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SLAC NATIONAL ACCELERATOR LABORATORY

MEMORANDUM

Skin hazard and guidance to protect skin from long exposures to UV laser radiation – e.g., from diffuse reflections

Abstract. This technote examines the potential for hazardous skin exposures to ultraviolet (UV) laser radiation and provides guidance for safety controls to protect the skin. Summaries are presented of skin hazard descriptions and controls requirements related to UV lasers found in the ANSI safety standard and OSHA Technical Manual on Laser Safety, as well as in laser safety programs at LLNL, LBNL and Stanford.

1. MPE Values and Examples of Calculated NHZs

Maximum Permissible Exposure (MPE) values are shown in Figure 1 for an example exposure of 1000s, which could represent a prolonged exposure to diffuse radiation. These MPEs are the same outside of the retinal hazard region from 400-1400nm. The MPE is shown to drop by a factor of 300 in the UV at about 300nm. Figure 2 shows more detail of the MPE in the UV, where it depends on the cumulative dose.

The Nominal Hazard Zone (NHZ) is a region in which exposures can exceed the MPE. At SLAC, eyewear protection is mandatory in the NHZ calculated from MPE values for the eye. Table 1 gives examples of NHZ distances for diffuse reflections from a small UV laser beam incident on a target, for an exposure duration of 1000s. The examples assume a reflectivity of 50% for the diffuse target and a viewing angle of 45 degrees. The example calculations show that for the NHZ to be 20cm or greater at 380nm, the incident beam power on target must be ≥ 3.5W. But at 255nm, only 10mW or greater power is needed for the NHZ to be at least 20cm.

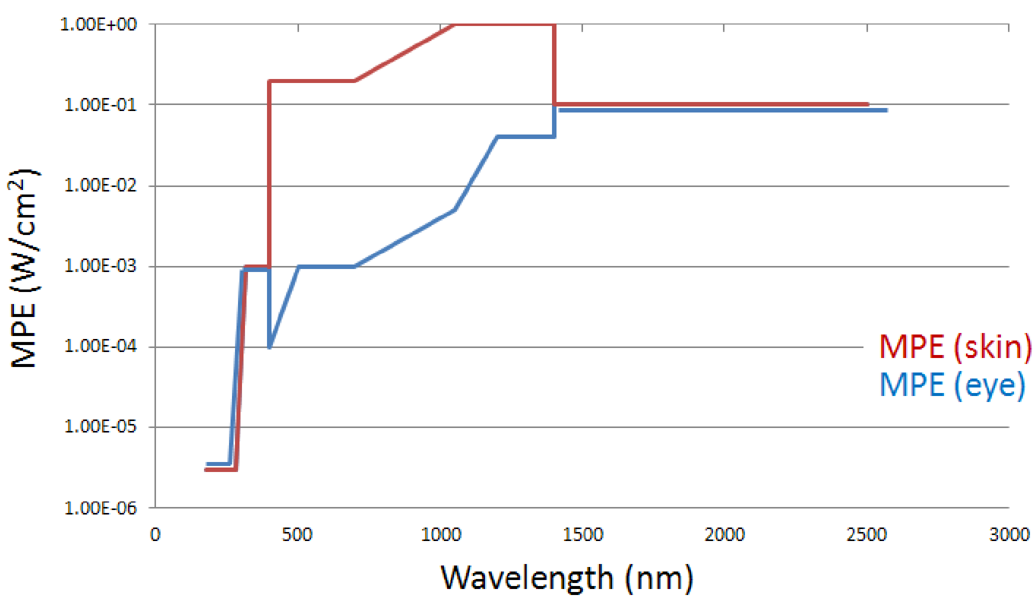

Figure 1: MPEs for eye and skin for 1000s exposure, using Tables 5a and 7 in ANSI Z136.1-2007. These MPEs are the same outside of the retinal hazard region, 400-1400nm.

