Multiwavelength Laser Safety Calculations

Case Studies in Supercontinuum Lasers

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Outline

1. **The Basics**
   Calculation of maximum permissible exposure and optical density figures

2. **Multi-Wavelength Calculations**
   Calculations involving multiple discrete wavelengths and wavelength bands

3. **Supercontinuum Lasers**
   Case-studies in extremely broad-band “white light” lasers

4. **Advanced Control Measures**
   Methods for operating high-power supercontinuum lasers safely

Motivation

- Laser safety calculations typically treat laser light as a single wavelength or as several discrete wavelengths
- But emerging nonlinear technologies result in lasers that emit in broad wavelength bands, sometimes spanning the entire visible spectrum

Maximum Permissible Exposure (MPE)

- Calculated using Tables 7a-7d in ANSI Z136.1
- Depends on the wavelength and exposure time
- Units: irradiance (W/cm^2) or radiant exposure (J/cm^2)
- Goal: limit accessible irradiance (E) or radiant exposure (H) to less than the MPE, or:

$$\frac{E \text{ or } H}{MPE} < 1$$

Optical Density (OD)

- Characterizes the attenuation provided by filter materials
- Order of magnitude (OD 3 attenuates by 10^3=1,000)
- Minimum required OD for a given wavelength will be:

$$OD = \log\left(\frac{E_{in}}{MPE}\right)$$

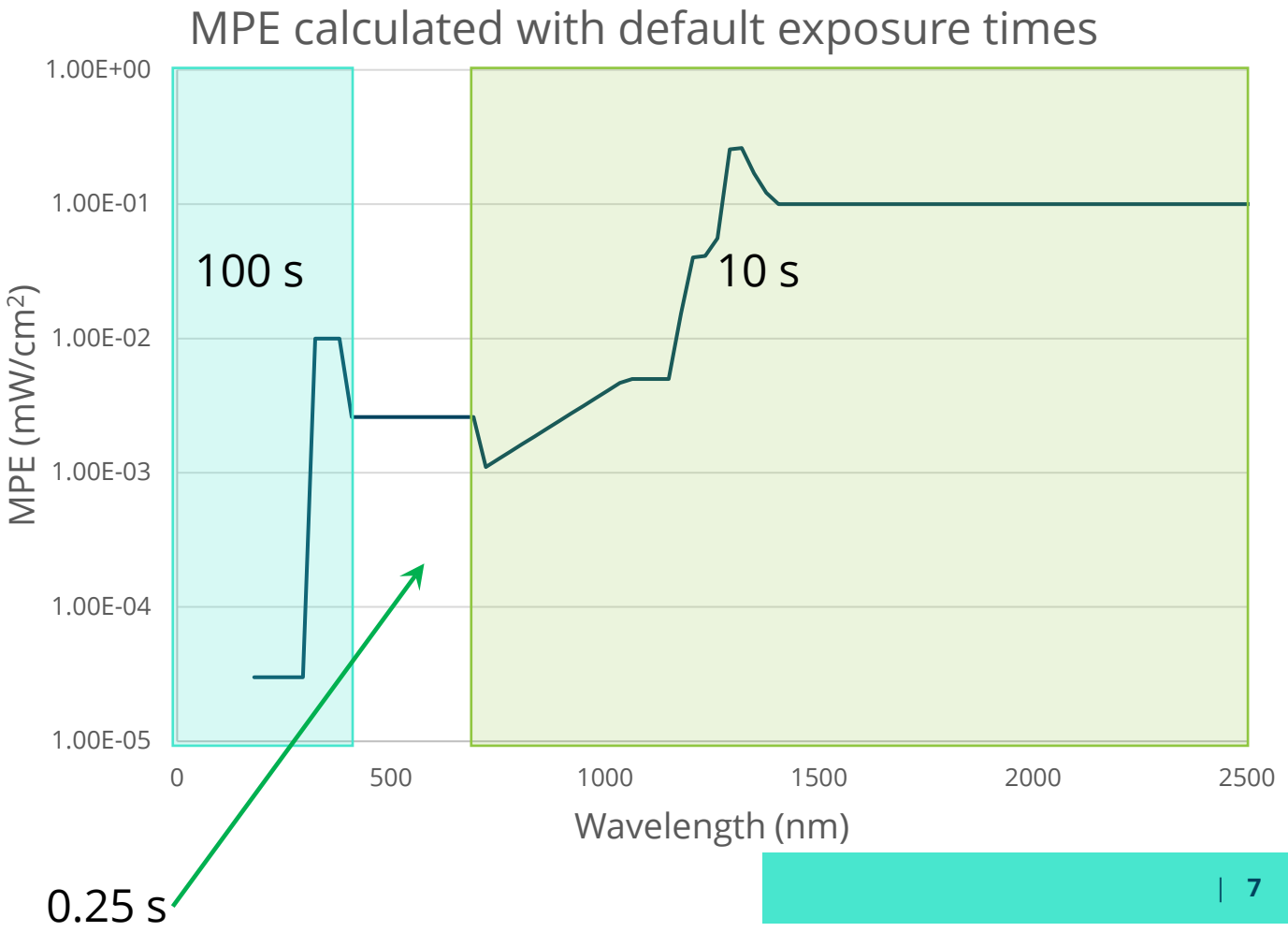
Multiple Wavelength Considerations

- When multiple wavelengths are present in a single laser beam, total accessible radiation as a fraction of MPE must not exceed 1, that is:

$$\sum_{\lambda} \frac{E_\lambda \text{ or } H_\lambda}{MPE_\lambda} < 1$$

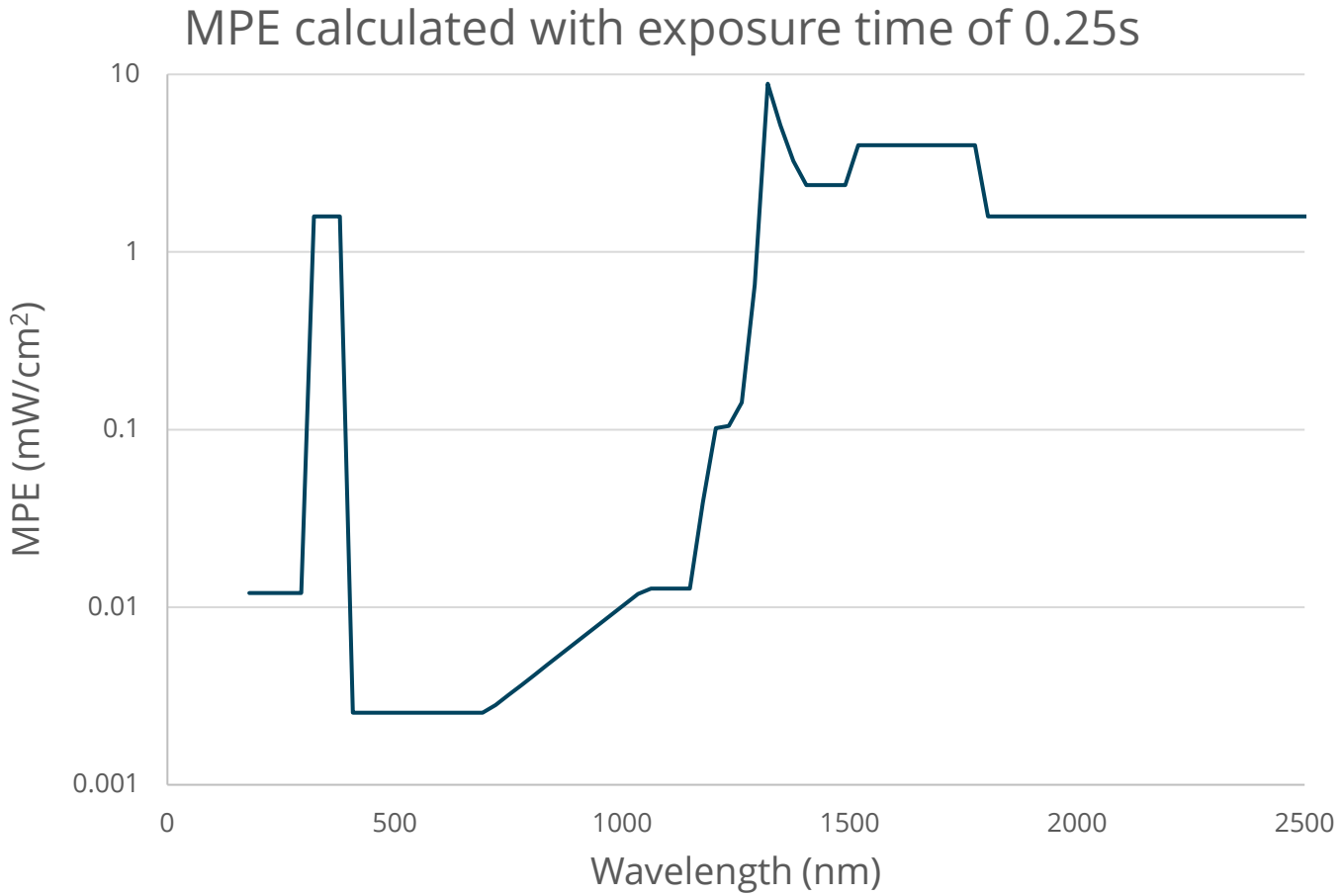
Default exposure time varies by wavelength

