UVC Testing of Materials

팬더믹 시대에 대두되는 중요성

New Importance in the Pandemic Era

Q-Lab Corporation

이응제 팀장 / IJ INC.

녹음하기

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Topics

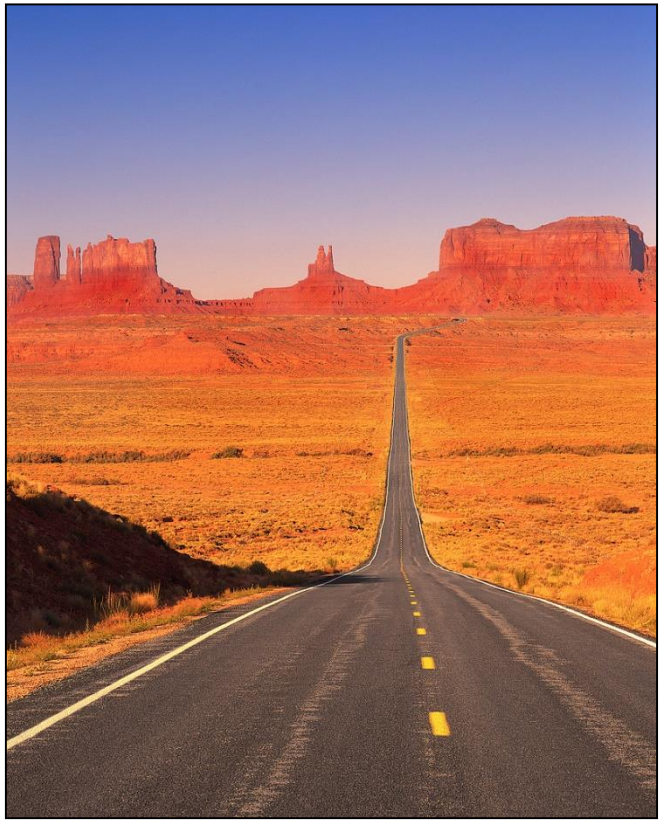
- UV 빛에 노출된 물질의 내구성
  Durability of materials exposed to UV light
- 자외선 광 살균
  Ultraviolet Germicidal Irradiance (UVGI)
- UVC 노출의 표준
  Standard UVC Exposures
- 팬더믹 시대의 UVC 노출에 대한 고찰
  Considerations for UVC exposures in the pandemic era
- QUV/uvc 폭로시험과 물질에 대한 연구
  QUV/uvc for exposure tests and material research

Disclaimer: *We aren't supporting use of our products for UVGI applications, just material testing.*

Material Durability to UV Exposure

- 태양빛과 광열화
  Sunlight & Photodegradation
- 인공 태양빛 시뮬레이션 & 내후성
  Artificial Sunlight Simulation & Weathering
- UVC 복사
  UVC Radiation

Irradiance



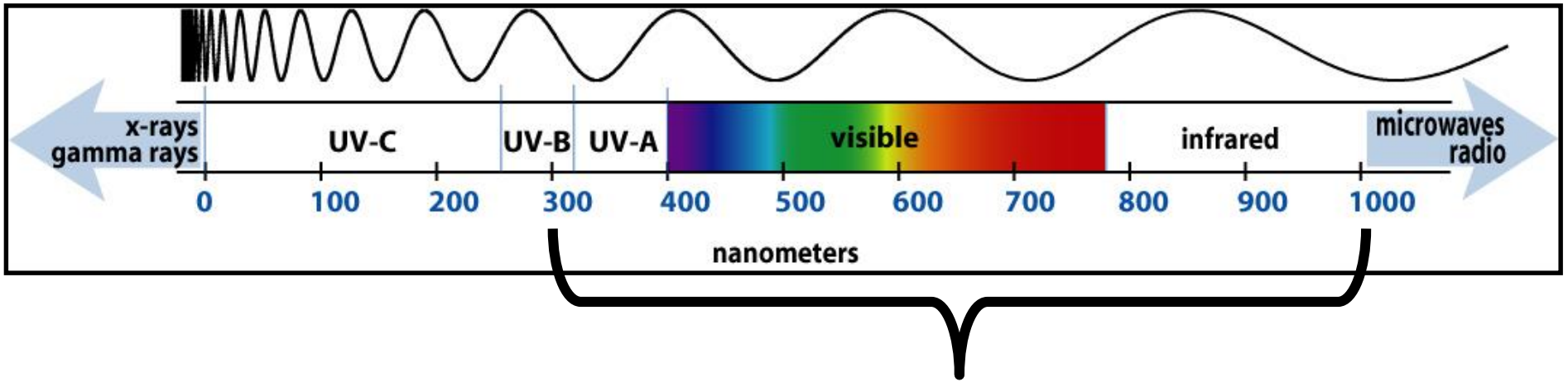
조도(Irradiance)[1]
단위 면적당 빛 에너지가 표면에 떨어지는 비율
[W/m^2] or [$J/s \cdot m^2$]
[mW/cm^2] or [$mJ/s \cdot cm^2$]

복사 노출(Radiant exposure)[1]
(또는 **복사용량(radiant dosage)**)
일정 기간 동안의 조도
[J/m^2] or [$W \cdot s/m^2$]
[mJ/cm^2] or [$mW \cdot s/cm^2$]

스펙트럼 조도(Spectral irradiance)[2] 단위 파장 당 표면 조도
[$W/m^2/nm$]
[$mW/cm^2/nm$]

[1]ASTM G113 –Terminology
[2]ISO 9288 – Physical quantities and Definitions

Electromagnetic Spectrum



Sunlight

UV	**295-400 nm**	**~7%**
Visible	400-800 nm	~55%
IR	800-3000 nm	~38%

UVC is the UV range below 280nm; sometimes the energy below 200 nm is called "vacuum UV"