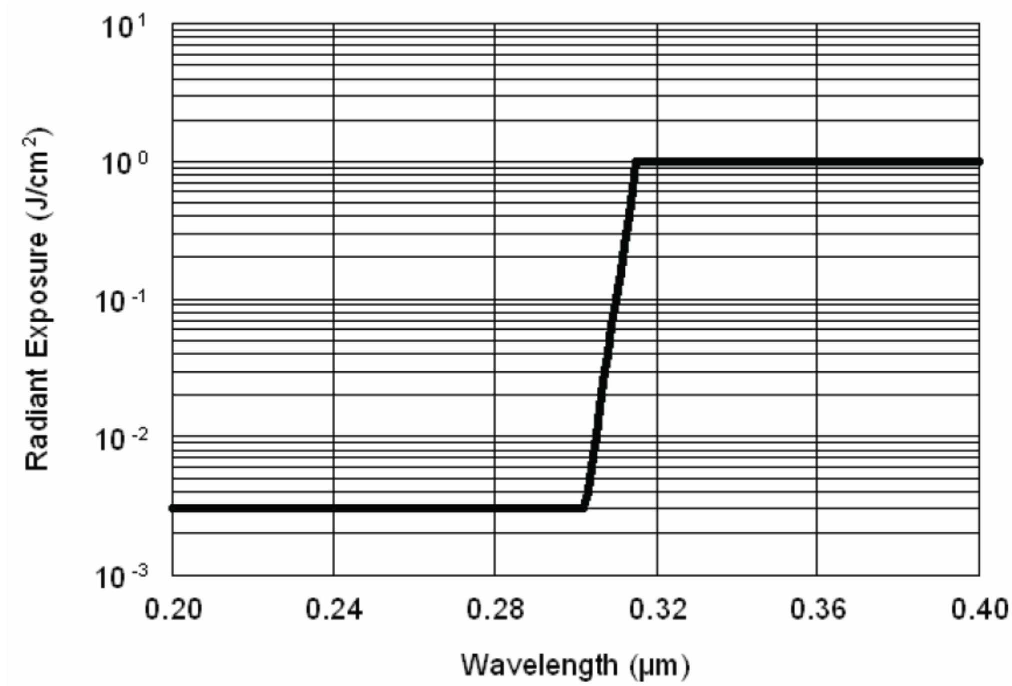

Figure 2: MPE for UV Radiation for exposure durations from 10^{-9} to $3 \cdot 10^{4}$ s for ocular exposure and 10^{-9} to 10^{3} s for skin exposure. This is taken from Figure 5 in ANSI Z136.1-2007.

Table 1: EasyHaz Calculation Examples for Nominal Hazard Zone (NHZ)

Wavelength	**Average Power**	**Diffuse Target Reflectivity**	**Viewing Angle (degrees)**	**Exposure Duration**	**MPE (W/cm^2)**	**Diffuse Reflection NHZ**
380 nm	90 W	50%	45	1000s	0.001	1.0 m
380 nm	3.5 W	50%	45	1000s	0.001	20 cm
380 nm	300 mW	50%	45	1000s	0.001	6 cm
255 nm	250 mW	50%	45	1000s	$3.0 \cdot 10^{-6}$	1.0 m
255 nm	10 mW	50%	45	1000s	$3.0 \cdot 10^{-6}$	20 cm
255 nm	1 mW	50%	45	1000s	$3.0 \cdot 10^{-6}$	6 cm

2. Literature Review and Summarizing Safety Considerations for Skin Hazard from UV Lasers

Currently there is little in the way of requirements or guidance in SLAC laser safety policy [1] for skin protection. Skin exposure hazards are noted, in particular for Class 4 lasers, but no controls requirements are given. SLAC laser safety policy focuses on protecting eyes from hazardous exposures. Sections 4-9 in this document summarize discussions of hazardous skin exposures from UV lasers found in safety standards and other institutional laser safety programs.

Based on the analysis in Section 1 of this document and a review of the safety documents in Sections 4-9, the following conclusions can be made:

