Assessing Ultraviolet (UV) Safety with a Single-Grating Rapid-Scan Digital Spectroradiometer

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Abstract

Broad-band UV safety meters have been employed in safety evaluations of indoor lighting and other optical radiation sources. Such instruments can be used to provide a reasonably good estimate of the presence of trace actinic UV emissions from fluorescent and incandescent lamps. Single-grating rapid-scan spectroradiometers can provide a cost effective alternative to survey meters and double-grating monochromators, but measurement errors can be significant without further precautions.

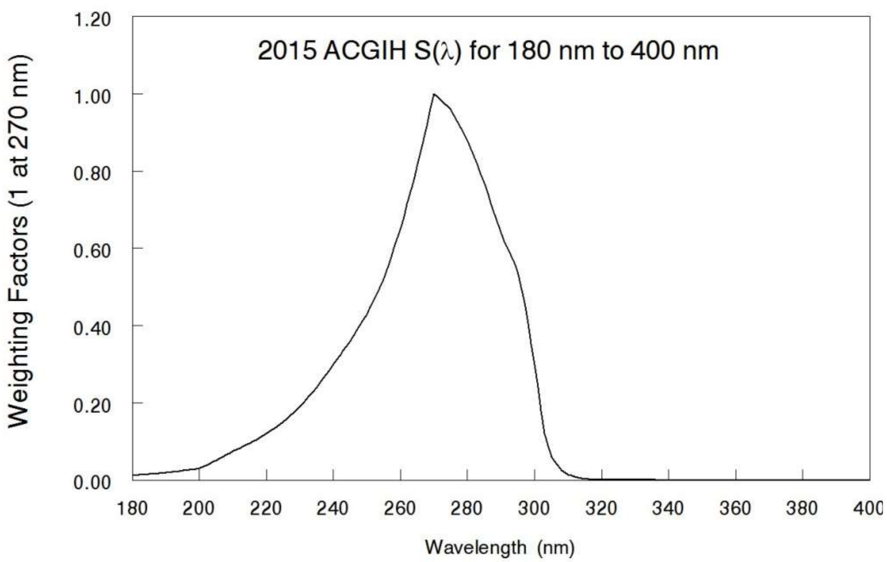
Purposes of this study

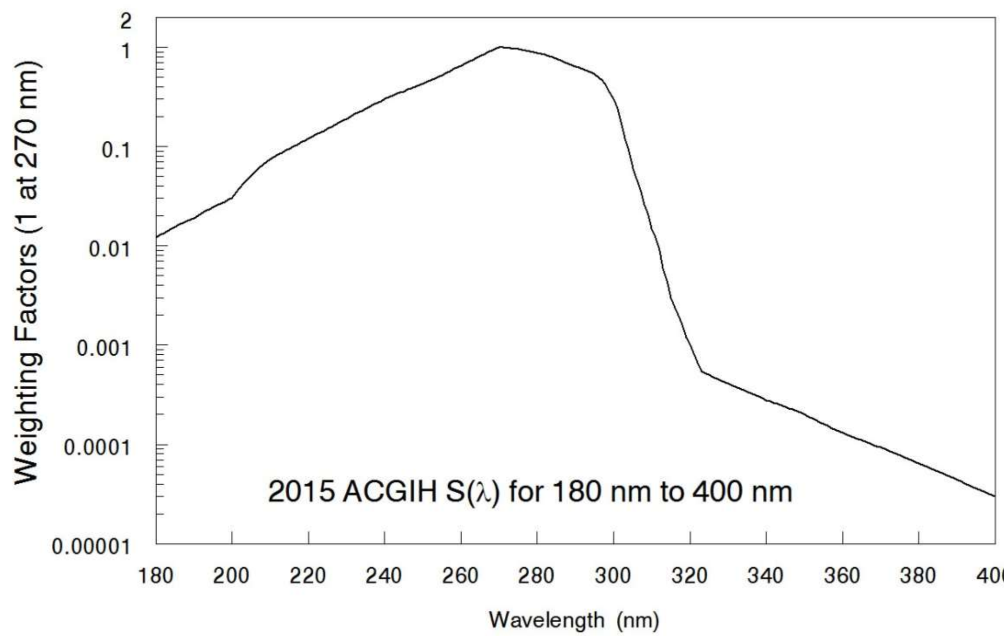
Concern for Personnel Exposure to UV. Reasonable estimate of ACGIH weighted UV (180 nm to 400 nm) irradiance and unweighted UVA (300 nm to 400 nm) irradiance.

Identify and Observe Errors. Significant errors can arise from failure to recognize problems with incorrect high readings resulting from stray-light, detector noise, and spurious noise.

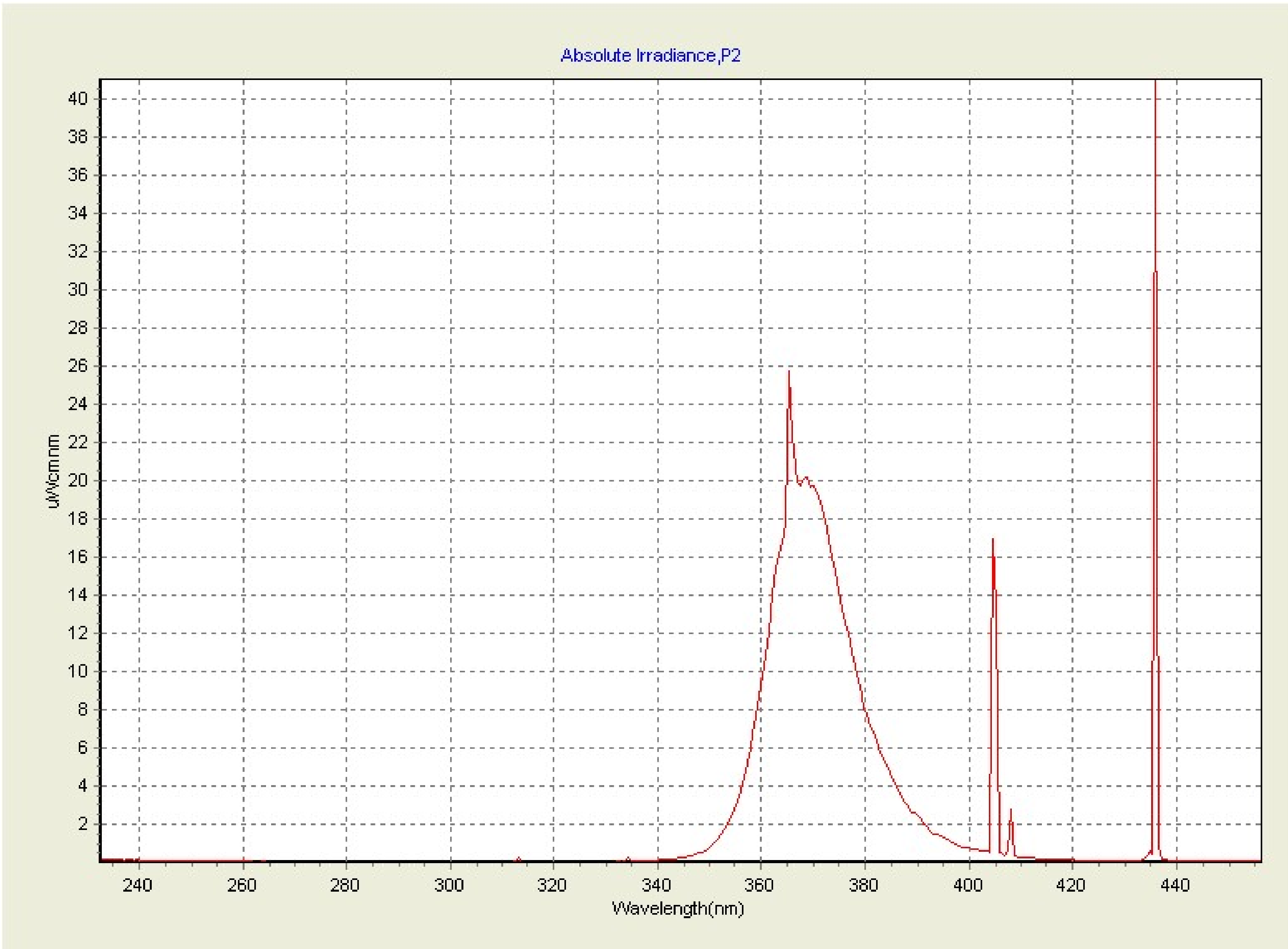
Develop Improved Strategies. Methods for recognizing and correcting errors are evaluated for single-grating rapid-scan digital spectroradiometers.