Weathering vs Photodegradation

광열화, Photodegradation, *n*—광 화학적으로 물질의상태에 변화가 유발되는 것을 의미

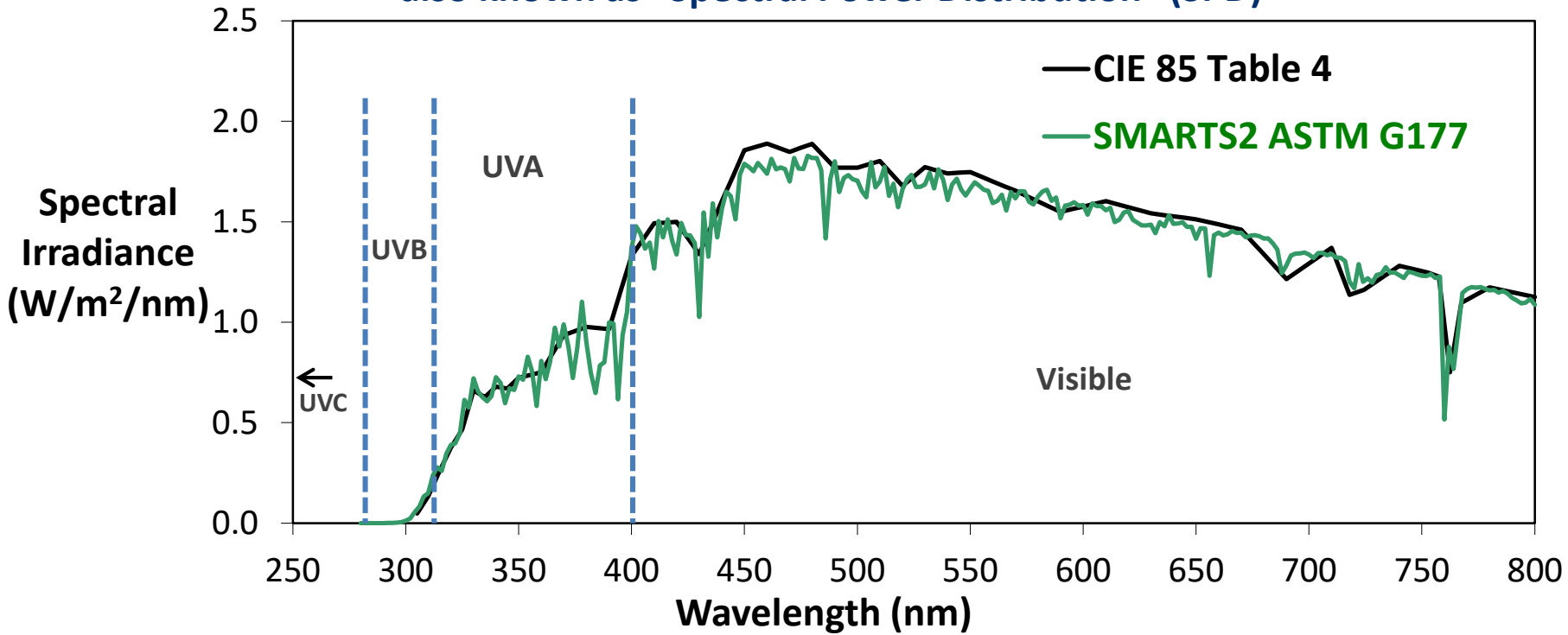
photochemically induced changes in the condition of a material (ASTM G113)

내후성, Weathering, *n*— 물질이 대기 환경에 노출되어 햇빛 및 열(온도 변화에 따른), 수분(주로 습기, 이슬, 강우 등) 인자의 복합적 영향으로 변화되는 것을 의미

Changes in material properties resulting from exposure to the radiant energy present in **sunlight** in combination with **heat** (including temperature cycling) and **water** in its various states, predominately as humidity, dew, and rain.

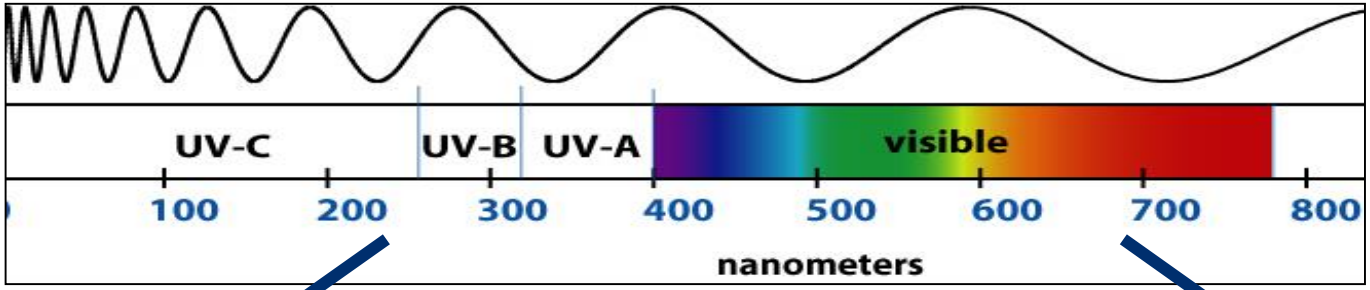
Spectral Irradiance

also known as “Spectral Power Distribution” (SPD)



SPD: The absolute or relative radiant power emitted by a source, or incident upon a receiver as a function of wavelength. (ASTM G113)

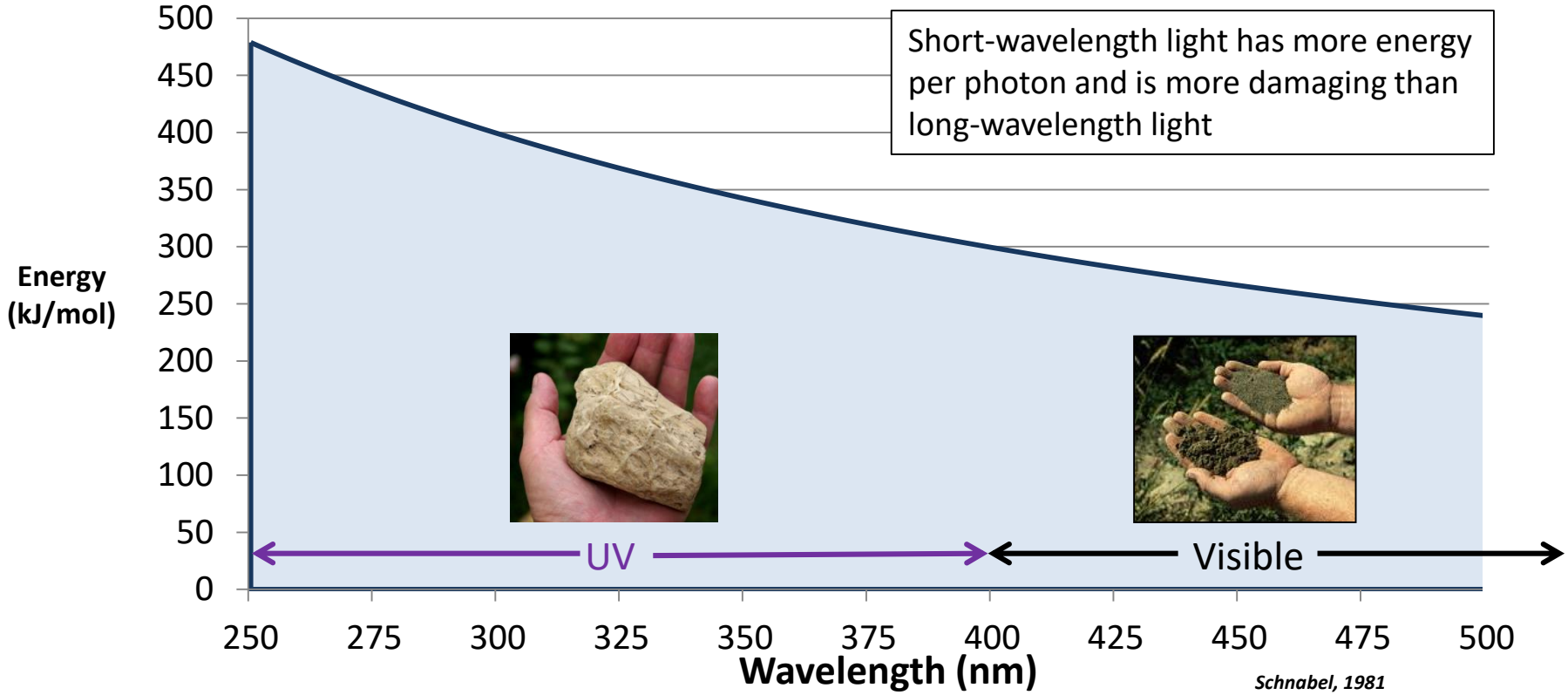
Electromagnetic Spectrum



광자 에너지는 파장과 반비례 한다

The energy of a photon is inversely proportional to its wavelength

Energy per Photon (Quantum)



