speed options are:

- Normal: Integration time automatically adjusted between 0.005 and 120 s.
- Fast: Integration time automatically adjusted between 0.005 and 16 s.
- Multi-Normal: Multiple cycles of Normal measurements. Option *INTEG TIME* determines the combined integration time of the measurements and can be set between 1 and 16 s. *Note: INTEG TIME does not correspond to the number of cycles. If the automatically determined integration time is longer than the one set in the options, the integration time will be the same as in Normal measurement.*
- Multi-Fast: As with Multi-Normal but with multiple cycles of FAST measurements.
- Manual: Fixed integration time between 0.005 and 120 s. Value is given in ms.

The instrument has an internal ND filter that extends the measurement range of the instrument to higher radiation levels. The available options for the internal ND filter are Auto, Off, and On.

Note: If the instrument gives an error message "OVER" during the measurement, the object is too bright for the measurement range. To overcome this issue, enable the internal ND filter, decrease the integration time if in Manual speed mode, and/or decrease the measurement angle of the instrument.

Instrument controls: The measurement speed can be set by pressing MENU and navigating to *MEAS > SPEED*. After selecting the measurement speed, there is an option to set the internal ND filter to AUTO, OFF, or ON.

Measurement software: The measurement speed and internal ND filter can be set in *Instrument > Instrument settings...* menu of the software. In addition, the instrument can be set to repeat the measurement multiple times in *Instrument > Measurement Options... > Averaging Measurement Setting*.

4.7. Initiating the measurement

Instrument controls: Press the MEASURE button on top of the instrument.

Measurement software: Select *Instrument > Measure* or press the *Measure* button in the user interface.

4.8. Viewing, exporting and processing the measurement data

The measured spectrum in the wavelength range of 380–780 nm can be viewed both in the display of the instrument and in the measurement software. In addition to showing the radiometric data, the instrument also calculates the corresponding photometric quantity (luminance or illuminance depending on the configuration) as well as various colorimetric and other quantities from the measured spectrum.

Instrument controls: The display mode of the instrument can be changed by repeatedly pressing the COLOR MODE button on the back panel. You can save the data to one of the 100 memory slots of the instrument by pressing MEMORY, selecting the slot, and pressing ENTER.

Measurement software: The spectrum as well as the photometric and the colorimetric data of the measurement can be inspected in the Display View of the measurement software. To save the entire measurement sheet, select *File > Save as...*. To save the measurement data, select the row(s) of interest in the measurement data table, right click, and select *Save Selection as Text...* (see Figure 5). In order to save the spectral data using this method, navigate to *Tool > Options...* > *List* and tick *Save spectral data at the time of "Save Selection As Text"* as well as *Replace rows with cols at the time of "Save Selection As Text"*.

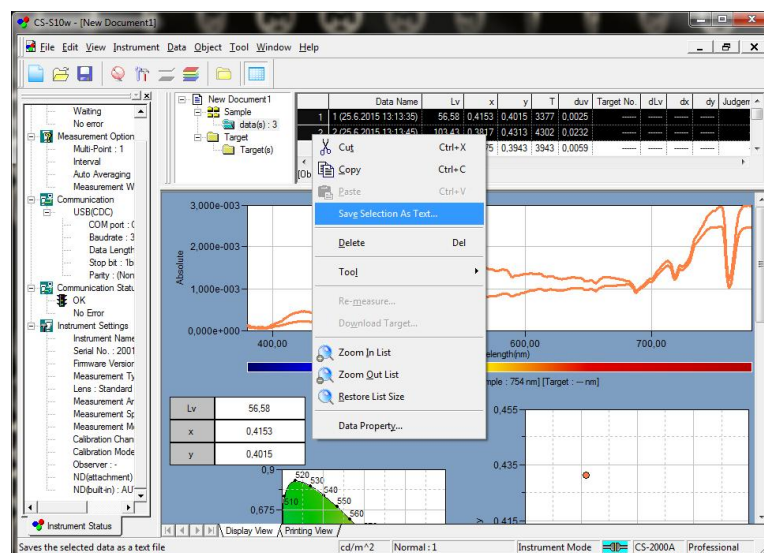


Figure 5: Saving measurement data to a text file in CS-S10w Professional.

