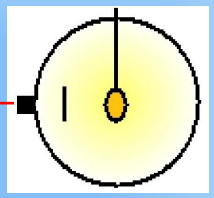
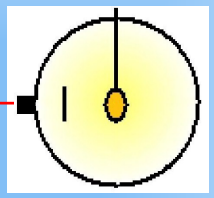
Rolf Bergman Consulting



Analysis of KrCl Excimer lamps for safe **whole room** disinfection

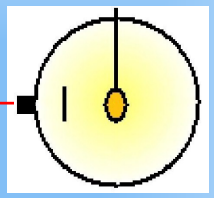
Rolf S Bergman

Rolf Bergman Consulting



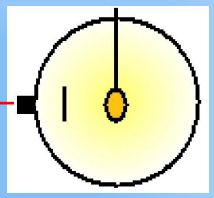
Outline

- Krypton-chloride excimer lamps (KrCl*) emit strongly at about in the lower wavelength end of the UV-C spectrum (~222 nm)
- Skin penetration of radiation at this wavelength is small enough that it is absorbed in the outer (dead) layers of the skin
  - ACGIH TLVs for UV-C are in the process of revision, particularly below 250 nm.
- 222-nm radiation has been found to be very efficient in inactivating viruses.
- KrCl* lamps appear to be a viable method for air and surface disinfaction in the presence of humans



Excimer Lamps

- An Excimer lamp is a quasimonochromatic photon emission source that can, over a wide range of ultraviolet wavelengths (100 to 400 nm), emit a photon by spontaneous emission of short-lived dimer molecules.
- The spontaneous emission was first shown to exist in rare gas discharges, particularly xenon. It was found that the metastable excited state of xenon could form a diatomic molecule with a ground state xenon atom that would dissociate by emitting a photon at 172 nm (vacuum UV range)
- Since then, combinations of the rare gases (not He) and all the alkali elements have been shown to emit (from 108 nm for NeF* to 351 nm for XeF*)