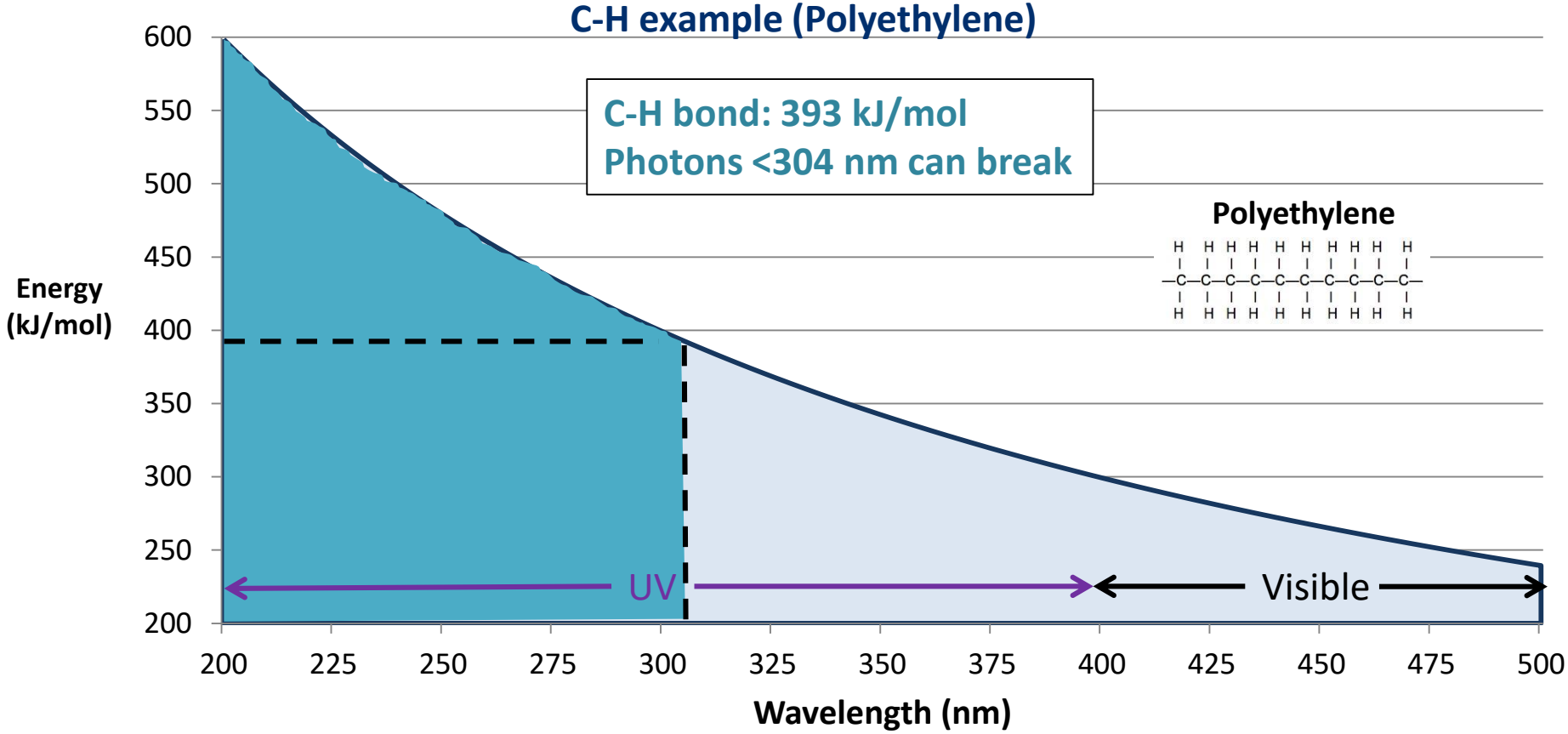
Chemical Bond Breaking and Photon Energy

Chemical Bond	Energy to break bond (kJ/mol)	Wavelength of photon with equivalent energy
C-N	330	363 nm
N-H	339	353 nm
C-C	348	344 nm
C-O	372	321 nm
C-H	393	304 nm
O-H	426	281 nm
Si-O	452	265 nm
C-F (CH_3F)	460	260 nm
C-F (CF_4)	544	220 nm

Bonds can only be broken by photons with a wavelength shorter than the threshold value shown