5. Calibration instructions

This section provides instructions on how to calibrate the instrument using CS-S10w Professional software. For instructions on how to initiate the software, refer to Section 4.2. More detailed instructions on the software side of instrument calibration can be found in [2]. General instructions on irradiance and radiance calibrations can be found in [4] and [5], respectively.

The instrument has a permanent factory calibration (calibration channel 00) and additional 10 slots for user calibrations (channels 01 to 10). New calibration data should be stored in first empty calibration channel of the instrument, in order to make checking for the stability of the calibration easier. Once all the calibration channels have been filled, the calibration channel containing the oldest calibration data should be overwritten first.

The calibration utility can be accessed by navigating to *Instrument > User Calibration...* in CS-S10w Professional software. If the calibration channel needs to be overwritten, select the channel and press *Clear*. The name of the channel can be set by pressing the *Edit ID...* button.

Note: The format of the name of the calibration data should be TYPMM-YYYY, where TYP is the type of calibration (RAD for radiance/luminance calibration and DIF for irradiance/luminance calibration), and MM and YYYY are the month and year of the calibration.

Each calibration channel comprises both the wavelength and the level calibration data. If both calibrations are to be carried out, the wavelength calibration has to be performed before the level calibration. It is also possible to skip the wavelength calibration and only carry out the level calibration. If necessary, the wavelength scale of the instrument can then be corrected afterwards by manipulating the measured spectrum.

5.1. Wavelength calibration

The wavelength calibration of the instrument is carried out using a source with narrow intensity peaks whose wavelength is well-known. These sources include gas discharge lamps, such as mercury-vapor (Hg) lamp, as well as various lasers in the visible wavelength range. When possible, the wavelength scale should be calibrated at several wavelengths over the wavelength range of the instrument 380-780 nm. *Note: The FWHM bandwidth of the instrument is about 5 nm which means that closely spaced intensity peaks of some gas discharge lamps cannot be used in the wavelength calibration.*

The wavelength calibration is initiated by pressing the *Wave Cal...* button in the *User Calibration* window of the measurement software. *Wavelength Calibration* window (see Figure 6) should open. With the instrument pointing at the source, press *Measure*. Isolate the intensity peak whose wavelength is well known, by adjusting the *Wavelength Range* settings, and pressing *Zoom*. When *Add* button is pressed, the utility cal-

culates the center-of-gravity wavelength of the peak, and adds it in the list on the right to a location determined by *Register Number* field. This process can be repeated for multiple intensity peaks.

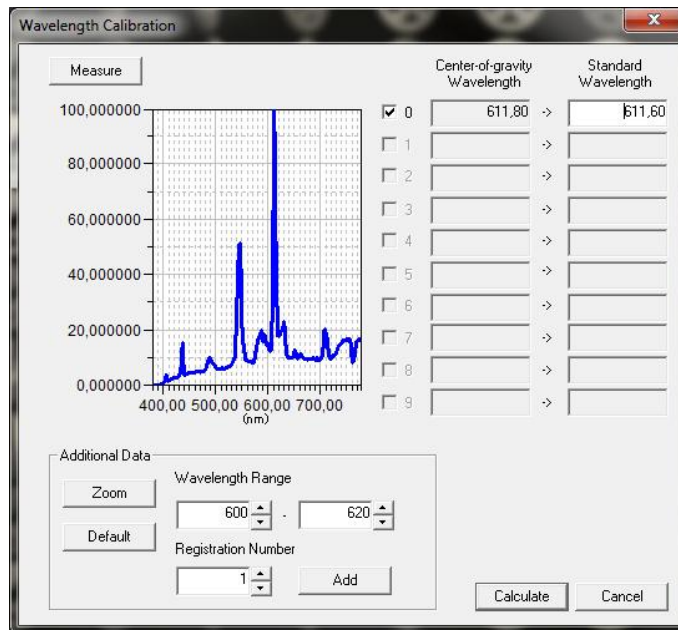


Figure 6: *Wavelength Calibration* window of CS-S10w Professional. Note that the spectrum of the figure is not optimal for wavelength calibration.