2015 ACGIH S(λ) weighting factors on a linear scale and on a log scale

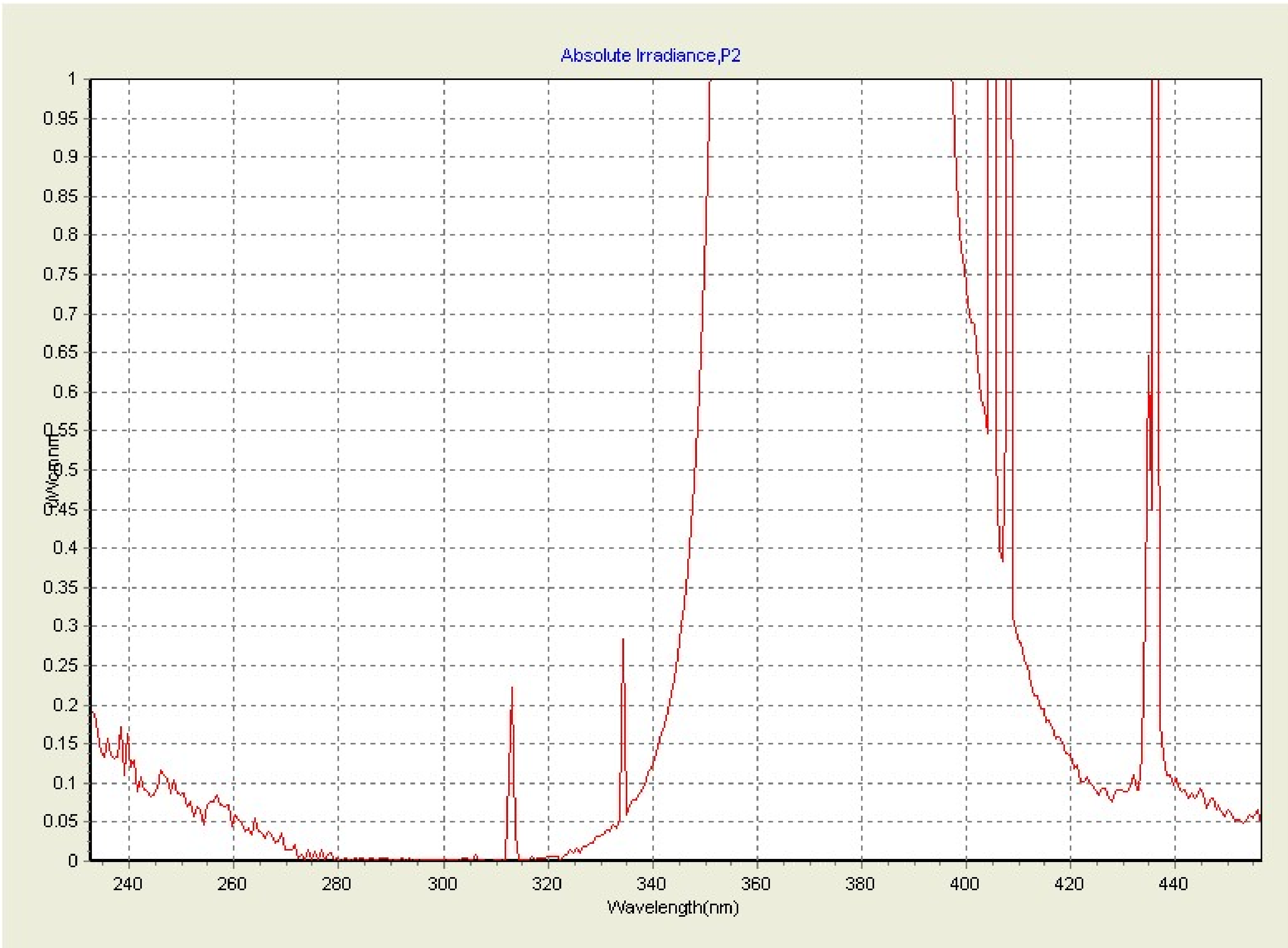




Spectral irradiance of a typical blacklight.
Linear scale suggests nothing significant below 340 nm.



Expanded irradiance scale of the same blacklight. Linear scale examining UV region showing noise below 280 nm.



Recognizing measurement expectations, artifacts, and detector noise

- Lamp design can help identify leakage emission spectra
- Scan to scan differences can show noise contribution
- Noise can increase where the instrument is less sensitive
- Emission lines should appear above noise if present
- Lamp envelop is a long-pass filter with a cutoff wavelength
- Blacklight example with Hg shows lines at 302.2 nm and 313.2 nm but not 296.7 nm so choose a cutoff λ of 280 to 300 nm
- Keep the signal on scale as otherwise other artifacts can surface
- Close evaluation distances greatly improve the signal/noise

Stray-light tests and cancellation with a single-grating rapid-scan spectroradiometer

- Use a UVB (280-315 nm) and UVC (180-280 nm) blocking filter like a UVA (315-400 nm) long-pass filter (Schott WG320, etc.) to observe UVB and UVC stray-light compared to a normal opaque blocked zeroing
- Cleverly cancel the stray-light by zeroing with a UVA long-pass filter (Schott WG320, etc.) to observe UVB and UVC. This also cancels the UVA which can be observed with a second scan and opaque blocked zeroing
- While not exceeding the spectroradiometers peaks counts, observe the normal & expanded irradiances with opaque blocked and UVA long-pass filter zeroing