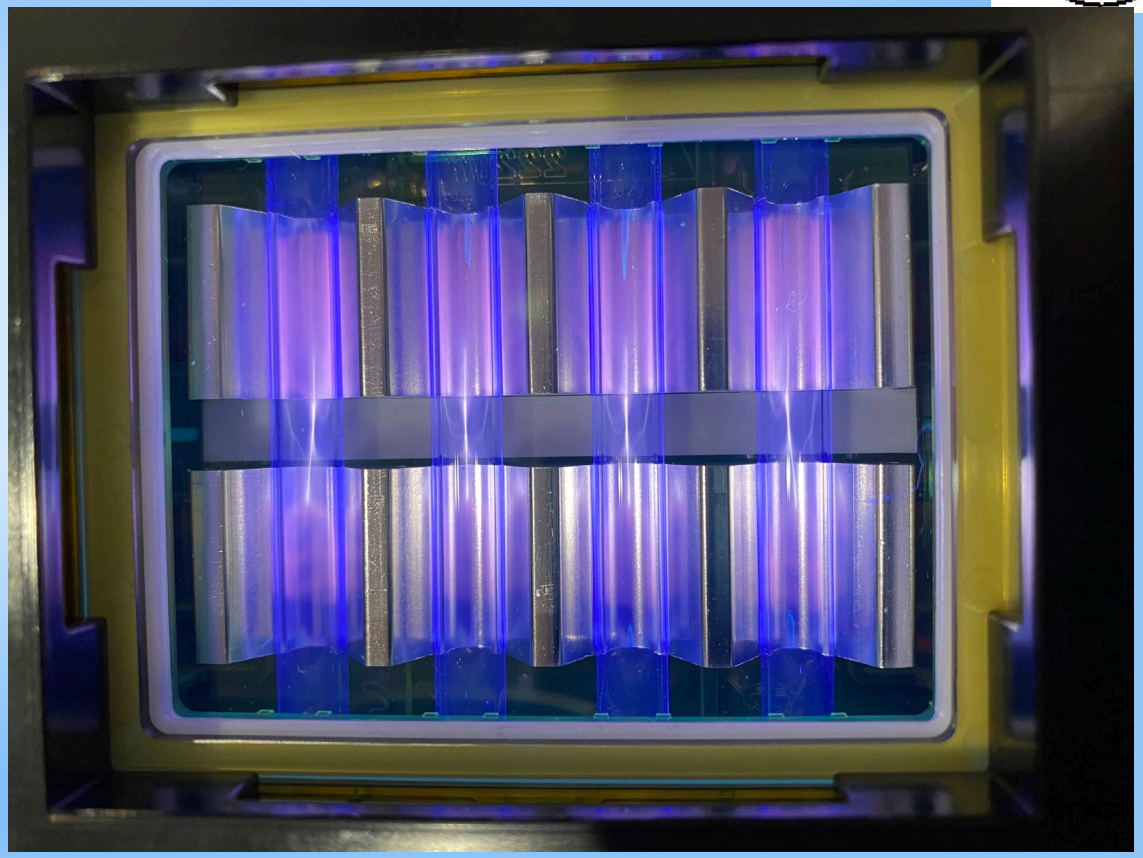


Kr-Cl Excimer lamps

- KrCl* emit in a narrow wavelength band centered on 222 nm
  - On the order of 1 % of the input power is emitted at in this band
- The photon efficiency of inactivating viruses appears to be about the same as that of higher wavelength UV-C sources at 260-270 nm
  - ✓ D-90 is about 3 J/m^2
- For low-power KrCl* lamps (<50 watts) ozone generation is small and can normally be handled by ventilation systems in place.

Excimer Lamp

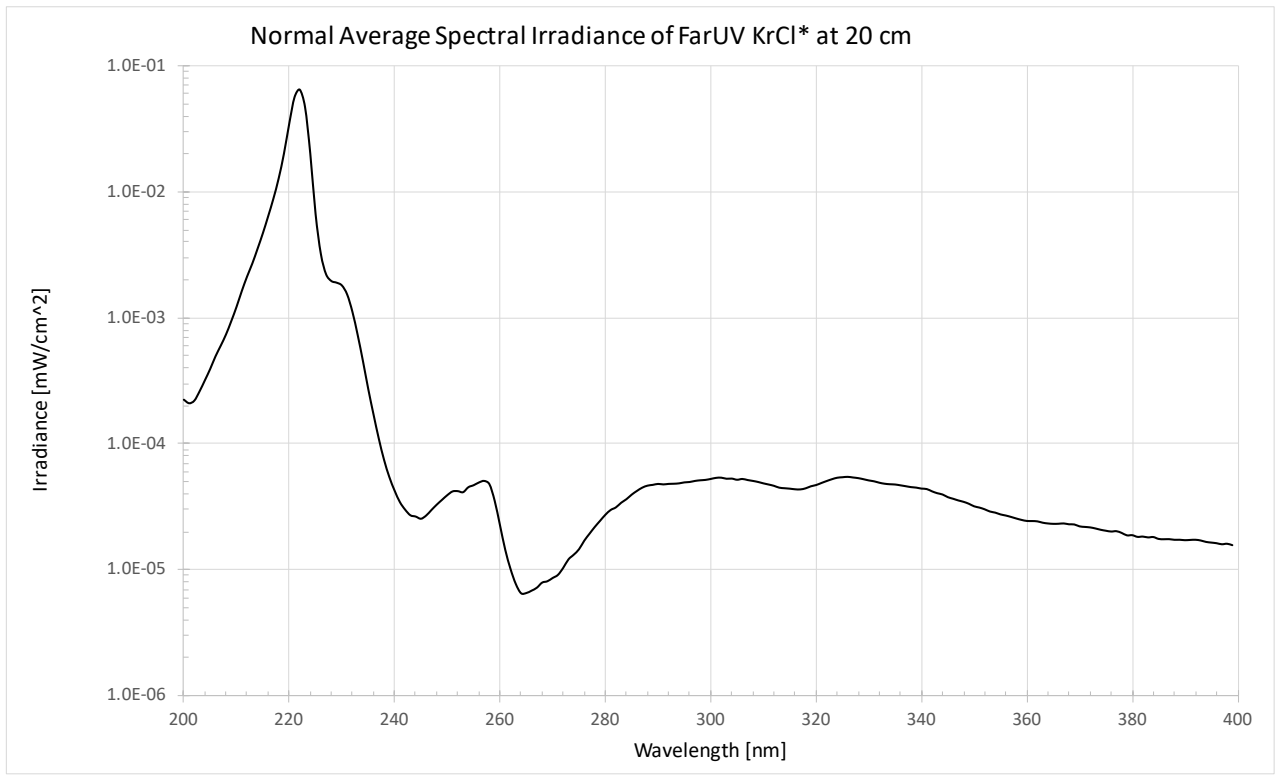
FarUV Technologies, Inc.



