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SHORT REPORT



## Evaluating optical hazards from plasma arc cutting

Reported By

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### ABSTRACT

The Health Hazard Evaluation Program of the National Institute for Occupational Safety and Health evaluated a steel building materials manufacturer. The employer requested the evaluation because of concerns about optical radiation hazards from a plasma arc cutting system and the need to clarify eye protection requirements for plasma operators, other employees, and visitors. The strength of the ultraviolet radiation, visible radiation (light), and infrared radiation generated by the plasma arc cutter was measured at various distances from the source and at different operating amperages. Investigators also observed employees performing the plasma arc cutting. Optical radiation above safe levels for the unprotected eyes in the ultraviolet-C, ultraviolet-B, and visible light ranges were found during plasma arc cutting. In contrast, infrared and ultraviolet-A radiation levels during plasma arc cutting were similar to background levels. The highest non-ionizing radiation exposures occurred when no welding curtains were used. A plasma arc welding curtain in place did not eliminate optical radiation hazards to the plasma arc operator or to nearby employees. In most instances, the measured intensities for visible light, UV-C, and UV-B resulted in welding shade lens numbers that were lower than those stipulated in the OSHA Filter Lenses for Protection Against Radiant Energy table in 29 CFR 1910.133(a)(5).<sup>[1]</sup> Investigators recommended using a welding curtain that enclosed the plasma arc, posting optical radiation warning signs in the plasma arc cutter area, installing audible or visual warning cues when the plasma arc cutter was operating, and using welding shades that covered the plasma arc cutter operator's face to protect skin from ultraviolet radiation hazards.

### KEYWORDS

Optical radiation; plasma arc cutting; ultraviolet light; visible light

## Introduction

### Background

The National Institute for Occupational Safety and Health (NIOSH) Health Hazard Evaluation (HHE) Program received a health hazard evaluation request from a custom steel building materials manufacturer concerning exposures to optical radiation hazards during plasma arc cutting (PAC). The company asked the HHE Program for guidance on the appropriate shaded protective eyewear for employees during PAC operations. The Occupational Safety and Health Administration (OSHA) had cited the company for not having employees wear the correct shade number during PAC per 29 Code of Federal Regulations (CFR) Part 1910.133(a)(5), which stipulates a welding lens shade 8 on the basis of the PAC amperage.<sup>[1]</sup> The company was concerned that requiring all employees in the vicinity of the plasma arc cutter to wear shade 8

welding glasses would create safety hazards by impeding their ability to clearly see overhead cranes moving materials. The OSHA compliance officer suggested that the company contact the HHE Program for an optical radiation evaluation.

NIOSH investigators visited the facility to observe work activities and processes, measure optical radiation levels during PAC, and assess potential controls. At the time of the OSHA inspection, the company had no welding curtains or engineering controls in place to reduce the PAC optical radiation hazard to employees. As a result, the plasma arc was visible to employees working nearby. At the time of the OSHA inspection the company required employees near the plasma arc cutter to wear shade three welding glasses, while the plasma arc cutter operators were required to wear shade five welding glasses. The company reported no eye injuries from welding, cutting, or brazing activities.

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### Process description

At the time of the NIOSH evaluation the company employed 253 employees on-site, and work occurred over three 8-hr shifts. Typically, three PAC operators each worked about 3 hr per shift cutting mild steel using hot plasma, an electrically conductive ionized gas. A plasma arc cutter works by using the electrically conductive plasma to transfer energy from an electrical power source through a torch to the material being cut.<sup>[2]</sup> When not cutting, the PAC operators spent their time moving materials into and out of the PAC tables and adjusting the computer-controlled PAC systems for the desired cut. Other employees worked in adjacent areas moving materials or finishing product. The company had designated safe walking paths for employees and visitors to avoid forklift traffic and overhead crane work.

The company used two identical Messer Cutting Systems computer-controlled PAC systems to cut sheets of carbon steel to desired shapes. The PAC systems operated at 130 amperes (amps) 95% of the time. For thicker steel sheets cutting was done at 260 amps.

Following the OSHA inspection, the company installed a manufacturer-designed welding curtain on each PAC system (Figure 1). The curtain was designed to reduce optical radiation exposures to operators and nearby employees during PAC operation. The welding curtain design blocked the plasma arc over a 180-degree viewing range and extended from the top of the curtain to about 0.5 in above the steel being cut.