- 100s in UV
- 10s in IR
- Shortest is the visible range at 0.25s, limited by the natural aversion response of the eye.



Visible component dominates MPE

- If a laser has a visible component, we can use 0.25s as the exposure time across all wavelengths.
- This increases MPE in IR and UV ranges by several orders of magnitude.



Ex: Nd:YAG with higher harmonics

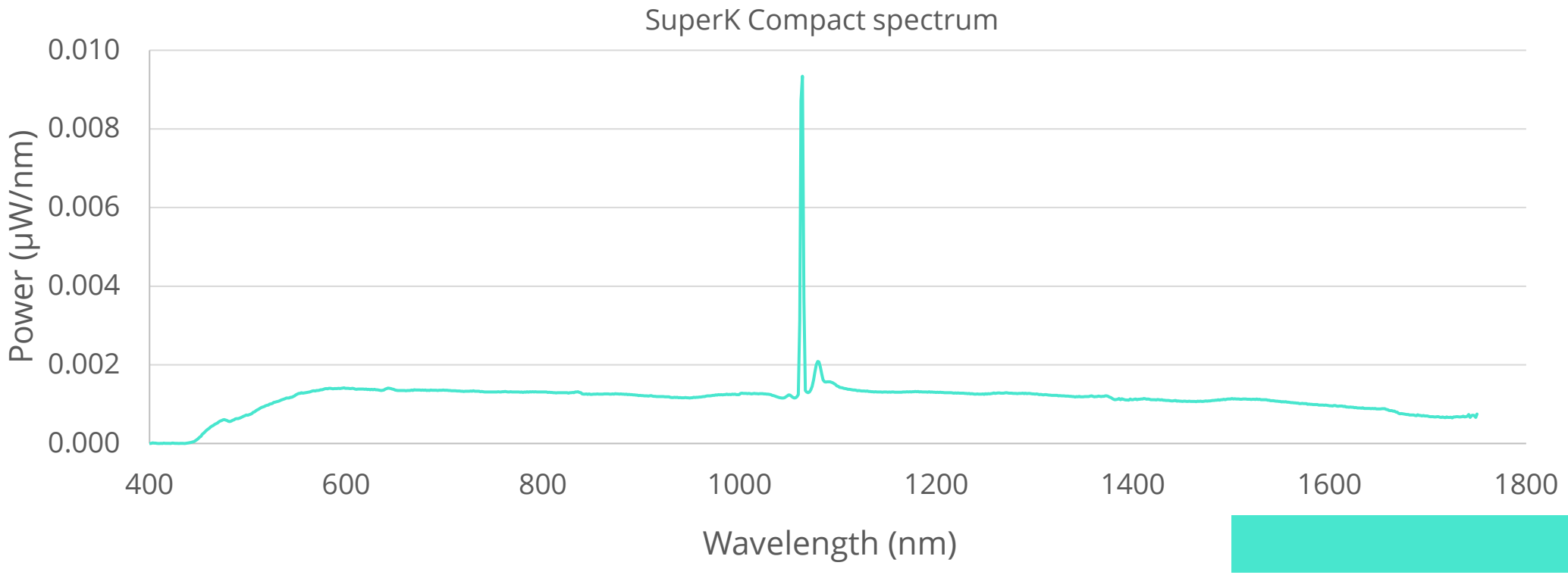
- First harmonic
  - 10W Nd:YAG emitting exclusively at 1064nm
  - Minimum OD of 3.71
  - MPE calculated using 10s exposure
- Second Harmonic
  - 10W Nd:YAG with 40% conversion to 532nm
  - Both MPEs calculated using 0.25s exposure time.
  - Minimum OD of 3.09 at 1064nm and 3.61 at 532nm
  - $\sum_{\lambda} \frac{E_{\lambda}}{MPE_{\lambda}} \approx 2$ if precisely the minimum OD is provided
  - Rounding up is sufficient, but more wavelengths add more problems.