UV Spectra of FarUV filtered KrCl* Lamp

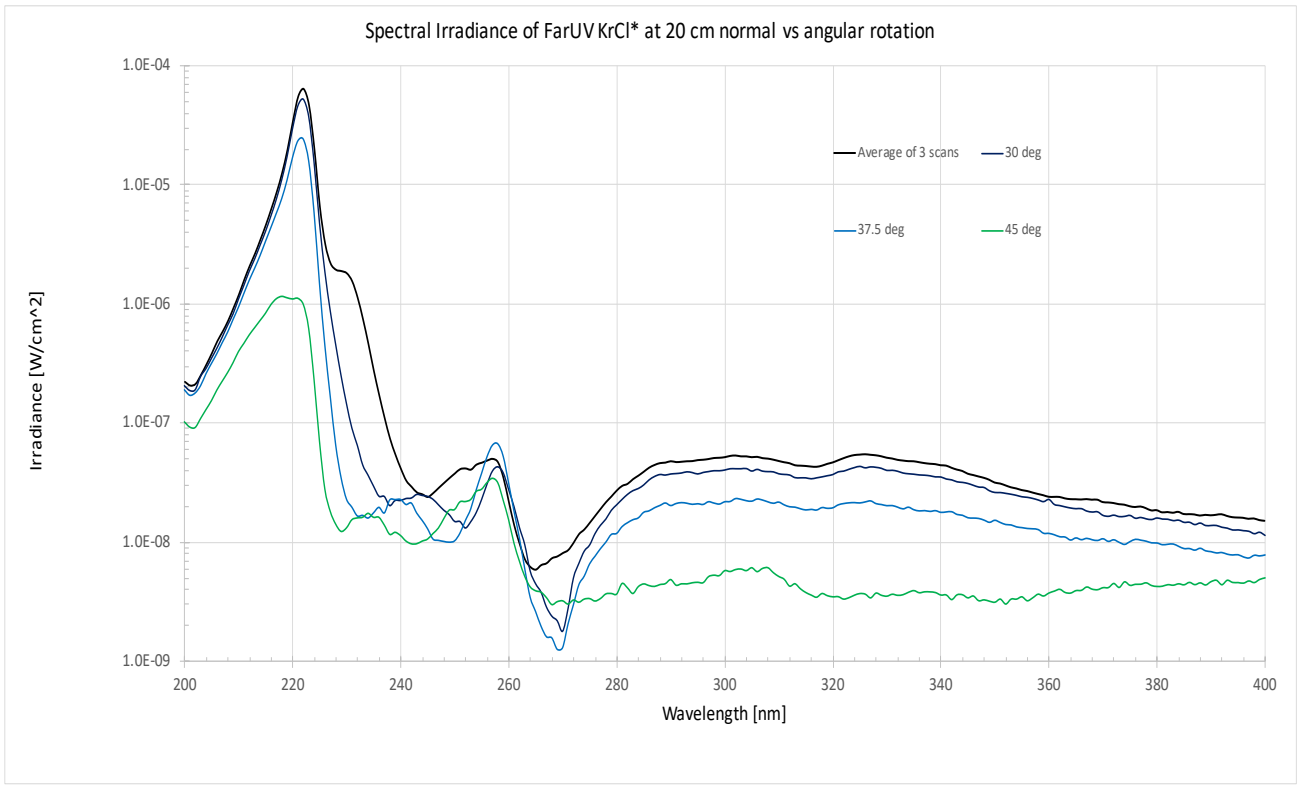
- measured at 20 cm
- Input power = 16.5 w
- 222 nm Irradiance = 0.28 mW/cm^2
- UV Irradiance = 0.32 mW/cm^2

