Challenges when measuring Far UV-C
Correctly and meaningfully

- Dr. Holger Claus

2021 CORM/CIE Conference

November 15, 2021

Agenda

- Far UV-C (200nm-230nm) Light Sources
- Measurements
  - Electrical
  - Spectroscopic
  - Radiometers
  - Indicators
- Hazard assessment of light sources
  - ACGIH TLVs, IEC62471

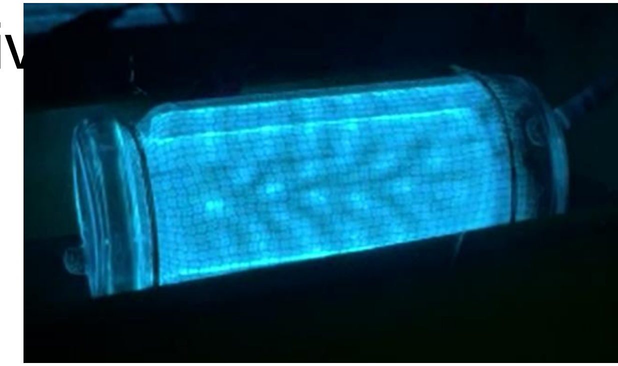
Why we measure light sources

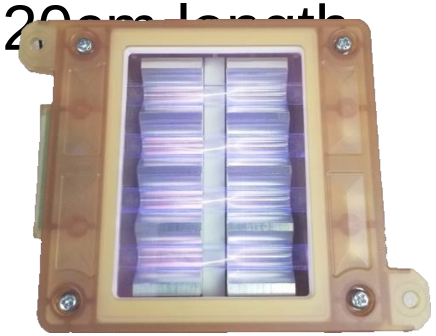
- Visible light sources- total output (lumen)
  - Easy to measure (in Sphere)
  - Good for comparing products, but almost no relevance in application
  - In application- illuminance or luminance is important
  - And – color
  - And – (blue light) hazards
  - Electrical parameters (current, power) -efficiency

- UV-C sources
  - Difficult to measure total output (watts) (in Sphere)
  - In application – irradiance is important
  - And- Spectrum!
    - Pathogen reduction depends on wavelength
    - (Photobiological) hazards strongly depend on wavelength
  - Irradiance can be used for comparing (similar) products
    - What is actually important is the Dose!
  - Electrical parameters can be difficult to measure
  - -> various IES committees working to create new standards!

Far UV-C lamps – KrCl Excimer lamps

- Electrodeless lamps
  - Filled with Krypton and small amount of Chlorine
  - Electrodeless
  - Driven by high pulses (3-10kV) by special, customized driv
  - Various mechanical lamp designs
    - Typical style – 2 concentric tubes with inner and outer electrode
    - Microdischarge lamp(flat)
    - Care222® – 4 small tubes that are driven axially
      - Bandpass Filter (<230nm) is part of design
  - Sizes and power can vary, but most common types <2

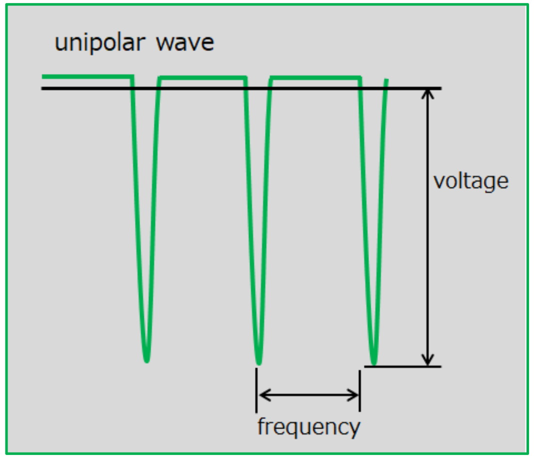




- Main applications
  - Surface and air disinfection
    - Low power (10-20W)

Far UV-C Lamp Measurements - electric

- Example of lamp Voltage and current
  - Frequency 30-100kHz
  - Peak Voltage 3-10kV
  - Lamp may not be grounded