- Eye and skin MPEs are the same in the UV and in the IR outside of the retinal hazard region. In the retinal hazard region between 400-1400nm, eye MPEs are ~x100-1000 less than skin MPEs for a 1000s exposure.
- MPEs in the UV are the same for coherent (laser) and incoherent sources.
- MPEs in the UV depend on the cumulative exposure. For example the MPE is $3mJ/cm^2$ between 180-300nm for exposures from 10^{-9}s to 1000s. Potential for hazard of long exposures to diffuse reflections must be considered.
- Skin injuries are less serious than eye injuries
    - Vision impairment has much higher consequences
    - Skin injuries are usually self-repairing
- Skin injuries are much more probable than eye injuries
    - Large surface area
    - Hands close to laser beams
- For skin injuries, need more consideration for chronic exposure from diffuse reflections.
- MPEs drop by a factor of 300 at ~300nm. This is because photochemical effects become important, meaning that chemical bonds can break resulting in risk for cancer. UV-B radiation between 280-315nm seems to have the most hazardous consequences.
- Chronic skin damage from UV laser operations is not well documented in the literature, but MPEs and injury thresholds should be fairly well understood from studies with incoherent light sources, sunlight etc.
- Reporting of skin injuries is much less than for eye injuries. Given exposure probability, there must be far greater skin injuries than eye injuries but there are more reported eye injuries than skin injuries. However there is a recent report for a hand injury at Idaho National Lab in 2011 (but this was not for a UV laser). [2]

3. Guidance for Protecting Skin from Hazardous Exposures to Class 3B and Class 4 UV Laser Radiation

Laser personnel need to be aware that high power lasers have significant potential to be a skin hazard as well as eye hazard. Some skin PPE recommendations are given in Table 2. Additional guidance for skin protection:

- Engineering controls (enclosures and barriers)
  - Enclose UV laser beam paths to extent practical. If they can't be enclosed, then implement adequate barriers to minimize potential skin exposure from chronic exposure to beam losses and other sources of diffuse reflections.
  - Beam dumps. Design barriers or enclosures for beam dumps to minimize potential exposure to diffuse UV reflections from them.
- Administrative procedures
  - Attenuate laser beam to minimum power required when there are open beams, in particular when alignment is done.
  - Use remote steering controls and diagnostics as much as practical for aligning UV beams.
  - Plan work so minimize time with potential skin exposure to hazardous UV beams.
  - Keeps exposed skin as far as practical from open beams.
- PPE for skin
  - Wear long-sleeved shirts.
  - Use gloves when working with hands near accessible laser beams (direct beam exposure hazard for primary or stray beams).
  - Use gloves when diffuse reflection NHZ > 20cm if hands may be within this distance of an open beam path when diffuse reflections may not be well shielded.
  - Use face shield when diffuse reflection NHZ > 1m if working within this distance of an open beam path when diffuse reflections may not be well shielded.

  Skin Protection vendor product information can be found in Reference [9].
- Medical exams
  - Skin exams can be performed by SLAC Medical and are available to laser personnel.
  - Periodic skin exams are recommended for laser personnel who may have chronic exposures exceeding MPE values.
- Site-specific training
  - On-the-Job Training (OJT) and the SOP document need to describe potential for skin injury and controls to use. These need to emphasize barriers and enclosures for UV beams and when to use skin PPE.

Table 2: PPE recommendations for conditions considered in Table 1 if working near an open UV beam when diffuse reflections may not be well shielded.

Wavelength	Average Power	NHZ	Use Gloves?	Use Face shield?
315-400 nm	>90 W	>1 m	Yes	Yes
315-400 nm	>3.5 W	>20 cm	Yes	-
190-315 nm	>250 mW	>1 m	Yes	Yes
190-315 nm	>10 mW	>20 cm	Yes	-

4. ANSI Z136.1-2007[3]

The following sections are taken directly from ANSI Z136.1-2007. Some sentences are put in italicized boldface for added emphasis.

4.6.2.2 UV Laser Protection. Particular care shall be taken when using UV lasers or laser systems. Thus, in addition to other laser controls which apply to all laser systems, the following requirements shall also apply. Exposure to UV radiation shall be minimized by using beam shields and clothing which attenuate the radiation to levels below the applicable MPE for the specific UV wavelengths.
Hazardous byproducts: Special attention shall be given to the possibility of producing undesirable reactions in the presence of UV radiation. For example, formation of skin sensitizing agents, ozone, LGACs, etc. (see Section 7.4). ***Personal Protective Equipment (PPE), shall be used when working with open beam Class 3B or Class 4 UV lasers. This shall include both eye and skin protection***.

