Challenges when measuring Far UV-C Correctly and meaningfully

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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 drivers
- 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 <20cm length

- 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!

![Various KrCl lamps](chart1.png)
![Various KrCl lamps](chart2.png)
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

Spectral sensitivity various UVC meters

Assumption:
Radiometer calibrated at 222nm

<table>
<thead>
<tr>
<th>Meter</th>
<th>Filtered lamp</th>
<th>Unfiltered lamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>98</td>
</tr>
<tr>
<td>B</td>
<td>82</td>
<td>64</td>
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<tr>
<td>C</td>
<td>100</td>
<td>100</td>
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<td>D</td>
<td>100</td>
<td>101</td>
</tr>
<tr>
<td>E</td>
<td>98</td>
<td>109</td>
</tr>
</tbody>
</table>
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

Exposure time (s) | Dose 222 nm (mJ cm⁻²)
--- | ---
5 | 1.5
10 | 3
20 | 6
40 | 12
60 | 18
120 | 36
180 | 54

3 mJ/cm² Check
6 mJ/cm² Check
Why we need accurate spectral measurements - HAZARD

- 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

<table>
<thead>
<tr>
<th>wavelength shift nm</th>
<th>NIC skin unfiltered</th>
<th>NIC skin filtered</th>
<th>ACGIH unfiltered</th>
<th>ACGIH filtered</th>
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</thead>
<tbody>
<tr>
<td>-2</td>
<td>91%</td>
<td>78%</td>
<td>92%</td>
<td>91%</td>
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<tr>
<td>-0.6</td>
<td>97%</td>
<td>93%</td>
<td>97%</td>
<td>97%</td>
</tr>
<tr>
<td>-0.4</td>
<td>98%</td>
<td>95%</td>
<td>98%</td>
<td>98%</td>
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<tr>
<td>-0.2</td>
<td>99%</td>
<td>98%</td>
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<tr>
<td>0</td>
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<td>108%</td>
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<td>103%</td>
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<tr>
<td>2</td>
<td>111%</td>
<td>128%</td>
<td>109%</td>
<td>109%</td>
</tr>
</tbody>
</table>
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)

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

- IEC62471 - measure light source at 200mm distance!
  - 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
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?)