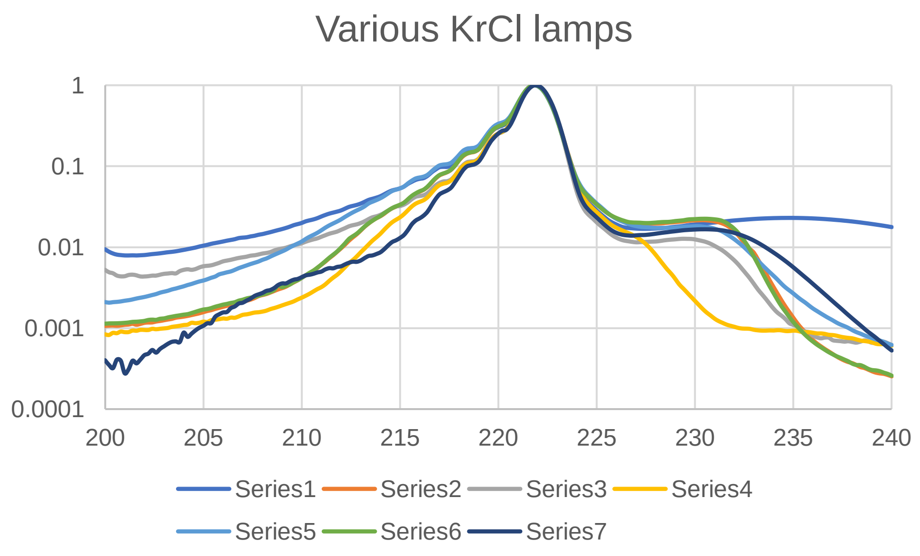
- No commercial measurement equipment available (very high voltage, and high frequency)

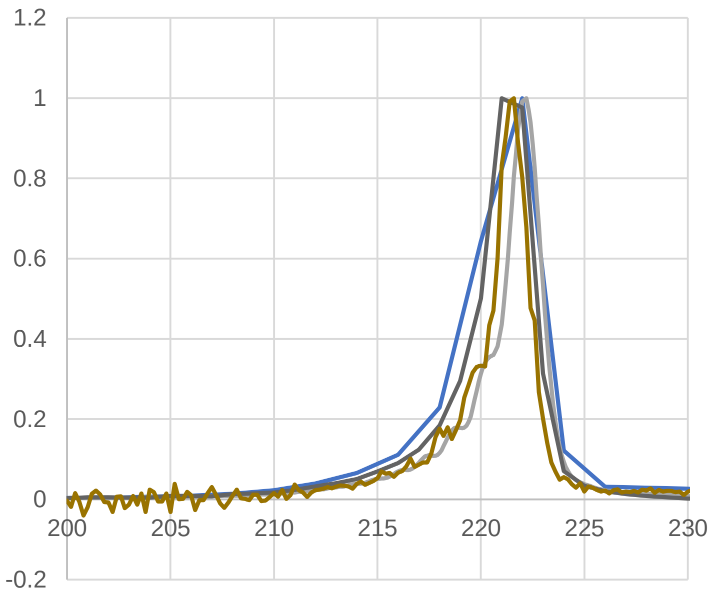
→for typical measurements

- measure input voltage, current, power of **Driver**
  - driver is part of the lamp package anyway
  - Many drivers have low voltage (12-24V) DC input – simple measurement