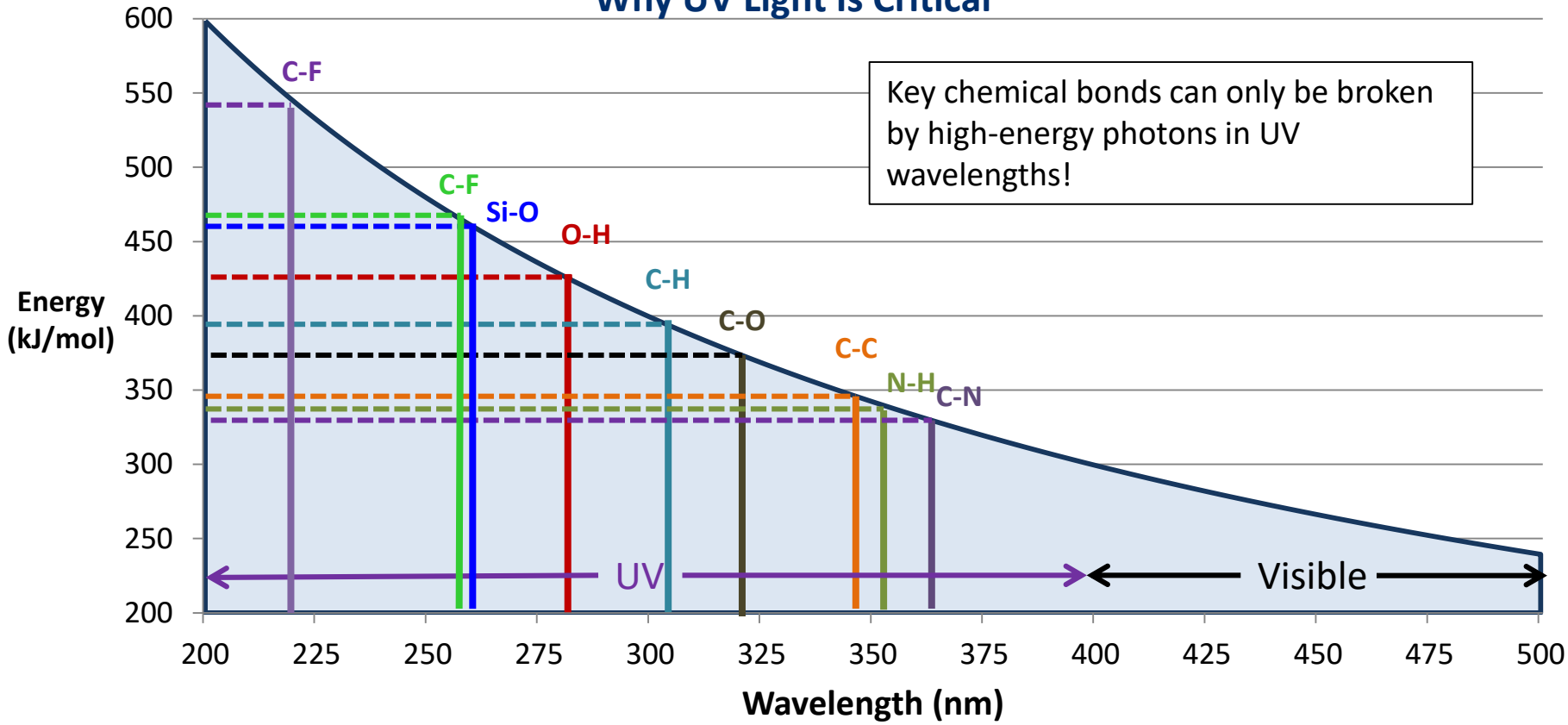
Schnabel, 1981

Chemical Bond Energy and Photon Wavelength



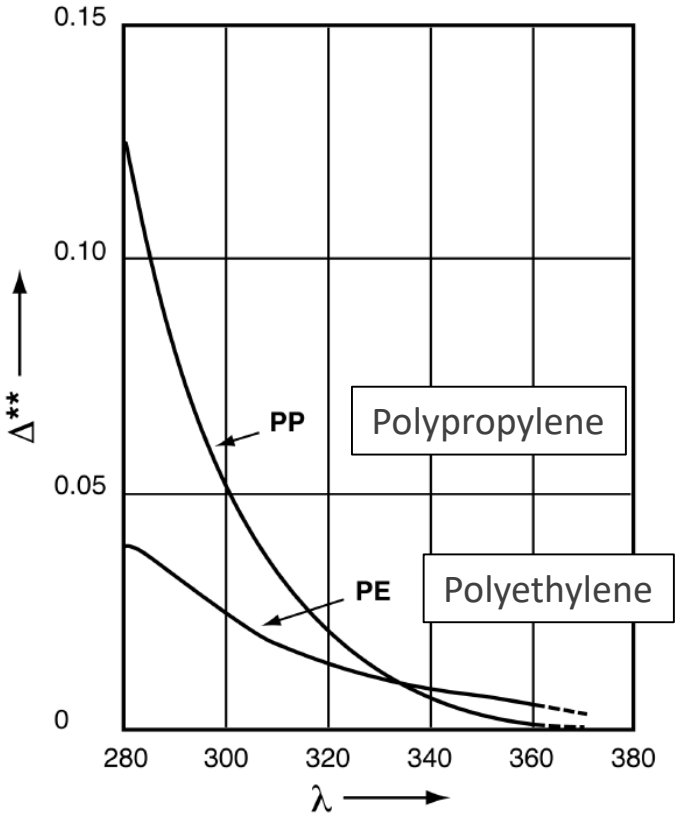
Chemical Bond Energy and Photon Wavelength

Why UV Light Is Critical



Spectral Sensitivity

Carbonyl Formation
(measure of degradation)

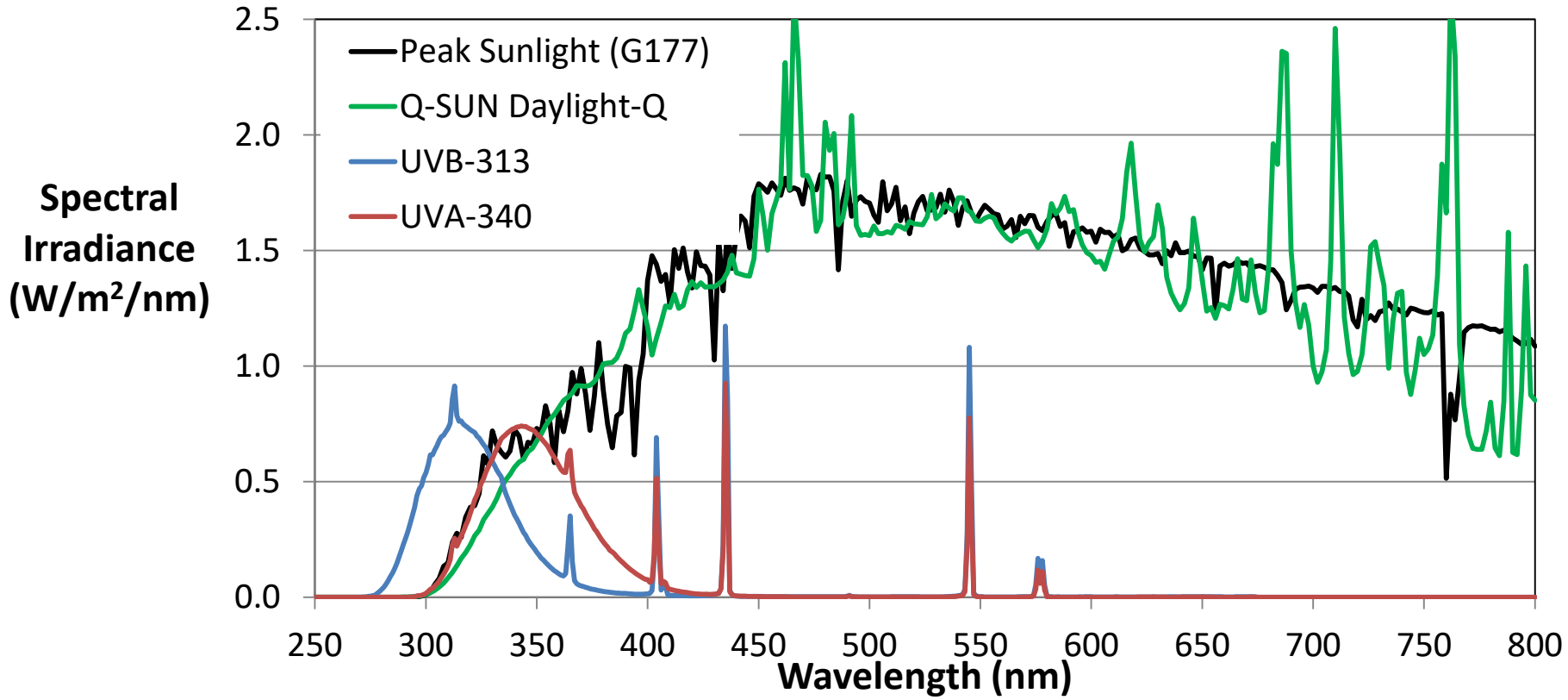


Trubiroha

Effects of Weathering

Effects of Photodegradation

Fluorescent UV, Xenon Arc, and Sunlight



Poll Questions

True or false: 오랜 시간의 UVB 노출로 짧은 시간의 UVC 노출에 따른 내구성 예측이 가능할까?