Recommendations based upon 100s of UV spectral measurements

- Obtain initial measurements at very close range (10 to 20 cm)
- Use various UV long-pass filters to appreciate UV spectrum
- Rigidly mount source and spectroradiometer receptor
- Determine ratio of ACGIH weighted UVB_{eff}/UVA at close range
- Use ratio of UVB_{eff}/UVA to predict UVB_{eff} at longer ranges
- Many of these techniques have been used for Hg line leakage from CFL bulbs and commercial bug and blacklights
- Not as effective for incandescent lamps and the terrestrial solar disk

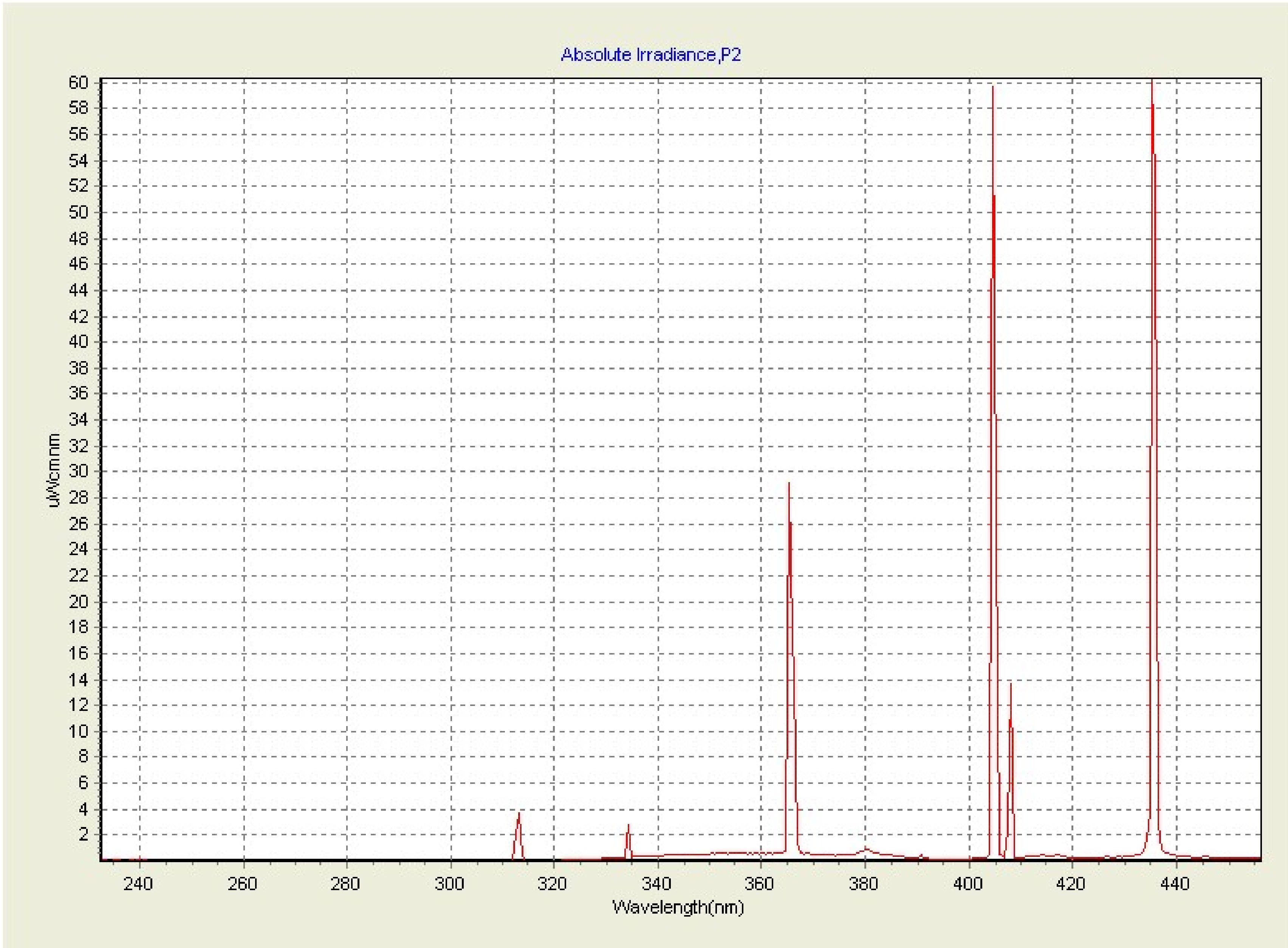
CFL lamp UVB_{eff} testing

- Many CFL's surveyed for leakage ACGIH UVB emissions
- Initial survey conducted with survey meter and single-grating rapid-scan UV spectroradiometer for highest UVB_{eff}
- Some CFLs selected for further testing by FDA and other national labs
- Lesser CFL was evaluated further for UV versus operating time
- Spectral irradiance measurements obtained at a constant lamp voltage
- UV spectroradiometer and CFL both rigidly mounted
- Focus on leakage through CFL glass bends where glass was thinner