Ex: Nd:YAG with higher harmonics

- Third harmonic
  - 10W Nd:YAG with 40% conversion to 532nm and 10% conversion to 355nm
  - All three MPEs calculated with 0.25s exposure time
  - Irradiance is calculated differently: Both 1064nm and 532nm use the retina (7mm) as the limiting aperture, while 355nm uses the cornea (1.0mm)
  - Minimum OD is 3.01 at 1064nm, 3.61 at 532nm and 1.91 at 355nm
  - Again, if only minimum is provided, the relative sum is 3

Supercontinuum or “White Light” Lasers

- Use a nonlinear process to broaden a pulse of laser light at 1064nm to an extremely broad band: 400-2,400nm



Unique Safety Concerns

- Finding eyewear for a broad spectrum is challenging
- Typical control measures include:
  - Aligning on 1064nm beam without spectral broadening
  - Operating in an opaque enclosure
  - Filtering unnecessary wavelengths
- We present several alternatives when free-space operation at all wavelengths is required:
  - Adjusting power to permit Class 3R operation
  - Advanced eyewear calculations
  - Augmented reality headsets

Option 1: Limit power to Class 3R

- Constraints:
  - The power density at each wavelength is less than the AEL at that wavelength
  - The sum of the ratios of spectral power density to spectral AEL must be less than one
- Calculation depends on specific laser parameters