Irradiance measurements

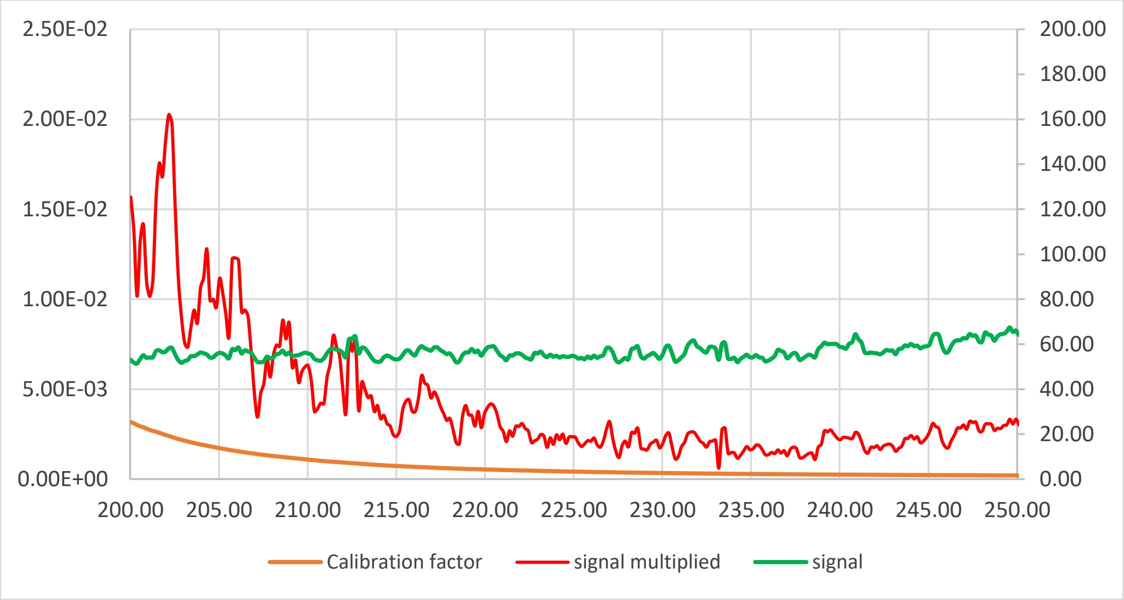
- With Spectrometer – double monochromator(!?)
  - 222nm peak very stable (does not seem to depend on lamp design)
    - But measured peak wavelength depends on spectrometer!
      - Example 1: lamps from various manufacturers. Measured with same spectrometer (0.2nm resolution) –note log scale!
        →all peaks at 221.8nm
      - Example 2: same lamp measured with different spectrometers →221-224nm peak wavelength Notice – NOISE!