Long UVB exposures can be used to indicate durability to short UVC exposures.

(FALSE)

UVC

- UVC 복사의 광자 에너지는 UVA 나 UVB 를 견딜 수 있는 일부 화학 결합을 깰 수 있을 만큼 크다. UVA 나 UVB 의 분자 결합 해체 에너지로는 분자 구조 파괴는 가능하지 않다.

— Photon energy in UVC radiation is much higher and can break some chemical bonds that withstand UVA or UVB radiation. If the UVA or UVB photon lacks the dissociation energy of the bond, sending more of those photons won't break the bond.

Your standard weathering tests won't tell you much about UVC durability.

자외선 살균

Ultraviolet Germicidal Irradiation (UVGI)

공기와 표면의 소독을 위해 사용되는 200-320nm 의 살균 영역대의 자외선 파장

The use of ultraviolet (UV)wavelengths of light in the germicidal range (200–320 nm) for the disinfection of air and surfaces.

Ultraviolet Germicidal Irradiation Handbook

미생물을 죽이거나 비활성화 시키는 240nm에서 280nm 파장대의 복사를 이용하여 공기와 물, 표면을 소독하는 방법

Method for disinfection of air, water and surfaces that uses radiation with wavelength in the range 240 nm to 280 nm to kill or inactivate micro-organisms

ISO 29464

UVGI Applications

Medical facilities

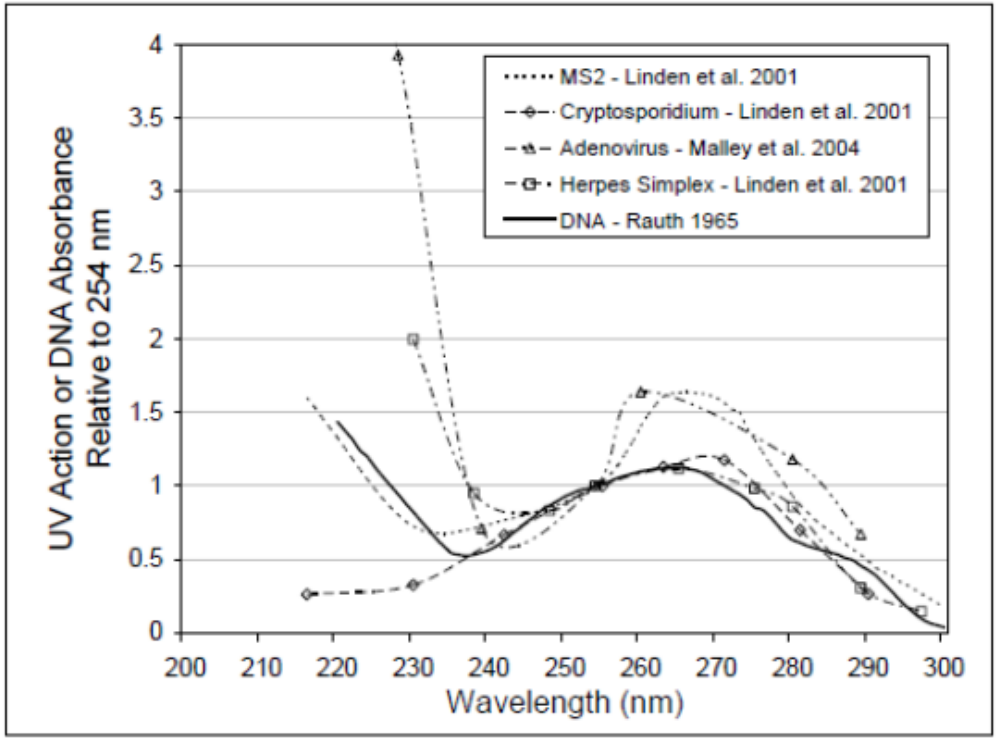
HVAC

Emergency response vehicles

Airports

Schools

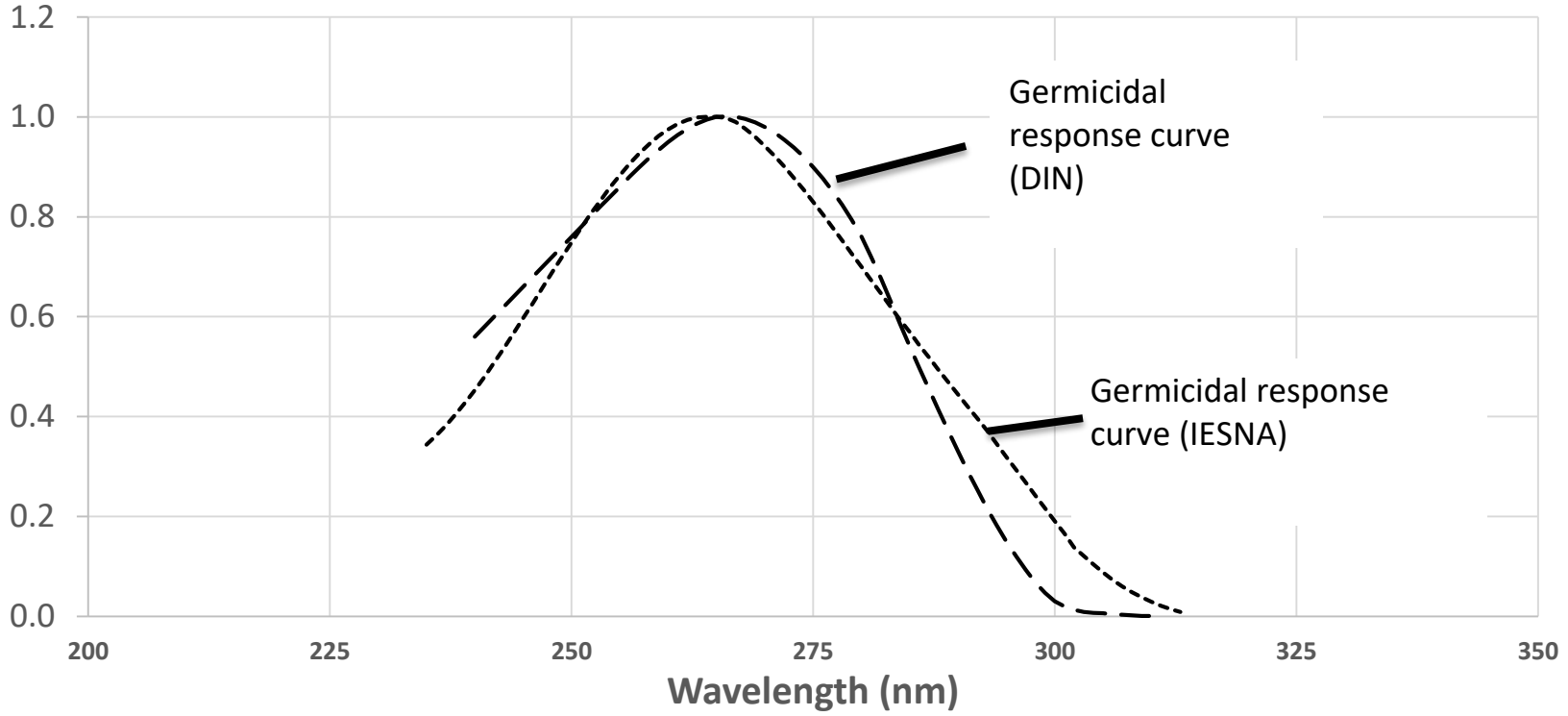
Action Spectra of DNA and Select Microorganisms