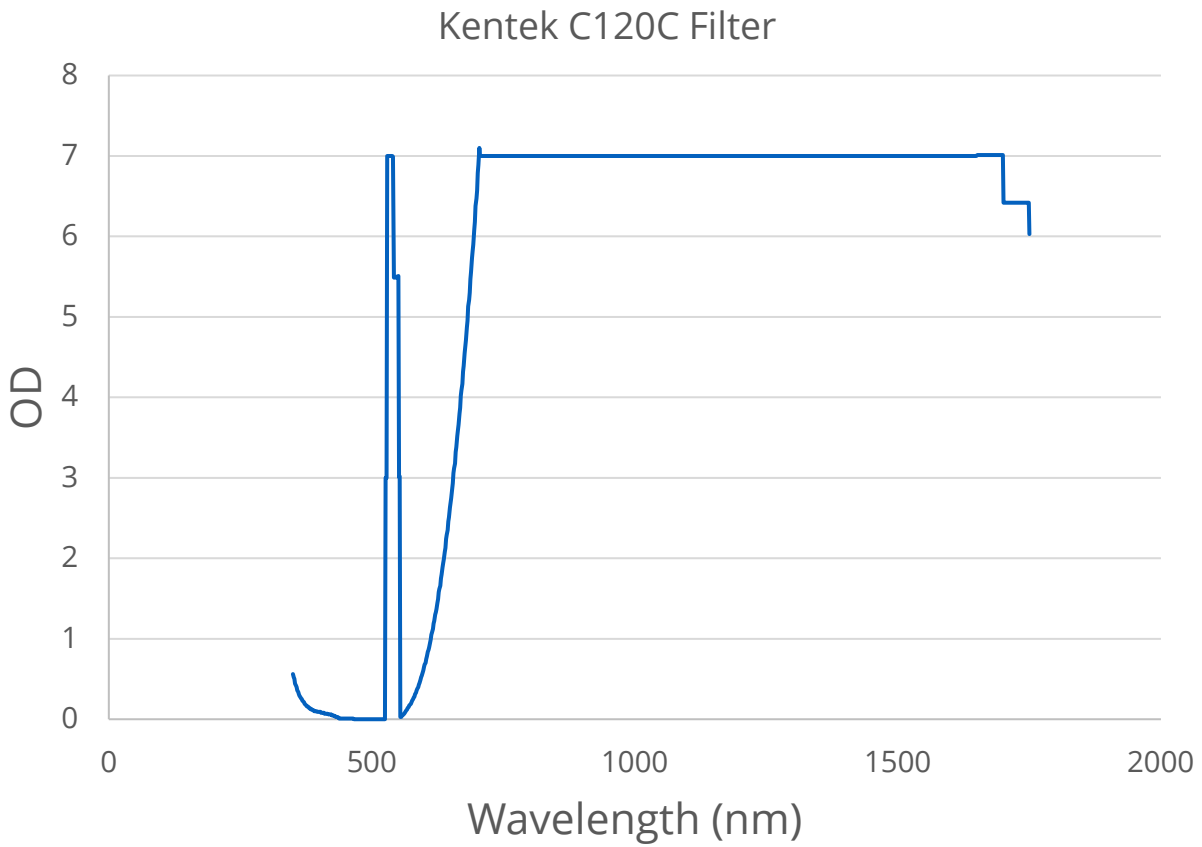
Option 2: Specialty Eyewear Evaluation

KBS-C120C

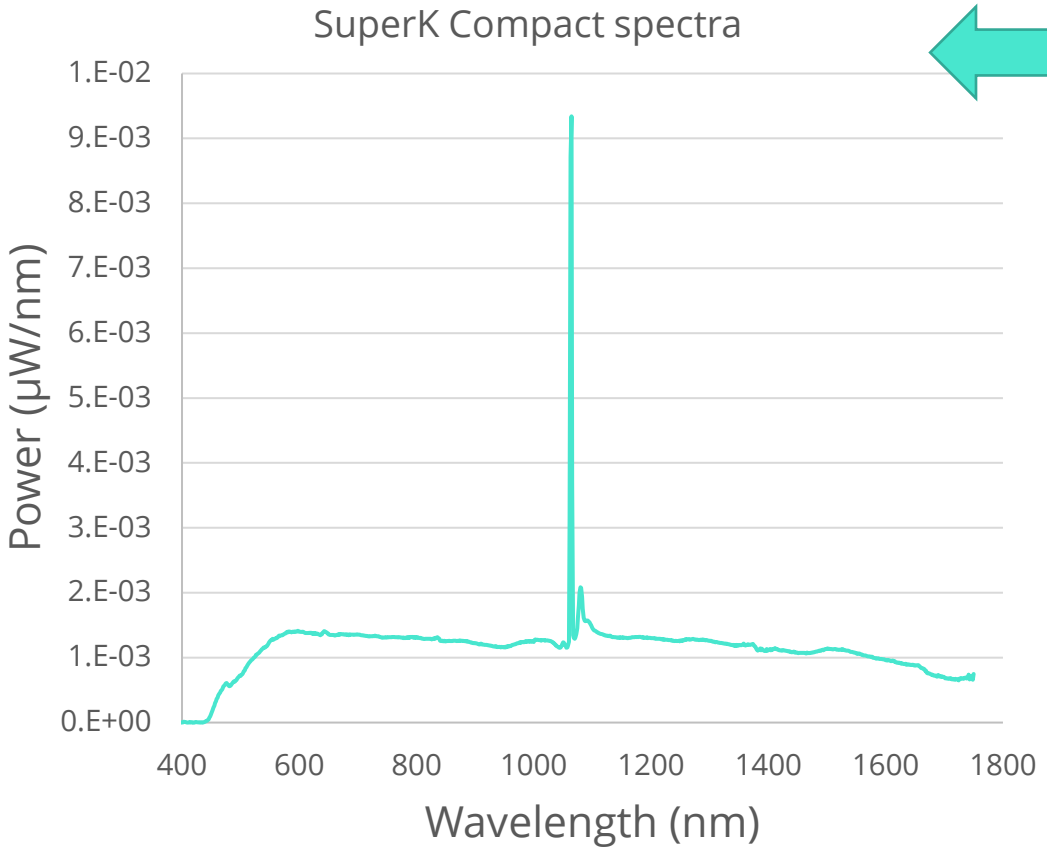
ANSI Protection Markings

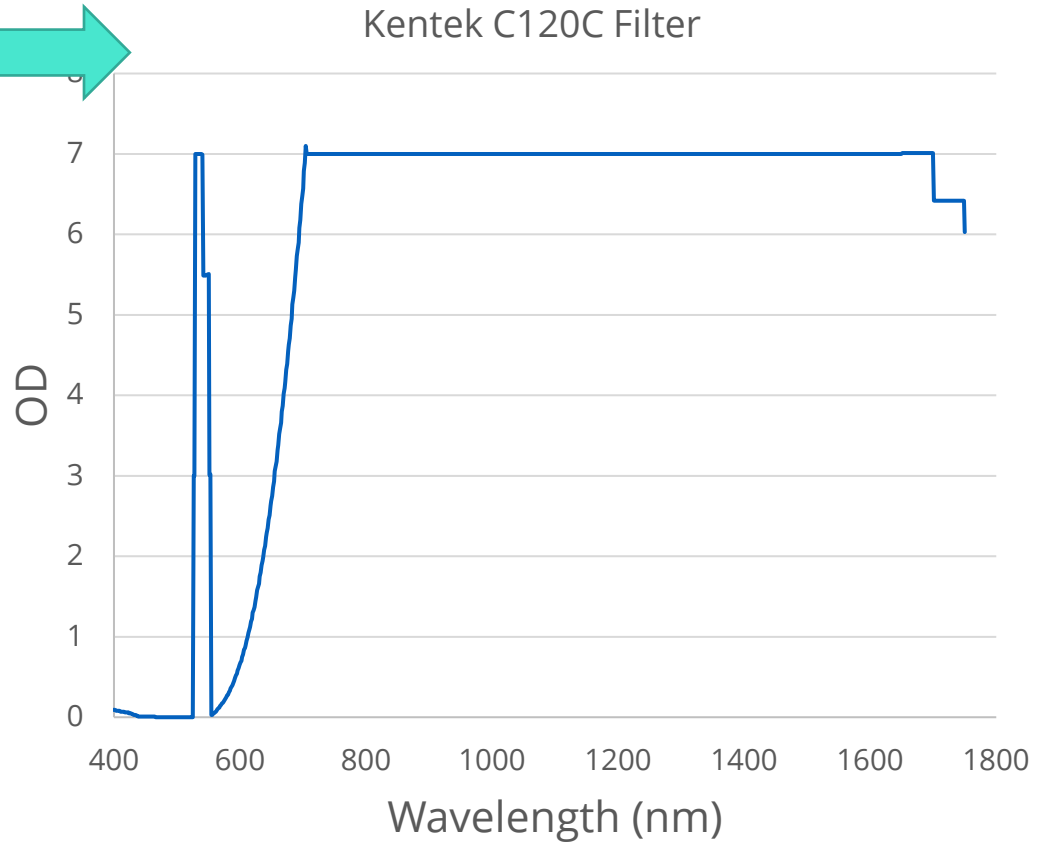
OD 7+ @ 532nm
OD 1-2 @ 620-655nm
OD 5+ @ 690-710nm
OD 7+ @ 710-1200nm
OD 5+ @ 1200-1700nm
OD 5+ @ 2100-2200nm
OD 5+ @ 2900-3200nm

Catalog: [KBS-C120C Laser Safety Glasses | Diode | CO2 | KTP | Holmium | IR | Kentek Laser (kenteklaserstore.com)]