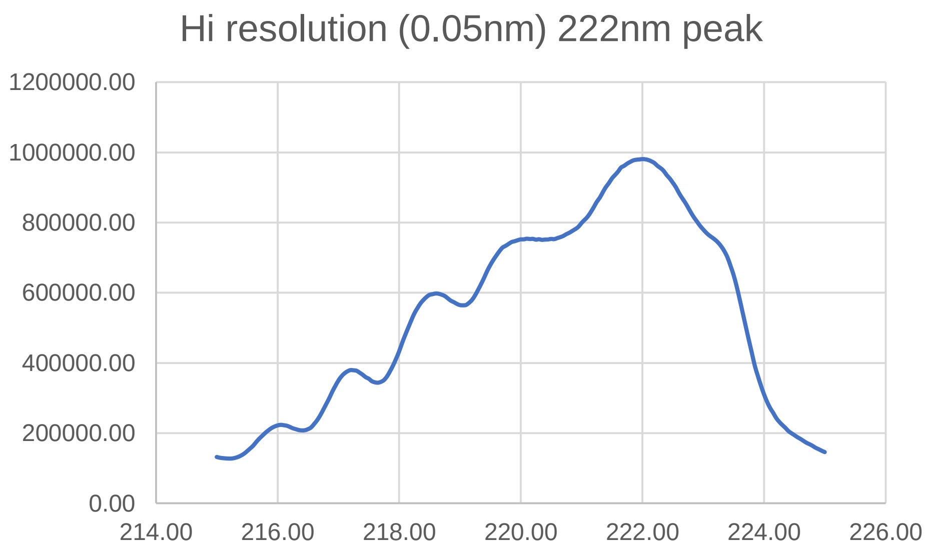




Spectrometer questions

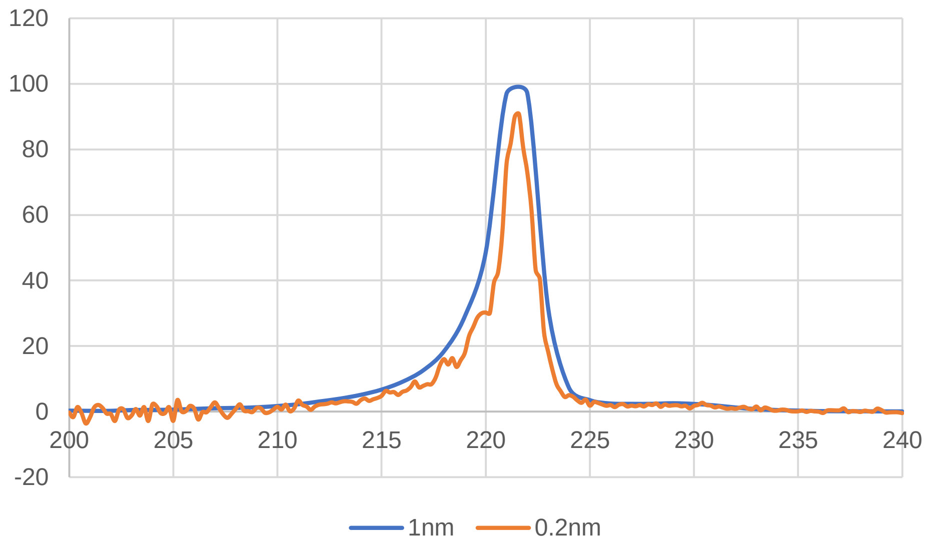
- Noise
  - How much is too much?
  - How to measure/ estimate?
- Wavelength calibration
  - Typical wavelength calibration lamps are Mercury pen lamps – no peaks below 254nm!
  - Ushio measurement of peak with 0.05nm resolution->peak at 222.0nm
  - Alternative wavelength calibration lamps?
    - Hollow cathode lamps (Sn, Bi, Sb, Pb)





Spectral bandwidth and irradiance calibration

- Smaller bandwidth= more noise!
- Averaging many measurements?
- Recommended >=1nm bandwidth?
- OR- measure closer to the lamp
  - Much higher signal! Less Noise