The PAC process began with operators loading stock steel sheets onto the PAC system table. The PAC operators then performed a zero-zero alignment, a task that positioned the PAC head at the starting point prior to “striking” (activating) the plasma arc. For this task the welding

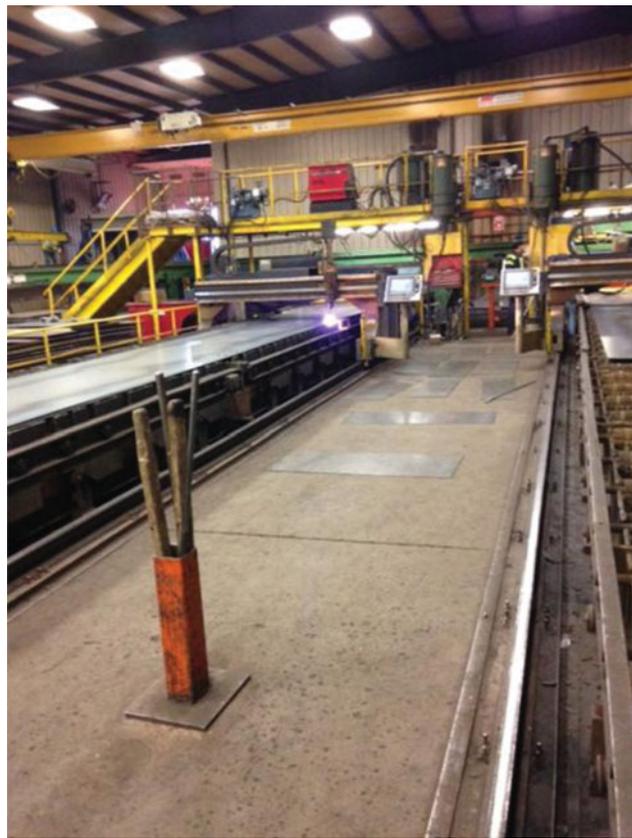


**Figure 1.** Factory-designed welding curtain on the south PAC system. The welding curtain covers 180° of the arc. The PAC system is not operating in the photo. Photo by NIOSH.

curtain had to be opened to allow the PAC operator to precisely see the starting point for the cut. For this task the PAC operator wore shade 8 protective eyewear that consisted of a flip-down tinted lens mounted to his hard hat. Once the arc was struck the PAC operator closed the curtain and let the computer guide the remaining cutting.

Occasionally the PAC operator performed a “rip cut,” a cut perpendicular to previous metal cuts. Because of the precision required to make a rip cut of only a few inches in length the PAC operator opened the curtain and stood within 3–4 ft of the plasma arc to have a clearer view. The welding curtain remained attached to the plasma cutting head to shield viewing by other PAC operators and nearby employees. For this task the PAC operator wore the same shade 8 protective eyewear as zero-zero alignment. Other tasks performed by the PAC operators that did not require direct viewing of the arc included loading and unloading metal pieces and working at a computer between the two PAC tables, close to the off-bearing end.

The distance between the operator and the plasma arc varied as the PAC head moved to complete the desired cut on the metal slab. The distance from the cutting head to the PAC operators typically ranged from 10–45 ft, but could be slightly shorter or longer. Figure 2 shows



**Figure 2.** View of the intense visible light generated from an operating PAC without attached welding curtains at a typical distance an employee may stand. Photo by NIOSH.

**Table 1.** Summary of occupational exposure levels used and primary health effects.

Physical agent	ACGIH TLV	NIOSH REL	OSHA PEL	Primary health effect
UV-C and UV-B (200–315 nm)	0.1 $\mu\text{W}/\text{cm}^2$ (effective) <sup>a,b</sup>	0.1 $\mu\text{W}/\text{cm}^2$ (effective) <sup>b</sup>	None	Photokeratitis and erythema
UV-A (315–400 nm)	1.0 $\text{mW}/\text{cm}^2$ <sup>c,d</sup>	1.0 $\text{mW}/\text{cm}^2$ <sup>d</sup>	None	Erythema
Visible (400–760 nm)	1.0 $\text{cd}/\text{cm}^2$ <sup>e</sup>	None	None	Retinal burns
IR (760 nm–1,000,000 nm)	10 $\text{mW}/\text{cm}^2$ <sup>d</sup>	None	None	Cataracts, dry eyes and skin

<sup>a</sup>Biological effective units.

<sup>b</sup>These values represent 8-hr exposures, but higher exposures are permitted in certain cases for shorter time periods.

<sup>c</sup> $\text{mW}/\text{cm}^2$  = milliwatts per square centimeter.