Measurements made at GE Current NELA Park



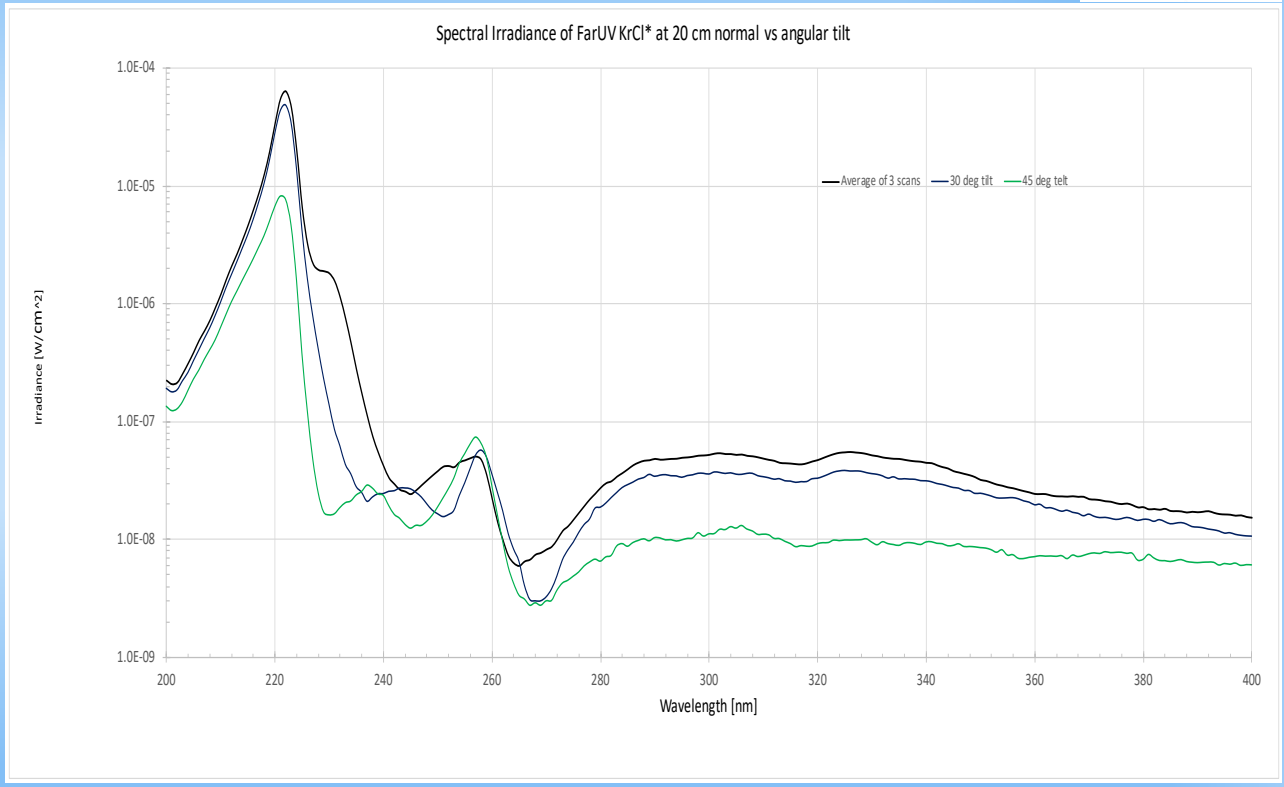
UV Spectra of FarUV filtered KrCl* Lamp vs. angle