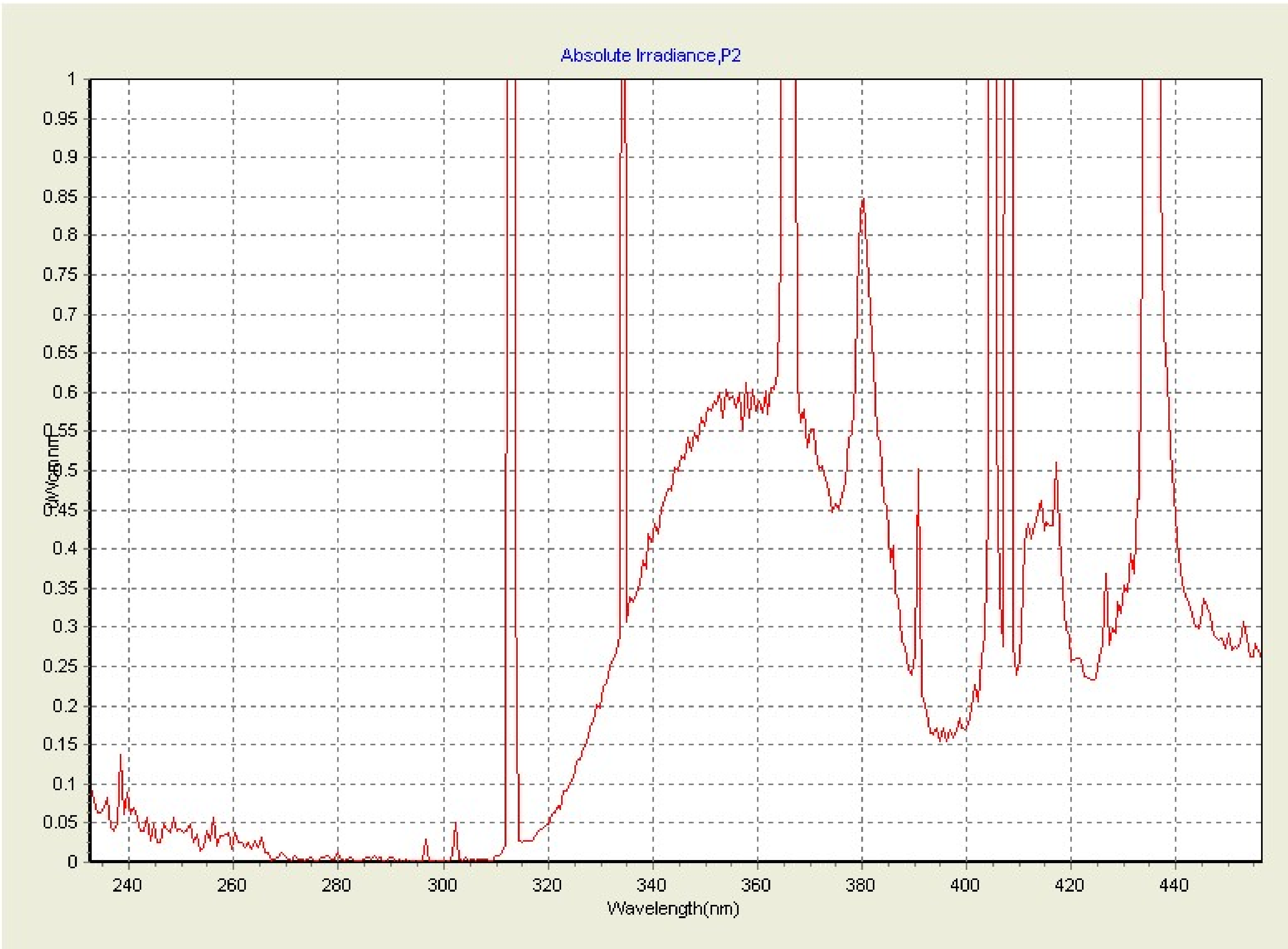
Sylvania CF20EL/MICRO/827
20 W 1300 lumen CFL bulb

Vertical optical rail over CFL with spectroradiometer receptor and 2x2 inch filter tray

Irradiance scan of CFL bulb shows 313.2 nm line



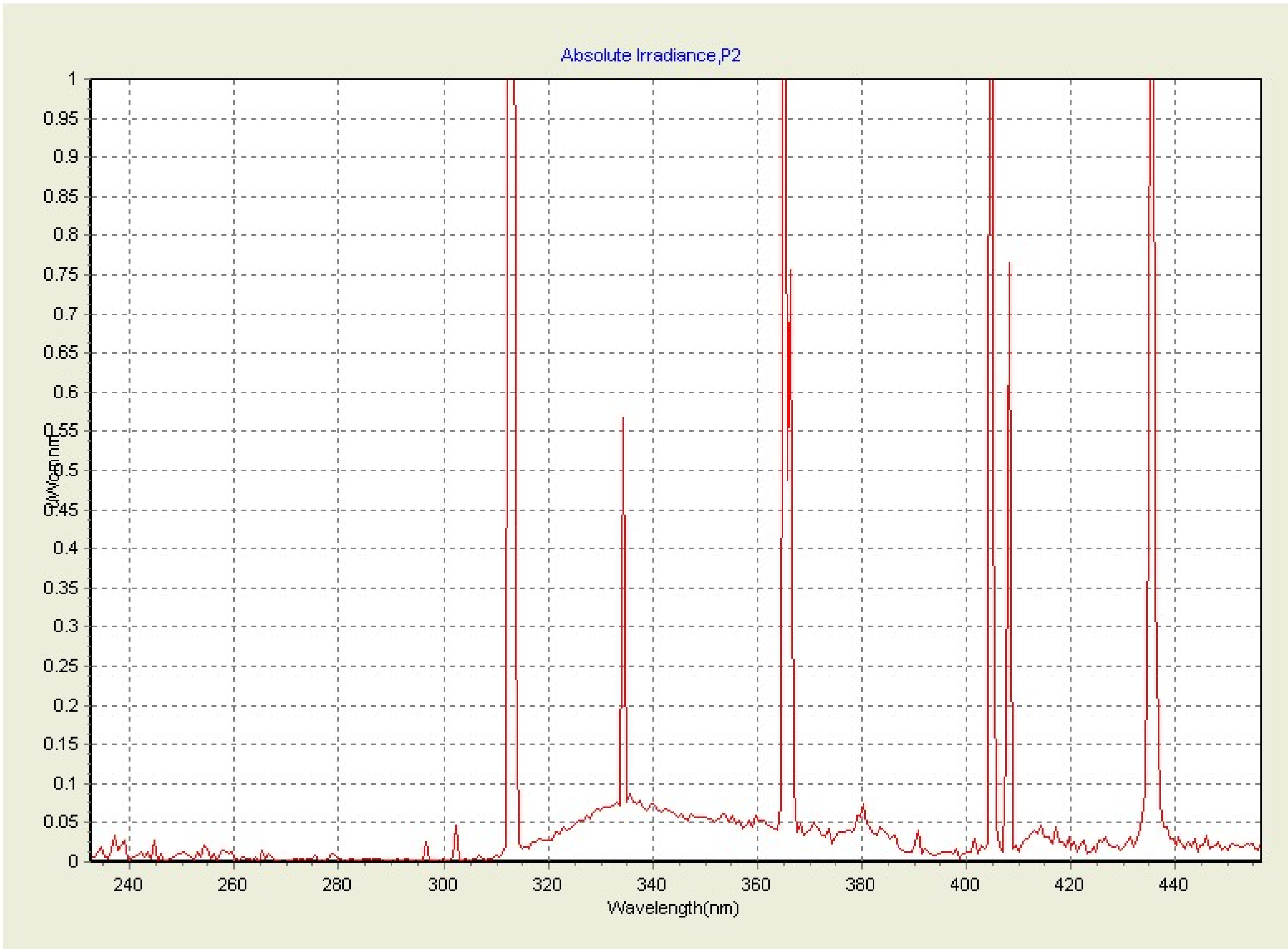
60x magnification shows more Hg lines (297.7 nm and 302.2 nm) and stray-light below 280 nm