<sup>d</sup>These values are based on 17-min exposures or greater.

<sup>e</sup>For any viewing duration.

the PAC systems during operation without welding curtains attached and at a distance typical for bystanders and employees. Adjacent to the PAC systems other employees moved metal pieces with an overhead crane or performed welding tasks. Visitors and employees not involved in the operation could stand approximately 35–70 ft away in the safe walkway with a direct view of the PAC systems.

Required personal protective equipment (PPE) for PAC operators included a hard hat, flip-down shade 8 welding eyewear (worn during zero-zero alignment and rip cutting), shade 5 protective eyewear (worn during other PAC tasks), high-visibility safety vests, long sleeve garments, arm guards, and steel-toe safety shoes with metatarsal guards.

### Nonionizing radiation

Welding, cutting (e.g., PAC), and brazing emit nonionizing radiation energy over a broad range of wavelengths, typically from 100–10,000 nm. This range includes ultraviolet (UV) radiation from 200–400 nm, visible radiation (light) from 400–760 nm, and infrared (IR) radiation from 760–10,000 nm. Within the UV radiation range are three subranges: UV-A (315–400 nm), UV-B (280–315 nm), and UV-C (100–280 nm).<sup>[3]</sup> Eye exposures to UV and IR radiation and high intensity visible light can cause thermal and photochemical eye injuries.<sup>[4,5]</sup> Table 1 presents the occupational exposure limits (OELs) that apply to ocular hazards from nonionizing radiation, as well as the primary health effects from exposures above OELs. In this evaluation, the lowest OELs were used as the basis for the optical density (OD) calculation and shade number determinations.<sup>[6,7]</sup> For visible radiation, the American Conference of Governmental Industrial Hygienists has more specific threshold limit values (TLVs) than are listed in Table 1, for example light in the blue spectrum or intense visible light causing retinal thermal damage for unprotected eyes.<sup>[6]</sup> However, only when the luminance (intensity) exceeds 1 candela per square centimeter ( $\text{cd}/\text{cm}^2$ ) would calculating specific TLVs on the basis of spectral data of a visible light source apply.<sup>[6]</sup>

Therefore, a value of 1  $\text{cd}/\text{cm}^2$  was used as a threshold OEL to indicate whether eye exposure was above safe levels and to determine an appropriate protective shade.

### Methods

The objectives of the NIOSH evaluation were to (1) evaluate the optical radiation hazards present at the PAC systems and (2) determine the appropriate protective eyewear for PAC operators and for employees and visitors who come into the viewing area of the PAC systems. The UV and IR radiation levels were measured with an ILT1700 research radiometer/photometer (International Light Technologies, Peabody, MA) using three different detectors (UV-C/UV-B, UV-A, infrared). Visible light levels were measured with an LS-110 luminance meter (Konica Minolta Sensing Americas, Inc., Ramsey, NJ). Table 2 summarizes the direct reading instruments, detectors, and the units of measurement.

### Calculating optical density

To compare nonionizing radiation measurements to applicable OELs for eye exposure, field measurements were converted to the same units as the OELs. Once the measurement units were converted, the optical density (OD), a measure of the effectiveness of a filter (like the filtered lenses worn for lasers, welding, or PAC operations)

**Table 2.** Summary of direct-reading instruments.

Instrument	Detector	Unit of measurement	Light wavelength band measured
ILT1700	SED240 <sup>a</sup>	Effective <sup>c</sup> $\text{W}/\text{cm}^2$ <sup>d</sup>	200–315 nm (UV-C)
	SED033 <sup>a</sup>	$\text{W}/\text{cm}^2$	315–400 nm (UV-A)
	SED623 <sup>a</sup>	$\text{W}/\text{cm}^2$	760–10,000 nm (infrared)
Konica Minolta	LS-110 <sup>b</sup>	$\text{cd}/\text{m}^2$ <sup>e</sup>	400–760 nm (visible)

<sup>a</sup>Detector used with ILT1700 radiometer/photometer instrument.

<sup>b</sup>Konica Minolta luminance meter.

<sup>c</sup>Biological effective units.

<sup>d</sup> $\text{W}/\text{cm}^2$  = watts per square centimeter.

<sup>e</sup> $\text{cd}/\text{m}^2$  = candela per square meter.