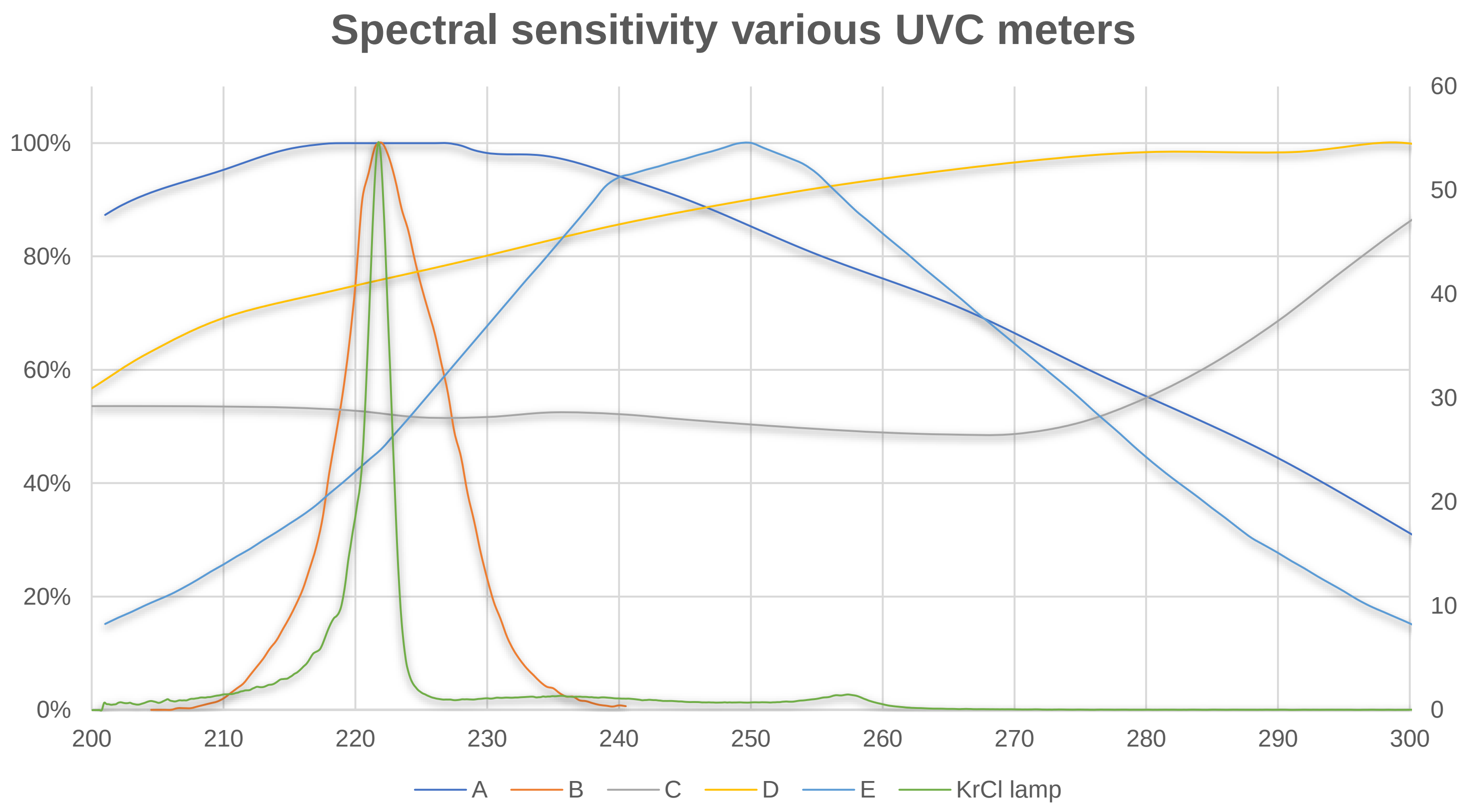


- Graph:
  - Both measurements done with same instrument, same distance
  - Both settings were calibrated with same calibration lamp
  - Difference in measured total irradiance: 5% (including negative values)
    - 7% difference not including negative values

Radiometers

- Good meters with sufficient sensitivity and cosine correction are available
  - Should be calibrated at 222nm
  - Note: Uncertainty of calibration (can be 20%!)!
- Solar blind detector important
- Flat spectral response(?)
- DO NOT use narrow filtered “222nm meters”!
- Cosine response is very important (especially in applications!)
  - By the way.. Cosine response of monochromators can be also important!
- Filtered vs. unfiltered lamp measurements – Problem!
- Note: In application settings (for verification) – radiometers will be used!
  - Measurements will most likely not agree with irradiance measurements done by spectral method