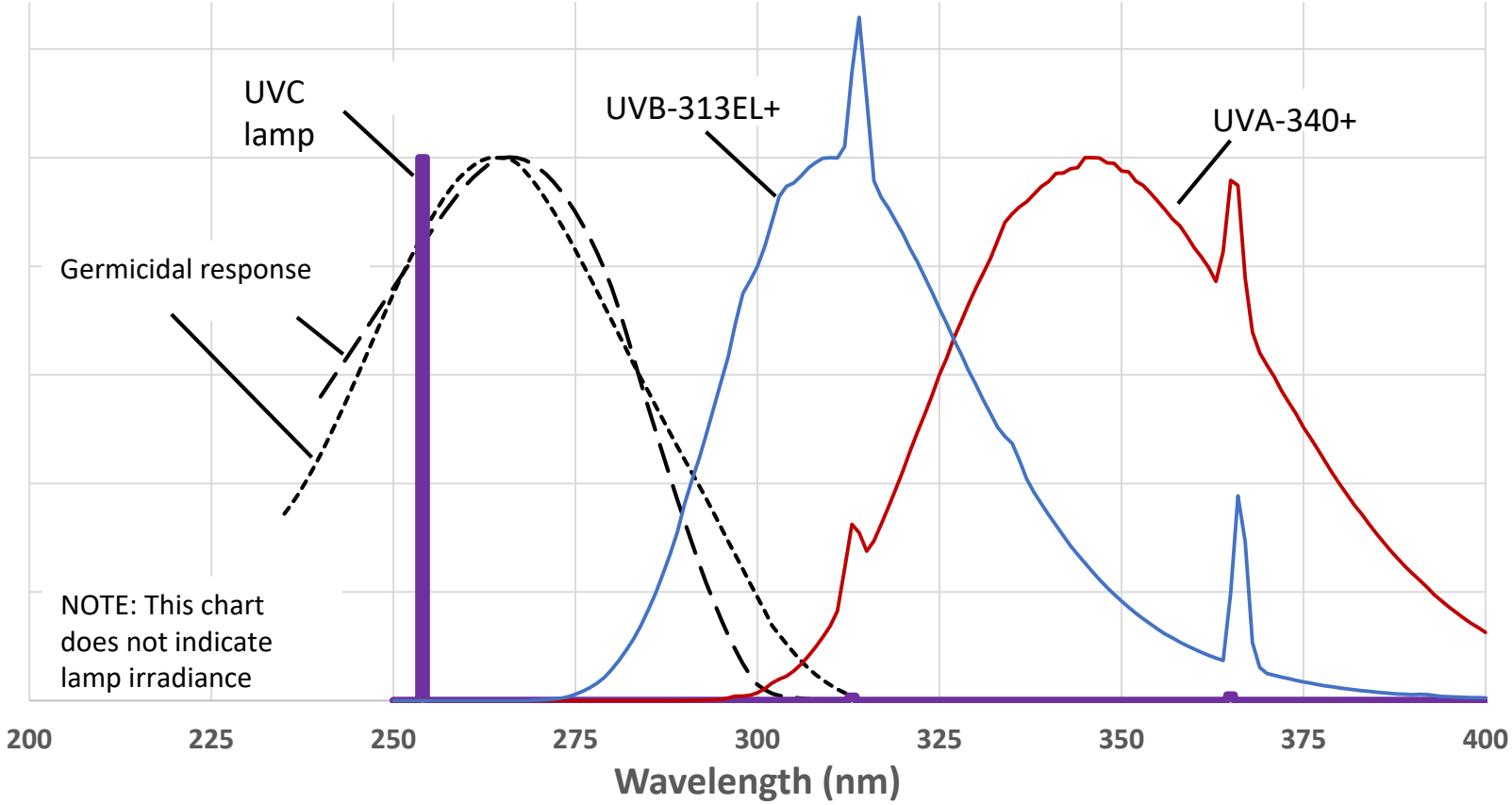
Source: Adapted from Rauth (1965), Linden et al. (2001), and Malley et al. (2004)