**Table 3.** Results of visible light (400–760 nm) measurements.

PAC power	Location	Result (cd/cm <sup>2</sup> ) <sup>a</sup>	Calculated OD <sup>b</sup> (unitless)	Shade number <sup>b,c</sup> (unitless)
130 amperes	3–4 ft from arc, zero-zero task, with curtain, arc partially visible	8	1	4
	3–4 ft from arc, with curtain, no visible arc	1	0	1
	3–4 ft from arc, rip cutting, no curtain, direct arc view	23	2	5
	10 ft from arc, edge cutting, with curtain, direct arc view, some metal reflectance	9	1	4
	10–15 ft from arc, with curtain, sparks, some metal reflectance	3	1	2
260 amperes	12 ft from arc, no curtain, direct arc view	87	2	6
	5 ft from arc, no curtain, direct arc view	99 <sup>d</sup>	—	8 <sup>d</sup>
	10 ft from arc, no curtain, direct arc view	57	2	6
	18 ft from arc, no curtain, direct arc view	16	2	4
	34 ft from arc, no curtain, direct arc view	5	1	3
	46 ft from arc, no curtain, in safe walkway	3	1	2

<sup>a</sup>cd/cm<sup>2</sup> = candelas per square centimeter.

<sup>b</sup>OD and shade number values were rounded up to the nearest whole number.

<sup>c</sup>A shade number 1 or less means no shaded protective eyewear is needed.

<sup>d</sup>Visible light measurement exceeded the instruments' range of detection.

was calculated.<sup>[8]</sup> The OELs were used in the OD calculation. Once the OD was calculated, the equivalent shade number, a value used to describe welding eye protection, could be determined for each of the radiant energies.<sup>[8]</sup> The shade number calculation reflects broadband attenuation of optical radiation energy and includes protection to visible, UV, and IR radiation.<sup>[4]</sup> The following formulas were used to calculate the OD and shade number:

$$OD = \left\lceil \log \frac{\text{Measurement}}{OEL} \right\rceil,$$

where the OEL is the level at which one can be exposed to without adverse eye effects from the optical radiation energy

$$\text{Shade number} = \left\lceil \frac{7}{3} \times OD \right\rceil + 1.$$

Shade numbers above 1 indicate that eye protection should be worn to protect against radiant energy. Shade numbers of 1 or less indicate that the optical radiation energy is below the applicable OELs for the eye and thus no protective shaded eyewear is required. In this evaluation the highest shade number calculated for each scenario and spectral region was selected for the appropriate safety eyewear.

## Results

Results are presented by type of radiant energy measured, sample location, approximate distance from the PAC systems, and the OD and protective shade number. The OD and shade number values were rounded up to the nearest whole number. For the unadjusted and negative OD and shade number values see Supplemental Files. Instrument zero checks (performed by covering the sensor with an

opaque cap) and background readings were taken prior to the operation of the PAC systems (data not shown).

### Visible light

Visible light measurements are presented in Table 3. During close range tasks such as the zero-zero alignment or rip cutting, particularly when no welding curtain was used or the plasma arc needed to be visible to the plasma operators, the luminance meter produced an error reading, meaning that the visible light intensities exceeded the instrument's detection limit of 99 cd/cm<sup>2</sup>. In these situations the OSHA recommendation for a shade 8 welding lens for PAC below 300 amps was used.<sup>[1]</sup>

At the company-designated safe walkway area (at least 35 ft from the PAC systems) part of the plasma arc was visible because the welding curtain did not fully contact the metal slab being cut. At 35 ft from the PAC systems the measured visible light energies (at 260 amp operation) would require a welding lens shade of 3. At 130 amp operation, the measured visible light energies did not require eye protection. However, UV radiation levels were high enough to require a shade 3 for welding lenses or alternative eyewear designed specifically for UV protection.

### Ultraviolet-C and ultraviolet-B radiation

The UV-C and UV-B measurements are summarized in Table 4. The highest calculated shade number for UV-C and UV-B protection of 5 was for PAC operations at 260 amps, without a welding curtain in place, and with the PAC operator 10 ft from the arc.

At 130 amps and with a welding curtain in place, the measurements determined that welding shade numbers

**Table 4.** Results of UV-C and UV-B (200–315 nm) measurements.

PAC power	Location	Result (effective $\mu\text{W}/\text{cm}^2$ ) <sup>a</sup>	Calculated OD <sup>b</sup> (unitless)	Shade number <sup>b,c</sup> (unitless)
130 amperes	10–15 ft from arc, with curtain	0.02	– 1	0
	10–15 ft from arc, without curtain	0.1	– 1	1
	35–40 ft from arc, with curtain	0.4	1	3
	35–40 ft from arc, no curtain	0.3	1	3
260 amperes	10 ft from arc, no welding curtain	6	2	5
	10 ft from arc, with curtain	0.5	1	3
	35 ft from arc, with curtain	0.5	1	3

<sup>a</sup> $\mu\text{W}/\text{cm}^2$  = microwatts per square centimeter.