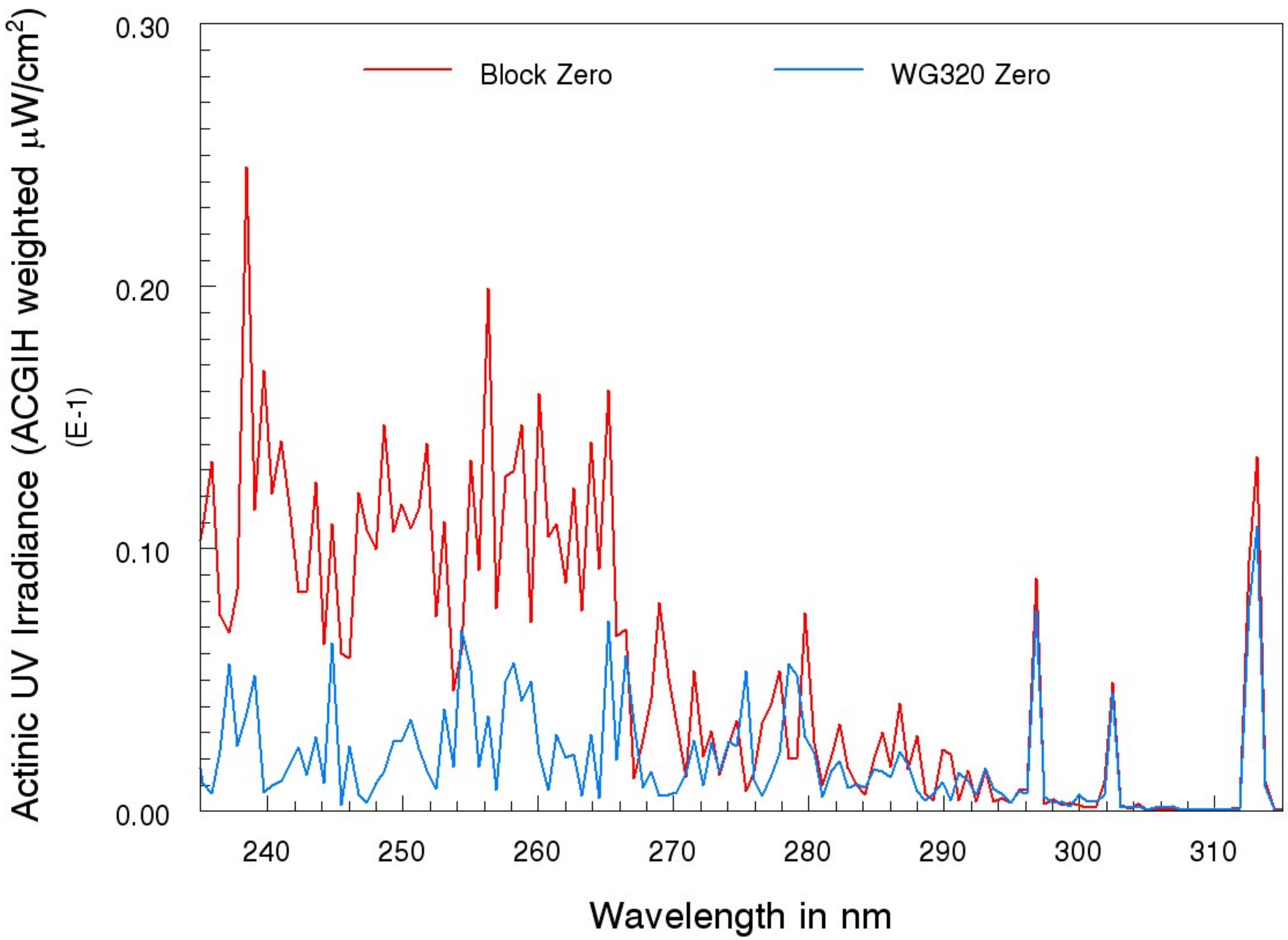
Process to measure UV with reduced errors

- Obtain two spectral irradiance data sets by zeroing with an opaque beam block and with a UVA long-pass filter (Schott WG320, etc).
- Observed linear and expanded spectral irradiances for the two spectral irradiance data sets
- Choose a cutoff wavelength for your lamp envelop (often between 280 nm and 300 nm) and determine by spreadsheet the ACGIH weighted or UVB_{eff} cutoff-λ to 315 nm for the WG320 filter and 315 nm to 400 nm for the beam block zero data.
- The net UVB_{eff} will be the sum of the two UVB_{eff} spreadsheet ACGIH weighted calculations with WG320 and with an opaque beam block.

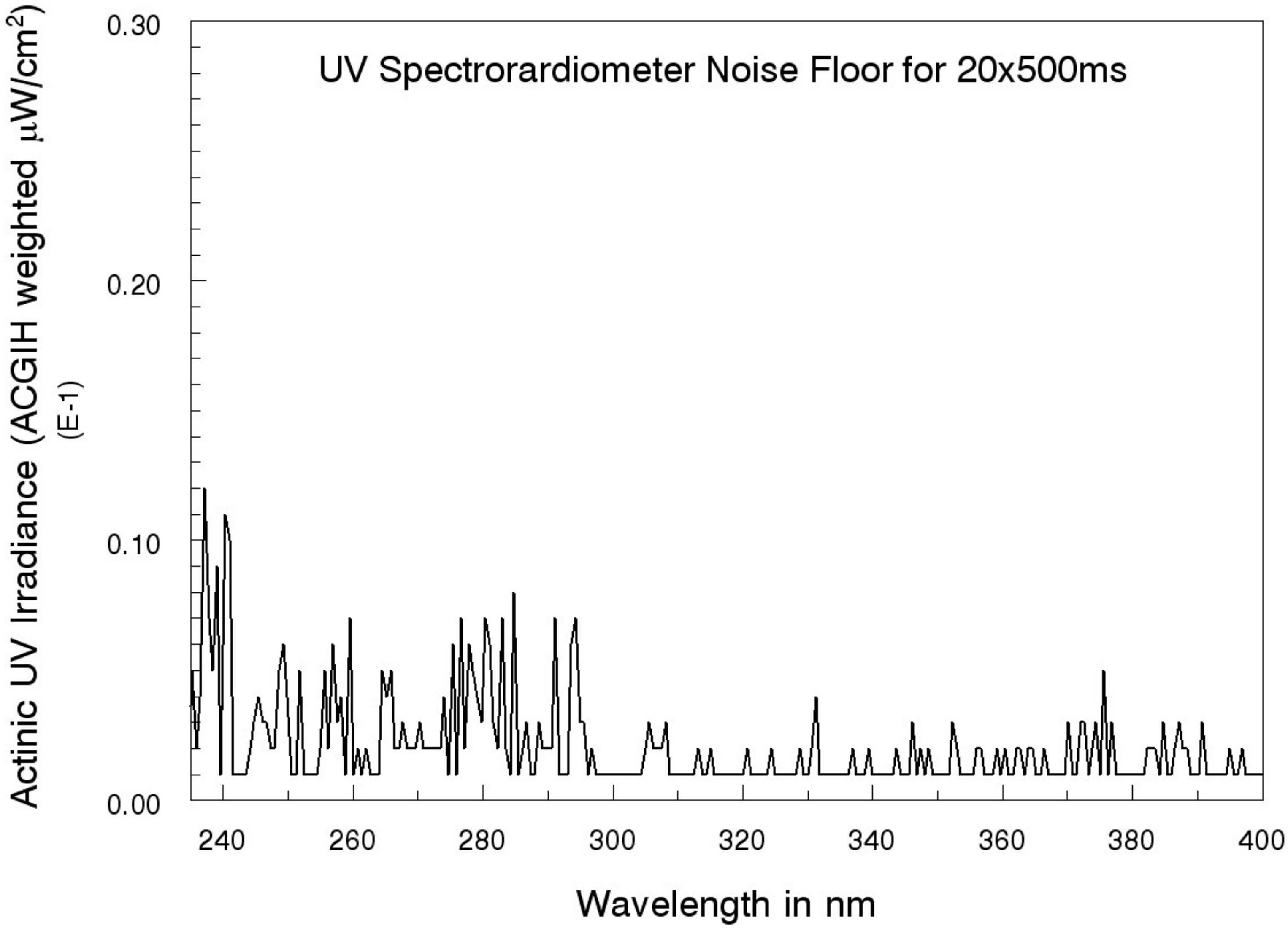
60x magnification zeroed with WG320 to cancel stray-light for cutoff-λ to 315 nm