4.6.6 Skin Protection (Class 3B or Class 4). In some laser applications, such as use of excimer lasers operating ***in the ultraviolet***, ***the use of a skin cover shall be employed if chronic (repeated) exposures are anticipated at exposure levels at or near the applicable MPEs for skin***.
Skin protection can best be achieved through engineering controls. If the potential exists for a damaging skin exposure, particularly for ultraviolet lasers (0.295-0.400 μm) and/or laser welding/cutting application, then skin-covers and / or "sun screen" creams are recommended. Most gloves will provide some protection against laser radiation. Tightly woven fabrics and opaque gloves provide the best protection. In some cases a laboratory jacket or coat may fulfill the requirement. For Class 4 lasers, consideration shall be given to flame-retardant materials.
For wavelengths greater than 1.4 μm, "large-area" exposures can cause heat loading — causing skin dryness and with excessive exposure, may lead to heat stress (see Section 8.4.2). In these cases, personnel exposures shall be minimized.
Chronic exposure may have long term adverse health effects which are not fully understood at this time.

E3.1.1 Preassignment Medical Examinations. Except for examination following suspected injury, these are the only examinations required by this standard. ..
…Although ***skin damage from chronic exposure to laser radiation has not been reported, and indeed seems unlikely, this area has not been adequately studied***. ***Limited skin examinations are suggested to serve as a baseline until future epidemiologic studies indicate whether they are needed or not.***

E3.2.6 Skin Examination. Not required for preplacement examinations of laser workers; however, it is ***suggested for employees with history of photosensitivity or working with ultraviolet lasers***. Any previous dermatological abnormalities and family history are reviewed. Any current complaints concerned with the skin are noted as well as the history of medication usage, particularly concentrating on those drugs which are potentially photosensitizing. Further examination should be based on the type of laser radiation, above the appropriate MPEs, present in the individual's work environment.

G2. Biological Effects of Laser Radiation on the Skin

G2.1 General. The large skin surface makes this body tissue readily available to accidental and repeated exposures to laser radiation. The biological significance of irradiation of the skin by lasers operating in the visible and infrared regions is considerably less than exposure of the eye, as skin damage is usually reparable or reversible. Effects may vary from a mild reddening (erythema) to blisters and charring. Depigmentation, ulceration, and scarring of the skin and damage to underlying organs may occur from extremely high-power laser radiation.

Outside of the UV region, latent and cumulative effects of laser radiation to the skin are not known at this time. The possibility of such effects occurring, however, should not be ignored in planning for personnel safety in laser installations.

Little or no data is available describing the reaction of skin exposed to laser radiation in the 0.2 to 0.4 µm spectral region, but chronic exposure to ultraviolet wavelengths in this range can have a carcinogenic action on skin as well as eliciting an erythematous response.

On the basis of studies with noncoherent ultraviolet radiation, exposure to wavelengths in the 0.25 to 0.32 µm spectral region is most injurious to skin. Exposure to the shorter (0.2 to 0.25 µm) and longer (0.32 to 0.4 µm) ultraviolet wavelengths is considered less harmful to normal human skin. The shorter wavelengths are absorbed in the outer dead layer of the epidermis (stratum corneum), and exposure to the longer wavelengths has a pigment darkening effect. However, the sensitivity of skin to the longer wavelengths may be increased by known or inadvertent usage of photosensitizers.

5. OSHA Technical Manual on Laser Safety[4]

A. **OTHER**.

1. Other damage mechanisms have also been demonstrated for other specific wavelength ranges and/or exposure times. For example, photochemical reactions are the principal cause of threshold level tissue damage following exposures to either actinic ultraviolet radiation (0.200 µm-0.315 µm) for any exposure time or "blue light" visible radiation (0.400 µm-0.550 µm) when exposures are greater than 10 seconds.
2. To the skin, UV-A (0.315 µm-0.400 µm) can cause hyperpigmentation and erythema.
3. ***Exposure in the UV-B range is most injurious to skin***. In addition to thermal injury caused by ultraviolet energy, there is the possibility of radiation carcinogenesis from ***UV-B (0.280 mm - 0.315 mm)*** either directly on DNA or from effects on potential carcinogenic intracellular viruses.
4. Exposure in the shorter UV-C (0.200 µm-0.280 µm) and the longer UV-A ranges seems less harmful to human skin. The shorter wavelengths are absorbed in the outer dead layers of the epidermis (stratum corneum) and the longer wavelengths have an initial pigment-darkening effect followed by erythema if there is exposure to excessive levels. These biological effects are summarized in Table III:6-3.
5. ***The hazards associated with skin exposure are of less importance than eye hazards; however, with the expanding use of higher-power laser systems, particularly ultraviolet lasers, the unprotected skin of personnel may be exposed to extremely hazardous levels of the beam power if used in an unenclosed system design***.