Note: The center-of-gravity wavelength calculation is affected by the choice of the wavelength range. To get most reliable results, a source with no or very little continuous spectrum around the intensity peak is preferred. The wavelength range should be selected so that only the intensity peak contributes significantly to the calculation. On the other hand, one must make sure that the selected wavelength range covers the entire intensity peak.

After all the intensity peaks are added in the list, the actual air wavelengths of the peaks should be inserted in the *Standard Wavelength* column next to the corresponding center-of-gravity wavelengths. When this is done, press *Calculate* to determine the wavelength correction and to close the *Wavelength Calibration* window. *Level Calibration* window is opened automatically. *Note: If level calibration is cancelled, the wavelength calibration data will not be saved.*

5.2. Level calibration

The level calibration of the instrument is carried out by measuring a standard light source whose irradiance or radiance is well known. At MRI, the irradiance calibration can be performed directly by using modelled FEL lamps, while radiance calibration has to be performed by transferring the irradiance calibration to the radiance geometry.

5.2.1. Irradiance mode

In irradiance mode calibration, a modelled 1 kW irradiance standard FEL lamp is used as the calibration source. Attach the diffuser adapter (Figure 4) to the spectroradiometer, and mount the instrument on the optical rail using a dedicated stand, consisting of an aluminium plate and ½" optical posts (see Figure 7). It is recommended to use two rail carriers with ½" post holders as the base for the stand as shown in Figure 7. The measurement distance between the front surface of the diffuser and the outermost surface of the lamp base is 500 mm.

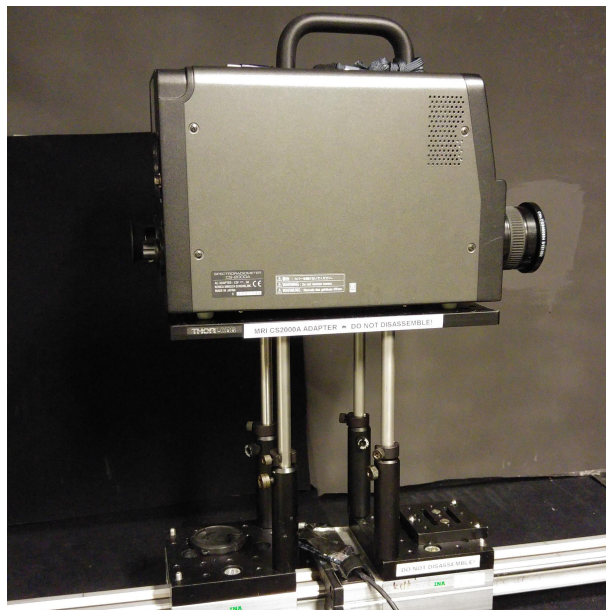


Figure 7: CS-2000A on the dedicated stand for optical rail mounting.

Before the measurement, align the lamp and the instrument on the optical axis of the setup with help of a two-beam alignment laser. Place a baffle with adjustable aperture between the lamp and the instrument. The lamp should be allowed to stabilize for at least 30 minutes before the measurement. The modelled spectral irradiance of the lamp in units of $W/(m^2 \text{ nm})$ is used as the lamp data in the level calibration utility. For detailed instructions on spectral irradiance measurements and on operating standard lamps, refer to [4] and [6].

5.2.2. Radiance mode

In radiance mode calibration, an existing irradiance mode calibration is transferred to radiance mode using the L-1009 luminance meter and the integrating sphere luminance source. It is recommended to operate the integrating sphere source with the same output aperture as in the calibration of the luminance meter. Align the luminance meter and the spectroradiometer on the optical axis of the setup at a distance of approximately 0.8 m from the luminance source. The 1° measurement angle should be used with both devices. Use baffles between the source and the spectroradiometer for straylight rejection, when measuring in the irradiance mode. Adjust the luminance level of the sphere close to 10000 cd/m^2 and the CCT of 2856 K. The sphere should be

allowed to stabilize for at least 1 hour before the measurements. For detailed instructions on how to operate the combined luminance and radiance setup, refer to the instruction manual [5].