Measurements made at GE Current NELA Park



UV Spectra of FarUV filtered KrCl* Lamp vs. tilt angle

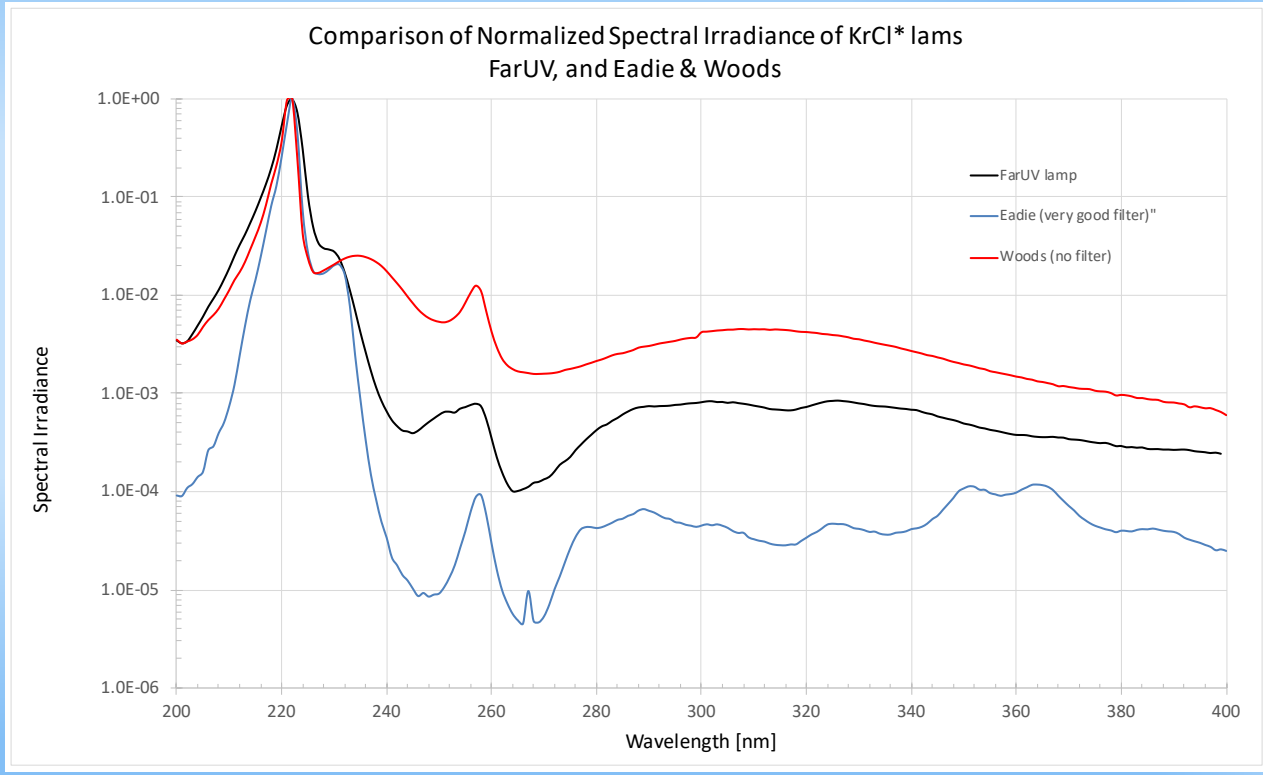
Measurements made at GE Current NELA Park