Available meters

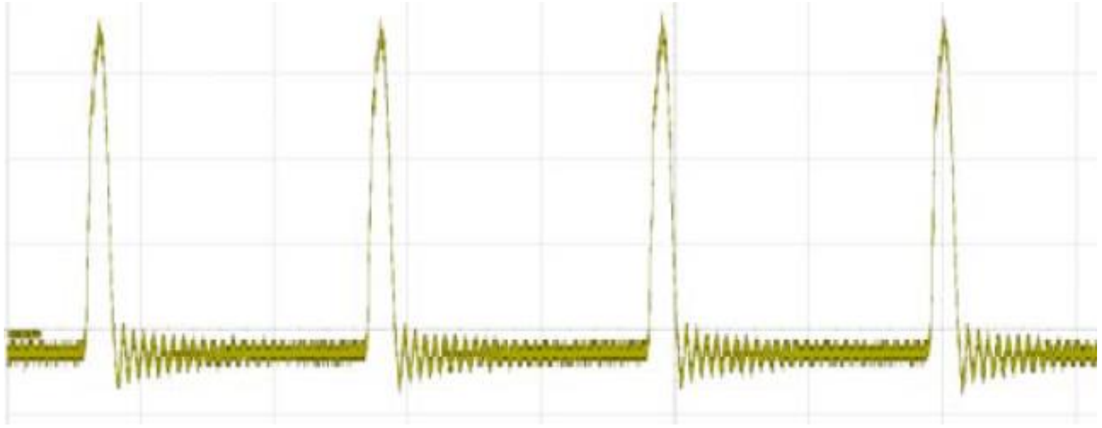


Assumption:
Radiometer calibrated at 222nm

	Measurement Accuracy %	
Meter	Filtered lamp	Unfiltered lamp
A	100	98
B	82	64
C	100	100
D	100	101
E	98	109

Waveform of light

- -> Not comparable to other lamps

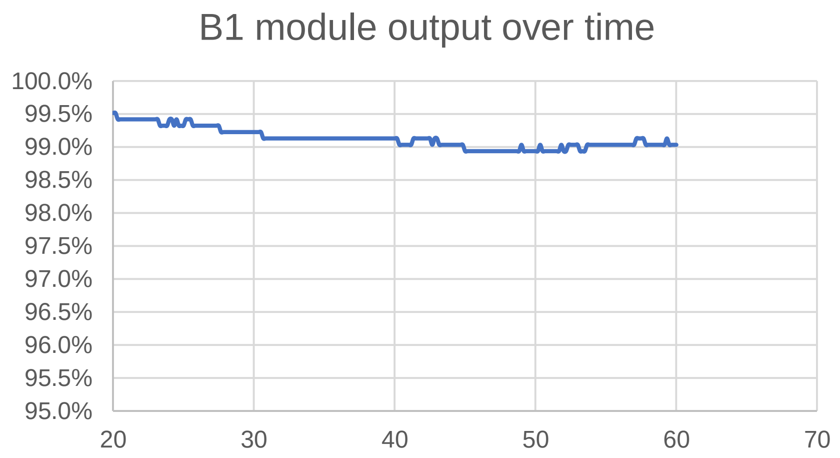


- Narrow pulses – 2-5µs
- Duty cycle? (10-15% ?)
- 30-100kHz
- Peak intensity is 10* Average!!

- Does it matter?
  - Likely not, but has not been verified
  - Linearity of detector could be compromised if sensor saturates
    - Based on measurements at various distances (and curve following 1/R^2) - it is not a concern at relevant distances

Notes of caution

- When measuring very close to lamps (or on the surface)
  - Radiometer may saturate (observe maximum irradiance specification!)
  - More important is cosine correction of detector
  - Electrical noise from lamp (4kV at 100kHz!!) may disturb detector
- Do NOT assume that a black surface does not reflect in the UVC range!
  - Measure/ verify
  - Use baffles
- Calibration of radiometers
  - Comparison of various meters (manufacturers) seem to be in 5% agreement!
- For consideration: Use 222nm lamp as verification source
  - Peak is stable
  - Output can be very stable (0.5%)!



A word about Dose indicators

- It is an INDICATOR!!
- VERY useful, inexpensive tool to check functionality of installation
  - For inexperienced end- users (!?)
  - Record keeping (!?)
  - “Definitely” cosine corrected!
  - Inexpensive (!!)
- Users will need a basic understanding of the meaning of “Dose” and “Log reduction”
  - Pathogen dependent
- Color matching is not very accurate
  - Depends on print color
  - Depends on lighting

3 mJ/cm^{-2} Check

6 mJ/cm^{-2} Check

Exposure time (s)	5	10	20	40	60	120	180
Dose 222 nm (mJ cm^{-1})	1.5	3	6	12	18	36	54