<sup>b</sup>OD and shade numbers were rounded up to the nearest whole number.

<sup>c</sup>A shade number 1 or less means no shaded protective eyewear is needed.

were below 1, indicating that the welding curtains were effectively controlling UV-C and UV-B exposures and no eye protection was needed. However, measurements at 260 amps at the same distance and with welding curtains in place stipulated that a welding lens shade 3 was needed. Levels measured 35–40 ft from PAC operations, the approximate location of the company-designated safe walkway area, stipulated that a welding shade lens of 3 was needed, regardless of the use of welding curtains or the PAC power level. The plasma arc was partially visible in the walkway area because the welding curtain did not fully contact the metal slab being cut.

### Ultraviolet-A and infrared radiation

The UV-A and IR levels were similar to background levels in the work area without the PAC systems operating (data not shown). This means that IR and UV-A radiation energies generated by the two PAC systems were minimal and not the main energy sources driving eye protection requirements. NIOSH investigators reached similar conclusions in a 1996 HHE at another facility where similar PAC systems and amperages were evaluated.<sup>[9]</sup>

### Workplace observations

Employees wore the company-required PPE in the PAC area, as well as other areas of the facility. However, signs were not posted in the PAC areas warning employees and visitors of the potential for optical radiation hazards. Welding curtains or panels were not in place around the PAC system area, a commonly used engineering control to protect employees and bystanders from optical radiation.<sup>[3,10]</sup> However, because employees frequently used overhead cranes in this area to move raw and finished metal stock, the company believed that welding panels and curtains created obstacles in safely using overhead cranes.

### Discussion

This evaluation found that in most instances the PAC curtain greatly reduced the visible light reaching the PAC

operator and nearby employees, regardless of the amperage, meaning that eye protection for visible light radiant energy was not needed. However, there were instances when visible light intensities resulted in welding shade lens numbers above 1, such as when light reflected off the metal slab being cut or when part of the plasma arc was visible even with the welding curtains in place. At lower amperages (130 amps), with the welding curtain in place, and at locations roughly 10 ft away, measurements indicated that a welding shade protection of at least 4 should be used to protect eyes from viewing edge cuts and reflectance off metal.

UV-C intensities exceeded safe levels in locations where the visible light intensity was below safe levels for the unprotected eye. In these instances, UV protective eye protection that meets the American National Standards Institute (ANSI) standard can be worn. This standard, ANSI Z87.1-2015, provides requirements for safety eyewear that is protective against UV.<sup>[11]</sup> These eyewear have a “U” marking with a number rating from 2–6 which indicates the degree to which UV is reduced. Such eyewear can be worn as an alternative to the darker (tinted) welding lens eyewear. For example, clear (no tint) safety eyewear that meets ANSI Z87.1-2015 with at least a U2 rating for UV protection could be worn by visitors and employees in the company-designated safe walkway during PAC operations at 130 amps. This was the amperage that the PAC systems operated about 95% of the time. Audible or visual warnings could be used to alert employees and visitors when PAC tasks at 260 amps are occurring and a shade 3 welding lens is needed.

An interesting finding from this evaluation was that in most instances the measured intensities for visible light, UV-C, and UV-B resulted in welding shade lens numbers that were lower than those stipulated in the OSHA *Filter Lenses for Protection Against Radiant Energy* table in 29 CFR 1910.133(a)(5).<sup>[11]</sup> This OSHA table recommended a shade 8 welding lens for PAC below 300 amps, with no adjustment for distance from the optical radiation source or the use of controls, such as a welding curtain. The advantage of using the OSHA table is simplicity, in that no measurements of the optical radiation hazards

are needed, just information on the PAC amperage. A disadvantage of using the OSHA table, however, is that the recommended protective shade number may be, in some instances, overly conservative, meaning that darker tinted safety eyewear than needed is recommended.