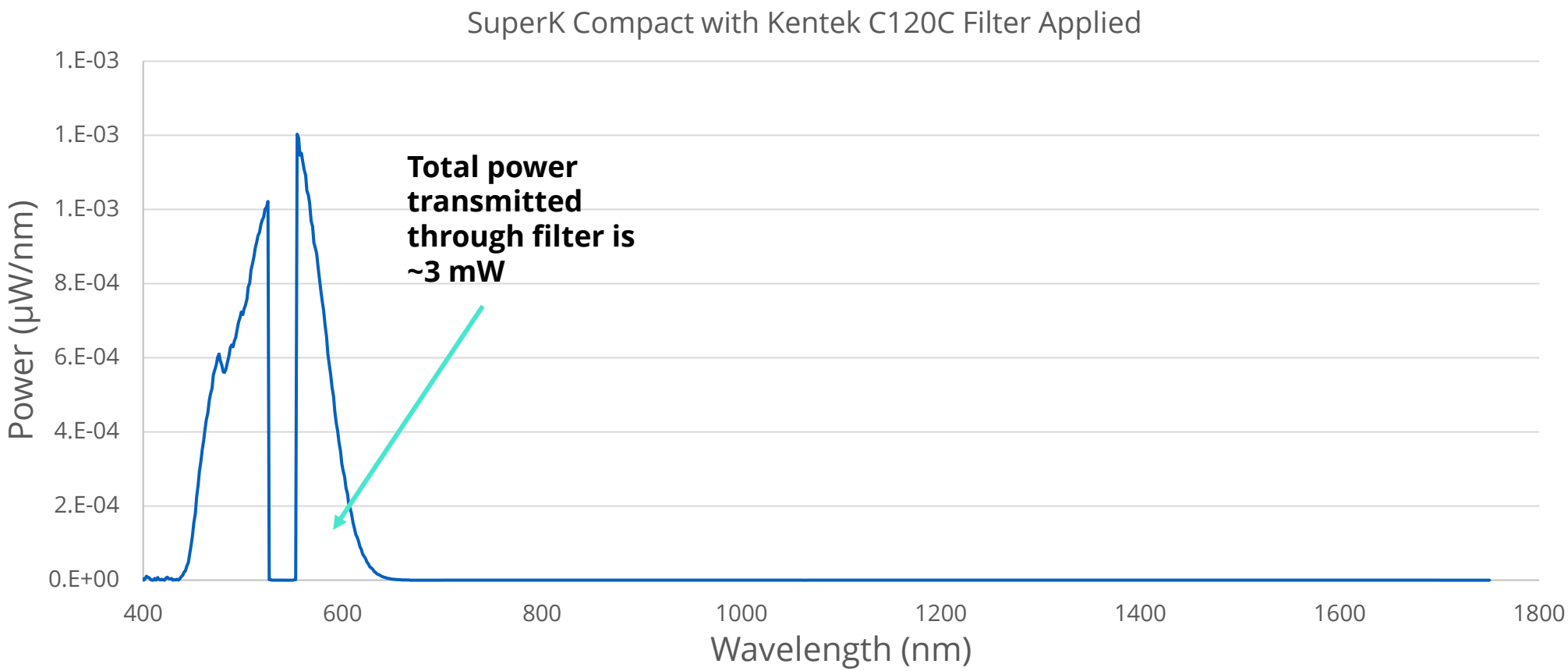


Specialty Eyewear Evaluation (2/3)





Specialty Eyewear Evaluation (3/3)



Option 3: Augmented Reality Tools

- AR/VR Headset allows user to see while eyes remain completely covered
- Remote manipulation of lab equipment
- Virtual screens
- Screenshot capture possible
- Belt-mounted EPO in case of AR/VR system failure

Conclusion

- Multi-wavelength lasers, especially supercontinuum or white light lasers require more complex calculations of MPE and OD than monochromatic lasers
- Advanced calculations allow classification and enable evaluation of specific filter materials for a given laser system
- Creative solutions are possible!

More wavelengths
More problems

Any questions?