USEPA UV Disinfection guidance manual, 2006

Standard Germicidal Response Curves

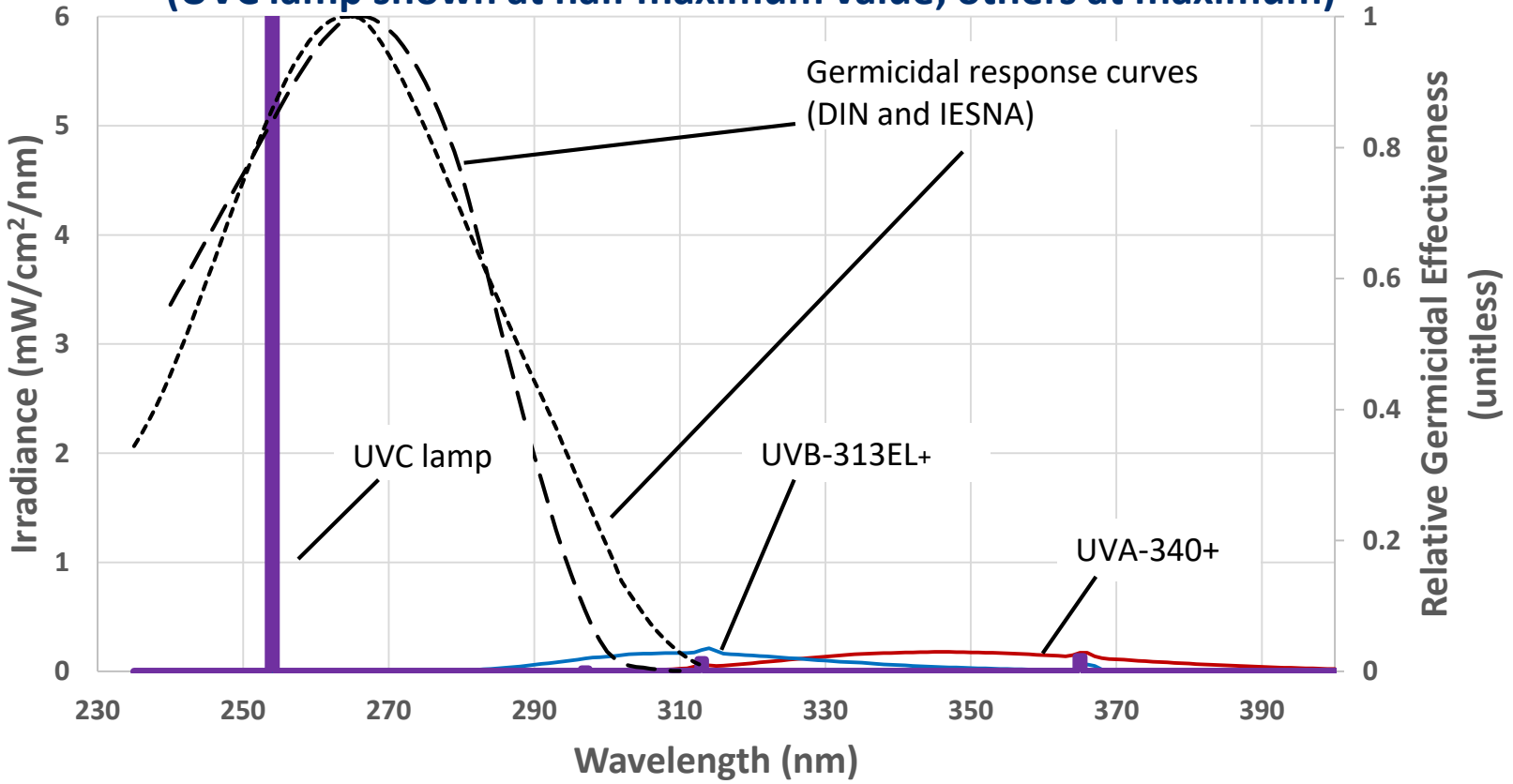


Relative Lamp Spectral Irradiance and Germicidal Response Curves



Actual Lamp Spectral Irradiance and Germicidal Effectiveness Curves

(UVC lamp shown at half maximum value; others at maximum)



Disinfection Levels

Term	Kill/Deactivation Ratio	Comments
1-Log	90%	Also called D90 Disinfection; commonly-used benchmark
2-Log	99%	
3-Log	99.9%	
4-Log	99.99%	
5-Log	99.999%	Lowest level of “sterilization”
6-Log	99.9999%	Typically the lowest level measureable

Dose vs kill ratio varies by microorganism and follows a logarithmic decay rate

Irradiance and Dose Units

$10\ W/m^2 = 1\ mW/cm^2$

$10\ J/m^2 = 1\ mJ/cm^2$

SARS-CoV-2 를 비활성화 시킬 수 있는 UVC 양은?

What UVC dose deactivates SARS-CoV-2 ?

That question is

QUV/uvc 는 자외선살균(UVGI)를 위한 장비가 아닙니다.

We aren't supporting use of our products for UVGI applications, just material testing.

하지만, 2 mJ/cm² to 1.5 J/m² 의 양이 여러 미생물의 살균 정도로 인용됩니다.

However, doses of 2 mJ/cm² to 1.5 J/m² have been cited for various microorganisms and disinfection levels

1 J/cm² 자외선살균(UVGI) 의 표준 사이클로 제안 됩니다.

1 J/cm² has been suggested as a standard UVGI cycle

UVC 표준 시험법
Standard UVC Test Methods

- IEC 60335-1, Household and similar electrical appliances - Safety - Part 1: General requirements, Annex T UVC Radiation Effect on non-metallic materials

- BIFMA HCF 8.1-2019, Health Care Furniture Design Guidelines for Cleanability

IEC 60335-1, Annex T

통신선 및 전자기기 장치에 사용되는 일반적인 규격
저압의 수은 램프 사용

Typically used for wire and other electrical insulation materials
Low-pressure mercury lamp

- Irradiance: 10 W/m^2 (1 mW/cm^2)
- Duration: 1000 hours
- Temperature: 63 °C black panel according to ISO 4892-1

Total dosage achieved: 3.6 kJ/cm^2

Business and Institutional Furniture Manufacturers Association (BIFMA)

BIFMA HCF 8.1-2019, Health Care Furniture Design Guidelines for Cleanability

Specifically designed to address UVGI exposures

- Dose: 291 kJ/m^2 at 254 nm, using low-pressure mercury lamp
- Duration: 12-24 hours but can be done faster
- No temperature specified (normal room condition implied; we recommend 30°C.

C. Difficle 를 살균하는 광량으로 주 단위로 사용되는 방법
Method based on weekly UVGI at a dose to kill *C. difficle*

Considerations for the Pandemic Era

- 실내에서 사용되는 제품은 UVC 에너지에 의해 품질저하 현상이 발생될 수 있다.
  Indoor materials are now being subjected to highly destructive UVC energy
- 실제 UVC 광량은 대부분의 자연상태 실제 적용분야에서 예측이 어렵다.
  Actual UVC dose experienced is unpredictable in most applications
- 적절한 광원을 사용하면 UVC 폭로가 일반적인 내후성 시험 표준보다 더 빠른 결과를 보일 것이다.
  With the proper light source, UVC exposures will be much faster than standard weathering tests for outdoor materials

UVGI Applications

일반적으로 실내 사용 제품은 UV 폭로에 견딜 수 있도록 설계되지 않습니다. UVC 폭로 또한 제품 개발 단계에서 고려되지 않는 것이 일반적 입니다.

Interior materials are not typically designed to withstand UV exposure, and UVC exposures are not often considered during material development

시험법 개발 및 제품 수명 시뮬레이션
Test Method Development and Service Life Simulation

- BIFMA 표준이 좋은 견본을 제공
  BIFMA standard provides a good template
  - 알려진 병원체를 바탕으로 표준 광량을 정의
    Define a standard dose based on a known pathogen
  - 어떤 주기로 UVGI 사이클을 실행할지 예상
    Estimate how often UVGI cycles will be performed
  - 제품 수명을 예상한 UVC 양을 계산
    Calculate the estimated UVC dose over product's lifetime
  - 비 활성화 양은 조도와는 독립적(조도 2배, 시험기간 절반으로)
    Inactivation doses are independent of irradiance (double the irradiance, cut the duration in half)
    - 호혜성 Reciprocity
    - 이런 예상으로 제품의 품질저하를 방지할 수 있을까?
      Does this assumption hold for material degradation?

Material Exposure to UVC

제품의 표면은 아마도 목표한 양보다 10배 정도 많은 충분한 광량을 받을 만큼 상당부분 과노출 될 것이다.

Many surfaces will be significantly over-exposed in an effort to ensure all areas receive sufficient dose, possibly 10 × the target dose.

시험 온도
Test Temperature

- 대부분 UVGI는 일반적인 방의 온도에서 수행된다.
  Most UVGI applications are performed at typical room temperature
  - 추천 세팅 온도 30 °C
    We recommend 30 °C set point
  - 과도한 온도 조건은 비현실적인 품질저하 현상을 야기할 수 있고 UVC 복사의 왜곡효과가 나타날 수 있다.
    Excessive temperature may produce unrealistic degradation or mask effects of UVC radiation
- 일부 제품은 40-60°C 가 적절함.
  40-60°C may be reasonable for some applications

QUV/uvc

New model of "The World's Most Widely Used Weathering Tester."