Spectral irradiance x S(λ) for two data sets shows correlation for λ > 294 nm and noise for λ < 294 nm



Spectroradiometer noise floor with opaque blocked zero and scan shows residual noise which varies with integration



Spectroradiometer noise floor error contribution to ACGIH weighting for various cutoff wavelengths

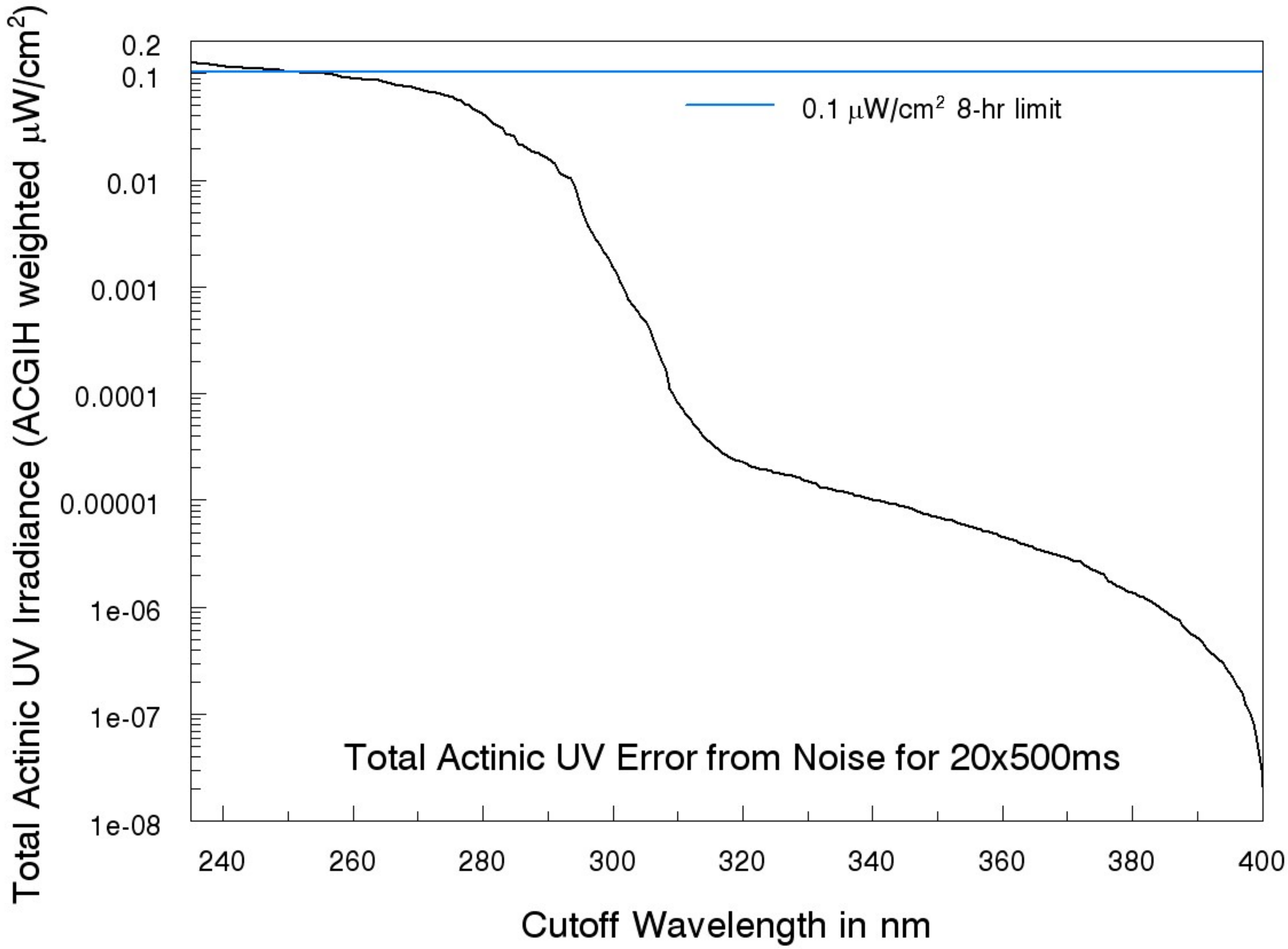
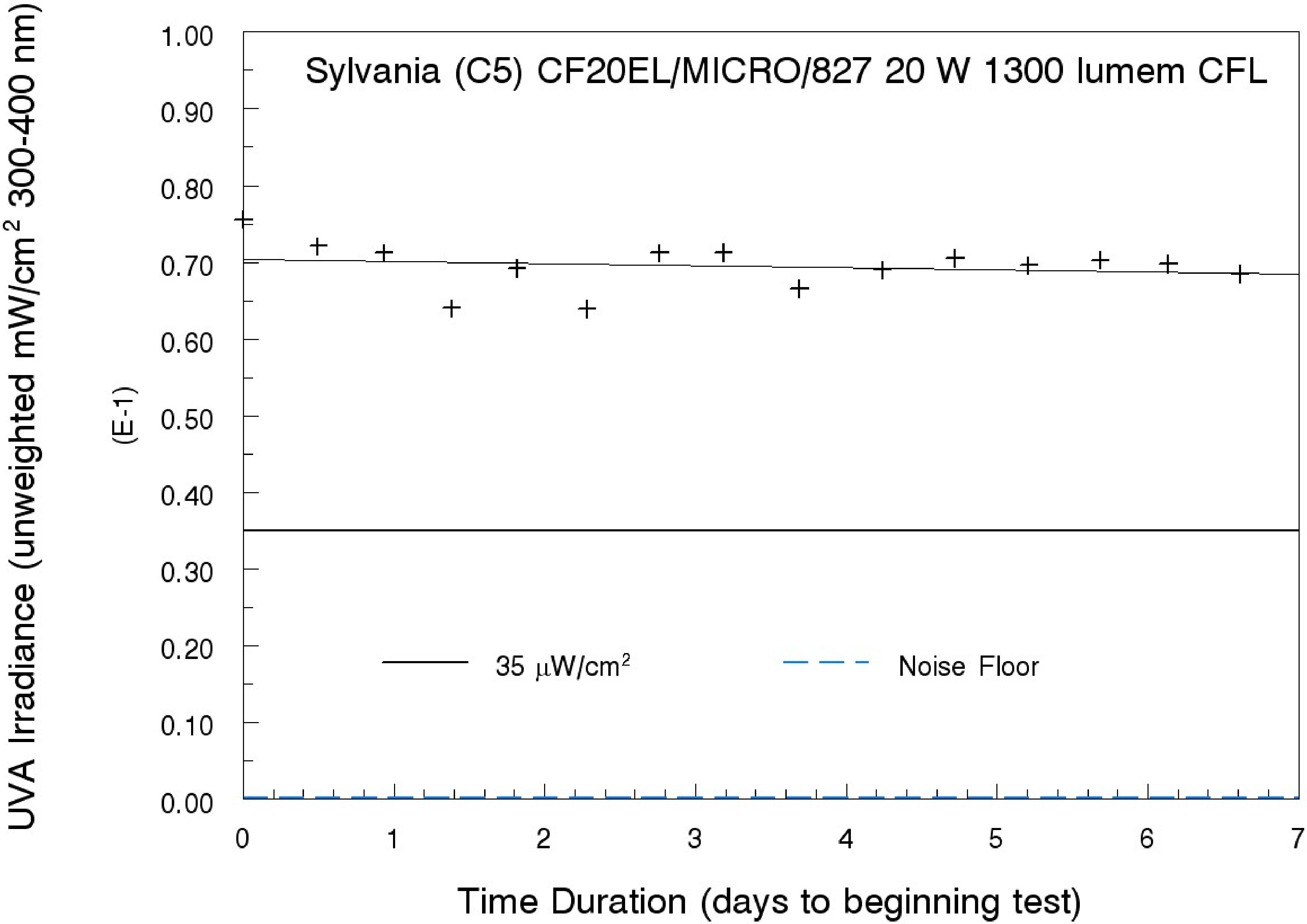
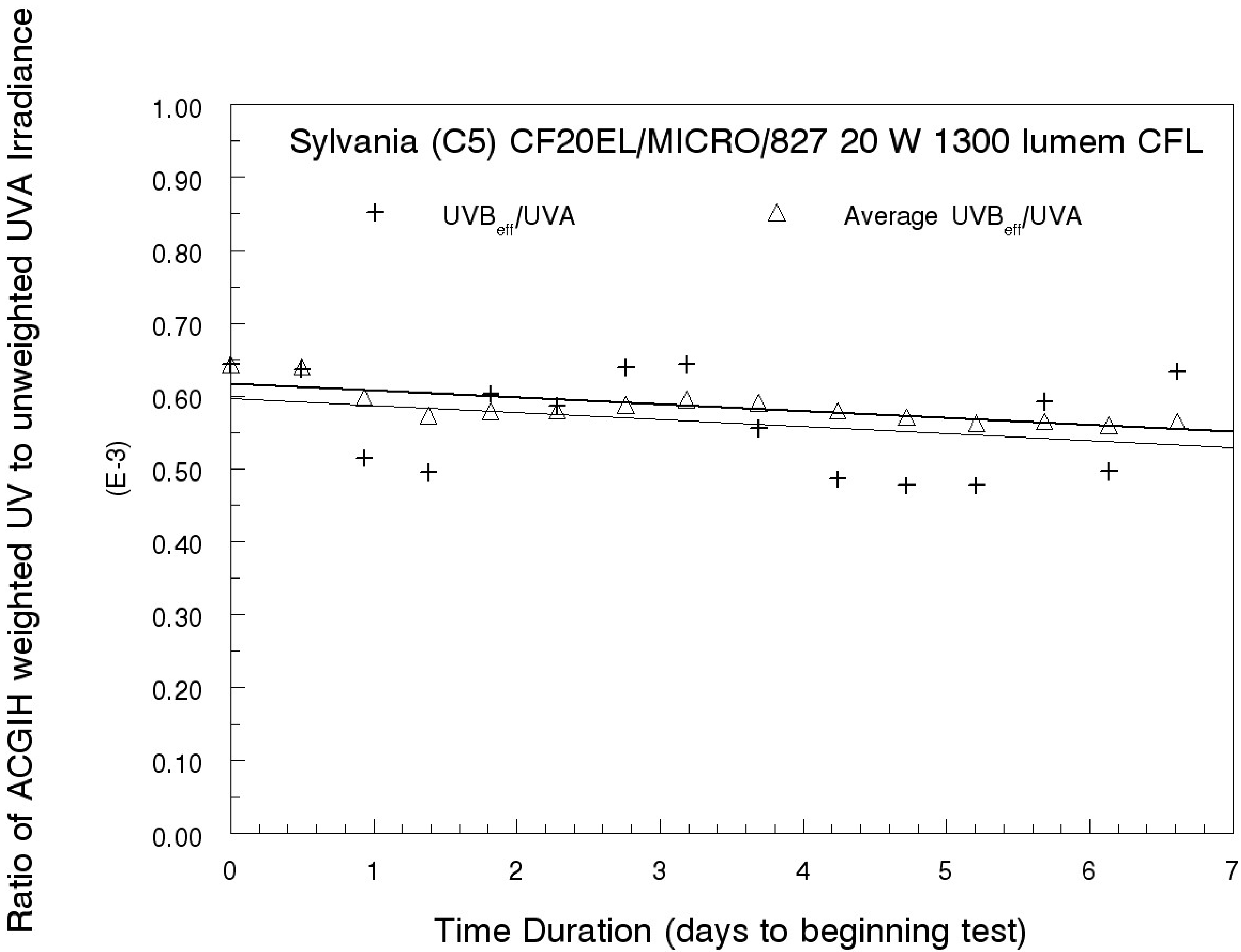