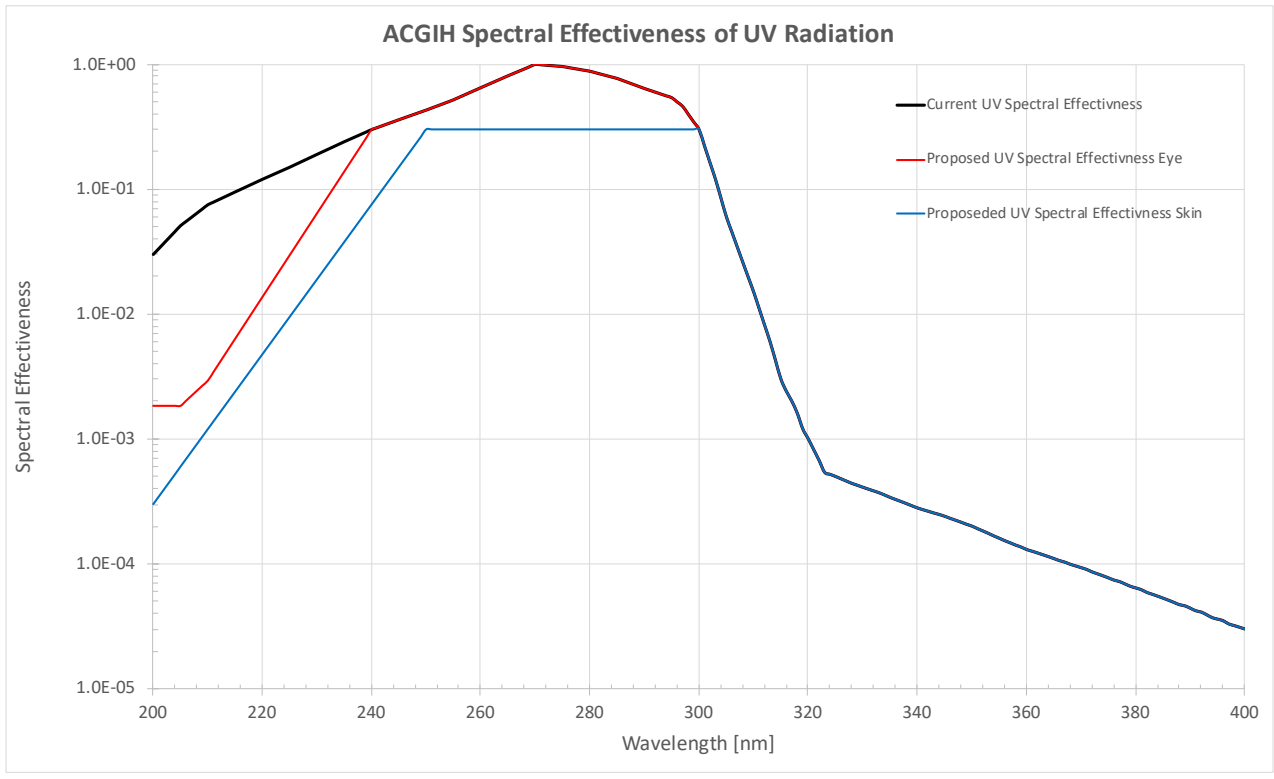
UV Spectra of three KrCl* Lamps

1) FarUV lamp
2) lamp with very good filter
3)lamp with no filter

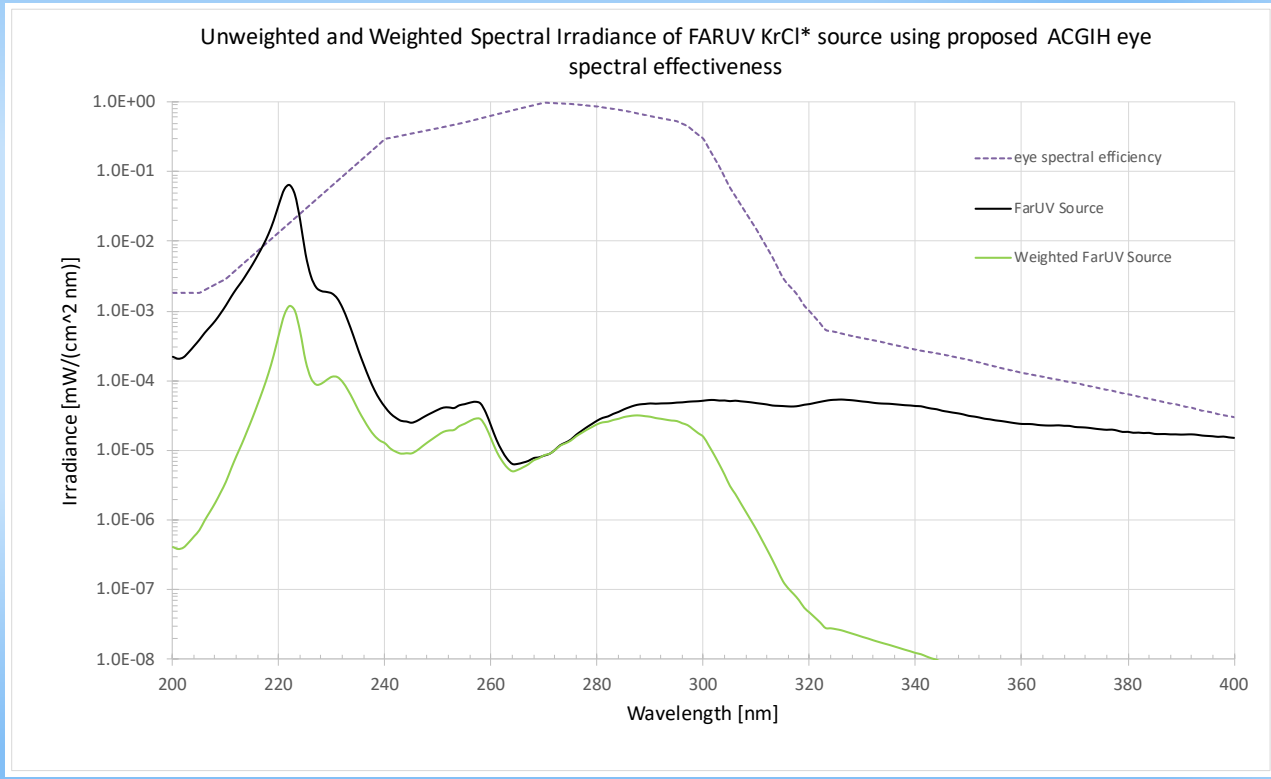
Curtesy of Ewan Eadie & Kenny Wood

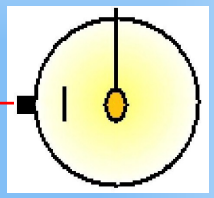


ACGIH UV Spectral Effectiveness Function vs. Wavelength or UV Actinic Weighting Function



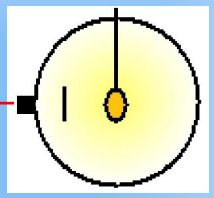
Normal and effective (proposed ACGIH eye spectral effectiveness) UV Spectral Irradiance of FarUV KrCl* source vs. Wavelength





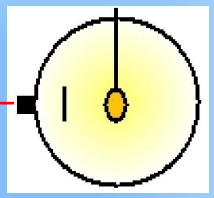
Limiting Dose Considerations for the eye

- At 222 nm the ACGIH proposed eye TLV dose is 161 mJ/cm^2
  - ✓ The proposed ACGIH TLV dose for the skin is 478 mJ/cm^2 (3 times larger)
  - ✓ The current ACGIH TLV dose (for eye and skin) is 23 mJ/cm^2 (7 times smaller)
- At 100 % duty cycle the measured 222 nm band irradiance (sum from 215 -225 nm) of the FarUV KrCl* lamp at 20 cm is 0.28 mW/cm^2
  - ✓ The measured irradiance of the lamp at 1 m (100 cm) is 0.016 mW/cm^2 (16 µW/cm^2)
- The cumulative irradiance at 1 m after one hour of exposure is 56 mJ/cm^2
  - The 1-hr dose exceeds the current TLV but neither the proposed eye or skin TLV
- The cumulative irradiance at 1 m after eight hours of exposure is 448 mJ/cm^2 (3 times greater than the TLV)
  - ✓ The TLV dose limit of 161 mJ/cm^2 would be reached at 8 hrs. at 1.7 m, or at 36 % duty cycle
  - ✓ The TLV dose limit for the ACGIH proposed skin TLV would not be exceeded by the lamp in 8 hrs.