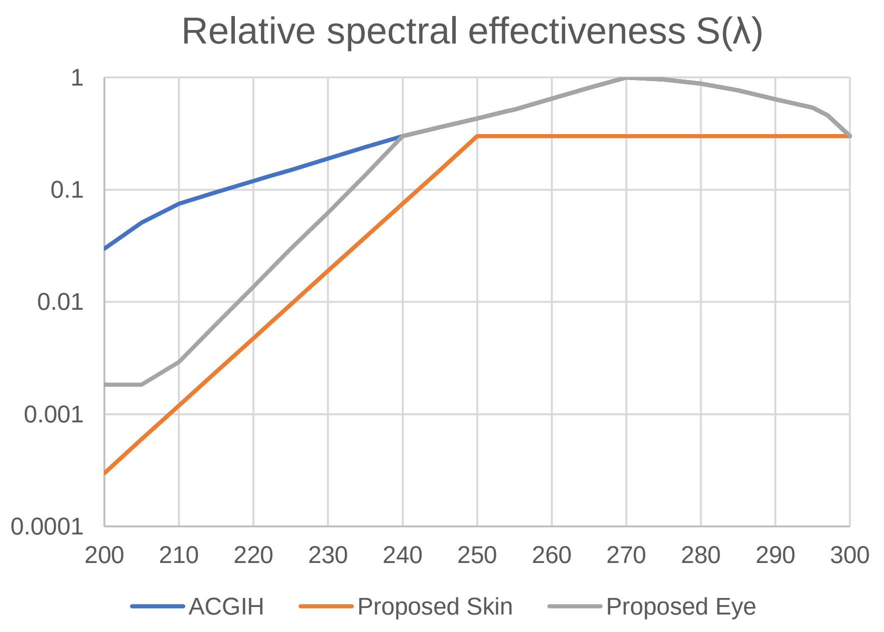
Why we need accurate spectral measurements - HAZARD

USHIO

- ACGIH/ IEC62471 – effective spectral irradiance (spectrum weighted)
  - ACGIH – mentions narrow band
    - Is 222nm narrow band?
  - RP27
    - Measurement distance vs. assessment distance
    - Mentions “measurements can be transferred to assessment distance”