내장 검교정 라디오미터로 254nm 조도 정확히 컨트롤

Onboard radiometer precisely controls irradiance at 254 nm

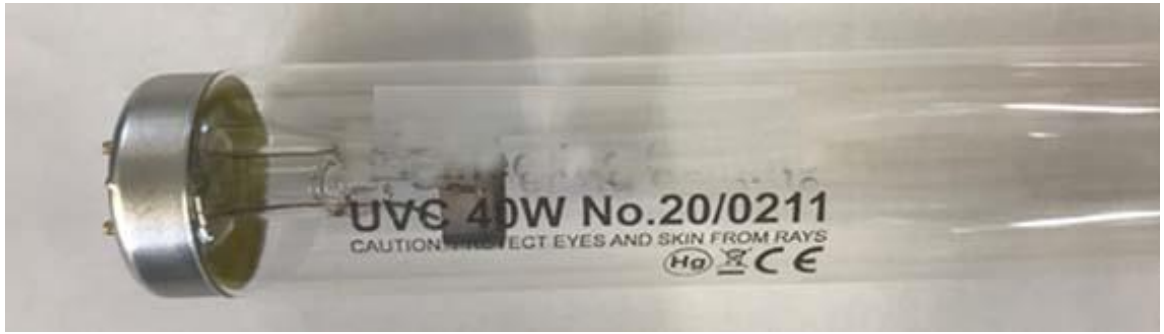
빛 칸막이 및 안전한 자동 차단 기능

Light baffles and automatic safety shut-off features

단순함을 위한 수분 기능 제거

Water functions removed for simplicity

UVC-254 Lamp



각 면에4개의 램프 설치
4 lamps on each side of QUV

2개씩 조절
Controlled in pairs

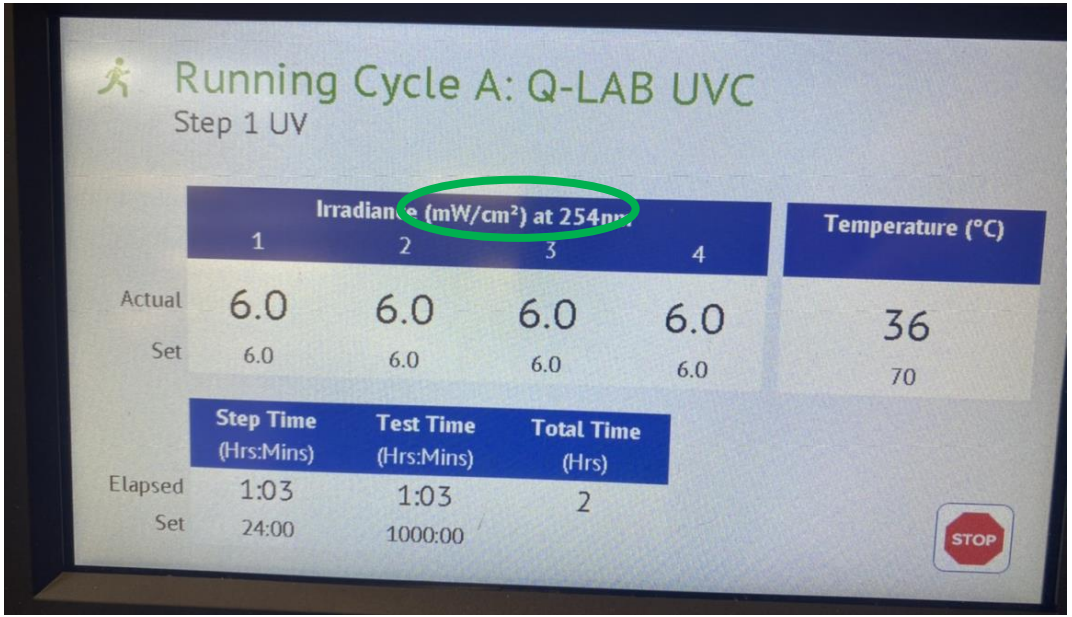
조도를 일정하게 유지하기 위해 전력 자동 조절
adjusted automatically to maintain irradiance level

UC10/UVC Smart Sensor

- 내장 QUV/uvc 광량 센서를 사용하여 검교정
  Used to calibrate QUV/uvc onboard irradiance sensors
- 단파장 254nm 필터를 포함하여 254nm 에서 조도를 검교정
  Calibrated for irradiance at 254 nm, including a narrow band 254 nm filter
- NMI-traceable calibration
- 매년 교체 혹은 재교정 필요, 모든 Q-Lab 사의 Smart Sensors 동일
  Yearly replacement or recalibration required, like all of Q-Lab's irradiance Smart Sensors

UVC 상태 창

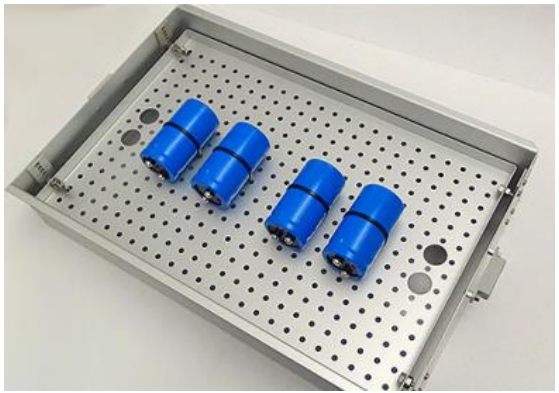
UVC Status Screen



Solar Eye 조도 조절장치가 램프의 수명을 고려하여 조도를 안정적으로 유지함.

Solar Eye irradiance control system maintains stable irradiance at the set point for the lamps' lifetime

시편 거치
Specimen Mounting



Flat or three-dimensional items

Note: Lamps shown for illustration purposes—they will not operate with the door open

QUV/uvc Operating Specifications

- Irradiance range: 1.0 - 13.0 mW/cm^2
  - 6.0 mW/cm^2 @254 nm is a typical value
  - *Note that 1 mW/cm^2 = 10 W/m^2*
- Black Panel temperature range: 24-76 °C
  - Tests will often be **near room temperature** to simulate indoor environments

UVC Radiant Dosage

Assume 1 cycle of UVGI is a dose of 1 J/cm^2

At typical irradiance, 6 mW/cm^2, a single does is achieved in 167 seconds

UVGI Cycle Frequency	Time to achieve one year of UVC dosage at normal QUV irradiance (hours)
Daily	17
Weekly	2.4
Monthly	0.6

UVC Dose Reciprocity

Will these exposures deliver the same result?

100 hours at 1.5 mW/cm^2
50 hours at 3 mW/cm^2
25 hours at 6 mW/cm^2
12.5 hours at 12 mW/cm^2

All achieve 540 J/cm^2

In the QUV/uvc you can run all of these tests to verify reciprocity (on/off cycling also possible)

Conclusions

- 자외선살균(UVGI)은 빠르게 확대되고 있다.
  UVGI is growing quickly (any commercial space is a candidate for use)
- 우리가 사용하는 제품은 생각보다 더 많은 UVC 에 노출되고 있다.
  Your products may be exposed to more UVC energy than anyone can predict.
- UVC 시험은 제대로 표준화 되지 않았다.
  UVC testing isn't well standardized.
- QUV/uvc 시험기는 팬더믹 시대의 제품 시험에 새로운 도구이다.
  QUV/uvc is a new tool for material testing in the pandemic era.

Questions?

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