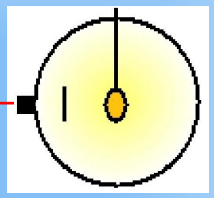
Application to whole room disinfection

- Assume FarUV KrCl* lamp is mounted on ceiling at 2.7 m (9 ft) from floor
- A tall person standing under the lamp would have eyes less than 1.8 m (6ft) from floor or about 0.9 m below source.
  - The longest time one would be expected to stand there in a day is about 1 hr.
  - In 1 hour, the dose received would be about 70 mJ/cm^2 or less than half of the proposed eye TLV value
  - The 1-hr dose is much greater than ACGIH current TLV value (23 mJ/cm^2)
    - For the current TLV values, the 1-hr dose would be reached at a 33 % duty cycle



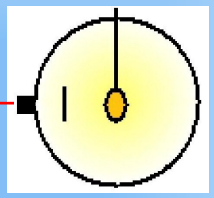
Application to whole room disinfection

- A person sitting under the lamp would have eyes about 1.3 m (4.5 ft) above floor, or about 1.4 m below source
  - ✓Assume the person sits in that position for 8 hrs
  - ✓The irradiance dose received would be 265 mJ/cm^2 significantly above the TLV of 161 mJ/cm^2
  - ✓At a lamp duty cycle of 60% the dose would be at the TLV limit
- However, a person would not be looking up much of the time
  - ✓An older time-motion study indicates that a person working looks up at the ceiling less than 20% of the time.
  - ✓Applying that puts the ACGIH proposed skin TLV as the limit, i.e., <478 mJ/cm^2



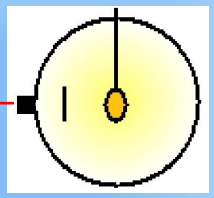
Disinfection capability of measured source

- Recent measurements reported by Eadie, et. al, (pre-publication) of inactivation of a continual source of airborne pathogens (S aureus) in a well-mixed room-sized chamber showed
  - ✓ With one lamp with a peak irradiance of 14.4 µW/cm^2 a 93 % reduction of pathogen concentration
  - ✓ With five lamps with a peak irradiance of 14.4 µW/cm^2 a 99.9 % reduction of pathogen concentration
  - ✓ KrCl* Lamp UV angular distribution in above reported measurements was much wider than current lamp through use of a diffusing filter
- Inactivation of S aureus has significantly higher inactivation D90 value than either the Covid-19 or influenza virus.



Conclusions

- One “FarUV” lamp, as measured, at 100 % duty cycle, is more than adequate to reduce continuously generated airborne viruses by over 90% in a 4.2 x 3.4 x 2.2 m room
- For application using current ACGIH UV TLV values the peak lamp irradiance is too high, but duty cycle, based on 10 sec on/off, can be reduced to lower peak irradiance to below TLV
  - ✓Peak lamp irradiance can also be reduced significantly through use of a diffusing filter
  - ✓Interaction of diffusing filter with UV-C/B attenuating filter may be an issue
- For application using proposed eye ACGIH UV TLV values the lamp can be safely applied as it designed if mounted at 2.7 m (9 ft) above the floor



Acknowledgements

- PJ Piper, Far UV Technologies, for loaning me the lamp to measure
- Mihaly Kotrebai, GE Current, for allowing time for spectral and electrical test of lamp