TABLE III:6-3. SUMMARY OF BASIC BIOLOGICAL EFFECTS OF LIGHT

Photobiological spectral domain	Eye effects	Skin effects
Ultraviolet C (0.200-0.280 µm)	Photokeratitis	Erythema (sunburn) Skin cancer
Ultraviolet B (0.280-315 µm)	Photokeratitis	Accelerated skin aging Increased pigmentation
Ultraviolet A (0.315-0.400 µm)	Photochemical UV cataract	Pigment darkening Skin burn
Visible (0.400-0.780 µm)	Photochemical and thermal retinal injury	Photosensitive reactions Skin burn
Infrared A (0.780-1.400 µm)	Cataract, retinal burns	Skin burn
Infrared B (1.400-3.00 µm)	Corneal burn Aqueous flare IR cataract	Skin burn
Infrared C (3.00-1000 µm)	Corneal burn only	Skin burn

6. LLNL ESH Safety Manual Chapter on Laser Safety[5]

9.3.11 Additional Controls for Invisible Beams

Ultraviolet Wavelengths *(*100_400 nm). UV radiation causes photochemical reactions in the eyes and skin and is particularly dangerous, because it is invisible to the eye and its effects may not appear for some time after exposure. In addition, a direct or reflected beam of UV radiation can also produce hazardous byproducts upon striking the surface of a material. Therefore, both the direct beam and scattered UV radiation should be shielded to the maximum extent practicable to avoid such problems. The use of long-sleeved coats, gloves, and face protectors is recommended. Some medications can increase the sensitivity of the skin or eye surfaces to UV radiation. Medical monitoring of the skin may be required for those working with or around exposed UV laser beams.

7. LBNL ESH Safety Manual Chapter on Laser Safety[6]

- ***For those who routinely receive ultraviolet exposure as part of their experimental work, an annual skin evaluation is recommended. This service is available through Health Services.***

8. LBNL Laser Reference Guide[7]

- ***Always wear gloves and long sleeves when aligning UV beams to prevent skin exposure. Skin exposure to lasers could lead to possible skin cancer.***

9. Stanford ESH Safety Manual Chapter on Laser Safety[8]

6.1.2 Skin Protection

Skin protection can best be achieved through engineering controls. If potential skin damaging exposures exist, skin covers and or "sun screen" creams are recommended. Minimize exposure to UV radiation by using beam shields and clothing (opaque gloves, tightly woven fabrics, laboratory jacket or coat) which attenuate the radiation to levels below the MPE for specific UV wavelengths. Consider flame retardant materials for Class 4 lasers. Special attention must be given to the possibility of producing undesirable reactions in the presence of UV radiation (formation of skin sensitizing agents, ozone, etc.).

10. References

1. SLAC ESH Manual Chapter 10, Laser Safety, http://www-group.slac.stanford.edu/esh/hazardous_activities/laser/.
2. Laser injury incident report from Idaho National Lab, http://www.efcog.org/wg/esh_ls/docs/Lesson_Learned_Reports/LessonsLearned_DOE-INL-2011_HandInjuryReport.pdf.
3. American National Standard for Safe Use of Lasers, ANSI Z136.1-2007, published by Laser Institute of America.
4. OSHA Technical Manual on Laser Safety, http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_6.html.
5. LLNL ESH Safety Manual Chapter on Laser Safety, Part 20: Ionizing Radiation/Nonionizing Radiation, Document 20.8 Lasers.
6. LBNL ESH Safety Manual Chapter on Laser Safety, http://www.lbl.gov/ehs/pub3000/CH16.html.
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9. Skin PPE vendor information, see SkinProtectionPPE file linked from https://slacspace.slac.stanford.edu/sites/esh/rp/laser/PPE_EyeSkin_Protection/.