Measure the luminance of the sphere output using the luminance meter with the 1° measurement angle. After that, measure the relative spectral irradiance using the spectroradiometer with the diffuser adapter. *Note: Before the measurement, make sure that the latest irradiance calibration file is selected in CS-2000A, as described in Section 4.4.*

Next, calculate the spectral radiance $L_e(\lambda)$ of the source based on the measured spectral irradiance $E_e(\lambda)$ and luminance L_v as

$$L_e(\lambda) = \frac{L_v}{K_m \int_{380 \text{ nm}}^{780 \text{ nm}} E_e(\lambda) V(\lambda) d\lambda} E_e(\lambda)$$

where $V(\lambda)$ is the luminous efficiency function, $K_m = 683.002 \text{ lm/W}$ is the maximum luminous efficacy of photopic vision, and λ is the wavelength in standard air. Save the calculated spectral radiance to a text file in units of $\text{W}/(\text{m}^2 \text{ nm sr})$. For detailed explanation of the calculation refer to Section 3.2 in [5].

Finally, remove the diffuser and focus the spectroradiometer to the center of the aperture plane of the sphere using the 1° measurement angle. Launch the level calibration utility and use the previously generated radiance text file as the lamp data.

5.2.3. Using the level calibration utility

The level calibration is initiated by pressing the *Level Cal...* button in the *User Calibration* window of the measurement software or by pressing *Calculate* at the end of wavelength calibration procedure. Level Calibration window (see Figure 8) should open. When the light source has stabilized, press *Measure* to obtain the measurement data. To load the corresponding lamp data, press *Load...* and select the data file.

The data file should contain one column with the spectrum of the lamp in the wavelength range of 380 to 780 nm. The unit of the data should be $\text{W}/(\text{m}^2 \text{ nm})$ and $\text{W}/(\text{m}^2 \text{ nm sr})$ in spectral irradiance and radiance modes, respectively. Period (.) should be used as the decimal separator.

Once the data is loaded, press *Calculate* to determine the level correction and to close the *Level Calibration* window. Press OK in the *User Calibration* window to return to the measurement view of the software. Enable the new calibration data in *Instrument > Instrument Settings...* menu of the software.

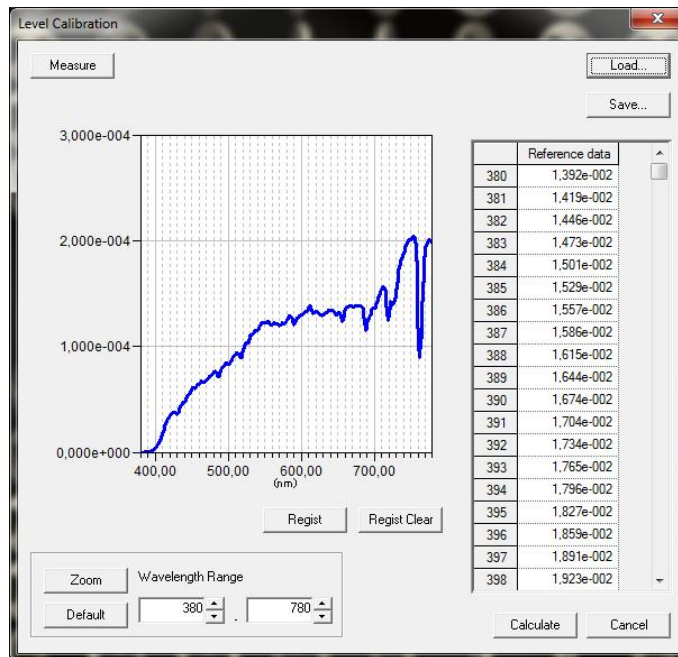


Figure 8: *Level Calibration* window of CS-S10w Professional. Note that the spectrum of the figure is for illustration purposes only.

References

1. Konica Minolta "Spectroradiometer CS-2000/CS-2000A," Instruction manual.
2. Konica Minolta "Data Management Software CS-S10w Professional," Instruction manual.
3. Konica Minolta "Data Management Software CS-S10w Professional," Installation guide.
4. Quality Manual of Spectral Irradiance Measurements.
5. Instruction Manual of Luminance and Spectral Radiance Calibrations.
6. Instruction Manual of Operating Standard Lamps.