A possible limitation of this evaluation is electromagnetic interference (EMI) to the instruments used to perform nonionizing radiation measurements during PAC operations.<sup>[12]</sup> However, if EMI was present its influence on these reported measurements may have been minimal because: (1) visible radiation levels were measured with a battery operated luminance meter and thus was not connected to the plant's electrical system; (2) after attaching the appropriate UV or IR detector and prior to taking a measurement, the radiometer/photometer was zeroed by covering the detector with an opaque cap; and (3) the nonionizing radiation readings obtained were similar to those reported in a study of a similar PAC operation,<sup>[9]</sup> and the magnitudes consistent relative to the plasma arc.

## Conclusions

Optical radiation hazards from UV-C and visible light were present during PAC operations. The highest exposures occurred when no welding curtains were used. The welding curtain reduced but did not eliminate optical radiation hazards to employees. On the basis of the measurements made in this evaluation the PAC operators should wear at least shade 5 eye protection for distances greater than 5 ft from the PAC head and when using a welding curtain. For tasks that required the PAC operators to be within 5 ft of the arc, and when a welding curtain could not be used, PAC operators should use shade 8 eye protection, which is in agreement with OSHA requirements. However, in other work locations the measured intensities for visible light, UV-C, and UV-B resulted in welding shade lens numbers that were lower than those stipulated in the OSHA standard. Modifying the PAC curtain design to reduce or eliminate any gaps between the curtain and the steel stock being cut would reduce the opportunity for employees and visitors in the surrounding areas to view the PAC arc.

## Recommendations

NIOSH investigators recommended that the company evaluate extending the PAC welding curtain further out from the plasma arc head or installing a welding curtain that draped onto the metal. These changes would eliminate accidental viewing of the plasma arc in the safe walkway area, thus further reduce optical radiation

hazards. NIOSH investigators also recommended posting optical radiation warning signs in the PAC operation area and installing audible or visual warning cues to indicate when 260 amperage PAC work was performed. Additional recommendations included routinely inspecting and replacing welding curtains and revising training and hazard communication procedures to reflect changes implemented on the basis of the recommendations. It was recommended that the PAC operators use welding shades that covered the entire face to protect skin from UV radiation hazards.

## Disclaimer

The findings and conclusions in this manuscript are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of any company or product does not constitute endorsement by NIOSH.

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## References

- [1] "Eye and Face Protection," *Code of Federal Regulations Title 29, Part 1910.133(a)(5)*.
- [2] **Bancroft, K.:** "Plasma Arc Cutting Hazards." Available at <https://ohsonline.com/Articles/2003/03/Plasma-Arc-Cutting-Hazards.aspx?Page=1>.
- [3] **Plog, B.A.:** *Fundamentals of Industrial Hygiene*. National Safety Council. pp. 303–307.
- [4] **Lyon, T.:** Knowing the dangers of actinic UV emissions. *Welding J*. 2002.
- [5] **Anna, D.:** *The Occupational Environment: Its Evaluation, Control, and Management*. Virginia: American Industrial Hygiene Association (AIHA). pp. 738–755.
- [6] **American Conference of Governmental Industrial Hygienists (ACGIH):** *2016 TLVs<sup>®</sup> and BEIs<sup>®</sup>: Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.
- [7] **National Institute for Occupational Safety and Health (NIOSH):** *Criteria for a Recommended Standard: Occupational Exposure to Ultraviolet Radiation*. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational

- Safety and Health, DHEW (NIOSH) Publication No. 73-11009.
- [8] **Stewart, J.:** *Industrial-Occupational Hygiene and Safety Calculations: A Professional Reference*. Belchertown: Millennium Associates. p. 138.
- [9] **National Institute for Occupational Safety and Health (NIOSH):** *Health Hazard Evaluation Report: Melroe Company, Bismarck, North Dakota*. by C.E. Moss. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Health Hazard Evaluation Report 1996-0119-2586. Available at <https://www.cdc.gov/niosh/hhe/reports/pdfs/1996-0119-2586.pdf>.
- [10] **Slincy, D.H., C.E. Moss, C.G. Miller, and J.B. Stephens:** Semitransparent curtains for control of optical radiation hazards. *Appl. Opt.* 20(14):2352-2366 (1981).
- [11] **American National Standards Institute (ANSI):** *American National Standards for Occupational and Educational Personal Eye and Face Protection Devices (ANSI/ISEA Z87.1-2015)*. Arlington, VA: International Safety Equipment Association, 2015.
- [12] **U.S. Army Environmental Hygiene Agency Report No. 42-0053-77/ADA033768:** *Evaluation of Potential Hazards from Actinic Ultraviolet Radiation Generated by Electric Welding and Cutting Arcs*. December 1975-September 1976.