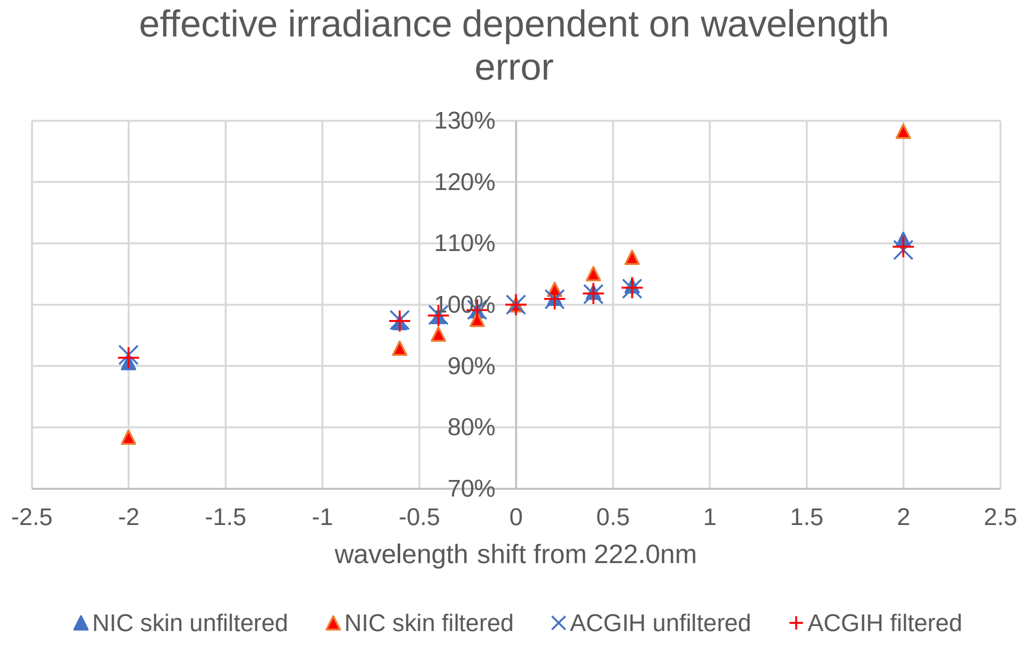
ACGIH/ IEC62471 hazard assessment

- Multiply spectrum with Relative Spectral Effectiveness and integrate
  - Spectral Effectiveness values are listed in 5nm steps
  - Important: to obtain intermediate values you must use log-linear interpolation!
  - Effective Irradiance: $$E_{\text{eff}} = \sum_{180}^{400} E_\lambda \cdot S(\lambda) \cdot \Delta\lambda$$



Effective irradiance error depending on wavelength calibration

- Some simulations:
  - Influence of wavelength calibration error on result
    - Wavelength calibration will become more important with increased TLV
    - Proposal: shift measured spectrum manually to peak at 222.0nm



	Error			
	NIC skin		ACGIH	
wavelength shift nm	unfiltered	filtered	unfiltered	filtered
-2	91%	78%	92%	91%
-0.6	97%	93%	97%	97%
-0.4	98%	95%	98%	98%
-0.2	99%	98%	99%	99%
0	100%	100%	100%	100%
0.2	101%	102%	101%	101%
0.4	102%	105%	102%	102%
0.6	103%	108%	103%	103%
2	111%	128%	109%	109%

Measure TLV with radiometer

- Comparison of spectral weighted irradiation to radiometer measurement
  - Method 1: Multiply measured (radiometer) irradiance with spectral effectiveness at 222.0nm
  - Method 2: full spectral analysis
  - Simulation: Filtered 222nm lamp (Care222)

	ACGIH-Current	NIC skin
Spectral effectiveness @222nm	0.1312	0.006265023
TLV (mJ/cm2) @222nm	22.9	478.8
radiometer (200-300)	264.7	
weighted spectrum	33.23	1.76
radiometer*spectral eff. @222	34.73	1.66
ratio radiometer/spectrum	105%	94%
adjusted TLV when measured with radiometer	21.9	508.2

A misunderstanding?

USHIO

- IEC62471- measure light source at 200mm distance!
- See: David H. Sliney, Rolf Bergman & John O'Hagan (2016) Photobiological Risk Classification of Lamps and Lamp Systems—History and Rationale, LEUKOS, 12:4, 213-234, DOI:10.1080/15502724.2016.1145551
  - Fact: There is NO UVC Light Source in the market that is NOT Risk Group 3 at 200mm distance
  - So, why measure at 200mm?
  - -> low noise spectrometer measurement!
- Assessment distance – for risk group classification of devices
  - Statement: .. Measurements performed at one distance, e.g. 20cm, can be transferred … to assessment distance
    - Problematic with "large" light sources, where 1/R^2 law does not apply (especially based on 20cm distance measurement!)
    - "disputable" in certification process
- Solution – see RP27-20 section "6.2.2 Broadband detectors"
  - Measure with monochromator and radiometer at the same distance (i.e. 200mm)
  - **Calculate correlation factor**
  - Measure at longer distances with radiometer and apply correlation factor
    - Note: for filtered 222nm sources the correlation factor should be 1.00! (with calibrated, "good" radiometer, and calibrated monochromator)- but it is unlikely

Summary

USHIO

- Measurements of Far UVC lamps can be challenging and need attention to details
  - Filtered vs. unfiltered lamps
  - Radiometers: spectral sensitivity, cosine correction, calibration at 222nm
  - Spectrometers: bandwidth, spectral and spectral irradiance calibration, cosine correction, noise
- Accurate measurements are needed for hazard assessment (ACGIH/ IEC62471) as part of Safety Standard certification (e.g. UL8802)
- Users need more, practical guidance – NOW
  - Standards take a long time to develop and sometimes “miss” the little, important details
  - Published papers are needed (but where to publish?)