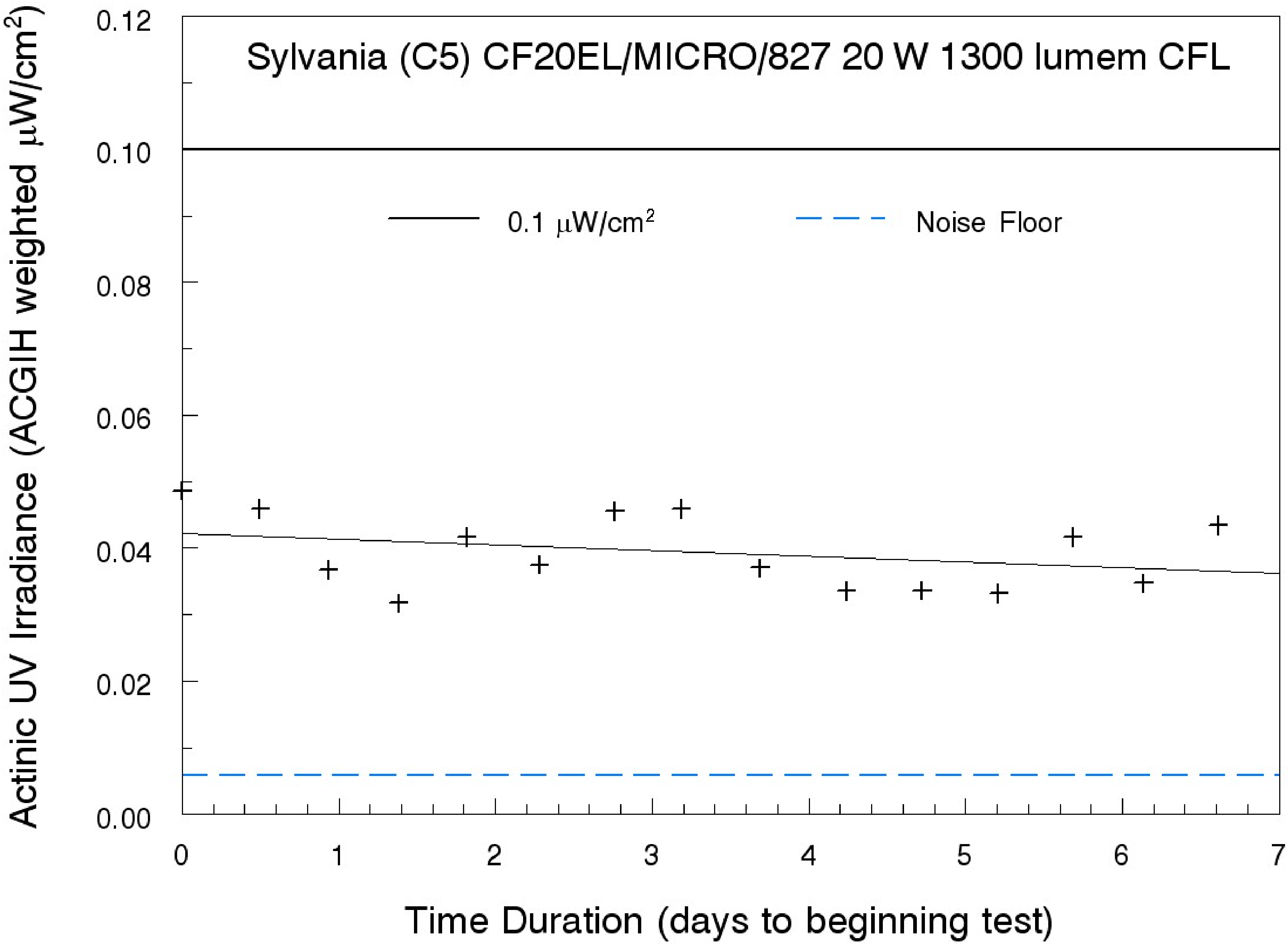
Table 1. Noise floor data integrated to specific cutoff wavelengths for Mightex UV spectroradiometer. The spectroradiometer receptor was blocked for both zero and measurement for an integration of 20×500 ms. The UVA results are unweighted and the actinic UV results were ACGIH weighted.

Cutoff Wavelength (actual nm)	UVA from Noise (mW/cm^2)	ACGIH actinic UV from Noise ($\mu W/cm^2$)
285 (284.80)	0.00015	0.0257
290 (289.85)	0.00015	0.0162
295 (294.89)	0.00015	0.0059
300 (299.93)	0.00015	0.0015
305 (304.96)	0.00015	0.00048
310 (309.98)	0.00015	0.000083

Note: These results were for an integration of 20×500 ms and likely differ for other integration times. One might assume that these values could be subtracted from measured and analyzed data with the appropriate cutoff wavelength. Ignoring these results can result in a conservative analysis. By comparison, the 8-hr human exposure limits are 0.035 mW/cm^2 for unweighted UVA and 0.1 $\mu W/cm^2$ for actinic UV.


Sylvania (C5) CF20EL/MICRO/827 20 W 1300 lumem CFL
UVA Irradiance (unweighted mW/cm 2 300-400 nm)
(E-1)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
35 µW/cm2
Noise Floor
0
1
2
3
4
5
6
7
Time Duration (days to beginning test)


Sylvania (C5) CF20EL/MICRO/827 20 W 1300 lumem CFL
UVB$_{eff}$/UVA
Average UVB$_{eff}$/UVA
Ratio of ACGIH weighted UV to unweighted UVA Irradiance
(E-3)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
1
2
3
4
5
6
7
Time Duration (days to beginning test)



Sylvania (C5) CF20EL/MICRO/827 20 W 1300 lumem CFL
0.1 μW/cm2
Noise Floor
Actinic UV Irradiance (ACGIH weighted μW/cm2)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
5
6
7
Time Duration (days to beginning test)

Table 2. Estimated external transmission characteristics for 2-mm and 3-mm thick Schott WG320 filters and correction factors at 1-nm intervals. Spectral data collected at 1-nm intervals and when zeroed using the WG320 filter should be corrected by these multiplicative factors.		
Wavelength (nm)	**Transmission** **(2-mm & 3-mm X100 for %)**	**Multiplicative Correction Factor (2-mm & 3-mm)**
310	0.05, 0.074 measured	1.05, 1.080
311	0.09, 0.095	1.10, 1.105
312	0.13, 0.122	1.15, 1.139
313	0.17, 0.154	1.20, 1.182
313.155	0.18, 0.158	1.22, 1.188
314	0.21, 0.183	1.27, 1.224
315	0.25, 0.217	1.33, 1.277
316	0.30, 0.261	1.43, 1.353
317	0.34, 0.303	1.52, 1.435
318	0.39, 0.338	1.64, 1.511
319	0.43, 0.384	1.75, 1.623
320	0.47, 0.416	1.89, 1.712

Spectroradiometer software and evaluation spreadsheet design

Output spectral data at 1nm intervals if possible otherwise smooth pixel data over a few pixels to further average and smooth the noise

Reverse order wavelength spectral data can be re-reversed using spreadsheet SORT command to maintain the association between wavelength and data

Design a spreadsheet that interpolates the ACGIH weighting factors for either 1 nm or at the pixel wavelength intervals

Create two spreadsheets or pages, one for WG320 zero and one for beam block zero, where the different spectral data can be analyzed by wavelength.

Do the math in a column $[\mu W/(cm^2\text{-}nm)][\Delta\lambda]$ for each wavelength and then sum that column from λ_{cutoff} to 315 nm for WG320 zero and 315 nm to 400 nm with beam block zero.

Add the results of the two summations together to find total UVB_{eff}

Conclusion

The single-grating rapid-scan UV spectroradiometer provides a cost-effective instrument to measure trace levels of actinic UV when stray-light and other potential measurement errors are addressed.